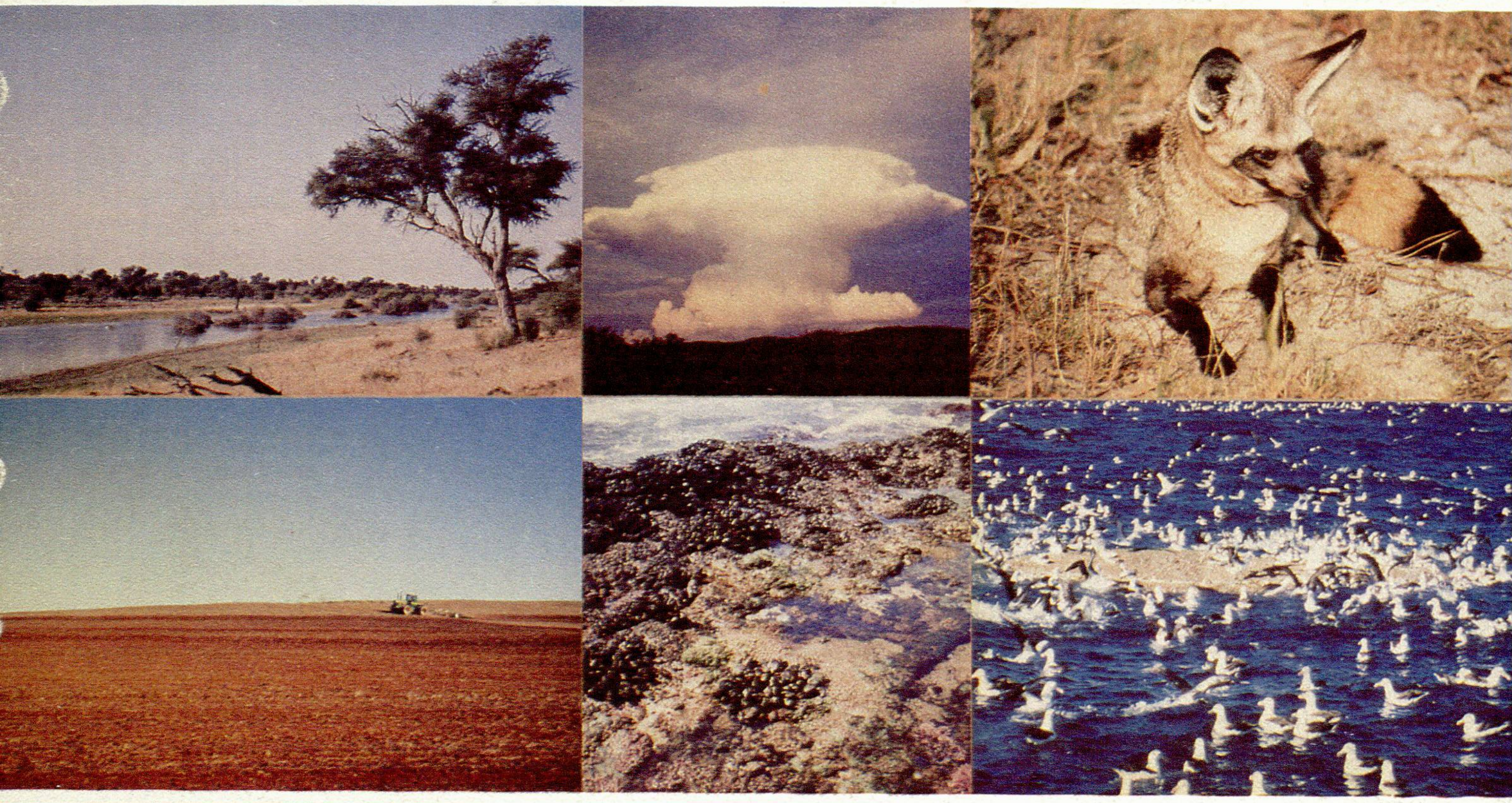
Long-term data series relating to southern Africa's renewable natural resources



I A W Macdonald and R J M Crawford (editors)

SOUTH AFRICAN NATIONAL SCIENTIFIC PROGRAMMES REPORT NO

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CAPTIONS AND ACKNOWLEDGEMENTS FOR COVER PICTURES

1. The usually dry Kuruman River flowing at the end of a period of high rainfall (Chapter 5 and 15). Radio-isotope determinations of ground waters in this river's basin provide a clue to the region's past climates (Chapter 14). I A W Macdonald.

2. On the central highveld plateau the grassland (Chapter 8) and savanna (Chapter 11) biomes receive much of their highly seasonal rainfall from thunderstorms (Chapter 15). I A W Macdonald.

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11. The fisheries off the West Coast provide some of the largest data series available for natural resources in the region (Chapter 1). P A R Hockey.

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PREFACE

This volume contains the proceedings of the "National Conference on Long-Term Data Series Relating to Southern Africa's Renewable Natural Resources" held at the CSIR Conference Centre, Pretoria, from 12 to 14 October 1987. The conference was convened by the Ecosystem Programmes section of the Foundation for Research Development, on behalf of the South African Special Committee for the International Geosphere-Biosphere Programme (IGBP). Some 135 delegates attended the conference which was organized as an alternating series of plenary, poster-paper and working sessions. The products of all three types of sessions are presented here.

The principal goal of the conference was to document what was known about how the environment and the renewable natural resources (marine, freshwater and terrestrial) of southern Africa had changed over the historical period, so as to provide a basis for improving our ability to predict future change. Auxiliary goals were to: a) bring together scientists interested in long-term environmental and resource change from different disciplines and areas of southern Africa; b) encourage publication of long-term data sets so that these could be evaluated and used by the wider scientific community; c) initiate the synthesis of existing information on changes that had occurred in the various ecosystems; and d) investigate whether relationships existed between data series from different ecosystems and, if so, to examine the possibility that large-scale forcing was influencing the related systems.

The conference was the first open meeting within South Africa's contribution to the IGBP. The IGBP, otherwise known as the Study of Global Change, is a programme of international cooperative research aimed at improving mankind's ability to model the global environment and the changes that are taking place within it. Organized by the International Council of Scientific Unions, the IGBP was officially launched at the Union's 21st General Assembly in Bern, Switzerland, in September 1986. The first phase of the IGBP, scheduled to run from 1987 to 1990, is aimed at the synthesis of existing knowledge on the processes regulating the earth's environment, the identification of priorities for future research in this field and the planning for implementation of such research in the programme's second phase. The latter phase is provisionally set to last until the year 2000. For a fuller description of the background to this conference, the IGBP and how the two are related, the reader is referred to Macdonald et al (1988).

The conference attempted to meet its objectives in three ways. In plenary papers, leading authorities in particular fields presented overviews of long-term data available for their discipline from southern Africa. In the working sessions, background documents on the long-term data available for specific biomes or disciplines, drawn up in advance of the conference by the session conveners, were improved upon by the group of specialists in that field attending the conference. Finally, poster papers described specific long-term data sets. In some cases these short papers were absorbed into the body of the appropriate background document, whereas in others they were considered to be of sufficient substance to warrant publication as discrete entities. In these cases they are published either immediately following the relevant working session document, or as individually authored subsections within the document.

The reader will soon become aware of the wide variation in the amount and quality of long-term data available for the different biomes and disciplines within southern Africa. As a generalization it can be stated that more quantitative data are available for the more easily measured physical attributes of the environment than for biological attributes. Within the biological data there appear, surprisingly, to be more long-term quantitative sets available from the marine environment than there are for terrestrial environments. This situation has probably arisen because quantitative monitoring of the ocean's renewable resources was obviously necessary if man was to effectively manage populations which are often difficult to assess. In terrestrial ecosystems man intuitively feels that he can assess the "health" of the production system, most of the components of which are readily visible, without recourse to elaborate quantitative measurements. Accordingly long-term data sets on those aspects of terrestrial ecosystems which are not easily assessed, such as rates of soil erosion and changes in plant populations, are generally unavailable or, at best, scarce. In several cases the necessity for assembling long-term data sets has only recently been recognized and in these cases the relevant chapters serve more to indicate the extent of current efforts in this regard (eg the savanna chapter) or possible future priorities for such efforts (eg the veterinary science chapter). Several chapters and poster-paper contributions address the possibility of retrospectively obtaining long-term data series on environmental or ecological variables from "cryptic" or archival data sources. However, for almost all cases the limitations of using such data, in terms of reliability, resolution and interpretation of the results, is readily apparent.

Most of the working groups emphasized the need for the establishment of well planned environmental and ecological monitoring systems. This was also one of the major points raised by Siegfried in his concluding address (see Chapter 18 which reproduces the spoken word rather than being a formal written account). The infra-structure which has been necessary for the long-term monitoring of just the climatic conditions occurring in the subcontinent (see Schulze and Scott's contribution to Chapter 5 for an indication of the adequacy of current efforts in monitoring precipitation alone), indicates the magnitude of the task that faces us in this regard. However, emergence of remote sensing technology might well make it possible for man to at last get to grips with changes that are occurring in the environment. The need for such monitoring has become all the more urgent following the realization that man himself has become a major factor in accelerating such changes.

ACKNOWLEDGEMENTS

The conference organization and the preparation of these proceedings were carried out by the staff of the Terrestrial Ecosystems Section of the Foundation for Research Development. Tisha Greyling supervised both operations with the able assistance of Diane Stafford. Wordprocessing of preconference documentation and the proceedings was carried out by Diane Stafford, Lorraine Horn, Marié Breitenbach, Diana Banyard and Sue Sonnenberg. Several of the figures were redrawn by the Graphic Arts section of the CSIR. The entire proceedings were copy-edited by Lynette van Niekerk.

We wish to express our sincere appreciation to the above people and to all who contributed to these proceedings, particularly the conveners of the working sessions who bore the brunt of what was often an enormous and difficult task of compiling a disciplinary overview. The Directors of the Percy FitzPatrick Institute of African Ornithology and the Sea Fisheries Research Institute are thanked for allowing us to devote much of our time over the last two years to the planning, organization and publication of the proceedings of this conference. Finally we thank Brian Huntley, Manager of Ecosystem Programmes, for believing in the concept of this meeting from its inception. Without his support and the accompanying financial backing from the FRD the objectives of this conference would possibly never have been achieved. As it is, with the publication of these proceedings, the South African contribution to the IGBP, with its important national priority of "laying the foundation for the management of natural resources in southern Africa during the next century" (South African IGBP Committee 1987) is one step closer to becoming a reality.

REFERENCES

Macdonald I A W, Crawford R J M, Siegfried W R and Huntley B J 1988. Long-term environmental change in and around southern Africa. South African Journal of Science 84.

South African Special Committee for IGBP 1987. A proposal for a South African Geosphere-Biosphere Programme (IGBP) to contribute to the ICSU international collaborative project on global change. Report of the IGBP-SA Secretariat, Foundation for Research Development, Pretoria

I A W Macdonald and R J M Crawford
CAPE TOWN, JUNE 1988

ABSTRACT

This volume presents the proceedings of a conference held to review the state of knowledge on long-term data series from southern African ecosystems. Three chapters relate to marine environments: those of the West Coast shelf, the South-East Coast shelf and the intertidal zone. Two chapters cover inland waters, estuaries and the hydrological cycle. Six chapters cover each of the terrestrial biomes: fynbos, forest, grassland, savanna, karoo and the Namib Desert. Two further chapters cover agricultural and veterinary data series. The remaining five chapters are of a more synthetic nature and examine the topics of palaeoenvironmental changes, environmental-forcing mechanisms, linkages between ecosytems, the analysis and storage of long-term data and some of the conclusions arising from the conference. Numerous short papers are included within individual chapters detailing particular data series. References included in each chapter introduce the reader to the key published works on the topic. However, much of the information presented has not been published previously.

SAMEVATTING

Hierdie werk bevat die handelinge van 'n konferensie wat gehou is om die stand van kennis van langtermyn datareekse van Suider-Afrika se ekosisteme te bepaal. Drie hoofstukke handel oor mariene omgewings: die kontinentale plat aan die Weskus en die Suidooskus, en die getysone. Twee hoofstukke dek binnelandse waters, riviermondings en die hidrologiese siklus. Ses hoofstukke dek die landekosisteme: fynbos, woud, grasveld, savanna, karoo en die Namibwoestyn. Twee verdere hoofstukke dek landbou- en veeartsenykundige datareekse. Die ander vyf hoofstukke is meer samevattend van aard en ondersoek die onderwerpe palaeo-omgewingsveranderinge, omgewingsdryfkrag, skakeling tussen ekosisteme, die analise en berging van langtermyn data, en sommige van die gevolgtrekkings wat uit die konferensie voortgevloei het. Verskeie kort referate wat spesifieke datareekse beskryf is binne individuele hoofstukke vervat. Verwysings binne hoofstukke verwys die leser na die sleutelwerke wat reeds oor die onderwerp gepubliseer is. Heelwat van die inligting wat hier aangebied word, is egter nog nooit voorheen gepubliseer nie.

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CHAPTER 1. THE MARINE SHELF OFF THE SOUTH-WEST COAST OF SOUTHERN AFRICA

CONVENER: P A SHELTON, Sea Fisheries Research Institute

GROUP MEMBERS: G Avery, A Berruti*, A J Boyd**, G B Brundrit, L Hutchings, B Roel, F H Schülein, L V Shannon, P Stockton, H R Valentine, G E Venter, C A Villacastin-Herrero and N D Walker

* Rapporteur - biological series
** Rapporteur - physical series

INTRODUCTION

Shelf waters along the west coast of southern Africa, which extends from the Kunene River in the north to Cape Agulhas in the south, constitute a large, complex marine ecosystem characterized by considerable temporal and spatial variability. A major consequence of this variability is the existence of renewable marine resources, harvested both by local and international fishing fleets which together landed 2,4 million tons in 1985 (Anonymous 1985). The most important resources are anchovy *Engraulis* species, pilchard *Sardinops* species, hakes *Merluccius* species, horse mackerel *Trachurus* species and rock lobster *Jasus* species. The system is being subject to increasingly intensive sampling at a variety of temporal and spatial scales, aimed at understanding the mechanisms controlling fish production. The objective of these studies is to develop effective and timeous management measures which can be implemented to maintain or increase the harvest.

The Benguela system, is unique amongst eastern boundary upwelling systems in that an extensive cool and very productive central upwelling region is bounded to both the north and south by warmer and less productive water from the Angolan and Agulhas currents. To the west there is a long, convoluted boundary between upwelled water and oceanic water. Although winds are perennially favourable to upwelling, the intensity of the process, and the extent of cool water in the system, is modified seasonally by movement of the South-east Atlantic high pressure anticyclone. The passage of easterly moving cyclones south of the continent (often preceded by the rapid southward movement of a coastal low pressure system formed north of Lüderitz) creates high variability in upwelling winds on a time scale of several days (Nelson and Hutchings 1983; Shelton et al 1985; Kamstra 1987).

In contrast to upwelling, the influence of warm water in the Benguela system is dominated by seasonal changes which are amplified or suppressed by interannual variations, which may be responses to large-scale perturbations. Stander and De Decker (1969), for example, described an intrusion off Namibia of warm water from the north-west in 1963.

Shelton et al (1985) noted a possible relationship between sea surface temperature (SST) off the west coast and the 10 to 12-year oscillation in rainfall off southern South Africa shown in Vines (1980) and discussed by Tyson (1986) and references therein. It seems probable that both the patterning in rainfall and the trends in SST are associated with large-scale changes in the Southern Oscillation and Walker Circulation discussed in Tyson (1986) and Walker (1987).

Thus three major components of variability, with very different time periods, characterize the Benguela system - upwelling events, seasonal changes and prolonged changes in normal advection patterns. Superimposed on these there may be a warming trend off the west coast of southern Africa since the mid-1940's (Taunton-Clark and Shannon 1988). The relative energy contributions of these different components to the overall variability of the system have yet to be adequately resolved.

Some populations of marine organisms off southern Africa are highly mobile, covering large distances during regular seasonal migrations, whereas others appear to be separated by environmental discontinuities (Crawford et al 1988). If these discontinuities are disrupted during episodic events, then there may be temporary range extensions which may both complicate interpretation of the dynamics of populations and also lead to the re-establishment of locally depleted populations.

The biota are adapted to natural variability of the environment at different scales of time and space (Shelton et al 1985; Shelton 1987). Species living in deep waters are apparently subject to less environmental fluctuation at shorter time scales than species occurring in surface waters, but are ultimately dependent on the productivity of surface waters for food. Anthropogenic forces may be superimposed on natural fluctuations of the biota, particularly at higher trophic levels and in recent decades. This complicates interpretation of biotic responses to physical changes, because there are feedback loops and interactions between various components of the trophic web.

In contrast to terrestrial systems, aquatic systems have a large capacity to store heat. Processes therefore tend to be characterized by increasing variance with increasing period from days to decades, implying that long-period variability is more important than short-period variability in aquatic systems (Bakun 1986). Because of the significance of longer-period variability, it is unfortunate that in most instances measurement error in observations made in the Benguela system increases with the length of the time series. The generally low signal to noise ratio, the difficulty in filtering out the strong annual cycle, the effect of periodicities shorter than the sampling period, and the few available degrees of freedom combine to place the analysis of long-term pattern at the statistical limit, and this must be borne in mind in the discussion of the different time series below. Nevertheless, there appears to be evidence of nonrandom patterning within both physical and biological variability of the Benguela system.

LONG-TERM VARIABILITY

There is a paucity of time series of physical or biological data preceding intensification of commercial exploitation of fish resources around 1950, and very little data exist prior to 1900. The few data sets of more than 50 years obviously have most potential value for analysis of long-term changes. These, however, have a large measurement error which makes them more qualitative than quantitative. This limits the kinds of analysis that can be performed with them. Therefore most of the useful data sets fall in the 10 to 50 year range. Those of less than 10 years' duration should be used in conjunction with longer time series. These three groupings of data are discussed separately below.

Data sets longer than 50 years

Sea surface temperature. Shannon and Taunton-Clark (this volume) and Taunton-Clark and Shannon (1988) have analysed time series of SST and relative wind stress measured by shipping in six five-degree blocks encompassing both oceanic and coastal regimes in the South-east Atlantic for the period 1906 to 1984. Although there are some periods of inadequate sampling and complete gaps, the number of observations per square varied between 21 000 and 134 000 for the time series. Both the wind and SST measurements indicate that there have been major changes in the South-east Atlantic this century. An increasing trend in SST is suggested in all areas, with the post-1940's period being 0,8°C warmer than earlier years. However, a change in measuring apparatus places some uncertainty on this result. Superimposed on the general trend are warm Benguela Niños in about 1910, the mid-1920's, 1934, 1949, 1963, 1974 and 1984. These warm events are interspersed with cooler periods, suggesting a possible ten-year cycle, the existence of which is supported by principal component analysis of the monthly data (Taunton-Clark and Shannon 1988). In 1934, 1949, 1963 and 1984 the Benguela Niños corresponded with heavy rains or flooding in parts of Namibia (Shannon et al 1986).

Temperature and fish abundance from the sedimentary record. The shells of planktonic foraminifera and scales of fish accumulate in anoxic sediments. Their abundance has been analysed from cores taken in the diatomaceous ooze off Walvis Bay (Shackleton 1987; Johnson and Shackleton this volume). The ratio of the foraminiferan *Globigerina bulloides* to the combined abundance of *G bulloides* and *G pachyderma* is taken as an index of sea temperature and can be converted to degrees Centigrade from a known correlation (Kipp 1976). The record from the cores is estimated to go back at least 7 000 years, based on an assumed sedimentation rate of one centimetre of core per 10 years. Pending absolute dating, it is estimated that only the last 2 000 years have been analysed. Temperature records from two of the cores have been reconstructed and show evidence of the Little Ice Age about 300 years ago, followed by a generally warmer period. The period immediately prior to the Little Ice Age was characterized by quite variable temperature, preceded by a relatively constant temperature.

Simultaneously with the foraminiferan record reflecting sea temperature, the number of scales of anchovy, horse mackerel and pilchard in the cores indicate large fluctuations in past stock sizes (Shackleton 1987). The abundance of scales of horse mackerel and pilchard are negatively correlated with each other, pilchard abundance declining over cool periods and increasing over warm periods and vice versa for horse mackerel. Anchovy abundance appears to be partly correlated with that of horse mackerel, increasing during cool periods and declining during warm periods. Shackleton (1987) showed that the fluctuations in abundance of scales of these three species occurred over peiods of 20 to 25 years, which can be compared with the decadal period noted for Benguela Niño events by Shannon (1985), Shannon et al (1986), Walker (1987) and Shannon and Taunton-Clark (this volume).

Fish abundance from harvests of seabird guano. The production of guano by coastal seabirds probably reflects general trends in the abundance of surface shoaling species on which the seabirds prey (Crawford and Shelton 1978; Bergh 1986; Crawford et al 1988). Information on guano harvests goes back to the turn of the century, predating commercial exploitation of the epipelagic fish prey of the seabirds. Shelton and Crawford (this volume) show that the guano time series for islands off South Africa and Namibia have more temporal structure than random series. Intensification of commercial purse-seining of epipelagic fish in 1950 decreased the guano harvest and increased its variability. Time-lagged autoregression suggests that anthropogenic factors caused most of the patterning in the South African data, but obscured decadal scale physical forcing in the Namibian data (Shelton and Crawford this volume).

Seal harvests. Data on the number of seals *Arctocephalus pusillus pusillus* harvested at South African and Namibian colonies extends back as far as 1900, after earlier exploitation had greatly reduced seal populations. Legal controls over sealing were introduced in 1893 and subsequent harvests have been dominated by a population recovery, although recently harvests have declined because of a reduced market demand (Figure 1.1). Within this overall trend, a minor peak is associated with 1920 to 1925, followed by a trough in the early 1930's. The trough appears to be related to the economic depression of that time rather than to the environment (J H M David personal communication). In addition to these nonrandom features near the beginning of the series, there is considerable noise on the overall recovery trend, probably related to inter-year differences in harvesting intensity and human disturbance.

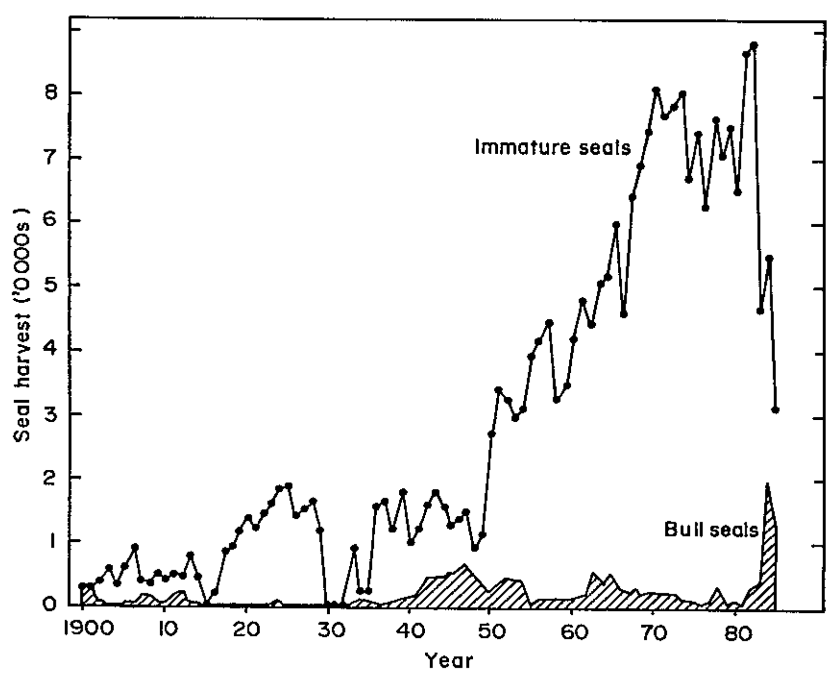

FIGURE 1.1 The annual harvest of bull and immature seals for the Benguela ecosystem (from Crawford et al 1988).

Data sets spanning between 10 and 50 years

Sea surface temperature. McLain et al (1985) examined monthly SST data for three-degree blocks adjacent to the coastline along the entire west coast of Africa for the period 1971 to 1984. Monthly anomalies from the long-term mean clearly show major warm events in the Benguela system (Figure 1.2). In contrast to the Peruvian system, the warm events have a larger degree of temporal coherence, persisting uninterrupted for a number of years before cooling takes place, but are less extensive longshore.

The period from the beginning of the series up to 1978 was characterized by a +0,5°C anomaly and the period from 1979 to 1983 by a -0,5°C anomaly. After 1983 there is evidence of the commencement of a further warm period.

This pattern is consistent with the longer time series from Shannon and Taunton-Clark (this volume). The greatest negative anomaly (less than -1,0°C) occurred off Namibia from November 1981 to May 1982, agreeing with observations by Boyd and Agenbag (1984). The record also shows the commencement of the intense warm water anomaly off Namibia at the beginning of 1984 first noted by Boyd and Thomas (1984) and discussed in Shannon et al (1986).

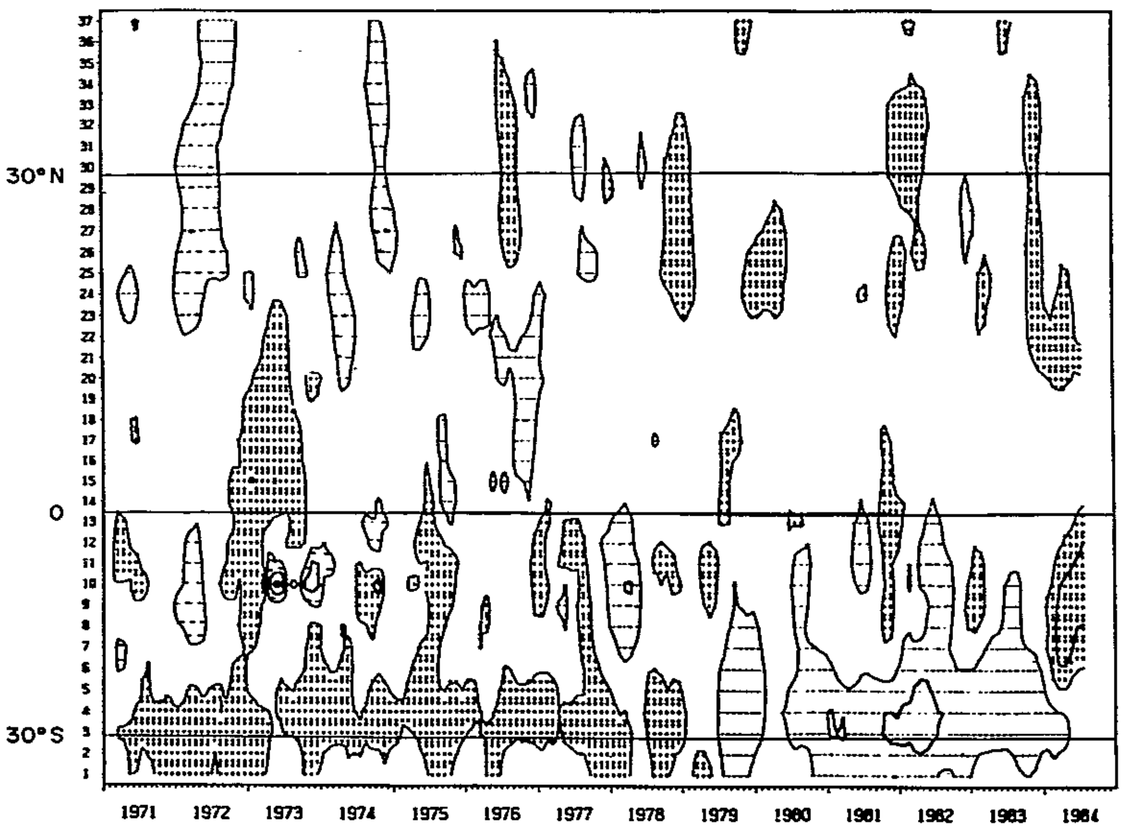

FIGURE 1.2 Anomaly of monthly SST for coastal three-degree blocks from March 1971 to June 1984, + indicates positive anomaly and - negative anomaly (from McLain et al 1985).

Walker (1987) used principal components analysis to investigate SST variability from "data rich" two-degree blocks in the South-east Atlantic between 1960 and 1983. The analysis showed that 75% of the nonseasonal SST variability could be accounted for by three principal components. PC1 demonstrated widespread trends of warming and cooling, with major warm events centred in 1963 and 1972 to 1975 and a cold period extending from 1969 to 1971. PC2 distinguished events in the southern Benguela from those farther north, partly on account of seasonal differences in upwelling in these regions. PC3 showed cool conditions inshore but not offsore from 1981 to 1983. This has been documented in other data sources (Shannon et al 1986) and was associated with increased tropical windstress. Comparison with information on atmospheric pressure for the region suggested that major warm events were accompanied by a reduction of average equatorward wind speed and cool events by its augmentation.

<u>Time-depth profiles of temperature</u>. Boyd (this volume) plotted time-depth profiles of temperature for an area about 16 km west of Walvis Bay, covering the period 1954 to 1967 and 1978 to 1987. The data clearly show the Benguela Niños of 1963 and 1984 as amplifications, in terms of both depth and duration (ie volume), of the seasonal advection of warm tropical water southwards and onto the shelf. The influence on the shelf of a poleward- propagating anomaly is likely to be greater than that of an equatorward propagating anomaly because of the effect of Coriolis force. The period 1954 to 1958 was characterized by cooler water on the shelf than at any other time covered by the data series.

<u>Sea level</u>. Monthly mean sea level (SL) variability along the west coast of southern Africa has been analysed for the period 1959 to 1975 by Brundrit (1984) and extended to 1985 by Brundrit et al (1987) and Brundrit (this volume). Very long records of SL from elsewhere show a general upward trend in SL of some 15 cm per century with fluctuations at the decadal scale and large amplitude events of shorter periods. The Benguela series is too short for an analysis of trend but the decadal structure is clearly evident (Brundrit this volume). Periods of elevated SL, centred on 1963, possibly 1974 and 1984, coincide with the warm-water anomalies discussed above. Lags in the occurrence of SL events with increasing latitude suggest poleward propagation from the equator in a similar manner to the Pacific El Niño (Brundrit et al 1987).

<u>Wind measurements</u>. In addition to wind measurements reported by Taunton-Clark and Shannon (1988), Shannon and Taunton-Clark (this volume) and Walker (1987), Hutchings et al (this volume) examined wind patterns in the south-west Cape from observations of lighthouse keepers for the 30-year period 1957 to 1987. They analysed deviations from the mean of progressive northerly and westerly wind vectors for two seasons (summer [October to March] and winter [April to September]) for lighthouses of Cape Columbine and Cape Point. The Cape Point data show marked decreases in southerly winds for the period 1963 to 1966, 1968/69, 1976/77 and 1982/83. The most noticeable feature in the Cape Columbine data is a prolonged decrease in the amount of equatorward wind for the period 1979/80 to the present. However, this may be due to a systematic error as a cup anometer replaced a pressure-plate instrument at the Cape Columbine lighthouse.

<u>Fish catches, catch rates and catch-based estimates of fish populations</u>. Time series of data on fish catches, changes in the location of catches,

catch rates and estimates of biomass of fish stocks are available for some important fish species in the Benguela system (Crawford et al 1987). Biomasses reconstructed from catch data are likely to have large systematic errors which are unknown (Bergh 1986), and therefore these series must be interpreted with caution. In the northern Benguela, Virtual Population Analysis (VPA) indicates that stocks of pilchard and Cape hakes declined in the late 1960's and in the 1970's respectively (Crawford et al 1987; Figure 1.3). In the southern Benguela VPA estimates indicate that stocks of horse mackerel and pilchard declined in the early 1950's and early 1960's respectively (Crawford et al 1987; Figure 1.4). Hake biomasses have shown a declining trend since the 1960's (Leslie 1986; Figure 1.4). Time series of catches of less important species are available for both northern and southern Benguela (Crawford et al 1987).

The percentage of jellyfish (*Scyphozoa*) in purse-seine catches off Namibia increased greatly after the collapse of the pilchard stock (G Venter this volume) suggeting a possible replacement. Trends in Namibian catches of linefish (J Venter this volume) are likely to reflect exploitation patterns, although the very low catches in 1984 occurred in a Benguela Niño year. Given the uncertainty about estimates of biomass from VPA (Bergh 1986) and the relationship between catches and stock sizes (Csirke 1980), correlation with physical time series (eg Villacastin-Herrero this volume) must be regarded with caution.

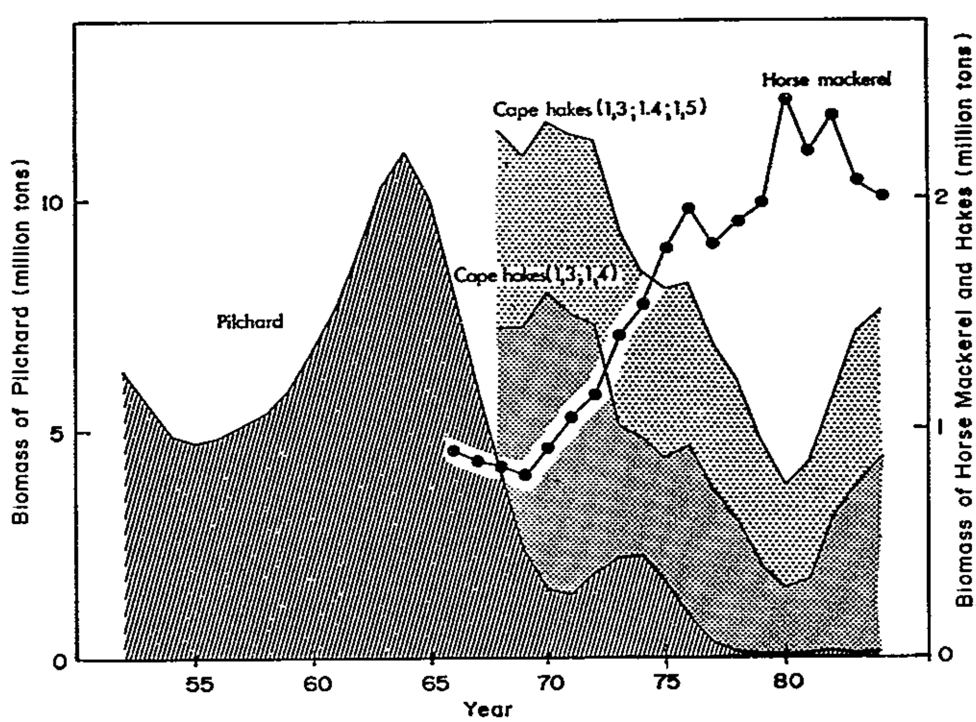

FIGURE 1.3 VPA estimates of the biomass of pilchard, Cape horse mackerel and Cape hakes for various ICSEAF divisions off Namibia (from Crawford et al 1988).

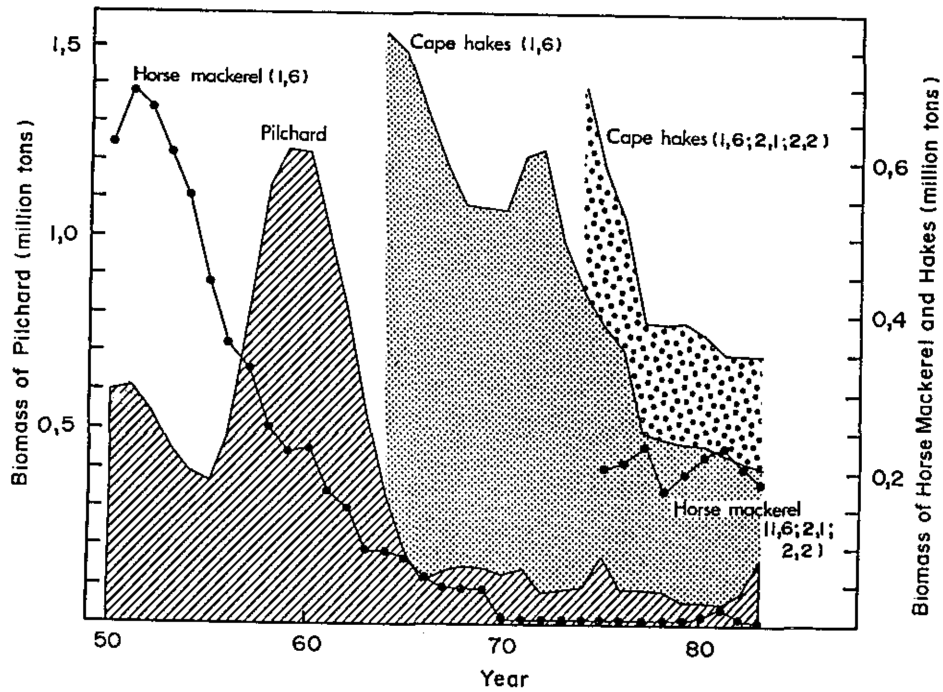

FIGURE 1.4 VPA estimates of the biomass of pilchard, Cape horse mackerel and Cape hakes for various ICSEAF divisions off South Africa (from Crawford et al 1988).

<u>Cross-correlations between SST, SL, wind stress and fish catches.</u> Villacastin-Herrero (this volume) related catches of pilchard to SST, SL and wind stress for three regions of the southern Benguela - the area where juveniles recruit to the fishery, the area of transport of eggs and larvae from spawning to recruitment grounds, and the spawning area. Pilchard catches were used as an index of biomass, although it was recognized that catches are influenced by fishing effort and availability of fish as well as by the biomass. Lower SST, lower sea level and lower SE wind component were positively correlated with pilchard catches. However, cross-correlation of two autocorrelated time series may result in values of spurious significance (Jenkins 1979) and may complicate further interpretation of these data until the autocorrelated component of variability is removed (pre-whitening).

<u>Indices of fish condition, oil yield and fecundity.</u> The routine sampling of fish caught by purse-seine has provided a number of time series related to the biology of fish, which may be a reflection of environmental conditions. Schülein (this volume) examined the oil yield and gonad mass for pilchard landed at Walvis Bay since 1950. There was a clear annual cycle in oil yield, but the data also showed that the mean monthly yield of oil was anomalously high from late 1967 to mid-1969. The mass of pilchard gonads appeared to increase from the late 1960's as the biomass was decreasing. Low oil yields coincided with the periods of warming in 1963 and 1972 to 1975, identified by Walker (1987). High oil yields coincided with successful recruitment in a number of years covered by the time series, but there was no apparent long-term trend in oil yield. Le Clus (SFRI in preparation) has calculated a gonad-free condition factor for pilchard landed at Walvis Bay for the period 1952 to 1986. A low

condition index associated with the period 1974 to 1977, a high index for the period 1981 to 1983, and a number of other minor peaks and troughs correspond quite closely with the SST anomaly data of McLain et al (1985), a low condition index occurring during warm periods.

In the southern Benguela, changes in a number of biological parameters since 1953 for pilchard, anchovy and roundherring *Etrumeus whiteheadi* caught off the west coast (north of Cape Point) have been examined (Prosch et al this volume). Of most significance appears to be a trend of increasing gonad condition factor in pilchard and possibly anchovy and roundherring. This is correlated with a decrease in the length at maturity and an increase in fecundity of pilchard, and may reflect a density-dependent response resulting from overexploitation of the pilchard.

Seabird diet. Diet of the Cape gannet *Morus capensis* at two colonies on South Africa's west coast has been examined for the period 1977 to 1987 (Berruti 1987 and this volume). The contribution of a fish species to the diet is likely to be influenced by the relative abundance of different prey items, their availability, and prey selection. The major signal in the time series is a trend for pilchard to contribute an increased proportion of the diet since 1978. This cannot be attributed to decreases in the abundance of other species as pilchard is the preferred prey (Berruti and Colclough 1987), and other prey populations, such as anchovy, do not appear to have decreased. It cannot either be attributed to increased availability of pilchard as a result of changing oceanographic conditions, such as the advection of warm water concentrating fish close to the shore, because this would also make other fish species more available. The trend is therefore interpreted as reflecting an increasing biomass of pilchard.

Data sets spanning less than 10 years

Physical parameters. Data series of less than 10 years' duration are normally collected in order to facilitate the understanding of specific oceanographic processes. Several such data series, which include satellite imagery, current meter measurements and data from two electronic coastal weather stations are already of five to nine years' length, and are being continued. Wind measurements are of particular importance with regard to the productivity of southern Africa's coastal regions and therefore meteorological monitoring should be carried out at as many sites as possible.

Stockton (this volume) presented the mean spatial distribution of upwelled water for the whole Benguela region for three-month seasons based on six years of infrared satellite imagery. These show features such as the 1984 Benguela Niño (Shannon et al 1986) and the cool water event off Namibia in 1982 (Boyd and Agenbag 1984). Agenbag and Shannon (1988) used satellite imagery to show the intrusion of Agulhas Current Water around the Cape of Good Hope into the Atlantic as far north as Lüderitz in winter 1986. All three of these features have had an apparent impact on the fisheries of the region (see Conclusions).

Current meter data have indicated regular reversals in flow of the waters on the shelf opposite Cape Columbine which are related to wind and pressure fields at coastal weather stations (Holden 1987).

Lutjeharms et al (this volume) present SST data for three islands in the Southern Ocean, with record lengths at Gough and Marion Islands of just under 10 years. Deviations from mean values in 1976 and 1982 may be related to events along the west coast of southern Africa and El Niño Southern Oscillation (ENSO) events. Measurements at Gough and Marion Islands are proceeding and a resumption of SST measurements at Tristan da Cunha is encouraged.

Abundance of fish larvae. The early planktonic stages of fish may be more easily sampled than the adults because their distribution is not as patchy and they are less likely to avoid the sampling gear. Hewitson (this volume) examined the spatial distribution of larvae of pilchard, anchovy and horse mackerel in three latitudinal bands of two degrees each off Namibia. The larvae of all three species favour the area to the north of Walvis Bay, but during the 1984 Benguela Niño event there was a significant southward shift.

Seabird strandings. Records have been kept of numbers of seabirds found dead along the southern African coast. Interannual and monthly variation in the number of dead birds exists for each species examined and there are also differences between study sites (Avery this volume). Seabirds which feed on the shelf and breed at coastal islands, such as jackass penguins *Spheniscus demersus*, Cape gannets and Cape cormorants *Phalacrocorax capensis* are frequently found dead along the west coast. For gannets and cormorants seasonal peaks coinciding with the breeding cycles are evident. Penguin data show a switch in 1982/83 from a positive to negative anomaly in the mean monthly number of strandings, coinciding with the Benguela Niño. The trend for gannets and cormorants is the inverse of this. In general the pattern of cormorant mortality appears to be strongly negatively correlated with SST.

The proportion of banded Cape Gannets recovered north of the Cunene River has decreased greatly since 1969 (Oatley this volume). This change may not be only the result of decreased reporting of recovered birds, because ringing recoveries are still received for other species from African countries.

Estimates of population size from surveys. Estimates of the population sizes of some species from surveys have begun recently. These include anchovy off South Africa (Hampton et al SFRI), hake off South Africa and Namibia (Payne et al SFRI), seals off South Africa and Namibia (David SFRI), penguins, gannets, cormorants *Phalacrocorax* species, gulls *Larus* species and swift terns *Sterna bergii*, off South Africa and Namibia (Crawford and Berruti SFRI), and southern right whales *Eubalaena australis* off South Africa (Best Mammal Research Institute). The data are of high quality, often with a known and relatively small measurement error, and in the case of acoustic determination of fish stocks, are collected in conjunction with environmental data.

Seabird diet. The proportion of anchovy in the diet of jackass penguins and swift terns on the west coast of South Africa is likely to reflect the relative availability of anchovy to these seabirds within their foraging ranges (Laugksch et al this volume).

CONCLUSIONS

A number of the time series considered above show unequivocal evidence of nonrandom patterning at the interannual time scale, but in very few instances have there been serious attempts to separate the underlying signal from the noise using some of the techniques available for time series analysis. In even fewer instances have there been attempts to draw comparisons between different series, and often where this has been done there have either been shortcomings associated with improper cross-correlation of autocorrelated series or the analyst has relied merely on visual correspondence of peaks and troughs in certain years to substantiate preconceived ideas about cause and effect. These data exploration exercises will inevitably turn up spurious relationships which are of little use, or worse, are misleading. Clearly more rigorous treatment (eg Shannon et al in press) is now essential if progress beyond the conclusion that nonrandom patterning does exist is to be made.

The analysis of the biological time series has additional problems not associated with the physical series. In many instances changes induced by the natural environment are completely obscured by anthropogenic forcing of exploited populations to collapsed states. In addition, the biological populations are self-regulating entities which induce their own patterning on physical input, dependent on such population features as natural mortality, age at maturity etc (Shelton et al 1985; Shelton 1987; Armstrong and Shelton 1988). Creative means of overcoming these limitations so that further characteristics of the underlying pattern can be revealed need to be developed.

The marine shelf of the west coast is spatially variable and this needs to be taken into account in interpreting time series. Intense upwelling at Lüderitz separates areas of less upwelling found to the north and south. In turn these areas of moderate upwelling are bounded by warm water masses of tropical origin. The most clearly defined interannual variability is associated with the northern Benguela region, where there are extended periods of generally high or low anomalies of temperature and sea level and intermittent peak events at the decadal scale. In the southern Benguela, both variable windstress and the penetration of Agulhas water around the west coast are responsible for anomalous years such as 1982/83 and 1986/87 respectively. However, despite these apparently different forcing mechanisms in the southern and northern Benguela, some major interannual events appear to be spatially homogeneous over much of the South-eastern Atlantic, indicating larger-scale changes (McLain et al 1985; Walker 1987).

As the environmental driving forces affecting southern Africa's marine shelf are subject to major ocean/atmosphere interactions in the Atlantic and Indian Oceans, South Africa's contribution to the World Ocean Circulation Experiment (WOCE) is set to play a vital role in providing the background necessary for the interpretation of data series collected in the shelf regions. In addition, the value of a central database (like SADCO - the South African Data Centre for Oceanography) where parameters such as SST, weather, and other basic hydrographic data are stored and are easily accessible, needs to be emphasized. SADCO has been successfully used by several authors (eg Walker 1987; Shannon and Taunton-Clark this volume; Villacastin-Herrero this volume), and it is suggested that it be maintained and expanded to include data sets from other disciplines (eg biology).

It is in the northern Benguela that the strongest links between physical driving forces and biological responses are found. However, many of the apparent linkages are tentative and require further analysis along more rigorous lines. Although there is less interannual variation south of Lüderitz, a number of potential linkings between physical forcing and biological variability have also been suggested, mainly associated with the penetration of Agulhas water onto the west coast. For example, Shannon et al (in press) have found a significant negative relationship between year-class strength of Cape hakes and SST. However, the complexity and nonlinearity of the system suggests that these relationships are likely to be of short duration. Instead of viewing them as long-term predictive aids, it may be more appropriate to investigate the possible mechanisms giving rise to the relationships, so that models that incorporate the essential features of the dynamic system can be parameterized.

REFERENCES

Agenbag J J and Shannon L V 1988. A suggested physical explanation for the existence of a biological boundary at 24° 30'S in the Benguela system. South African Journal of Marine Science 6, 119-132.

Anonymous 1985. Statistical Bulletin of the International Commission for South East Atlantic Fisheries 15, 1-375.

Armstrong M J and Shelton P A 1988. Bias in estimation of stock-recruit function parameters caused by nonrandom environmental variability. Canadian Journal of Fisheries and Aquatic Sciences 45, 554-557.

Bakun A 1986. Definitions of environmental variability affecting biological processes in large marine ecosystems. In: K Sherman and L M Alexander (editors) Variability and management of large marine ecosystems. American Association for the Advancement of Science Selected Symposium 99. 319 pp.

Bergh M D 1986. The value of catch statistics and records of guano harvests for managing certain South African fisheries. PhD Thesis, University of Cape Town, Cape Town.

Berruti A 1987. The use of Cape gannets Morus capensis in management of the purse-seine fishery of the Western Cape. PhD Thesis, University of Natal, Pietermaritzburg.

Berruti A and Colclough J C 1987. Comparison of the abundance of pilchard in Cape gannet diet and commercial catches off the western Cape, South Africa. In: Payne A I L , Gulland J A and Brink K H (editors) The Benguela and Comparable Ecosystems. South African Journal of Marine Science 5, 937-951.

Boyd A J and Agenbag J J 1984. Seasonal temperature and salinity trends off central Namibia between 1978 and 1983 with particular reference to the cool winter of 1982. South African Journal of Science 80, 77-79.

Boyd A J and Thomas R M 1984. A southward intrusion of equatorial water off northern and central Namibia in March 1984. Tropical Ocean-Atmospheric Newsletter 27, 16-17.

Brundrit G B 1984. Monthly mean sea level variability along the west coast of southern Africa. South African Journal of Marine Science 2, 195-203.

Brundrit G B, De Cuevas B A and Shipley A M 1987. Long-term sea level variability in the eastern South Atlantic and a comparison with that in the eastern Pacific. In: Payne A I L, Gulland J A and Brink K H (editors) The Benguela and Comparable Ecosystems. South African Journal of Marine Science 5, 73-78.

Crawford R J M and Shelton P A 1978. Pelagic fish and seabird interrelationships off the coasts of South West and South Africa. Biological Conservation 14, 85-109.

Crawford R J M, Shannon L V and Pollock D E 1987. The Benguela Ecosystem. Part IV. The major fish and invertebrate resources. Oceanography and Marine Biology Annual Review 25, 353-505.

Crawford R J M, Shannon L V and Shelton P A 1988. Characteristics and management of the Benguela as a large marine ecosystem. In: Sherman K and Alexander L M (editors) Biomass and Geography of Large Marine Ecosystems. American Association for the Advancement of Science, 171-221.

Csirke J 1980. Recruitment in the Peruvian anchovy and its dependence on the adult population. Rapports et Procès-Verbaux des Réunions 177, 307-313.

Holden C J 1987. Observations of low-frequency currents and continental shelf waves along the west coast of South Africa. In: Payne A I L, Gulland J A and Brink K H (editors) The Benguela and Comparable Ecosystems. South African Journal of Marine Science 5, 197-208.

Jenkins G M 1979. Practical experiences with modelling and forecasting time series. Time Series Library, Gwilym, Jenkins and Partners (Overseas) Ltd , Jersey, Channel Island. 146 pp.

Kamstra F 1987. Interannual variability in the spectra of the daily surface pressure at four stations in the Southern Hemisphere. Tellus 39A, 509-514.

Kipp N G 1976. New transfer function for estimating past sea surface conditions from seabed distribution of planktonic foraminiferal assemblages in the north Atlantic. Geological Society of America 145, 3-41.

Leslie R W 1986. Stock assessment for Cape hakes in ICSEAF Divisions 1.6, 2.1 + 2.2. Collection of Scientific Papers of the International Commission of South East Atlantic Fisheries 13, 27-36.

McLain D R, Brainard R E and Norton J G 1985. Anomalous warm events in eastern boundary current systems. California Cooperative Oceanic Fisheries Investigations Reports 26, 51-64.

Nelson G and Hutchings L 1983. The Benguela upwelling area. Progress in Oceanography 12, 333-356.

Shackleton L Y 1987. A comparative study of fossil fish scales from three upwelling regions. In: Payne A I L, Gulland J A and Brink K H (editors) The Benguela and Comparable Ecosystems. South African Journal of Marine Science 5, 79-84.

Shannon L V 1985. The Benguela ecosystem Part I. Evolution of the Benguela, physical features and processes. Oceanography and Marine Biology Annual Review 23, 105-182.

Shannon L V, Boyd A J, Brundrit G B and Taunton-Clark J 1986. On the existence of an El Niño-type phenomenon in the Benguela System. Journal of Marine Research 44, 495-520.

Shannon L V, Crawford R J M, Brundrit G B and Underhill L G (In press). Responses of fish populations in the Benguela ecosystem to environmental change. Journal du Conseil International pour L'Exploration de la Mer.

Shelton P A 1987. Life-history traits displayed by neritic fish in the Benguela Current ecosystem. In: Payne A I L, Gulland J A and Brink K H (editors) The Benguela and Comparable Ecosystems. South African Journal of Marine Science 5, 235-242.

Shelton P A, Boyd A J and Armstrong M J 1985. The influence of large-scale environmental processes on neritic fish populations in the Benguela Current system. California Cooperative Oceanic Fisheries Investigations Reports 26, 72-92.

Stander G H and De Decker A H B 1969. Some physical and biological aspects of an oceanographic anomaly off South West Africa in 1963. Division of Sea Fisheries, South Africa, Investigational Report 81, 1-46.

Taunton-Clark J and Shannon L V 1988. Annual and interannual variability in the South-east Atlantic during the 20th century. South African Journal of Marine Science 6, 97-106.

Tyson P D 1986. Climatic changes and variability in southern Africa. Oxford University Press, Cape Town.

Vines R G 1980. Analysis of South African rainfall. South African Journal of Science 76, 404-409.

Walker N D 1987. Interannual sea surface temperature variability and associated atmospheric forcing within the Benguela system. South African Journal of Marine Science 5, 121-132.

INTERANNUAL AND MONTHLY VARIATION IN FREQUENCIES OF BEACHED SEABIRDS FOUND IN SOUTH AFRICA

G AVERY
South African Museum

INTRODUCTION

Frequencies of beached seabirds are monitored monthly over several sections of the western and eastern Cape Province of South Africa. Surveys were initiated in 1977 by the African Seabird Group, first at False Bay (20 km) and then at Yzerfontein (15 km) (south-western Cape) and Cape Recife (five kilometres) (eastern Cape). Other stretches of beach of varying lengths have been monitored over shorter periods, some having been terminated, while others were initiated more recently. Observations follow the methods suggested by Cooper (1977). Data for jackass penguins *Spheniscus demersus*, Cape gannets *Morus capensis* and Cape cormorants *Phalacrocorax capensis* from the above-mentioned surveys are presented.

RESULTS

Interannual and monthly variation exists for each species and between study areas. Comparison with the long-term means shows variation in monthly frequencies of all individuals recovered which, particularly for cormorants (Figure 1.5) and gannets, reflects a relatively consistent seasonal pattern. The picture is complicated, but not obscured, by interannual trends (Figure 1.6). Peaks in mortality are evident for some years, while others remain below the mean. The exceptionally high frequencies of cormorants at Yzerfontein during the summer of 1986/87 raised the mean from 11,1 individuals per month between 1977 and 1982 to 22,3 overall, partly obscuring the seasonal pattern which is otherwise evident. At Cape Recife the high frequencies during the first three months surveyed had a similar effect. Fluctuations at the south-western sites do not always coincide with those at Cape Recife.

Interannual patterns, given for adults only, show differences between species and sites (Figure 1.6), with periodic switches from positive to negative values. A particularly marked switch occurred between 1982 and 1983. The trend followed by penguins at Yzerfontein varies inversely with those of gannets and cormorants, which are similar. At False Bay, the three species tend to covary. At Cape Recife penguins and gannets covary, and appear to follow a pattern similar to that of gannets at Yzerfontein. There is a strong tendency, particularly after 1982, for trends of gannets and cormorants at Yzerfontein and False Bay to be inverse.

Data from Natal were collected over a total of only 28 months and, in spite of the fact that over 32 000 km were checked during this period, are too few (three penguins, eight gannets, three cormorants) to warrant illustration. It is, nevertheless, clear that the Natal coast is very different to the other areas.

DISCUSSION

The effects of commercial fisheries on the occurrence of beached seabirds are largely unknown. Human predation, which leaves characteristic remnants, is responsible for a proportion of Procellariiformes (albatrosses, petrels, shearwaters) and, to a lesser extent, Cape gannets. Such individuals have been excluded from this analysis. Observable oil pollution is generally not a serious factor, except in the case of severe spills which can be accounted for.

Proportions of the common breeding seabirds recovered are similar to those of the living populations, and it has been concluded that fluctuating frequencies of beached seabirds may provide an index of their mortality in response to changing oceanic and climatic conditions (Avery 1985, 1987; Avery and Underhill 1986).

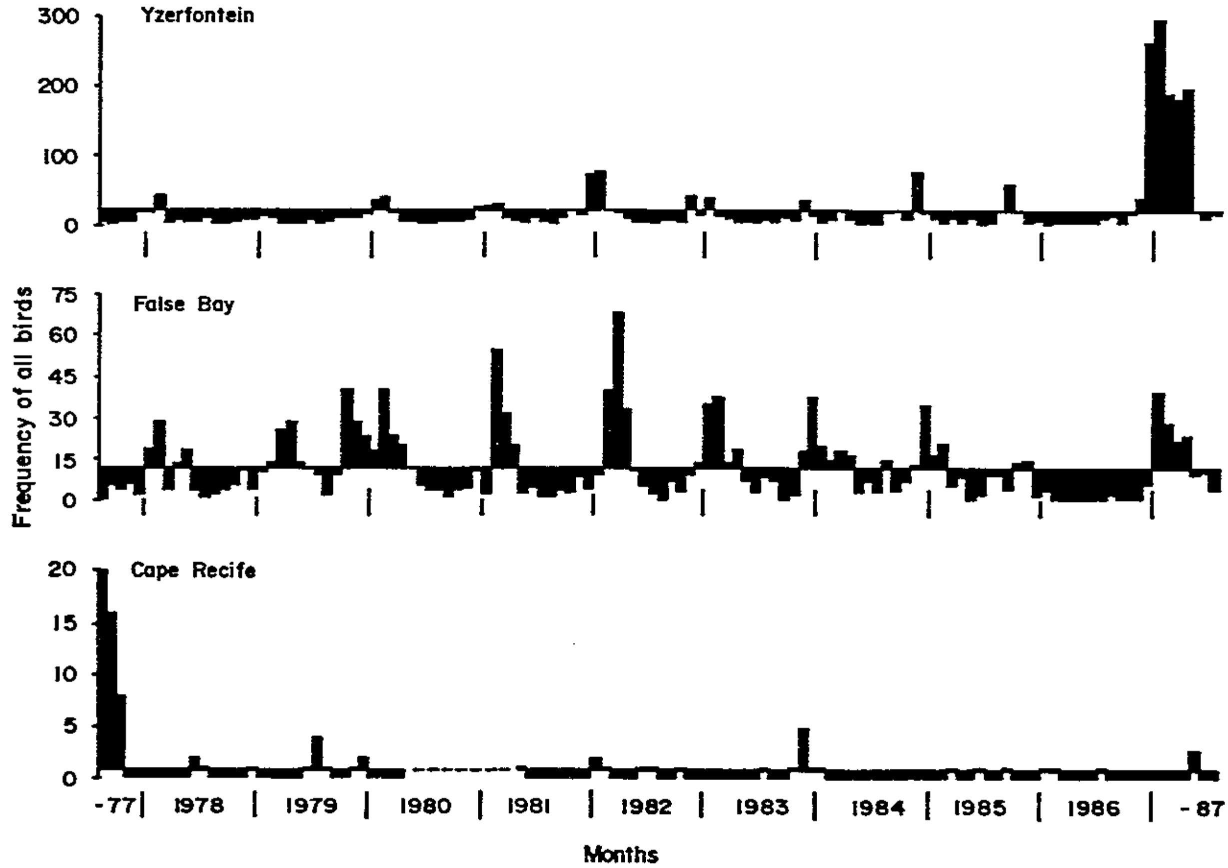

FIGURE 1.5 Variation from the mean in monthly frequencies of all individuals of Cape cormorants recorded at Yzerfontein, False Bay and Cape Recife for the ten-year period August 1977 to July 1987. Note the different vertical scales.

The higher summer mortality of Cape gannets and Cape cormorants, is related to their summer-breeding cycle and is strongly influenced by juvenile mortality, particularly of gannets. Further distinction is possible if adults and juveniles are treated separately. Differing local conditions, such as wind, orientation of the coast, locality of breeding populations and availability of food, could account for some variation between sites.

The 1982/83 change in values coincided with a strong Southern Oscillation (Avery 1985). Fluctuations, particularly of Cape cormorants in the Benguela region, correlate strongly with local changes of mean summer sea temperatures (Benguela Niños having a notable impact) and with some trends in the recruitment and local availability of pilchard *Sardinops ocellatus* and anchovy *Engraulis capensis* on which they prey (Shannon et al 1984; Walker et al 1984; Shannon this volume). Inverse responses probably relate to different foraging ranges and adaptability of the three species to changes in food availability (Duffy et al 1984).

Overall numbers of birds recovered are a reflection of local population numbers and the length of coast surveyed. This may be complicated further by patterns of dispersal (mainly juveniles and nonbreeding birds) around the coast towards Natal where the absence of breeding populations is reflected in the extremely low incidence of beached individuals near the limits of their distribution.

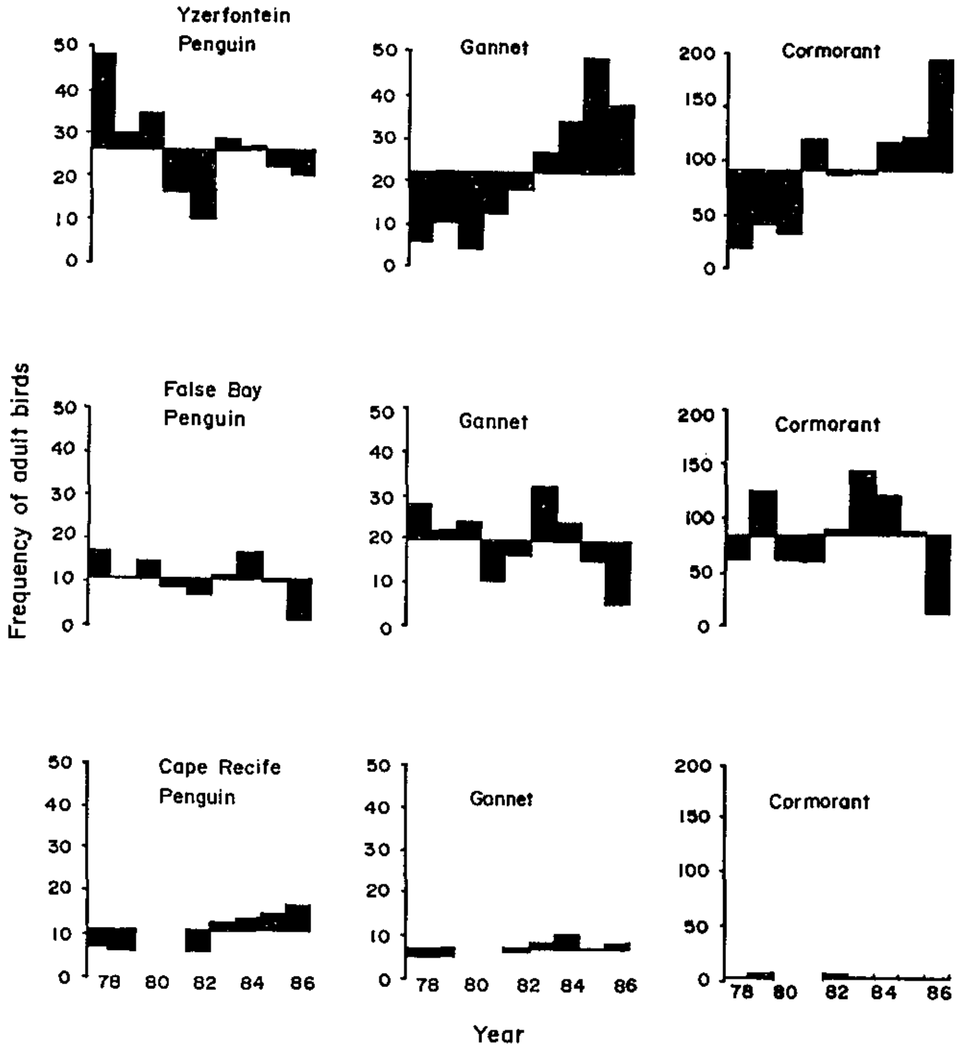

FIGURE 1.6 Variation from the mean in annual frequencies of adult jackass penguins, Cape gannets and Cape cormorants at Yzerfontein, False Bay and Cape Recife for the years 1978 to 1986. Note the different vertical scales.

REFERENCES

Avery G 1985. Results of patrols for beached seabirds conducted in southern Africa in 1983. Cormorant 13, 3-15.

Avery G 1987. Coastal birds and prehistory in the western Cape. In: Parkington J and Hall M (editors) Papers in the prehistory of the western Cape. British Archaeological Reports International Series 332(1), 164-191.

Avery G and Underhill L G 1986. Seasonal exploitation of seabirds by Late Holocene coastal foragers: analysis of modern and archaeological data from the western Cape, South Africa. Journal of Archaeological Science 13(4), 339-360.

Cooper J 1977. Suggested methods for beach walks. Cormorant 2, 30.

Duffy D C, Berruti A, Randall R M, and Cooper J 1984. Effects of the 1982-83 warm water event on the breeding of South African seabirds. South African Journal of Science 80, 65-69.

Shannon L V, Crawford R J M and Duffy D C 1984. Pelagic fisheries and warm events: a comparative study. South African Journal of Science 80, 51-60.

Walker N, Taunton-Clark J and Pugh J 1984. Sea temperatures off the South African coast as indicators of warm events. South African Journal of Science 80, 72-77.

THE DIET OF CAPE GANNETS OFF SOUTH AFRICA'S WESTERN CAPE, 1952 to 1956 AND 1978 to 1987

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INTRODUCTION

Cape Gannets *Morus capensis* feed on epipelagic shoaling fishes, particularly pilchard *Sardinops ocellatus* and anchovy *Engraulis capensis* (Berruti 1987). The diets of gannets from the two colonies on the western coast of South Africa's Cape Province, Bird Island (Lambert's Bay) (32°03'S 17°55'E) and Malgas Island (33°05'S 18°05'E), were monitored during 1952 to 1956 (Davies 1955, 1956; Rand 1959) and 1978 to 1987 (Berruti 1987). If the relationships between the contribution of a species to gannet diet and its abundance and availability are understood, gannet diet may be used as a measure of the relative or absolute abundance of one or more prey species.

METHODS

During 1953 to 1955, the stomach contents of 289 gannets shot at sea in St Helena Bay were examined (Davies 1955, 1956). This is the foraging area of gannets from the Lambert's Bay colony (Berruti 1987). During 1954 to 1956, the stomach contents of 257 gannets shot at sea mainly south of Cape Columbine to Danger Point were examined (Rand 1959). This is the foraging area of gannets from Malgas Island (Berruti 1987). The data from the 1950's can therefore be compared with the monthly samples collected at the colonies between 1978 and 1987. Sample sizes were fewer than 15 in 15 of the 117 months sampled at Lambert's Bay and in nine of the 107 months sampled at Malgas Island (Berruti 1987, unpublished).

The measures of diet composition used are frequency of occurrence (F), where %F of species n = [number of samples containing species n/total number of samples] X 100 or mass (M) where %M of species n = [total mass of species n/total mass of all species] X 100.

RESULTS

Four species dominate the gannet diet: anchovy, pilchard, saury *Scomberesox saurus* and hake *Merluccius* species. There are definite seasonal cycles, which are consistent from year to year, in the occurrence of prey species in gannet diet at both colonies (Berruti 1987). There are peaks in the anchovy contribution to gannet diet in April to May at both colonies and at Malgas Island in September to December. Hake occurs in winter and is particularly important at Malgas Island, whereas saury occurs in summer, again particularly at Malgas Island.

On an interannual time scale, anchovy made up an increasing proportion of the diet at Lambert's Bay until 1982, and has followed a decreasing trend since then (Figure 1.7). At Malgas Island, the contribution of anchovy has tended to decline since 1978 (Figure 1.8). Hake increased from 1981 to 1985, but declined in 1986 and 1987. Saury was variable. Pilchard

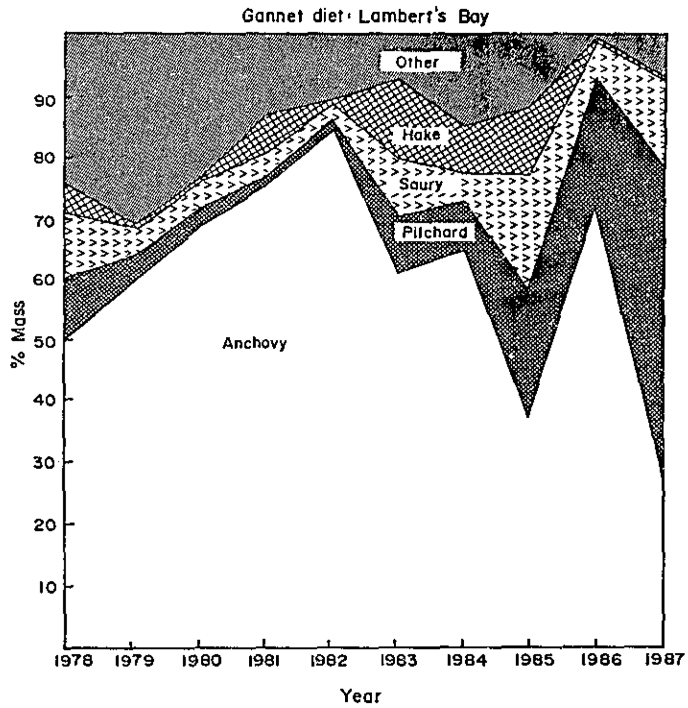

FIGURE 1.7 The annual diet composition (% mass) of Cape gannets at Lambert's Bay, 1978 to 1987.

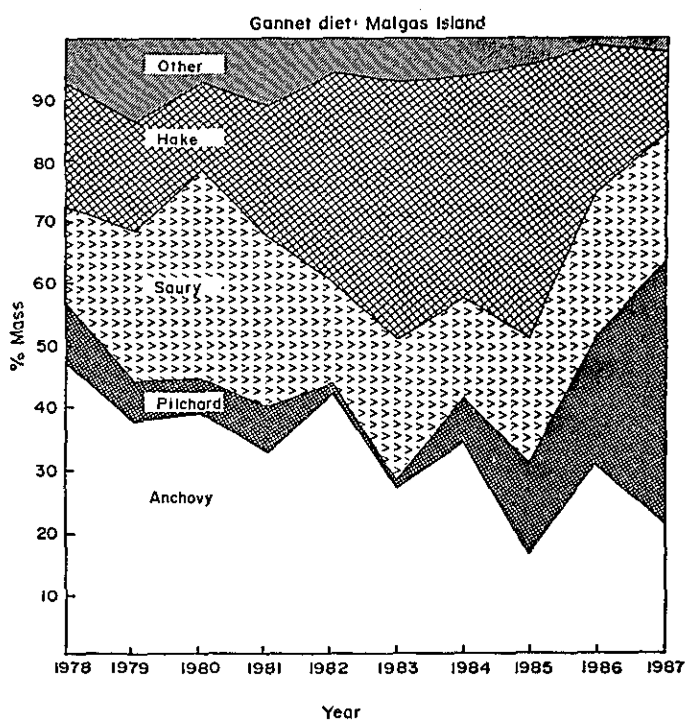

FIGURE 1.8 The annual diet composition (% mass) of Cape gannets at Malgas Island, 1978 to 1987.

declined at both colonies from 1978 until 1982 or 1983, and has since increased greatly to comprise about 50% of the diet at both localities.

Comparison with the 1950's shows that before the collapse of the pilchard stock in the 1960's, pilchard was even more important in gannet diet. However, the %F of pilchard in gannet diet has begun to approach levels reached in the 1950's.

DISCUSSION

It has been argued that pilchard is the preferred prey of gannets (Berruti 1987) and that the contribution of pilchard to gannet diet on an annual time scale is proportional to the absolute abundance of pilchard when pilchard abundance is low or moderate (Berruti and Colclough 1987). The contribution of anchovy and saury to gannet diet is inversely proportional to the the relative abundance of pilchard, whereas the occurrence of hake is inversely proportional to the relative abundance of epipelagic fishes (Berruti 1987, unpublished). Hake is eaten when the duration of foraging trips, meal size and breeding success of gannets suggest that other fish species are relatively scarce. The April to June peaks of anchovy in gannet diet are consistent with the winter occurrence of juvenile anchovy along the west coast. The summer occurrence of adult anchovy in gannet diet off the west coast has not previously been regarded as a regular occurrence.

Whether gannet diet reflects the absolute or relative abundance of pilchard, it is apparent that the biomass of pilchard has increased greatly since 1983, but has not reached the levels of the 1950's before the collapse of pilchard stocks. Gannet diet pinpoints the timing of changes in epipelagic fish populations, particularly pilchard, in relation to environmental and other perturbations.

REFERENCES

Berruti A 1987. The use of Cape Gannets Morus capensis in the management of the purse-seine fishery of the western Cape. PhD Thesis, University of Natal, Pietermaritzburg.

Berruti A and Colclough J 1987. A comparison of the quantity of pilchard in Cape gannet diet and commercial catches. In: Payne A I L, Gulland J A and Brink K H (editors) Benguela and comparable ecosystems. South African Journal of Marine Science 5, 863-870.

Davies D H 1955. The South African pilchard (Sardinops ocellata). Bird predators, 1953-4. Investigational Report of the Division of Fisheries of South Africa 18, 1-32.

Davies D H 1956. The South African pilchard (Sardinops ocellata) and maasbanker (Trachurus trachurus). Bird predators, 1954-55. Investigational Report of the Division of Fisheries of South Africa 23, 1-40.

Rand R W 1959. The biology of guano producing seabirds. The distribution, abundance and feeding habits of the Cape gannet, Morus capensis, off the south-western coast of the Cape Province. Investigational Report of the Division of Fisheries of South Africa 39, 1-36.

TIME SERIES OF MONTHLY TEMPERATURE DATA AT DEPTHS OF 0 to 100 M OFF WALVIS BAY, 1954 to 1967 AND 1978 to 1987

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DATA

Basic hydrographic data were collected monthly from certain stations off central Namibia from 1954 to 1967, and from 1978 to 1987 (Figure 1.9). A station about 16 km west of Walvis Bay in just over 100 m of water was selected to provide the data, presented here as time-depth profiles of temperature. This station was chosen for data continuity and because sampling was done to the bottom.

The temperature data were chiefly obtained by means of repeated dips with a Nansen-Pettersson insulated bottle, although on a few occasions reversing bottles, and more recently CTDs, were used. The Nansen-Pettersson thermometers are accurate and robust. They have a relative accuracy of 0,01°C and differences between thermometers have not been found to exceed 0,1°C in any instance from 1978 to 1987. A similar accuracy can be assumed for the period 1954 to 1967. Therefore the only possible errors are inaccurate position fixing, excessive drift whilst on station, and sampling depth variation due to the bottle not descending vertically. All should be small and would only apply to a single cruise, and therefore they are not significant in the present context. Similarly meso-scale events, which can influence conditions during a cruise, play a smaller role off central Namibia than at other more "exposed" sites (such as the Cape Peninsula), due to weaker, more constant winds, and a wide, shallow shelf. Therefore seasonal and interannual trends can be clearly followed without averaging the monthly observations.

SEASONAL FEATURES

Apart from the two "Benguela Niños" (Shannon et al 1986), interannual trends off Walvis Bay are comprised of persistent under or overdevelopment of particular seasonal features. These features are described briefly below.

Firstly, there is the intrusion of cool water of less than 12°C onto the shelf from June to August, and its retreat typically in December. This water generally reaches within 50 m of the surface, but can reach the surface for a month or two. Water of less than 11°C is not present in every year, and does not reach the surface. It is observed most often in September/October.

Secondly, there is the seasonal occurrence of water warmer than 14°C in the upper 20 m in summer largely due to solar heating. Such temperatures can also occur in spring and autumn, and occasionally in winter.

Thirdly, in autumn the 13°C isotherm often shows a dip, sometimes only to 30 m, sometimes to the bottom. The extent of the dip below 30 m indicates the degree of intrusion of warmer, more saline water off central Namibia as an undercurrent, autumn mixing inshore generally being restricted to 30 m depth.

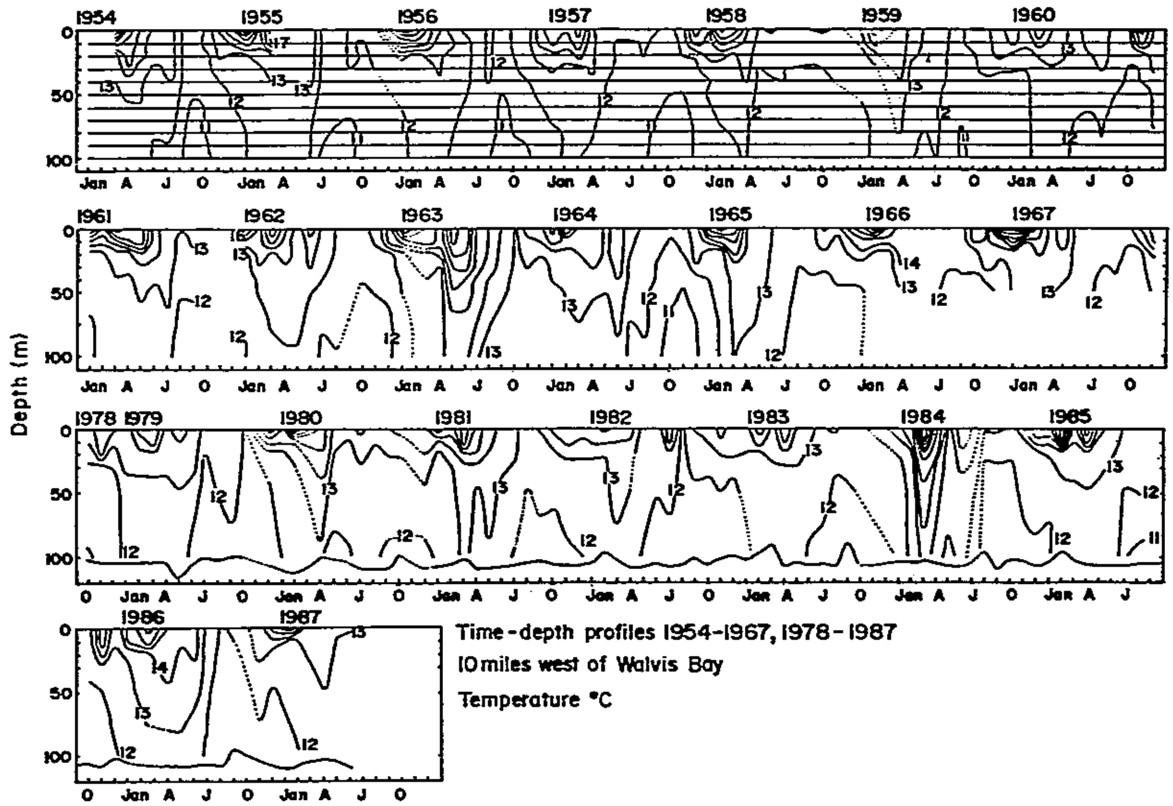

FIGURE 1.9 Time-depth profiles of temperature (°C) about 16 km west of Walvis Bay, 1954 to 1967 and 1978 to 1987.

INTERANNUAL FEATURES

First and foremost there are the documented occurrences of "Benguela Niños" in 1963 and 1984 (Stander and De Decker 1969; Shannon et al 1986). Only during these two "warm events", which have their immediate origin in the tropical Atlantic, was 14°C water encountered at 100 m depth (or even 50 m depth). The 1963 event was of longer duration and gained momentum from summer to winter, thereby excluding the intrusion of 12°C water onto the shelf. It may also have been part of a general warm period from 1961 to 1964. On the other hand the 1984 Niño in late summer/autumn was short and sharp, albeit followed by a little "hiccup" in winter. Nevertheless, nutrients in the source water for upwelling were dramatically reduced in comparison with other years (Boyd et al 1987). Secondly, interannual variation in the amount of 13°C water on the shelf can help to identify years of strong southerly advection, eg 1986 (Boyd et al 1987). Finally, it appears that cooler water occurred on the shelf from 1954 to 1958 than at any other time within the periods discussed.

SUMMARY AND DICUSSION

In summary, the influence of advection from tropical latitudes is clearly apparent as a seasonal undercurrent and in the two major Benguela Niños of 1963 and 1964. However, a question that arises is: "What is the cause of the regular occurrence of cool water on the shelf typically from July to

December?" Upwelling winds increase in strength from June to October and doubtless makes a contribution towards uplift. Alternatively, Shannon (1985) described how upwelling along the west coast of Africa may be primed by a coastally trapped wave reaching Namibia in July/August and the Cape a month later in August/September, and that local upwelling events are superimposed upon this. Other explanations consider cross-shelf digressions in the coastal arm of the subsurface cyclonic flow in the Cape Basin (G Nelson personal communication) or intensification of the South Atlantic Gyre (R Johnson personal communication). Possibly longer-term signals in the potential forcing factors may help to reveal the dominant cause on the seasonal level.

REFERENCES

Boyd A J, Salat J and Maso M 1987. The seasonal intrusion of relatively saline water on the shelf off northern and central Namibia. In: Payne A I L, Gulland I A and Brink K A (editors) The Benguela and comparable ecosystems. South African Journal of Marine Science 5, 107-120.

Shannon L V 1985. The Benguela Ecosystem. Part I. Evolution of the Benguela, physical features and processes. Oceanography and Marine Biology Annual Review 23, 105-182.

Shannon L V, Boyd A J, Brundrit G B and Taunton-Clark J 1986. On the existence of an El Niño-type phenomenon in the Benguela system. Journal of Marine Research 44, 495-520.

Stander G H and De Decker A H B 1969. Some physical and biological aspects of an oceanographic anomaly off South West Africa in 1963. Investigational Report of the Division of Sea Fisheries of South Africa 81, 1-46.

SEA LEVEL VARIABILITY IN THE BENGUELA SYSTEM

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Sea level is measured on tide gauges situated in harbours and the mean values taken over time periods of months and of years are of interest as integrated measures of the variability in the marine environment at the coast. The Permanent Service for Mean Sea Level (PSMSL) based at the Proudman Oceanographic Laboratory of the Bidston Observatory in England is responsible for the collection, publication, analysis and interpretation of sea level data from the global network of tide gauges. The longest records from around the world which satisfy the criteria of accuracy and datum stability demanded by the PSMSL cover a period of over a century and are shown in Figure 1.10 (Pugh et al unpublished). However, it is only over the past 30 years that the measurement of sea level has become routine at many sites and this is the case for the South African records which are derived from the tide gauges maintained by the South African Navy (Figure 1.10).

The very long records show a general upward trend of 10 to 15 cm per century and more detailed analysis confirms these figures (Hoffman et al 1984; Titus 1986). There also appears to be a definite structure on the decadal time scale and, on records such as the one from San Francisco, intermittent anomalously high events. The South African records are not long enough to exhibit the long-term upward trend, but could be long enough for the nature of their decadal structure to become clear.

The monthly mean sea level record at any site will show a strong seasonal signal which will tend to obscure the variability on longer time scales.

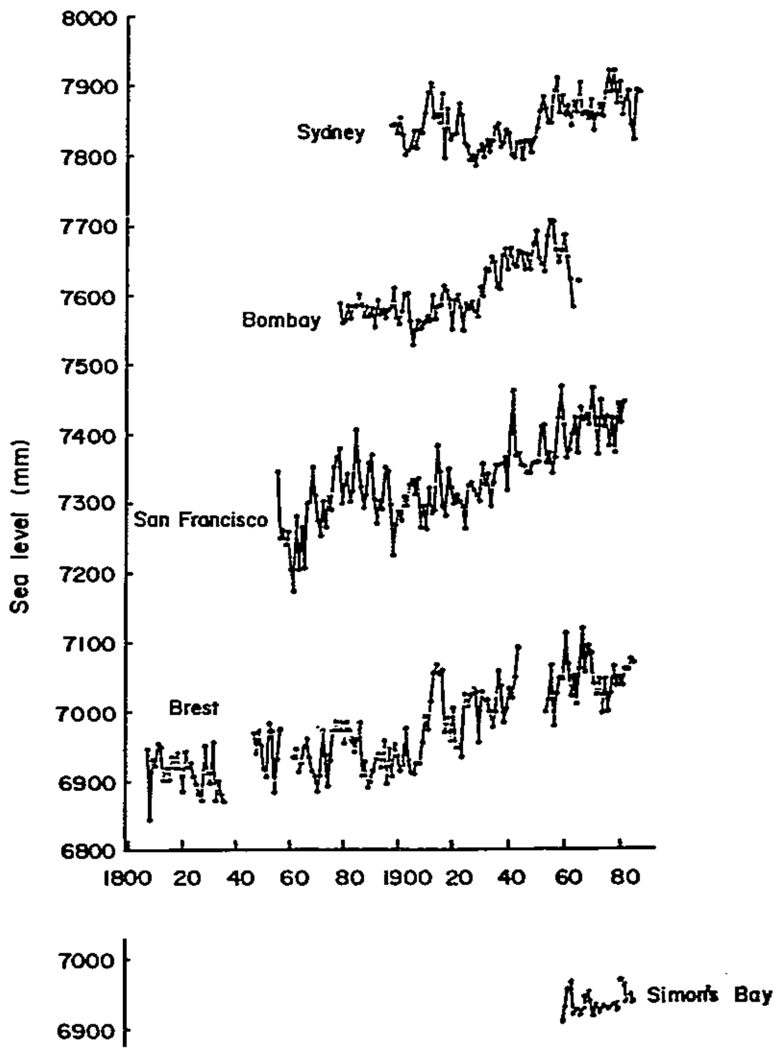

FIGURE 1.10 Annual mean values of sea level for some of the longest PSMSL records and for Simon's Bay. Each record has been given an arbitrary vertical offset for plotting purposes.

If long-term averages for each month of the year are calculated, this seasonal signal can be subtracted off the original record to produce a new record of monthly mean sea level anomalies. Such new records of anomalies for sites along the west coast of southern Africa are shown in Figure 1.11.

The structure in the Benguela system shows a consistency of response at the five sites from Walvis Bay to Simon's Bay, with periods of persistent high sea level anomaly and periods of persistent low sea level anomaly interspersed with anomalously high events (Brundrit 1984). Such a persistent and consistent interannual structure is typical of eastern ocean coastal upwelling regions (Enfield and Allen 1980; Brundrit et al 1987). The high events in 1963 (possibly 1974) and 1984 have also been recognized in time series of other environmental measurements of the Benguela system and have been termed Benguela Niños (Shannon et al 1986). Variability in the oceanic environment has an important influence on the levels of the principal exploited fish stocks of the Benguela system (Shannon et al in press).

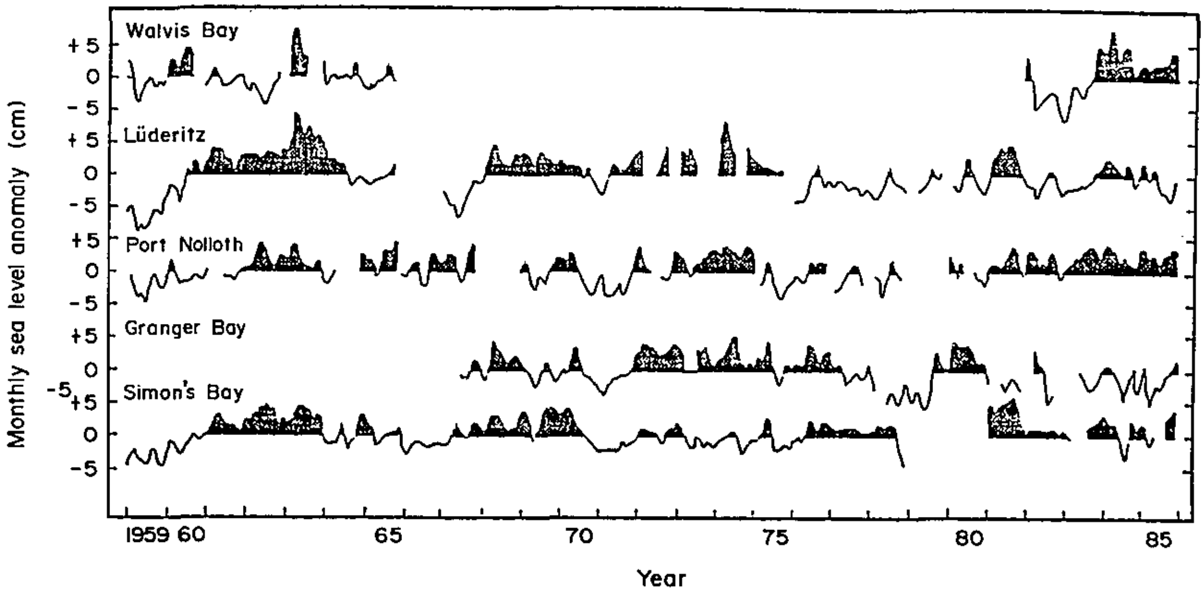

FIGURE 1.11 Pressure corrected monthly mean sea level anomalies for west coast stations.

REFERENCES

Brundrit G B 1984. Monthly mean sea level variability along the west coast of Southern Africa. South African Journal of Marine Science 2, 195-203.

Brundrit G B, de Cuevas B A and Shipley A M 1987. Long-term sea level variability in the eastern South Atlantic and a comparison with that in the eastern Pacific. In: Payne A I L, Gulland J A and Brink K H (editors) The Benguela and comparable ecosystems. South African Journal of Marine Science 5, 73-78.

Enfield D B and Allen J S 1980. On the structure and dynamics of monthly sea level anomalies along the Pacific coast of North and South America. Journal of Physical Oceanography 10, 557-578.

Hoffman J S, Keyes D and Titus J G 1984. Projecting Future Sea Level Rise. United States Environmental Protection Agency, Washington.

Shannon L V, Boyd A J, Brundrit G B and Taunton-Clark J 1986. On the existence of an El Niño-type phenomenon in the Benguela system. Journal of Marine Research 44, 495-520.

Shannon L V, Crawford R J M, Brundrit G B and Underhill L (In press). Response of fish populations in the Benguela ecosystem to environmental change. Journal du Conseil International pour L'Exploration de la Mer.

Titus J G 1986. Effects of changes in stratospheric ozone and global climate, Volume 4: sea level rise. United States Environmental Protection Agency, Washington.

ABUNDANCE AND SPATIAL DISTRIBUTION OF PELAGIC FISH LARVAE IN THE NORTHERN BENGUELA REGION

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INTRODUCTION

Time series are presented for the abundance and spatial distribution of larvae of the three most important epipelagic fish species caught off Namibia. The information was derived from the results of 52 ichthyoplankton cruises analysed in part by O'Toole (1977), Badenhorst and Boyd (1980) and Hewitson (1987). Mesh sizes of 0,50 mm and 0,94 mm were used from 1972 to 1974, but a 0,30 mm mesh was used thereafter. Stations north and south of the area sampled during the earlier period were included in the survey area after 1974 and contributed high numbers of larvae.

Figure 1.12 depicts larval abundance in terms of the mean numbers of larvae under 10 m^2 of surface area. Mean, rather than absolute abundances, are used because of the variable sampling intensity between cruises. O'Toole's (1977) larval abundances (those for 1972/73 and 1973/74) are considerably underestimated due to the loss of larvae by extrusion through the larger meshes. Larval abundance per station is highly variable due to patchiness in larval distribution and standard deviations are typically one to two times the mean and more. As an indication of the spatial distribution of the larvae, cumulative percentages of larval numbers for the areas shaded and numbered in Figure 1.13, are presented for each cruise in Figure 1.14.

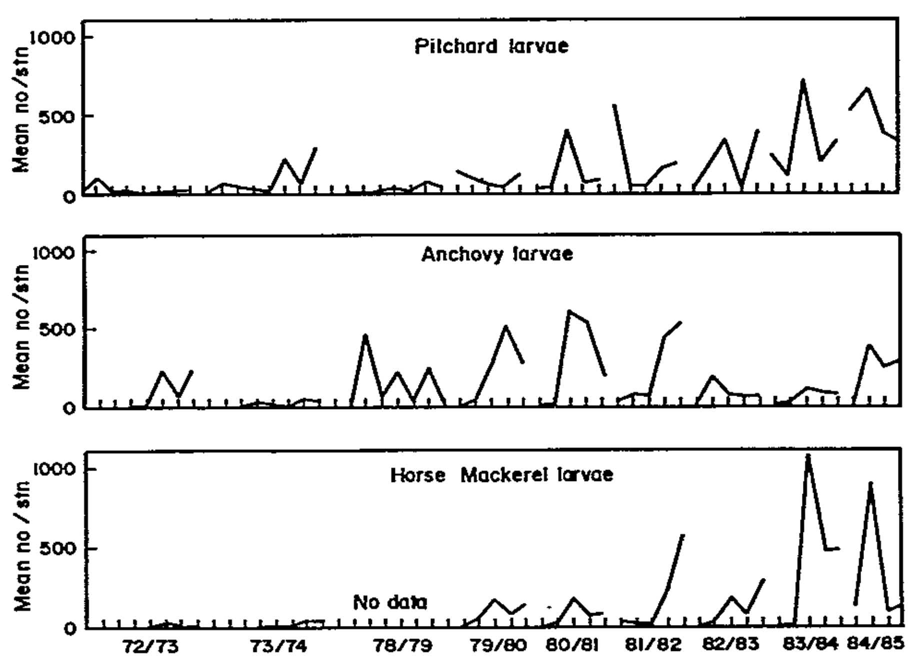

FIGURE 1.12 Mean numbers of larvae of three fish species at stations where larvae were present on sampling cruises conducted between 1972 and 1985.

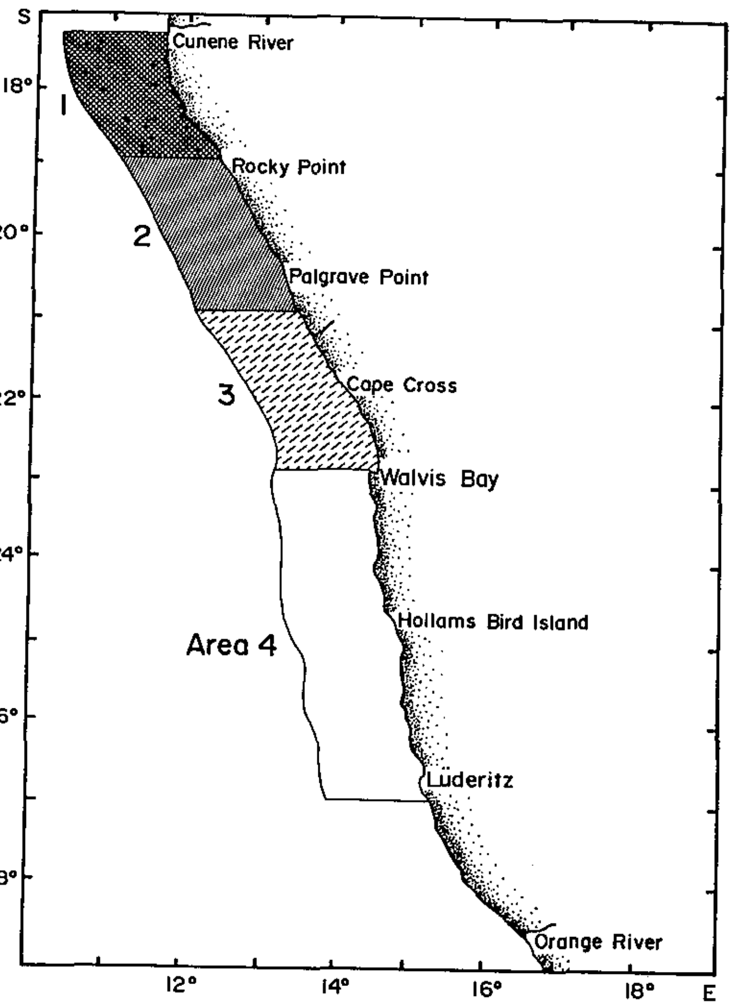

FIGURE 1.13 The Namibian coastline showing the areas referred to in Figure 1.14.

TRENDS IN COMMERCIAL FISH CATCHES

Off Namibia catches of pilchard *Sardinops* decreased sharply after the mid 1970's to a low point in 1980. Since then quotas have limited the annual landings to between 40 and 60 thousand tons. Catches of anchovy *Engraulis* have also shown an overall downward trend. Purse-seine catches of horse mackerel *Trachurus* have been variable.

TRENDS IN LARVAL ABUNDANCE (Figure 1.12)

1. PILCHARD - If one assumes that there was undersampling during the first two spawning seasons, for reasons explained above, abundances are likely to have decreased from initial high levels to low levels in period 1978 to 1981. There was then a steady increase in the following spawning seasons.

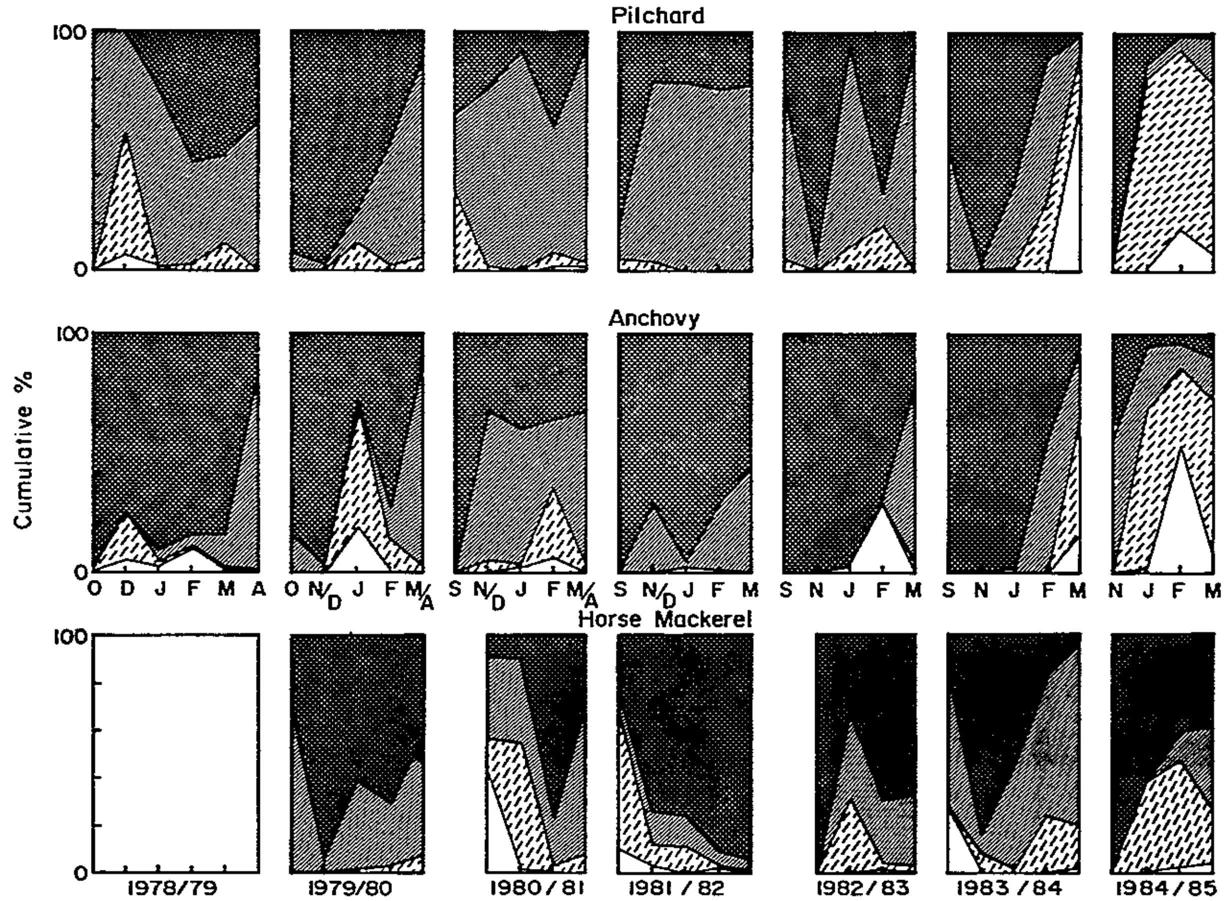

FIGURE 1.14 The percentage contribution of various areas (see Figure 1.13) to the numbers of larvae of three fish species sampled during each cruise off Namibia, 1978 to 1985.

2. ANCHOVY - Overall larval abundances were high initially and then showed a downward trend to reach minima in 1982/83 and 1983/84.

3. HORSE MACKEREL - Larval abundances have increased in the 1980's reaching a maximum in the 1983/84 spawning season.

TRENDS - SPATIAL DISTRIBUTION OF LARVAE (Figure 1.14)

As comparable data for 1972/73 and 1973/74 were not available, only spatial distributions for the seven spawning seasons 1978/79 to 1984/85 are shown in Figure 1.14. The general trends are:

1. there is often a southward shift in spatial distribution, generally from area 1 to area 2, of all species in late summer;

2. the larvae of all three species showed a marked southward shift in distribution, from area 1 to areas 2, 3 and, in the case of pilchard and anchovy, 4 between January and March 1984 during the anomalously warm Benguela Niño event of that summer; and

3. the southward shift in distribution that occurred in late summer 1984 continued into the 1984/85 spawning season.

DISCUSSION

After the low levels of the late 1970's and early 1980's an increase in the abundance of pilchard larvae was found. It has been shown that increased larval numbers do not necessarily result in a successful recruitment, although the high larval abundances of the 1983/84 spawning season did produce a strong pilchard year class (Thomas 1986). Conversely, the very low abundances of larval anchovy in 1982/83 and 1983/84 occurred in a period of decreased anchovy landings. Environmental conditions of the summer of 1984 that led to the southward shift of pilchard larvae also resulted in a southward displacemant of the parent stock (Thomas 1986). The distribution of pilchard larvae in the 1984/85 spawning season suggests that the parent population had not at that time returned to the north. The same observation may be made concerning horse mackerel, although with anchovy there appears to have been a partial return to the north.

REFERENCES

Badenhorst A and Boyd A J 1980. Distributional ecology of the larvae and juveniles of the anchovy Engraulis capensis Gilchrist in relation to the hydrological environment of South West Africa, 1978/79. Fisheries Bulletin South Africa 9, 23-31.

Hewitson J D 1987. Spatial and temporal distribution of the larvae of the anchovy, Engraulis capensis Gilchrist in the northern Benguela region. MSc Thesis, University of Port Elizabeth, Port Elizabeth.

O'Toole M J 1977. Investigations into some important fish larvae in the South-east Atlantic in relation to the hydrological environment. PhD Thesis, University of Cape Town, Cape Town.

Thomas R M 1986. The Namibian pilchard: the 1985 season, assessment for 1952 to 1985 and recommendations for 1986. Collection of Scientific Papers International Commission for the South-east Atlantic Fisheries 13(2), 243-269.

WIND PATTERNS IN THE SOUTH-WEST CAPE

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INTRODUCTION

Data on wind speed and direction, estimated by lighthouse keepers at Cape Columbine and Cape Point at hourly intervals, have been analysed. Records extend back to 1960 at Cape Point and 1957 at Cape Columbine. These manual estimates are compared with readings from nearby automatic weather stations (Aanderaa), installed within the past five years.

LOCATIONS AND METHOD

Cape Point lighthouse is at a height of 227 m. It has a deflection plate anemometer and a cup anemometer but these are not used because of localized anomalies. The automatic weather station is at Olifantsbos, 10 km distant, on a low sand dune field about 10 to 15 m above sea level, on a five-meter pole.

Cape Columbine lighthouse is at a height of 60 m, and lighthouse keepers have been using a cup anemometer since 1983/84. Prior to this manual estimates were made using a deflection plate anemometer. The automatic weather station is 700 m away, close to the rocks at about 10 m above sea level.

Data are loaded into a Wind Analysis System for editing, checking and conversion into wind roses, progressive vector diagrams, displacements and other suitable formats.

COMPARISONS BETWEEN LIGHTHOUSE AND AUTOMATIC DATA

January and May 1983 (Cape Point) and January and May 1985 (Cape Columbine) have been used for the comparisons (Table 1.1). It is rare that a complete time coverage of the entire month by both systems is achieved. Lighthouse data differs from information collected at the automatic stations as follows:

<u>Wind Roses</u>

Cape Point
- all the southerly winds are called SE, and speeds are overestimated.
- northerly and westerly winds are underestimated.

Cape Columbine
- southerly winds are overestimated, south-westerly winds are called S.
- a limited number of compass points are used.

TABLE 1.1 Comparisons between observations by lighthouse keepers and automatic weather stations on wind at Cape Point and Cape Columbine

	Cape Point lighthouse	Olifantsbos WX station	Cape Columbine lighthouse	Cape Columbine WX station
	January 1983		January 1985	
Average speed	7,5 m s^{-1}	5,1 m s^{-1}	5,9 m s^{-1}	4,3 m s^{-1}
% Calms	6,0	0,0	10,2	0,0
NS Displacement	9647,5 km	6819,9 km	11005,0 km	5677,9 km
EW Displacement	-1567,9 km	-1588,2 km	88,5 km	2435,5 km
	May 1983		May 1985	
Average speed	6,8 m s^{-1}	5,0 m s^{-1}	4,4 m s^{-1}	4,2 m s^{-1}
% Calms	12,0	0,4	8,2	0,0
NS Displacement	360,1 km	-3109,7 km	4651,6 km	3694,5 km
EW Displacement	1976,0 km	574,0 km	100,2 km	-1072,5 km

Speed Histogram

A bias towards higher speed estimates is obvious, with readings about 40% higher. This may be a function of the disparity in heights.

Wind Events

Stick vectors for both Cape Point and Cape Columbine indicate that changes in direction are well documented. It is clear that speeds are overestimated and intermediate directions are missed.

Progressive Vector Diagrams

This again shows the exaggeration of SE or S winds and the underestimation of N or W winds.

Table of Comparison

The displacements show that serious discrepancies can occur, particularly for northerly winds. For the long-term series, one needs to assume that the biases have remained constant over the whole period. Differences may be due to topography, distance apart, the effects of a lee shore versus a windward shore and the height of the measuring platform, both above sea level and above the ground.

RESULTS FROM LIGHTHOUSE DATA

Seasonality

Both lighthouses exhibit strong seasonality in the wind patterns, with the southerly winds dominating during summer and decreasing during winter. This is in part artefactual because of the biases in overestimating S winds and underestimating N winds.

Interannual variations

Cape Point - marked decreases in southerly winds occurred in 1965/66, and 1982/83, with slight decreases in 1968/69 and 1976/77.

Cape Columbine - much steadier winds, a slight peak in 1962/63, a decline to 1964/65, and a marked drop from 1979/80 to 1986/87.

Alongshore and cross-shelf components (see Figure 1.15)

Cape Point
- summer - dip in mid-1960's, slight peak in mid-1970's, sharp dip in 1982/83, but not as low as 1965/66.
- winter - no clear trends or patterns.

Cape Columbine
- summer - erratic throughout 1960's, rise in late 1970's, decline in 1980's.
- winter - no clear patterns.

CORRELATION WITH OCEANOGRAPHIC DATA

Moderate correlations (r=0,7) between the area of a cool-water tongue and the winds during the seven-day period prior to observations were found by Lutjeharms (1980) and Taunton-Clark (1985), so wind is related to upwelling.

Poor correlations (r=0,2 to 0,3) were found between wind, lagged over different periods ranging from one to 30 days prior to measurement, and zooplankton or phytoplankton stocks in the cool-water tongue downstream from the Cape Peninsula upwelling centre.

Poor correlations between annual wind displacements and fish catches were observed.

CONCLUSIONS

Winds only affect the near-surface current patterns. Deeper currents are due to large-scale, remote forcing which affects a large part of the biota.

There are good and bad effects of upwelling, eg nutrient enrichment versus excessive mixing, and marine animals are probably adapted to some sort of mean or optimal conditions or to a range of variability.

On an annual basis, there were no strong trends in the wind stress during the past 20 years, apart from relatively short-lived anomalies. The changes in fish populations as indicated by industrial catches, ie a decline in pilchard abundance and a rise in anchovy abundance, may therefore not be ascribed to changes in annual local wind stress, but perhaps to some remote forcing functions.

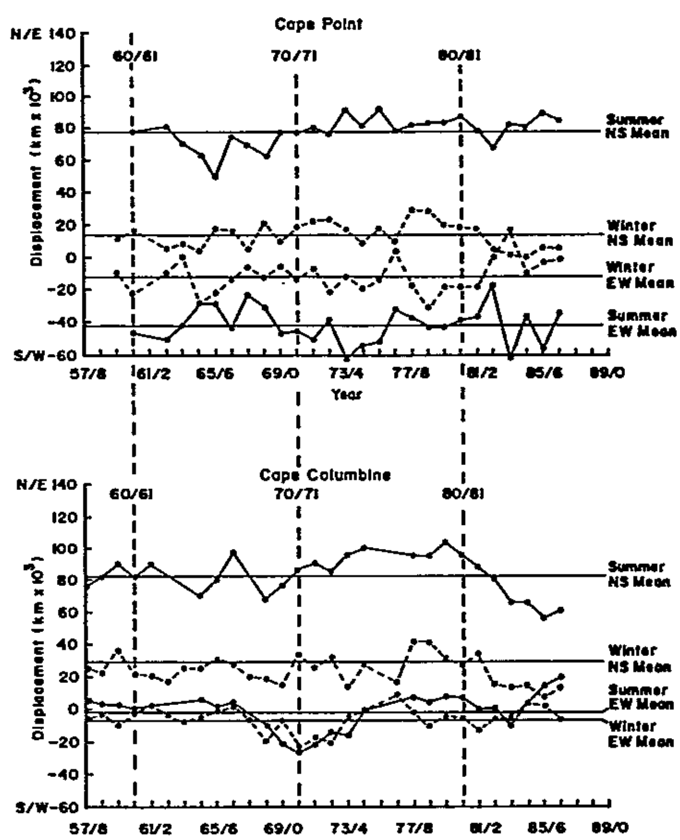

FIGURE 1.15 Interannual variation in summer and winter wind displacements at Cape Point and Cape Columbine, 1957/58 to 1986/87.

There is a dearth of reliable, unbiased, automatic recorders on exposed locations, including moored buoys, along the South African coastline.

REFERENCES

Lutjeharms J R E 1980. The influence of the Agulhas Current. Research Report of the South African Council for Scientific and Industrial Research 376, 14 pp.

Taunton-Clark J 1985. The formation, growth and decay of upwelling tongues in response to the mesoscale wind field during summer. In: Shannon L V (editor) South African Ocean Colour and Upwelling Experiment. Sea Fisheries Research Institute, Cape Town, 47-61.

FOSSIL FISH SCALES - PAST FISH POPULATIONS

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[2] Foundation for Research Development

A number of sediment cores have been collected from the bottom of the sea on the Walvis Shelf off Namibia by the Marine Geoscience Unit of the University of Cape Town (UCT). These cores comprise anoxic diatomaceous muds in which fish debris such as scales are extremely well preserved. An initial pilot study carried out by Shackleton (1986) showed that the sediments, like those off California (Soutar and Isaacs 1974) and Peru (de Vries and Pearcy 1982) hold potential for elucidating fluctuations of past fish populations.

The data presented here are counts of the numbers of scales of pilchard *Sardinops ocellata*, anchovy *Engraulis capensis* and, in some cases, horse mackerel *Trachurus trachurus* per centimetre downcore. An appreciation of the structure of the sediment containing these scales is a prerequisite before basing any conclusions on scale counts. The anoxic conditions which foster the preservation of fish debris also tend to exclude the benthic burrowing organisms which would disturb any depositional sequences. However, active bottom currents and erosion could distort the record. Evidence of these are cross bedding, lag deposits and concentrations of specific items such as faecal pellets. Ideally, the undisturbed sedimentary record is recognized by fine laminations which, if they are caused by seasonal variations in sedimentation, form varves.

Recent research (Shackleton in press) has indicated that most, if not all, fish scales in the sediment originate from scale-shedding by live fish, rather than by accumulation from dead fish. Furthermore, scales have been shown to be shed at different rates by pilchard and anchovy, thereby introducing a bias that must be taken into account when estimating fish populations from scale counts.

The scale data presented here are from two sources: i) a small cross-section core collected using a vibrocorer in 1983 and ii) 30 cm x 30 cm cross-section cores collected using the megacorer designed at the University of Cape Town (Johnson 1987). A detailed study of a 25 cm length of finely-laminated sediment collected by the vibrocorer has been reported on elsewhere (Shackleton 1986, 1987). This study showed that at least the central portion of the Namibian shelf appears to have been dominated by pilchard in the past, unlike the Californian and Peruvian systems (Soutar and Isaacs 1974; de Vries and Pearcy 1982), and that major prefishery stock fluctuations appear to have taken place (Figure 1.16). The data collected using the megacorer is being worked up at present. Preliminary results link fluctuations in the relative proportions of the scales of pilchard, anchovy and horse mackerel with changes in sea surface temperature as determined from counts of planktonic foraminifera in the sediments. The fish populations seem to be responding to changes in climate as, when the Medieval Warm Epoch deteriorated into a colder period (the Little Ice Age?), horse mackerel and anchovy increased relative to pilchard. Pilchard began to increase relative to the others during the cold period, but appeared to do best when the climate began to ameliorate (Figure 1.17).

As yet the cores have not been dated and only estimates can be made of the periods being looked at. However, the length of the data is unique. It potentially extends back some 7 000 years, showing decadal fluctuations in both relative and absolute fish populations which can then be related to changes in sea surface temperature. Interpreted with caution this data represents the best information available on natural, prefishery fluctuations of populations.

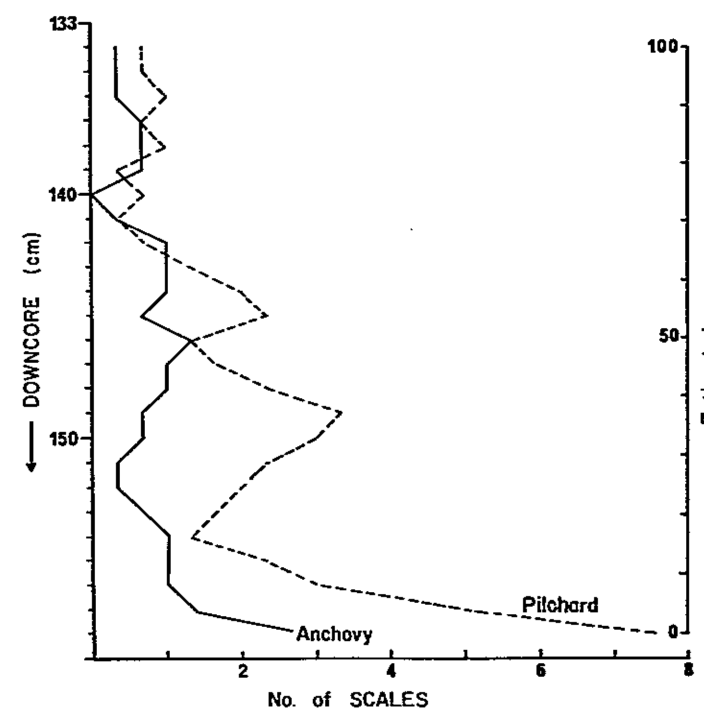

FIGURE 1.16 Counts of pilchard and anchovy scales down a 25 cm length of the pilot core. Counts have been smoothed by plotting a three-point running average.

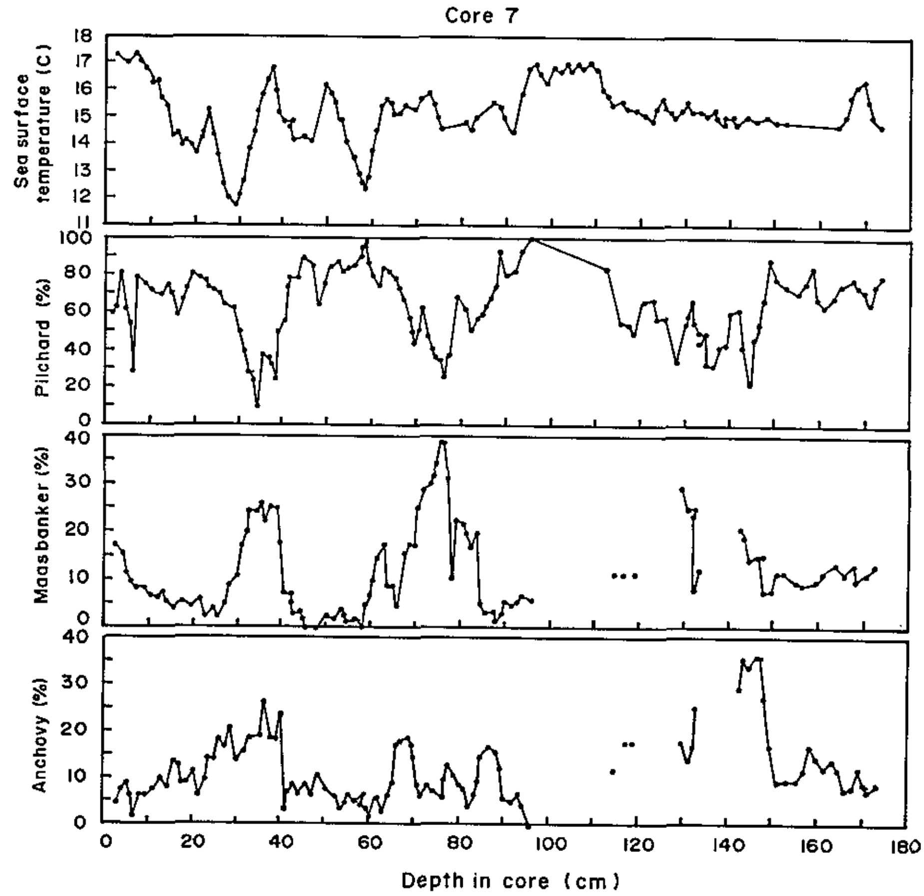

FIGURE 1.17 Records of sea surface temperature and fish scale proportions from core 7. The estimates of sea surface temperature come from counts of planktonic foraminifera. All curves have been smoothed with a three-point running average.

REFERENCES

De Vries T J and W G Pearcy 1982. Fish debris in sediments of the upwelling zone off central Peru; a late Quaternary record. Deep Sea Research 28(1A), 87-109.

Johnson R F 1987. A history of climate and marine productivity from sediments off the West coast of southern Africa. Joint Geological Survey/UCT Technical Report 17, 101-107.

Shackleton L Y 1986. An assessment of the reliability of fossil pilchard and anchovy scales as fish population indicators off Namibia. MSc Thesis, University of Cape Town, Cape Town.

Shackleton L Y 1987. A comparative study of fossil fish scales from three upwelling regions. South African Journal of Marine Science 5, 79-84.

Shackleton L Y (In press). Scale shedding - an important factor in fossil fish scale studies. Journal du Conseil International pour L'Exploration de la Mer.

Soutar A and Isaacs J D 1974. Abundance of pelagic fish during the 19th and 20th centuries as recorded in anaerobic sediment off the Californias. Fishery Bulletin, Washington 72(2), 257-273.

DIET AND POPULATION TRENDS OF JACKASS PENGUINS AND SWIFT TERNS ON THE WEST COAST OF SOUTH AFRICA, 1953 to 1986

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Jackass penguins *Spheniscus demersus* have decreased in numbers of unknown magnitude since the early 1900's on the west coast of South Africa. Shelton et al (1984) review factors influencing the species' population status. In the 1950's stomach samples were obtained by shooting birds at sea (Rand 1960). More recent diet studies (Wilson 1985; Duffy et al 1987) have used a water off-loading technique (Wilson 1984).

The relative abundance of anchovy *Engraulis capensis* in the diet of jackass penguins increased from two per cent in 1954/55 to 84% in 1978 (Figure 1.18). Between 1978 and 1982 the proportion of anchovy in the diet decreased to 40%, thereafter increasing to 88% in 1986. There was no annual trend in the relative percentage abundance of anchovy between 1980 and 1986 (Duffy et al 1987). The proportion of pilchard *Sardinops ocellata* dropped from 32% by mass of all fish prey between 1954 and 1956 (Rand 1960) to less than one per cent at present (Wilson 1985). The switch from pilchard to anchovy is probably attributable to the collapse of the pilchard fishery in the mid 1960's (Randall and Randall 1986). The reduced relative abundance of anchovy in 1982 may be related to the 1982/83 warm water event (Shannon et al 1984).

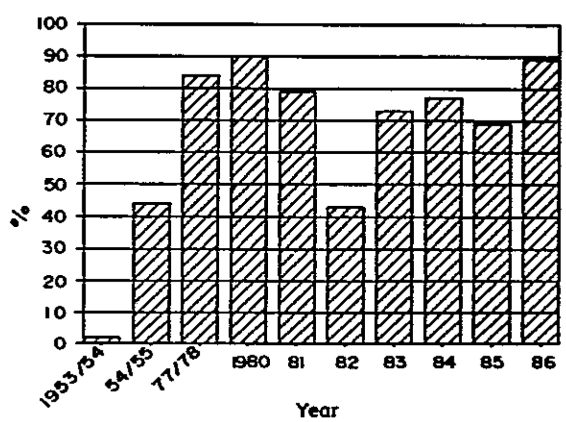

FIGURE 1.18 Annual variability is the percentage relative abundance of anchovy in the diet of jackass penguins during 1953/54 to 1986. (Data for 1953/54 to 1977/78 from Burger and Cooper (1984)).

La Cock et al (1987) observed a jackass penguin colony at Marcus Island monthly from 1979 to 1985. Annual total numbers of clutches laid, eggs hatched and young fledged decreased to very low levels (Figure 1.19). Breeding attempts decreased by 14% per year during 1979 to 1985, with a 50% decrease in clutches laid between 1983 and 1985. This decrease was significantly correlated with a decrease in annual adult survival rate (from 70,4% in 1979/80 to 33,3% in 1984/85; $r = 1,00$; $P < 0,005$; $n = 6$) (La Cock et al 1987).

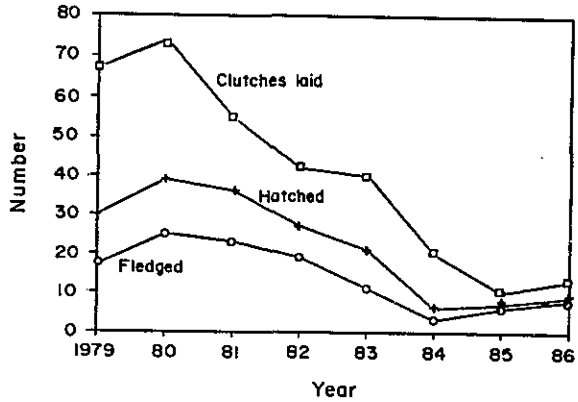

FIGURE 1.19 Annual total numbers of jackass penguin clutches laid, nests with eggs hatched and nests with young fledged during 1979 to 1986.

Annual hatching and annual fledging success varied between 30 to 65% and 15 to 61%, respectively, during 1979 to 1986. Annual hatching and fledging success reached a peak in 1982, decreased between 1982 and 1984, and has been increasing since 1984 (Figure 1.20). Therefore, the population decrease cannot be entirely explained by reduced breeding success (La Cock et al 1987) suggesting that competition from the commercial pilchard fishery does not affect penguins breeding at Marcus Island (Duffy et al 1987).

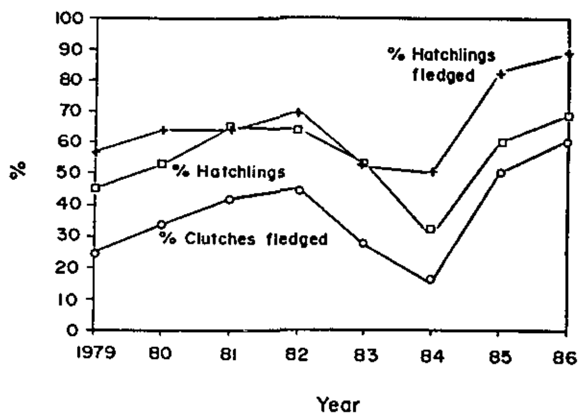

FIGURE 1.20 Annual percentage fledging and hatching success of jackass penguins during 1979 to 1986.

Although a switch to an anchovy dominated diet, as well as reduced breeding success and low survival of first-year penguins (La Cock et al 1987), have been implicated in the continued population decrease of jackass penguins on the west coast of South Africa, the underlying causes of the last two factors have yet to be identified.

The diet of swift terns *Sterna bergii* in Saldanha Bay was investigated over a 10-year period by collecting regurgitations from chicks during annual ringing operations. In 1984, regurgitations were collected at weekly intervals between February and April (Walter et al 1987a).

Anchovy was the most abundant prey in seven of nine years. The proportion of anchovy in the diet varied between 12 and 93% by number (Figure 1.21). Anchovy length varied from 33 to 117 mm and mass from 0,2 to 12,8 g. During 1984, anchovy in fishery landings were significantly larger than those taken by swift terns. Relative abundance of anchovy in the tern's diet increased from 12% in 1977 to 77% in 1982. Thereafter, the proportion in the diet decreased until 1984 before rising to over 90% in 1986, the highest recorded proportion of anchovy in the diet. The relative abundance of anchovy in fishery landings decreased sharply from 100% in 1979 to 48% in 1981, and again from 70% in 1982 to less than five per cent in 1983. Thereafter, it rose by 80% and remained high until 1986. There was no relationship between the proportion of anchovy in the diet of swift terns and fishery landings at time scales of weeks, months and years (Walter et al 1987b).

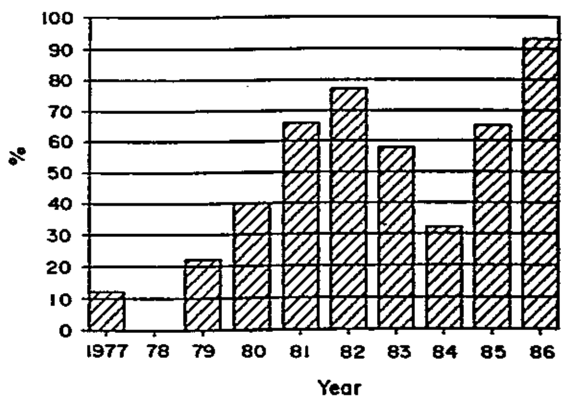

FIGURE 1.21 Annual variability in relative abundance of anchovy in the diet of swift tern chicks during 1979 to 1986.

REFERENCES

Burger A E and Cooper J 1984. The effect of fisheries on seabirds in South Africa and Namibia. In: Nettleship D N, Sanger G A and Springer P F (editors) Marine Birds: Their feeding ecology and commercial fisheries relationships. Minister of Supply and Services Canada.

Duffy D C, Wilson R P, Ricklefs R E, Broni S C and Veldhuis H 1987. Penguins and purse-seiners: competition or coexistence? National Geographic Research 3, 480-488.

La Cock G D, Duffy D C and Cooper J 1987. Population dynamics of the african penguin Spheniscus demersus at Marcus Island in the Benguela upwelling ecosystem: 1979 to 1985. Biological Conservation 40, 117-126.

Rand R W 1960. The biology of guano-producing sea-birds. The distribution, abundance and feeding habits of the Cape penguin, Spheniscus demersus, off the south-western coast of the Cape Province. Investigational Report of the Division of Sea Fisheries 41, 1-28.

Randall R M and Randall B M 1986. The diet of jackass penguins Spheniscus demersus in Algoa Bay, South Africa, and its bearing on population declines elsewhere. Biological Conservation 37, 119-134.

Shannon L V, Crawford R J M and Duffy D C 1984. Pelagic fisheries and warm events: a comparative study. South African Journal of Science 80, 51-60.

Shelton P A, Crawford R J M, Cooper J and Brooke R K 1984. Distribution, population size and conservation of the jackass penguin Spheniscus demersus. South African Journal of Marine Science 2, 217-257.

Walter C B, Cooper J and Suter W 1987a. Diet of swift tern chicks in the Saldanha Bay region, South Africa. Ostrich 58, 49-53.

Walter C B, Duffy D C, Cooper J and Suter W 1987b. Swift tern diets and fishery landings in the Benguela upwelling region, South Africa. South African Journal of Wildlife Research 17(4), 139-141.

Wilson R P 1984. An improved stomach pump for penguins and other seabirds. Journal of Field Ornithology 55(1), 109-111.

Wilson R P 1985. Seasonality in diet and breeding success of the jackass penguin Spheniscus demersus. Journal fur Ornithologie 126(1), 53-62.

SEA SURFACE TEMPERATURE RECORDS AT SUBANTARCTIC ISLANDS

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INTRODUCTION

Long-term records in the marine environment, with the exception of tidal records, are scarce. Records in the open or deep ocean, away from the influence of continental land masses, are particularly rare (World Climate Programme 1981). This is so to a superlative degree in the deep sea of the Southern Hemisphere. We have attempted to find all long-term, sequential records of daily temperature readings in the deep sea vicinity of southern Africa. Such readings have only been taken at three islands, namely Tristan da Cunha, Gough and Marion. A portrayal of the records and their durations for these three islands are given in Figure 1.22. A few important facts are immediately apparent from this figure. In the first place there does not exist an unbroken record of daily temperature readings at any of these three islands exceeding that of eight and a half years at Gough Island. We hope to fill the nine month gap (1983) in the Marion Island record to provide us with a 12-year continuous record.

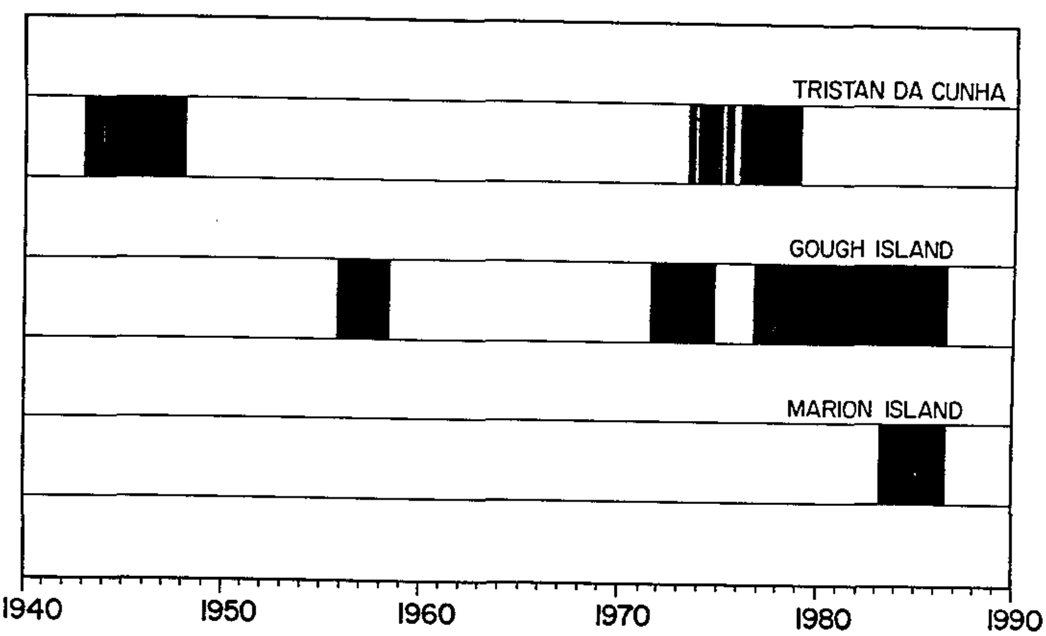

FIGURE 1.22 Duration of daily sea surface temperature records at the islands of Tristan da Cunha, Gough and Marion.

RESULTS

For the Tristan da Cunha, Gough and Marion time series, averages for each individual month and the respective standard deviations have been calculated. The climatic mean based on all available data has also been determined. The climatic mean is distributed almost sinusoidally for both Marion and Gough Islands. The average sea surface temperature at Marion Island is considerably lower than at Gough Island and the seasonal variations smaller, as would be expected from Marion's higher latitude.

The seasonal signal inherent in the monthly mean temperature records was removed to establish the interannual differences. Some results are shown in Figure 1.23 and a number of interesting trends are immediately apparent. In the first place it is clear that the sea surface temperature was above normal at Gough Island for the years 1981 to 1983 but below normal since then. The maximum thermal deviation was in early 1982, which precedes the "warm event" of that year observed elsewhere (see Shannon 1983) by about 12 months. The sea surface temperatures at Marion Island were above normal from 1983 to the beginning of 1986 in contrast to that at Gough Island. According to Philander (1983) 1976 can be considered as an ENSO (El Niño/Southern Oscillation) year. It is interesting to note that a thermal deviation of about three degrees Centigrade, the largest in this record, occurred at Tristan da Cunha in 1976/77. Another notable feature of the Tristan record is the trend towards lower than average temperatures for the years 1943 to 1945.

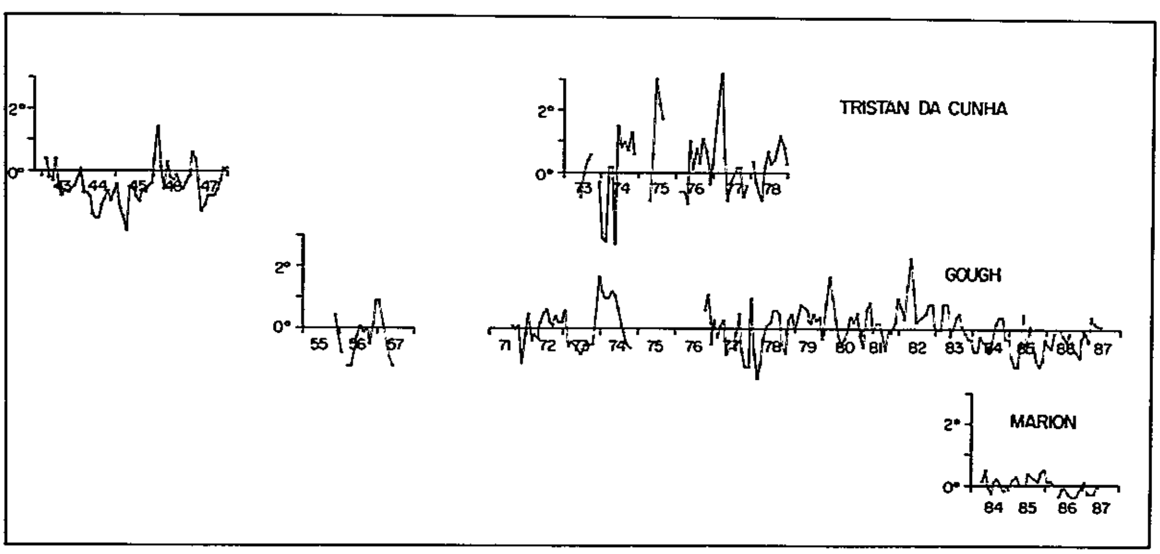

FIGURE 1.23 Monthly deviations from the climatological mean for each month for all available temperature records at the islands of Tristan da Cunha, Gough and Marion.

CONCLUSION

The initial stimulus for this investigation was a question raised on the possibility of a seasonal migration of the Sub-Tropical Convergence through Tristan da Cunha. Local fishermen claim that once this ocean front has travelled past Tristan in the autumn the fisheries become more productive (A E F Heydorn personal communication). Measurements made at the island group seem to confirm such a frontal migration (Shannon 1970). Both Gough and Tristan lie in a belt where sea surface thermal fronts corresponding to the Sub-Tropical Convergence are found (Meeuwis et al 1987). The present data are not able to confirm such a seasonal migration of the front. A further measurement program has been initiated in an attempt to establish the validity of this hypothesis.

REFERENCES

Meeuwis J M, Lutjeharms J R E, Hall L H and Van Rensburg P A J 1987. Ligging en aard van die Subtropiese Konvergensie in die Suid-Atlantiese Oseaan. Sesde Nasionale Oseanografiese Simposium, 6-10 Julie 1987, Stellenbosch, Simposium Handboek en Opsommings van Referate en Plakkate, p A-10.

Philander S 1983. El Niño - Southern Oscillation phenomena. Nature 302, 295-301.

Shannon L V 1970. Studies of alpha-radioactivity in the marine environment. Volumes I and II. PhD Thesis, University of Cape Town, Cape Town.

Shannon L V 1983. Preliminary report of the southern Benguela warm event, 1982 to 1983. Tropical Ocean-Atmosphere Newsletter 22, 8-9.

World Climate Programme 1981. Papers presented at the meeting on time series of ocean measurements. Tokyo, 11-15 May 1981. World Climate Programme Series, WCP-21. 400 pp.

CHANGE IN WINTER MOVEMENTS OF CAPE GANNETS

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INTRODUCTION

The South African Bird Ringing Unit (SAFRING) holds long-term data in the form of bird ringing and recovery records. Between one and two per cent of birds are subsequently recovered.

The Cape gannet *Morus capensis*, a colonially breeding, mainly inshore seabird, was first ringed in 1951. Altogether over 77 400 gannets have been ringed in three distinct periods and 849 recoveries involving movements from the ringing site have been recorded.

RESULTS

Cape gannets have been ringed at the following islands: Mercury (24°43S, 14°50E); Ichaboe (26°17S, 14°56E); Possession (27°01S, 15°12E); Bird Island, Lambert's Bay (32°05S, 18°17E); Malgas (33°03S, 17°55E, and Bird Island, Algoa Bay (33°50S, 26°17E). Three main pulses of ringing effort account for most of the birds ringed. These occurred in 1951 to 1959, 1966 to 1968 and 1979 to 1987. Total recoveries for the periods 1951 to 1959, 1960 to 1969 and 1979 to 1987 are 344, 139 and 366 respectively. Precise numbers of Cape gannets ringed in the 1950's and 1960's are not known because it is evident that the records held by SAFRING are incomplete. Some 2 195 gannets were recorded as ringed in the years 1966 to 1968 (Elliot and Jarvis 1970) and yielded 28 of the 139 recorded in the 1960 to 1969 period.

In the 1950's and 1960's, recoveries were regularly received from Angola, north to the Gulf of Guinea, and as far west as Nigeria. In recent years no recoveries of gannets have been forthcoming from these areas, although the number of birds ringed since 1979 (33 086) amounts to 75% of the provisional total of 44 332 gannets ringed up to 1968.

The apparent changes in movement pattern of Cape gannets is best illustrated if the percentage of recoveries attributable to different latitudinal belts is tabulated for the three periods (Table 1.2). The data show a clear trend of diminishing returns north of 17°S.

TABLE 1.2 Recoveries of Cape gannets at different latitudes. Figures represent percentages of total recoveries for a period

	1951-59 (n = 344)	1960-69 (n = 139)	1979-87 (n = 366)
North of 10°S	23	8	0
10° - 17°S	11	9	1
17° - 27°S	5	18	15
27° - 32°S	14	14	23
32° - 35°S	47	51	61

Political changes in what were previously west African colonial states have almost certainly resulted in a diminished reporting rate of bird rings, but are unlikely to be entirely responsible for the recent lack of records from the north. SAFRING still receives ring recovery reports of other birds from independant African states, including some in west Africa. Moreover, four Cape gannet recoveries have been reported from Moçambique (one from Maputo and three from Beira) since 1982; these compare with 14 reported recoveries from Moçambique in the 1950's and 1960's.

The majority of recoveries of Cape gannets are of first-year birds; the mean elapsed time since ringing of first-year birds recovered north of 17°S in the 1950's and 1960's was eight months, and ranged from one month to 12 months. Some adults of up to seven years of age were also recovered in the Gulf of Guinea, so the movement up the west coast in those years was unlikely to be solely a post-fledging dispersal of first-year birds.

One explanation for the recent lack of records from the north may be that Cape gannets are now able to find sufficient food in the vicinity of the demersal fishing fleets in the Benguela upwelling region, but the previous northward movement seems to have been sufficiently well marked to entertain the possibility that the birds were following a migration of fish prey.

Details of recoveries of ringed Cape gannets north of Mocamedes Province in Angola and Maputo province in Moçambique have been recently published by Crawford et al (1983).

REFERENCES

Crawford R J M, Shelton P A, Cooper J and Brooke R K 1983. Distribution, population size and conservation status of the Cape gannet Morus capensis. South African Journal of Marine Science 1, 153-174.

Elliot C C H and Jarvis M F J 1970. Fourteenth Ringing Report. Ostrich 41, 1-118.

HISTORICAL CHANGES IN BIOLOGICAL PARAMETERS OF SOUTH AFRICAN PELAGIC FISH

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INTRODUCTION

Changes over time of fish condition or reproductive activity may be caused by environmental variation or by changes in the abundance of intra- or inter-specific competitors. Therefore, examination of fish condition and reproductive parameters may help to interpret the extent to which observed environmental perturbations impact the marine biota, or may point to possible density-dependent processes controlling population growth rate. This paper documents interannual variations in fish condition and gonad condition of pilchard *Sardinops ocellatus*, anchovy *Engraulis capensis* and roundherring *Etrumeus whiteheadi* from samples of commercial catches off the west coast of South Africa, collected in the southern Benguela over two to three decades. Particular attention is focused on the possible causes of a substantial decrease in the length at maturity of the pilchard following the collapse of the fishery for this species in the 1960's.

DISCUSSION

The condition factors (fish mass/length^3) for juvenile anchovy, pilchard and roundherring caught on South Africa's west coast were investigated (Figure 1.24).

Between-species correlations of fish condition factors were significant for juvenile fish, but nonsignificant for adults (not shown). Although both the adult and juvenile condition factors show no increasing or decreasing trend over time, the latter show an increase in the mid-1970's in all three species.

The gonad condition factor (gonad mass/length^3) of pilchard, anchovy and roundherring was investigated for selected size classes.

A progressive increase with time of the gonad condition factor was observed for pilchard of 18 to 20 cm (Figure 1.25). Three possible reasons for this increase were investigated: a changing seasonal pattern (Figure 1.26), a decline in the length at maturity (Figure 1.27b) and a change in adult fecundity (Figure 1.27a).

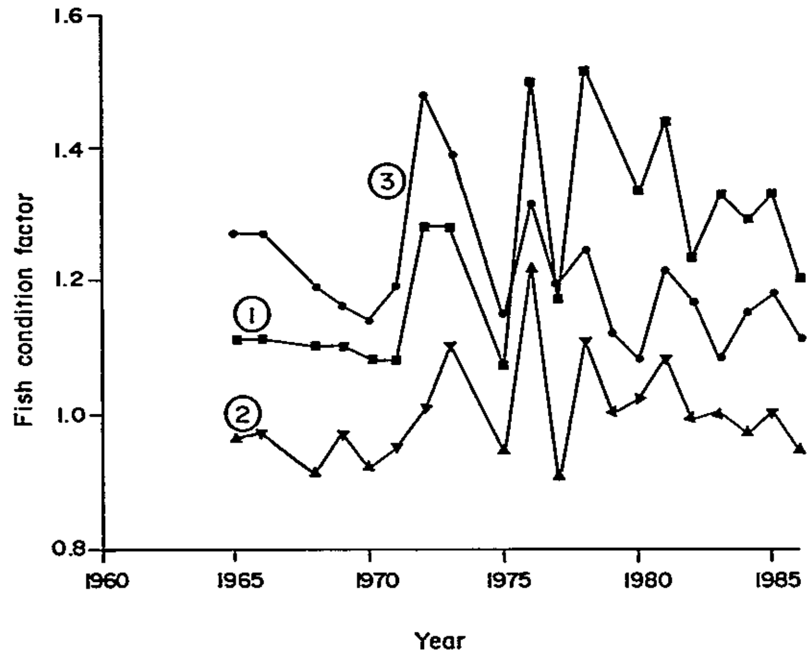

FIGURE 1.24 Time series of fish condition factors for juvenile fish:(1) round herring, (2) anchovy, (3) pilchard.

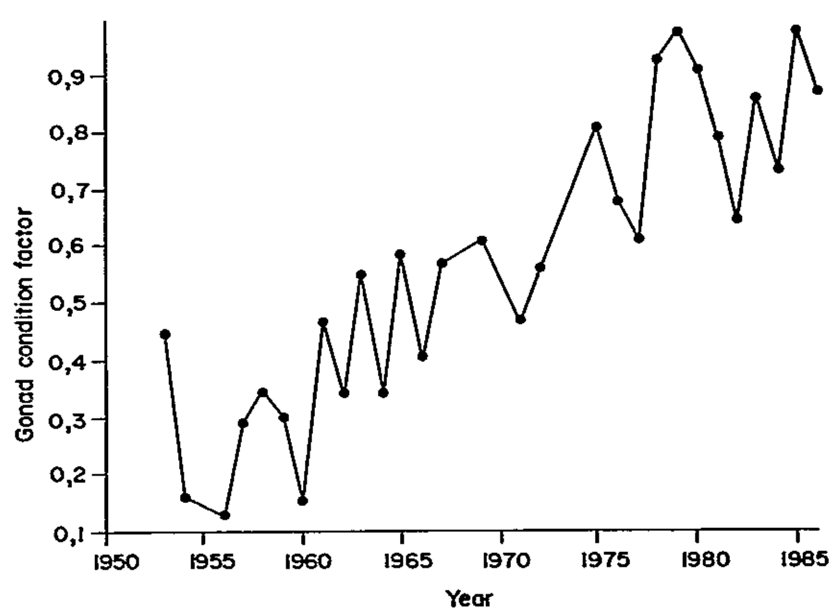

FIGURE 1.25 Increase of gonad condition factor with time for female pilchard.

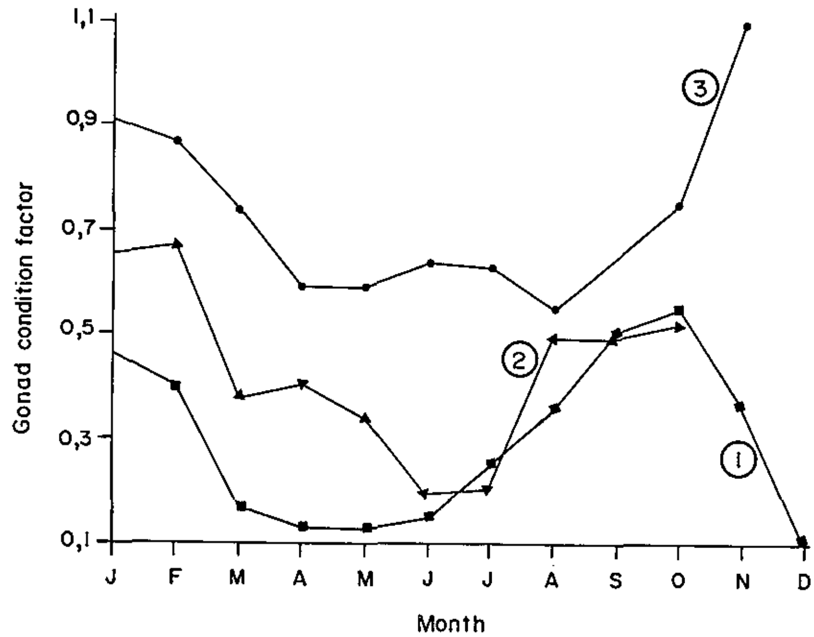

Figure 1.26 Seasonal pattern of gonad condition factor for *Sardinops ocellatus* in three periods: (1) 1953 to 1964, (2) 1965 to 1974 and (3) 1975 to 1986.

The seasonal pattern of gonad condition factor was similar in each of three successive time periods (Figure 1.26), but a decline in the length at maturity, and increases in the mean gonad mass in all classes of mature fish were observed (Figure 1.27). The proportion of 18 to 20 cm pilchard with mature ovaries has increased from 30% to 100% from the period 1953 to 1964 to 1975 to 1986. The length at 50% maturity has decreased from approximately 19 to 14 cm, representing a decrease in age from two-year olds to one-year olds.

PERCEIVED ARTEFACTS

The behaviour described may be a biological response of the pilchard population to overexploitation (no such response was found for anchovy and roundherring), or may be a sampling artifact caused by changes in the fishing pattern. This aspect was investigated by means of analysis of variance to assess the effects of both locality and year on the estimated gonad condition factor.

The results indicated that longshore distribution of catches and year of sampling contributed significantly to the variation in the gonad condition factor, whereas inshore/offshore distribution of samples did not contribute significantly. It must be borne in mind that this particular exercise is preliminary in that it was performed only from 1972 onwards; it indicates the possibility that a change in fishing pattern may have contributed at least in part to the observed increasing trend in the gonad condition factor.

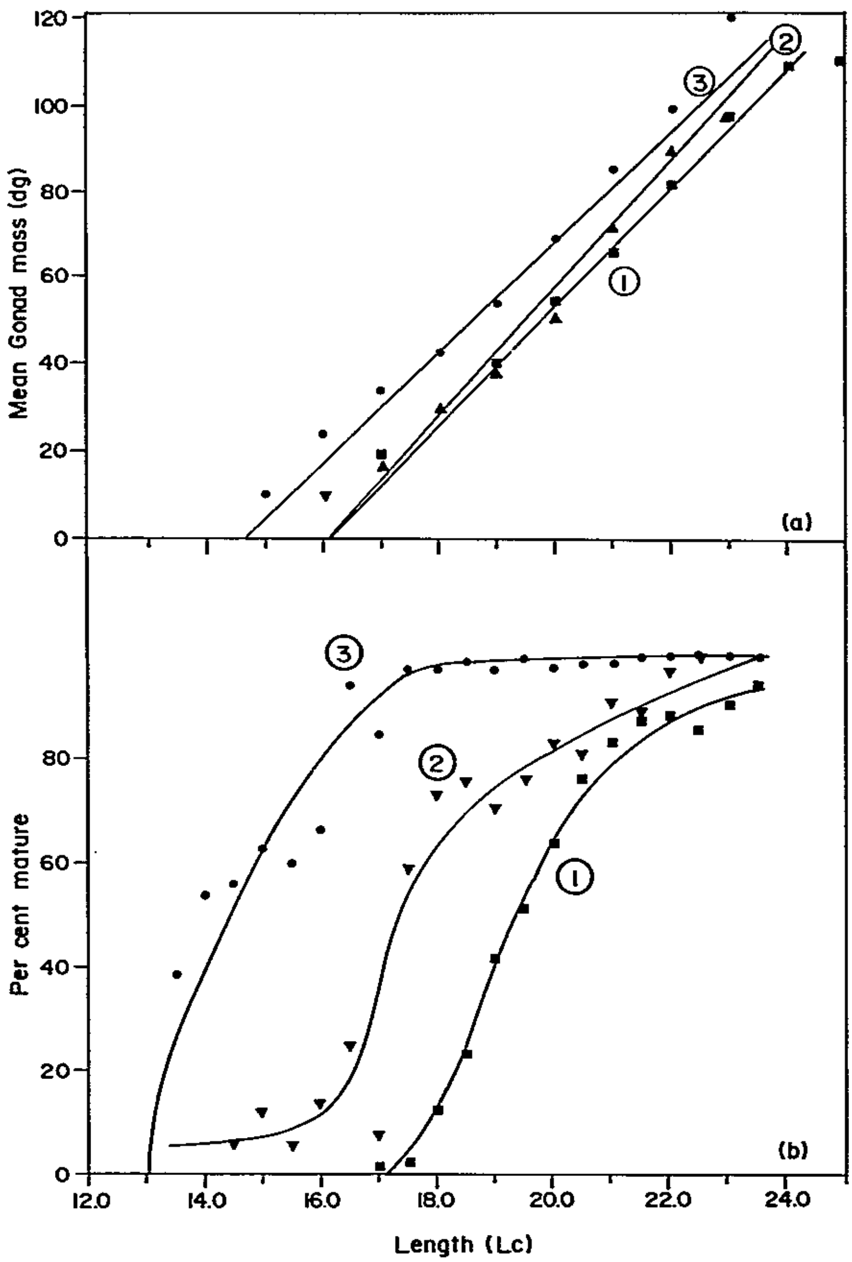

FIGURE 1.27 (a) The increase in size of mature ovaries over time for *Sardinops ocellatus* in three periods: (1) 1953 to 1964, (2) 1965 to 1974 and (3) 1975 to 1986.
(b) The percentage of sexually mature female *Sardinops ocellatus* in the catch in three periods: (1) 1953 to 1964, (2) 1965 to 1974 and (3) 1975 to 1986 as represented by maturity curves.

LONG-TERM TRENDS IN BIOLOGICAL PARAMETERS OF EPIPELAGIC FISH IN THE NORTHERN BENGUELA SYSTEM, 1947 TO 1987

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INTRODUCTION

The time series displayed in Figure 1.28 have been collected since the start of the purse-seine fishery off the Namib coast in 1947. Fishing techniques and sampling procedures have improved, particularly with the start of a mixed-species fishery in 1967/68 and in 1971 when more information was required on the general population biology of the relevant fish stocks.

LONG-TERM TRENDS IN CATCHES, CONDITION AND SIZE OF FISH

Landings of pilchard *Sardinops ocellatus* off Namibia (see Crawford et al 1987) were restricted by quota during most fishing seasons since 1954. Quotas were substantially exceeded between 1966 and 1969, during which period the annual catches reached an all time record of 1,4 million tons in 1968. Quotas were not filled in 1970, 1971 and from 1976 to 1980 when the pilchard biomass had declined from an estimated 11 million tons in 1965 to about 1,7 to 2,0 million tons in 1970 to 1975 or 0,1 to 0,2 million tons in 1977 to 1985 (Thomas 1986). Adult fish dominated the catches in most years.

Landings of pilchard off Angola prior to 1968 were dominated by juvenile fish and were not restricted by quota (Schülein 1971). Therefore, fluctuations in annual catches of the Angolan fishery may show variations in the abundance of nought- and one-year-old fish. When older, the fish move south to the Namibian fishery near Walvis Bay. Strong cohorts appear to have been formed in 1956 and 1957 (possibly one-year olds) and in 1964 and 1968 (Figure 1.28). The pattern of recruitment changed in 1968, since when nought- and one-year old pilchard have also been encountered off Walvis Bay.

Exploitation of anchovy *Engraulis capensis* off Namibia started in 1963, but large shoals first occurred in mid-1968. Landings of anchovy tend to be dominated by nought-year old recruits, and peak catches in 1968/69, 1973, 1978, 1983 and 1987 (Figure 1.28) are ascribed to there being powerful year classes in those years.

Records of oil yields from commercial landings of fish processed at Walvis Bay (given in tons of oil per 100 tons of meal produced) are based on extremely large and representative samples of the entire fish stock. It was suggested (Schülein 1971) that these records provide a useful index of ecological factors which determine the relative fecundity of parent fish and possibly also the potential rates of survival of eggs and larvae. The oil data show no clear long-term trend over the period under review (Figure 1.28). Thus, no major environmental change is apparent. However, high oil yields, a rise in the mean gonad mass of pilchard, and powerful year-classes of pilchard or anchovy in 1950, 1955, 1960, 1964, 1968 to 1970, 1973, 1978, 1980/81, 1983, 1985 and 1987 suggest favourable

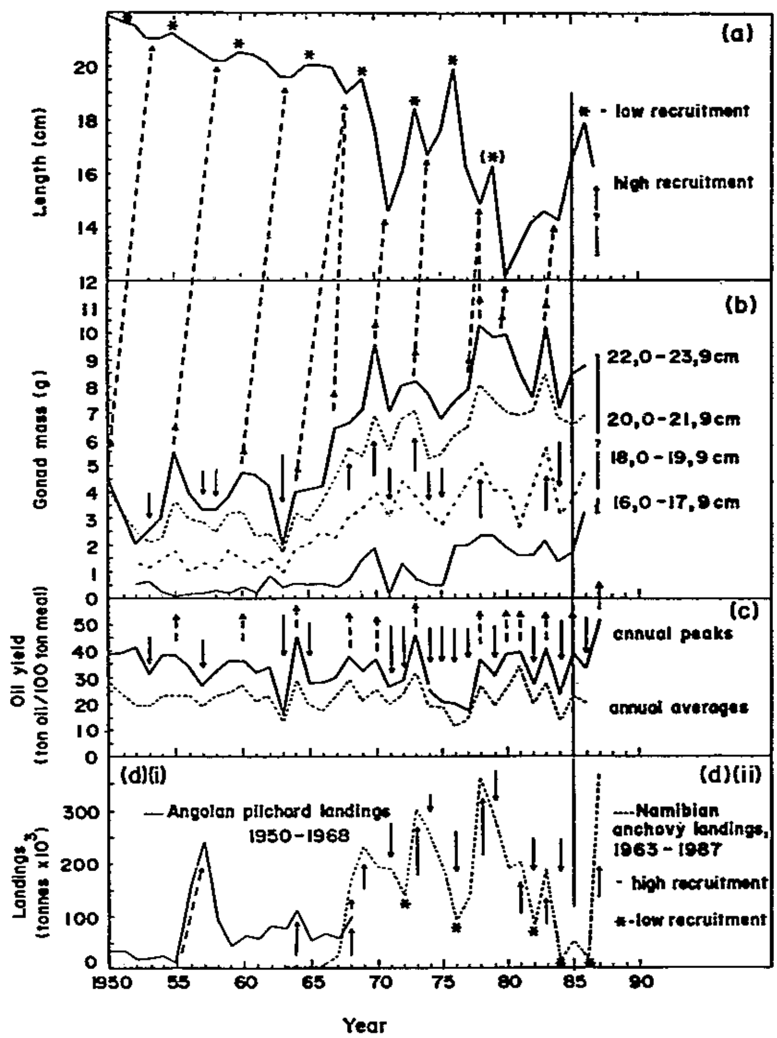

FIGURE 1.28 Annual averages of monthly means in the northern Benguela system of: (a) the lengths of pilchard landed at Walvis Bay; (b) the mass of gonads for discrete length groups of pilchard; (c) the oil yield of fish; and (d) annual fluctuations in (i) catches of juvenile pilchard off Angola (1950 to 1968), and (ii) catches of juvenile anchovy off Namibia (1963 to 1986).

environmental conditions in those years. Less favourable conditions, succeeded by a drop in recruitment of pilchard or anchovy were recorded in 1963, 1971/72, 1974 to 1977, 1979, 1982 and 1984 (Figure 1.28). This was particularly clear in 1976 when recruitment of pilchard and anchovy was alarmingly low and when the annual landings of pilchard started to decline despite a rising fishing effort. This situation can be linked to the collapse of the pilchard stock in 1978.

The mean caudal lengths of pilchard in commercial catches declined in an undulating manner between 1950 and 1969, and then fluctuated in an irregular way until 1987 (Figure 1.28). The oscillating pattern and the sudden change in 1968/69 are ascribed to variations in annual levels of recruitment and the impact of fishing mortality. Troughs in the length data result from rises in recruitment levels, and vice versa. Fluctuations in annual levels of recruitment inferred from the lengths (and numbers) of fish caught appear to be closely linked with variations in oil yields of epipelagic fish, and in average gonad masses of pilchards landed one to three years earlier (Figure 1.28).

The average mass of pilchard gonads increased noticeably between 1967 and 1970, suggesting a sudden increase in the relative fecundity of these fish. As the stock was declining, it may have been a density-dependent response (Figure 1.28).

CONCLUSIONS

1) Trends in the relative availabilty of pilchard and anchovy, the mean gonad mass of pilchard and the pattern of recruitment of pilchard in the northern Benguela change markedly in 1967 to 1968, indicative of overfishing of pilchard.

2) Oil yields of epipelagic fish were high from late 1967 to mid-1969, suggesting favourable environmental conditions at this time. However, long-term trends are not apparent.

3) It is suggested that the survival of eggs and larvae of pilchard and anchovy is largely determined by the same environmental factors that influence variations in oil yields and in the gonad mass of adult fish. However, gonad development also shows an inverse relationship with stock biomass.

4) Stocks with low oil yields appear more vulnerable to overexploitation than healthy stocks.

5) The oil yield and gonad mass data of pilchard and anchovy may be a useful tool for short-term prediction of recruitment levels of both these species.

REFERENCES

Crawford R J M, Shannon L V and Pollock D E 1987. The Benguela ecosystem. Part IV. The major fish and invertebrate resources. Oceanography and Marine Biology. An annual review, Vol 25, 353-505.

Schülein F H 1971. Rekruteringsstudies oor die Suidwes-Afrikaanse sardyn (Sardinops ocellata). MSc Thesis, University of Stellenbosch, Stellenbosch.

Thomas R M 1986. The Namibian pilchard: The 1985 season, assessment for 1952 to 1985 and recommendations for 1986. Collection of Scientific Papers, International Commission for the South-east Atlantic Fisheries 13(II), 243-269.

INTERANNUAL AND DECADAL CHANGES IN SEA SURFACE TEMPERATURE AND RELATIVE WIND STRESS IN THE SOUTH-EAST ATLANTIC THIS CENTURY

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Major changes in the distribution and abundance of several exploited fish populations in the Benguela ecosystem have occurred during the last four decades (Crawford et al 1987), which cannot be ascribed solely to fishing. Crawford and Shannon (in press) and Shannon et al (1988) have suggested that some of the observed changes are due to environmental modulation.

As possible environmental inputs into fisheries models, long time series of sea surface temperature (SST) and relative wind stress in six areas in the South-east Atlantic have been analysed. The areas are representative of oceanic, coastal upwelling and shelf regimes: (1) 10 to 15°S, 0 to 5°E characteristic of the tropical South-east Atlantic; (2) 20 to 25°S, 5 to 10°E, oceanic, west of the main Benguela upwelling centre; (3) 30 to 35°S, 10 to 15°E near to the Agulhas reflection zone; (4) Namibia coastal region 19 to 27°S; (5) coastal region off the west coast of the Cape Province 29 to 33°S; (6) coastal region on Agulhas Bank 19 to 24°E.

SST and wind data were obtained from the South African Data Centre for Oceanography. Numbers of observations per area for the period 1906 to 1984 ranged from 21 000 in (5) to 134 000 in (2). Monthly data density was inadequate during the two World Wars, low in the early 1930's, between 1946 and 1948 and after 1983, but otherwise sufficient. Overall there is a numerical bias towards the post 1960 era. Data in (3) has been augmented after 1983 by information extracted from CAC Climate Diagnostics Bulletins.

Mean monthly values of SST and equatorward and eastward components of relative wind stress (more correctly, wind speed squared) were calculated for each of the six areas. Monthly anomalies were calculated by subtracting the long-term monthly means from the mean monthly values in each area. Annual and six-monthly (October through March, April through September) indices of SST and relative wind stress were estimated by summation. The indices displayed in Figure 1.29 (histograms of 12-month cumulative SST and wind stress anomalies, 1906 to 1986) are thus unfiltered cumulative totals. The SST indices are regarded as fairly reliable, the wind stress less so. The mean wind stress in any given month had a standard deviation that was typically of similar magnitude.

Both SST and wind stress indices suggest that major changes have occurred this century in the South-east Atlantic (Figure 1.29). The periods prior to 1911 and after 1974 are characterized by significantly higher equatorward wind stress, with lower values during the 1920's, 1930's and immediately after 1945. The data suggest an increasing trend between the early 1950's and the early 1980's. Comparable changes are apparent in the SST. An increasing trend in SST this century is suggested in all areas, with the post 1945 era being typically 0,8°C warmer than earlier periods. Coherence between SST's is fair, with the monthly anomalies in (3) being significantly correlated with those in the other five areas over the period of record. At times, however, they are out of phase, eg the

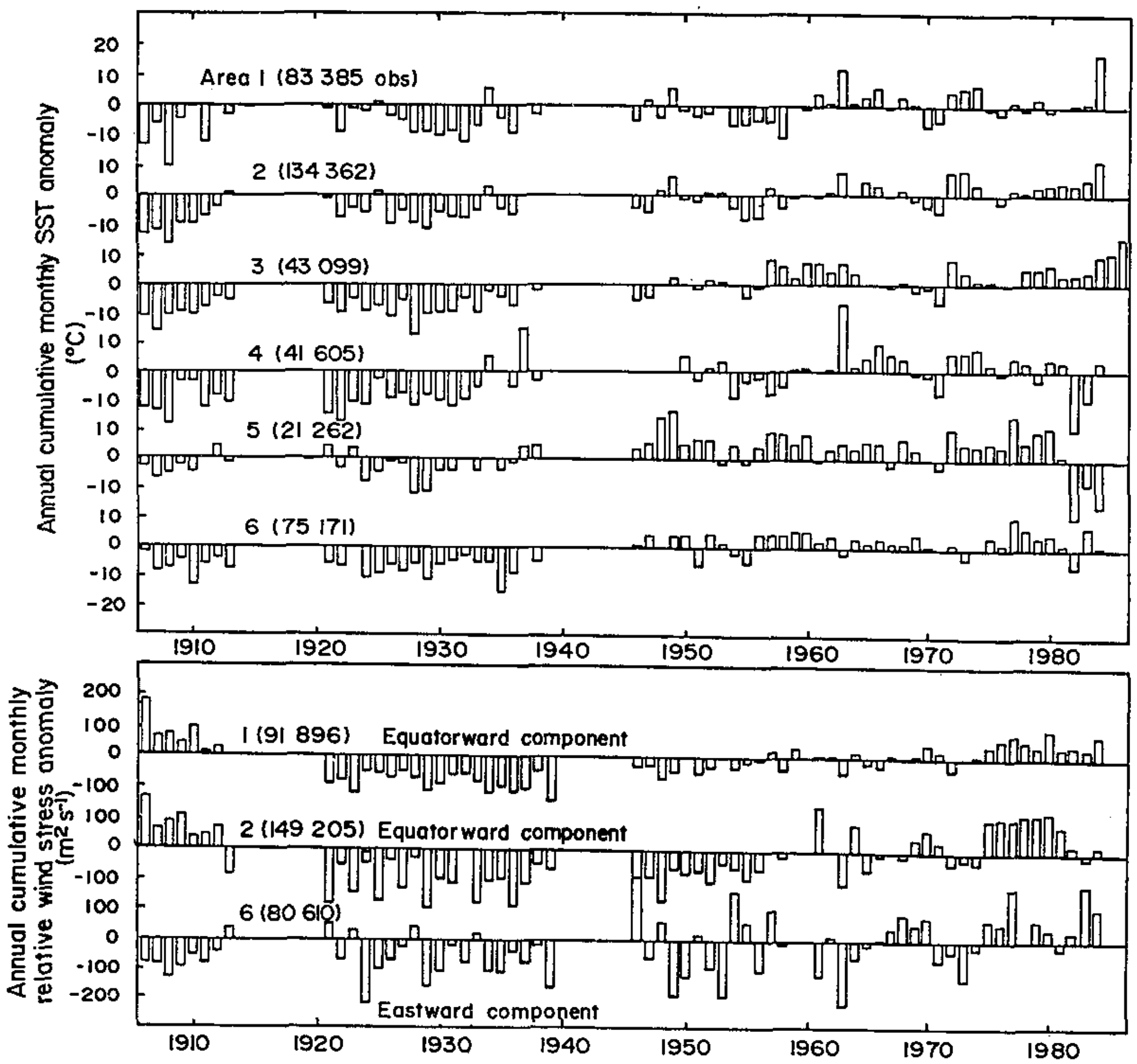

FIGURE 1.29 Histograms of 12-month cumulative SST and wind stress anomalies, 1906 to 1986.

post 1980 coastal and oceanic anomalies. Cool and warm periods are evident in the record, with Benguela Niños (Shannon et al 1986) having occurred in 1934, 1949, 1963 and 1984 and probably also around 1910, in the mid-1920's and in 1974. A more detailed study of the monthly data using principal component analysis (cf comparable investigations of Kamstra and Taunton-Clark 1986 on shorter data sets) suggests a possible, but weak, 10-year cycle (Taunton-Clark and Shannon 1988).

It is our view that the SST indices for area 3 may be helpful in explaining some aspects of ecosystem change in southern Africa. This square lies at the "cross roads" between three ocean systems and its signal may be expected to reflect to a greater or lesser degree changes in the Agulhas Current, the Subtropical Convergence, the South Atlantic gyre and in the tropical Atlantic. It is also on the approach route of the subcontinent's weather systems.

A more detailed examination of variability in the South-east Atlantic this century and possible causes for it, and a discussion of the implications of the observed variability for the fisheries of the region appears in Taunton-Clark and Shannon (1988) and Shannon and Taunton-Clark (1987).

REFERENCES

Crawford R J M and Shannon L V (In press). Long-term changes in the distribution of fish catches in the Benguela. International symposium on long-term changes in marine fish populations, Vigo, November 1986.

Crawford R J M, Shannon L V and Pollock D E 1987. The Benguela ecosystem. Part IV. The major fish and invertebrate resources. Oceanography and Marine Biology. An Annual Review 25, 252-405.

Kamstra F and Taunton-Clark J 1986. The climatic variability at Cape Town, South Africa, 1960-1985. International symposium on population and community ecology in the Benguela upwelling region and comparable frontal systems, Cape Town, September 1980 (abstract of poster).

Shannon L V, Boyd A J, Brundrit G B and Taunton-Clark J 1986. On the existence of an El Niño-type phenomenon in the Benguela system. Journal of Marine Research 44, 495-520.

Shannon L V, Crawford R J M and Brundrit G B and Underhill L G 1988. Responses of fish populations in the Benguela ecosystem to environmental change. Journal du Conseil International pour L'Exploration de la Mer.

Shannon L V and Taunton-Clark J 1987. Long-term indices of environmental change in the ICSEAF area: fisheries implications. Working paper, meeting of Standing Committee for the Environment, International Commission for the South-east Atlantic Fisheries, November 1987.

Taunton-Clark J and Shannon L V 1988. Annual and interannual variability in the South-east Atlantic during the 20th century. South African Journal of Marine Science 6, 107-117.

ANALYSIS OF TIME SERIES OF SEABIRD GUANO HARVESTED OFF SOUTHERN AFRICA

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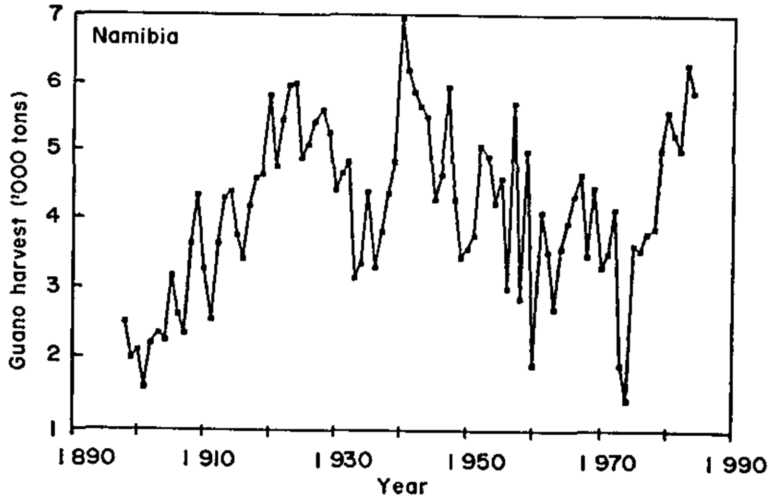
Seabirds such as Cape gannets *Morus capensis*, Cape cormorants *Phalacrocorax capensis* and jackass penguins *Spheniscus demersus* breed at coastal islands throughout the Benguela system and prey on a variety of epipelagic fish species. Early exploitation of their guano was so intensive that by 1845 no further accumulated deposits remained, and from then on many of the islands were scraped on a nearly annual basis (Crawford and Shelton 1978; Crawford et al in press). From 1931 man-made platforms off Namibia also contributed to the harvest. The annual guano production at the islands provides an uninterrupted time series going back to the turn of the century, and preceeds initiation of commercial exploitation of the epipelagic fish species on which the seabirds prey. Because of variability in guano runoff caused by rain, year to year changes in the intensity of harvesting, importation of sand to some islands, and influences of the self-regulating dynamics of both prey and bird populations on input signal, only broad trends in the guano data should be considered. Data for the South African and Namibian islands are plotted separately in Figure 1.30 and by inspection appear to have more temporal structure than the random series shown in Figure 1.31.

Inspection also suggests that initiation of commercial fishing around 1950 on epipelagic fish species preyed on by seabirds influenced guano production by decreasing average yield and increasing variability. Time-lagged autoregression was carried out on both the South African data set and the Namibian data set for the entire period and for the period prior to the commencement of fishing (Figure 1.32).

The deletion of that part of the data series influenced by fishing removed most of the patterning in the South African data, but improved the coherency of the Namibian data and revealed evidence of decadal-scale physical forcing. Application of maximum entropy analysis using the Berg algorithm and estimating the length of the prediction error filter by means of the Akaike Criterion (Ulrych and Bishop 1975), showed that the Namibian time series prior to 1950 could be best fitted by a third order AR Model $y(t) = 0,7884*y(t-1) - 0,2305*y(t-2) + 0,2914\ y(t-3)$.



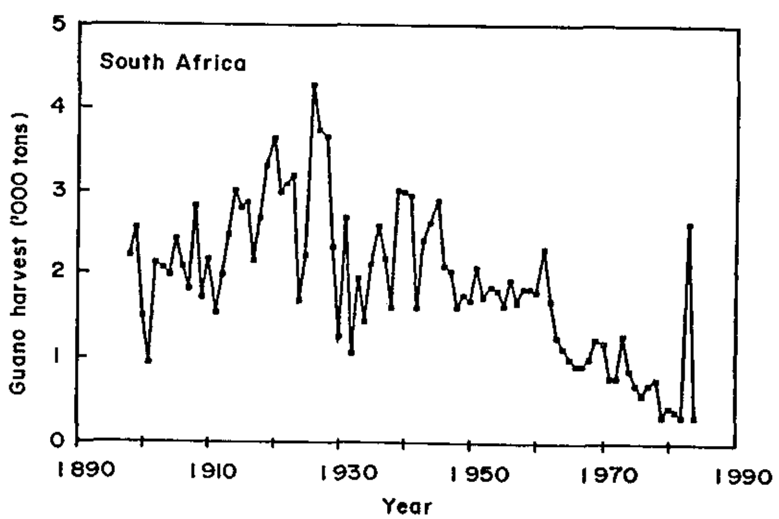


FIGURE 1.30 Annual guano harvests at islands off Namibia and South Africa.

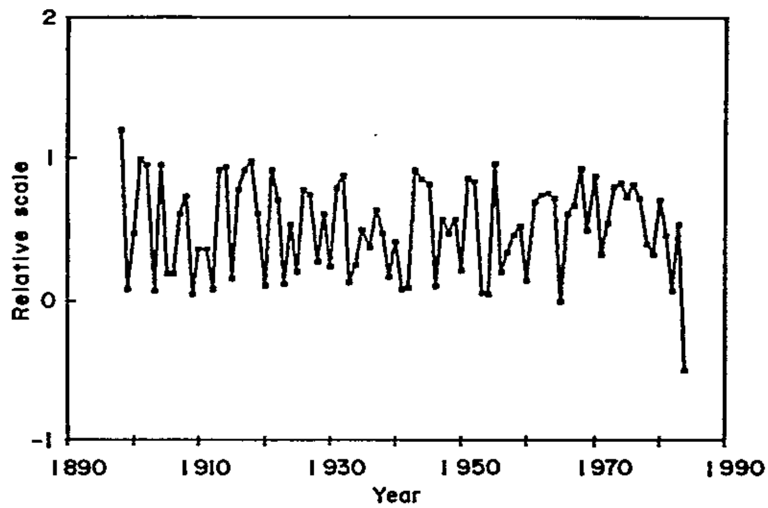


FIGURE 1.31 A random or "white noise" time series for comparison with Figure 1.30.

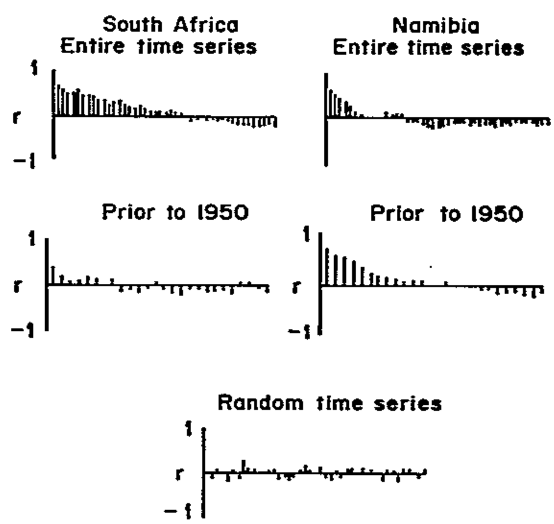


FIGURE 1.32 Results of the application of time-lagged autocorrelation to guano data and the random time series shown in Figure 1.31.

REFERENCES

Crawford R J M and Shelton P A 1978. Pelagic fish and seabird interrelationships off the coasts of South West and South Africa. Biological Conservation 14, 85-109.

Crawford R J M, Shannon L V and Shelton P A (In press). Characteristics and management of the Benguela as a large marine ecosystem. In: Proceedings of the American Association for the Advancement of Science Conference on Large Marine Ecosystems, Chicago 1987.

Ulrych T J and Bishop T N 1975. Maximum entropy spectral analysis and autoregressive decomposition. Reviews of Geophysics and Space Physics 13, 183-200.

THERMAL BOUNDARIES OF THE UPWELLING ZONE OF SOUTHERN AFRICA'S WEST COAST

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The ecological importance of upwelling areas has been well documented, with the primary data having been gathered mainly by ships. Since then aircraft, and more recently satellites, have been used to measure sea surface temperatures in upwelling regions. Despite the short time that this latter facility has been available (currently about eight years for Meteosat and Meteosat II), satellites have long been known to be effective in the macroscale analysis of the sea surface through the work of Lutjeharms (1981) and Shannon and Anderson (1982), amongst others.

DATA AND METHODS

For this investigation daily Meteosat and Meteosat II thermal infrared images in the 10,5 to 12,5 micrometre wavebands were used for the years 1978, 1979 and 1982 to 1985. The data are received by the Satellite Remote Sensing Centre of the CSIR at Hartebeeshoek in the Transvaal and those used here are held at the National Research Institute of Oceanology, in Stellenbosch. The spatial resolution achieved by Meteosat in the thermal infrared is 5 x 5 km at the nadir on the equator. It becomes, however, considerably poorer with increasing distance from this latitude. No atmospheric corrections or thermal calibrations were made for the data, so the portrayals of temperature differences are not absolute.

The analysis used the Meteosat images in the form of photographic negatives whenever they were sufficiently cloud-free. The line of maximum grey scale contrast in the South-east Atlantic Ocean was assumed to be the surface expression of the frontal boundary between the cold upwelled water and the offshore South Atlantic surface water.

The daily data were analysed in several ways. Firstly, the daily frontal boundaries were extracted and their positions were overlayed for each calendar month. These monthly overlays were then grouped into the four seasons of:

i) Summer - December (of the previous year), January and February
ii) Autumn - March, April, May
iii) Winter - June, July, August
iv) Spring - September, October, November

These seasonal patterns are presented in Figure 1.33.

The maps cover the entire west coast upwelling area from Cape Agulhas to 20°S, which corresponds to the boundaries of upwelling suggested by Shannon (1985). The dark shaded areas of the figure show zones that experienced constant upwelling over the season, with the lighter shading showing the extensive active frontal boundary.

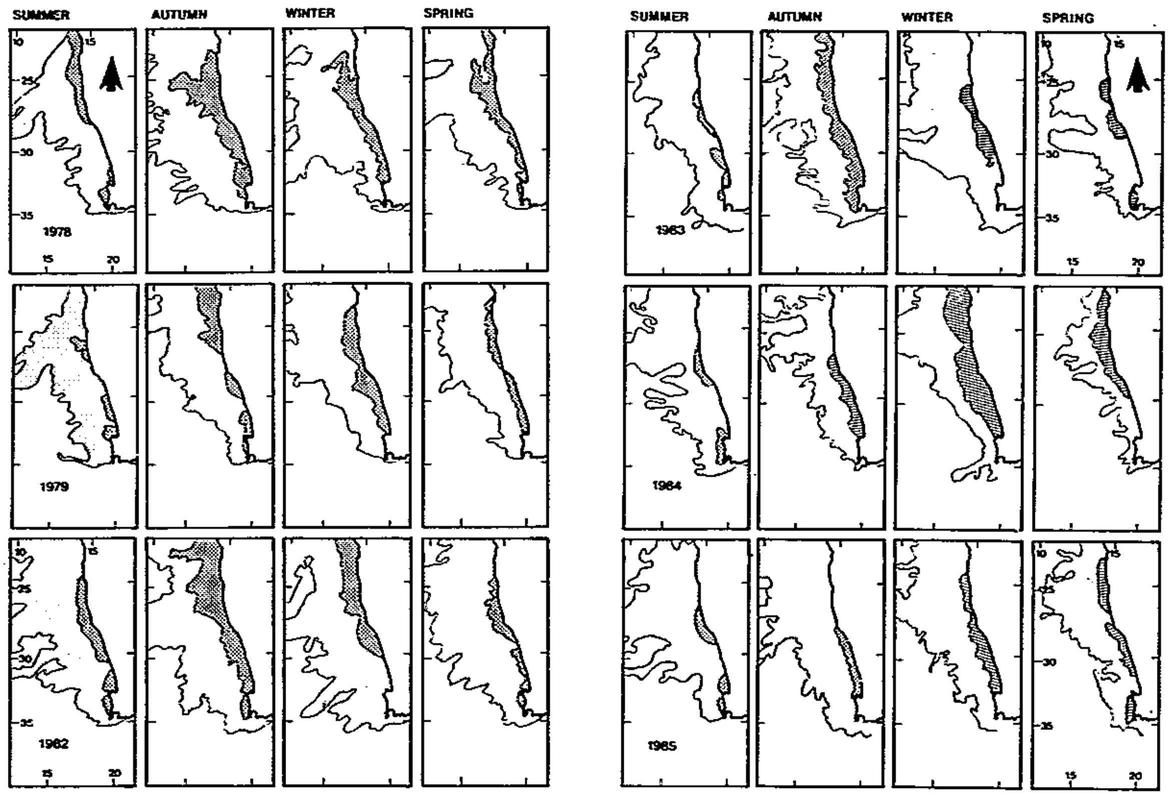

FIGURE 1.33 The seasonal location of the upwelling core along the west coast of southern Africa (dark shading) and the amorphous, active frontal zone (lighter shading) for 1978, 1979 and 1982 to 1985. The Meteosat satellite for this area was not operational during 1980 and 1981.

RESULTS AND DISCUSSION

Major upwelling cells identified by Lutjeharms and Meeuwis (1987) are apparent from the images, particularly in summer. A comparison between the zones of constant upwelling in the summer and the winter affirms the disparate seasonal upwelling regimes experienced by the northern and southern upwelling extremes (Hart and Currie 1960; Shannon 1985). The semipermanent upwelling at Cape Point during summer (Andrews and Hutchings 1980) occurs in all summers investigated, except for those of 1979 and 1983. In both cases, however, some evidence of this phenomenon appears in the autumn. The anomalously warm sea temperatures of 1983 resulted in a much reduced surface area of upwelled water in winter.

These preliminary results, using the short time series of data, show the capability of the medium as:

a) an effective tool for testing models and calibrating, as far as macroscale patterns are concerned; and

b) a new and potentially powerful primary source of data as the analysis techniques become more sophisticated, which may replace some of the measurements undertaken by ships.

CONCLUSION

It is vital, for the most effective use of the satellite information, that the data are kept up to date and allowed to develop into a long-term data set. With time, this already valuable upwelling monitoring tool will be an invaluable aid to the oceanographic component of the International Geosphere Biosphere Programme.

REFERENCES

Andrews W R H and Hutchings L 1980. Upwelling in the southern Benguela current. Progress in Oceanography 9(1), 1-81.

Hart T J and Currie R I 1960. "Discovery" Report 31, 123-298.

Lutjeharms J R E 1981. Satellite studies of the South Atlantic Upwelling System. In: Oceanography from Space, Plenum Press, New York. pp 195-199.

Lutjeharms J R E and Meeuwis J M 1987. The extent and variability of South-east Atlantic upwelling. In: Payne A I L, Gulland J A and Brink K H (editors) The Benguela and comparable ecosystems. South African Journal of Marine Science 5, 51-52.

Shannon L V 1985. The Benguela ecosystem. Part 1. Evolution of the Benguela, physical features and processes. Oceanography and Marine Biology: An Annual Review 23, 105-182.

Shannon L V and Anderson F P 1982. Applications of Satellite Ocean Colour Imagery in the study of the Benguela current system, South African Photogrammetry, Remote Sensing and Cartography 13, 153-169.

OCCURRENCE OF JELLYFISH ON THE WEST COAST OFF SOUTH WEST AFRICA/NAMIBIA

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INTRODUCTION

The abundant occurrence and wide distribution of jellyfish off the coast of South West Africa (Namibia) is a well known phenomenon, especially after the dramatic decrease in pelagic fishing in 1972. Jellyfish are present throughout the year. Two species in particular create a problem for commercial purse-seine fishermen, namely *Chrysoara hyoscella* (Linne 1766) and *Aequorea aequorea* (Forskal 1775).

For these fishermen jellyfish have become an increasingly irritating nuisance. They have no commercial value, and fishermen are therefore not reimbursed for any jellyfish landed. It is also extremely difficult to handle the nets once jellyfish have been caught or become entangled in the mesh. Local fishermen maintain that jellyfish take up valuable hold capacity which could have been used more profitably for fish.

Practically no research has been directed towards the jellyfish problem and the only data available come from commercial fish landings. These data are presented here as total jellyfish landings with no differentiation between the various species.

METHOD

A series of samples of catches were taken at fish processing factories during offloading of catcher boats in 1981 to 1987. Samples were collected from each boat every 15 to 30 minutes. Each sample was sorted by species, and each species was then weighed separately. The total weight of all samples was then computed and sample weights of each species were raised to conform with the total weight of the catch.

This, however, is by no means an accurate method to determine the real weight that jellyfish constitute when freshly caught. The greater part of jellyfish consists of fluid and jelly of a gelatinous nature. During the catch and pumping procedures the jellyfish are damaged, broken and liquidized to a great extent resulting in a consequent loss of weight.

Data presented in this paper must therefore be seen as a fraction of the real weight of the freshly caught jellyfish.

DISTRIBUTION

Catch positions of jellyfish are shown in Figure 1.34. Jellyfish are widely distributed from the Cunene River (circa 17°30'S) to Lüderitz (circa 26°30'S) and up to 60 nautical miles offshore.

The presentation of data might give the impression that certain areas and years are void of jellyfish or that dense concentrations were found in others. This is not true for the following reasons. The duration of fishing seasons varied annually according to fish availability and the size of quotas. Certain areas were closed for fishing activities from time to time. Fishing vessels operated mainly in the areas of highest fish concentrations without exploring other areas. In doing so "vacuum areas" were created. Areas offshore were only fished when exploitation of shoals inshore was not economically viable. No catches were reported when dumping of total catches took place. Areas north of Cape Frio (circa 18°30'S) and south of Conception Bay (24°S) were poorly fished due to there being only small concentrations of fish or none at all.

The presence of jellyfish in "vacuum areas" has, however, been established from surveys of plankton, fish eggs and fish larvae with the *R S Benguela.* It is quite clear that jellyfish occur throughout the year over a far more widespread area than that illustrated in Figure 1.34.

COMMERCIAL CATCHES

Catch data for jellyfish expressed as hundreds of metric tons and as percentages of the total annual catch for each year over the period 1981 to 1987 are presented in Figure 1.35 and Table 1.3. During the period 1981 to 1983 jellyfish catches were highest for the months June, July and August. Very little was caught during the 1984 season, which can be attributed to a very poor fishing season and restricted fishing activities

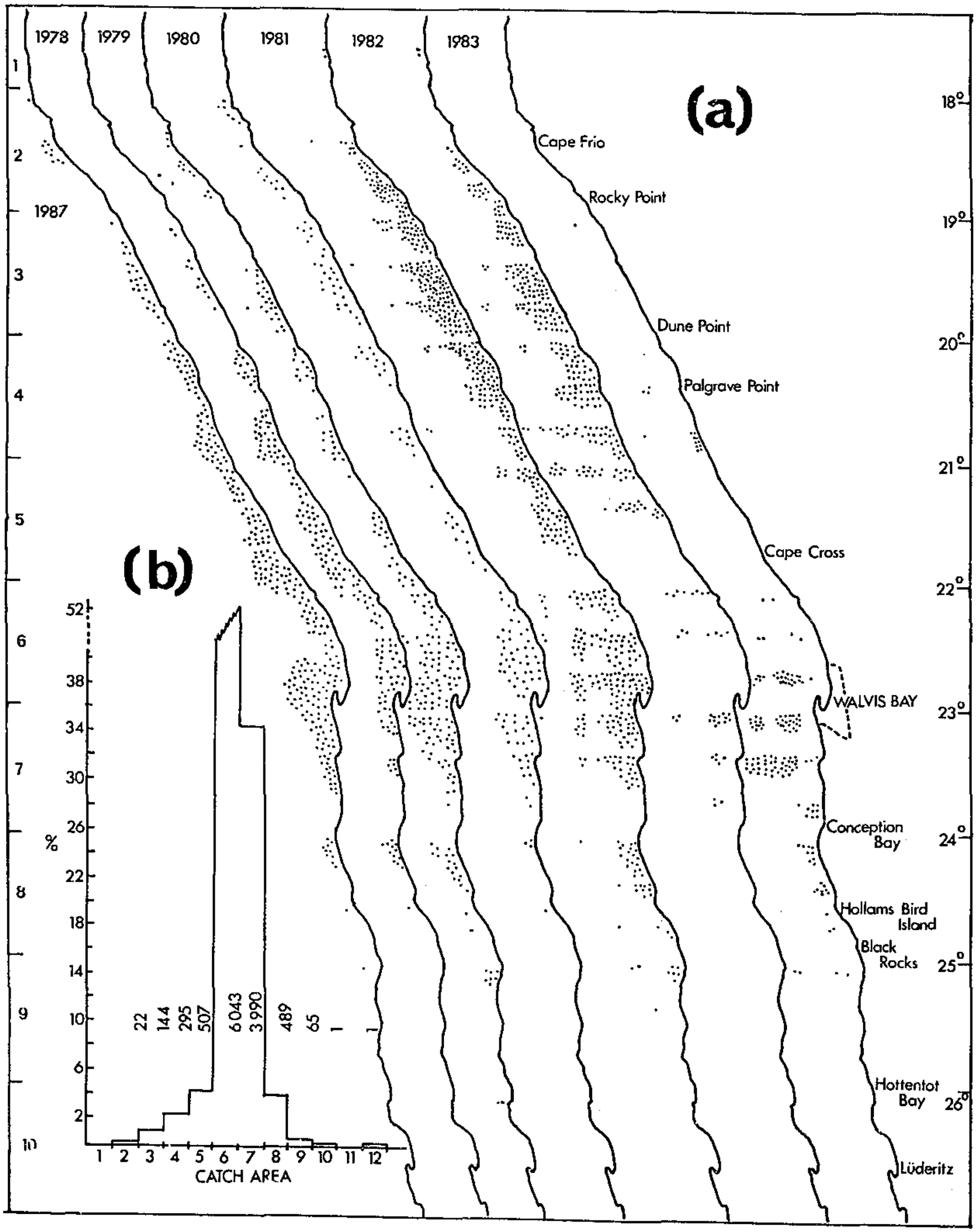

FIGURE 1.34 Distribution of jellyfish from commercial pelagic fish catches for the period 1981 to 1987.

throughout the year. Since the beginning of the 1985 fishing season until 1987 substantial quantities of jellyfish were landed almost throughout the period March to August, except for May and June of 1986 when again there was little fishing due to poor availability of fish.

Highest catch percentages of jellyfish and tonnages over the period under review (1981 to 1987) occurred during June and July with 25% and 22% and 2 895 and 2 512 metric tons respectively for these two months. Peak landings for jellyfish were recorded during 1987 (4 320 metric tons). For the period 1981 to 1987, highest catch percentages of jellyfish were recorded for area 6 (Cape Cross to Walvis Bay) and area 7 (Walvis Bay to Conception Bay): 6 043 metric tons (52,3%) and 3 990 metric tons (35,5%) respectively (Figure 1.36). During the early months of fishing seasons only the larger fishing vessels with chilled sea water (CSW) and refridgerated sea water (RSW) facilities were allowed to fish for pilchard and anchovy in the distant northern areas. Small boats were restricted to the proximity of Walvis Bay, and operated mainly in the region between Cape Cross and Conception Bay, which explains the higher catches from areas 6 and 7 (Figure 1.36).

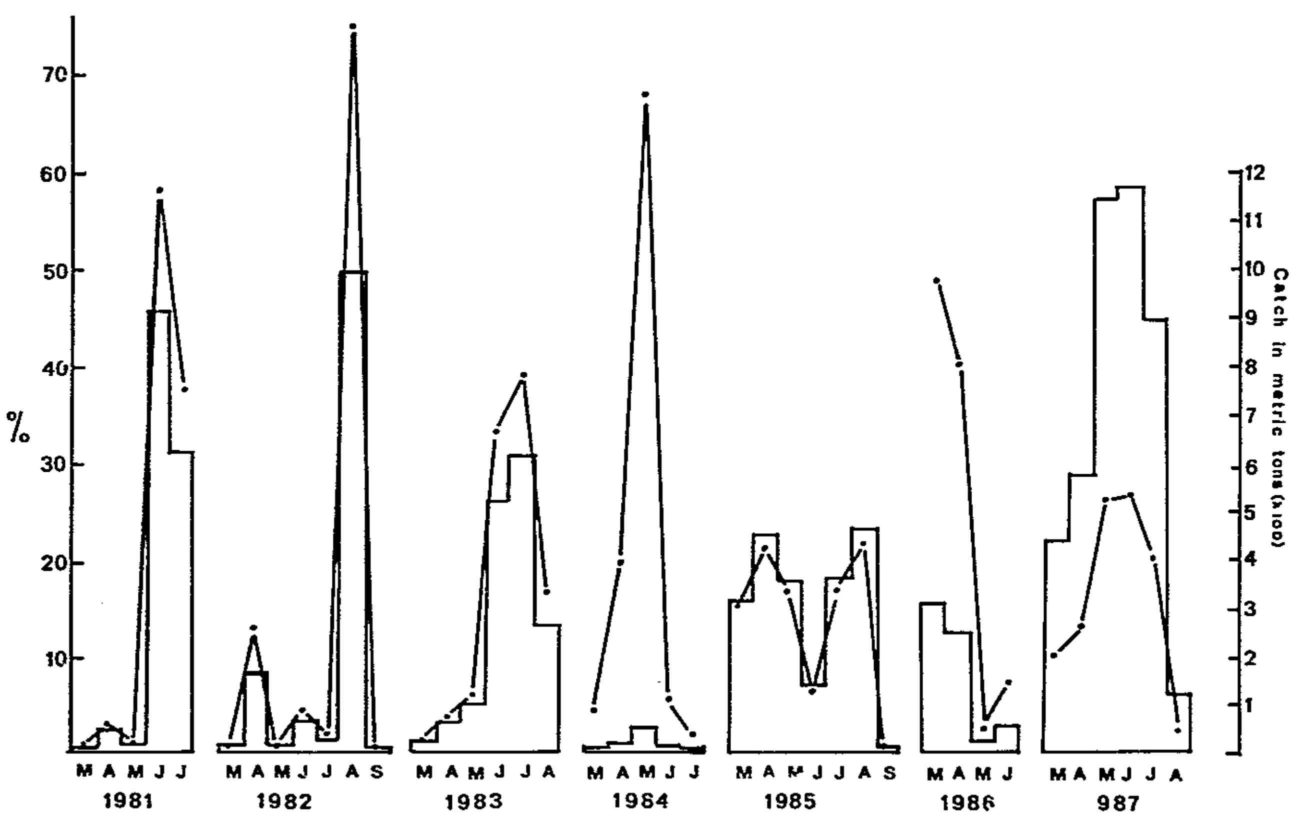

FIGURE 1.35 Monthly jellyfish landings in metric tons (X 100, histogram) and percentage of monthly totals from 1981 to 1987 (line graph).

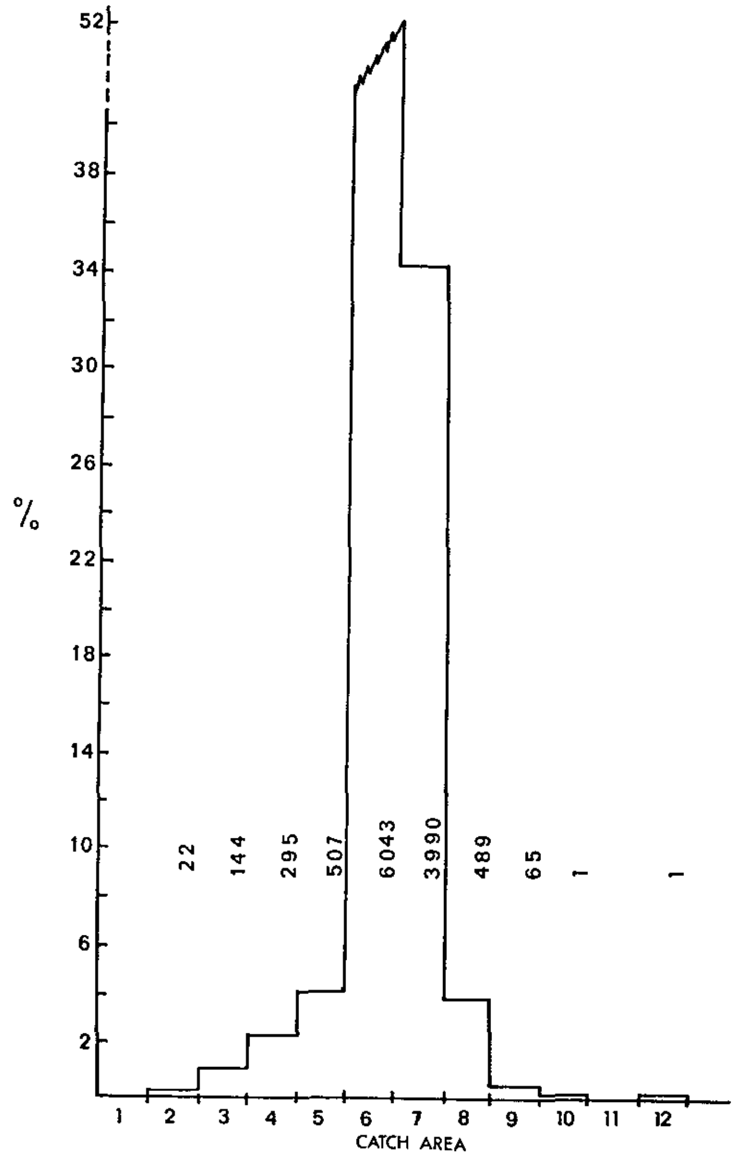

FIGURE 1.36 Percentage composition of total jellyfish catches per one-degree of latitude catch area for the period 1981 to 1987.

DISCUSSION

Cognisance needs to be taken of the fact that recorded catches of jellyfish are not accurate but depend on the extent of damage caused during catching, transport and pumping procedures, on dumping and on the intensity of fishing activities, and that data are only representative of the fishing areas. No backup research was carried out to examine the distribution and abundance of jellyfish over the remainder of South West African waters.

For a better understanding and interpretation of the occurrence of jellyfish along the South West African coastline, it is recommended that an intensive research programme be directed towards the jellyfish problem. It is also recommended that investors should be encouraged to research the possible nutritional value of jellyfish.

TABLE 1.3 Monthly total jellyfish catches (metric tons), mean and percentage for the period 1981 to 1987

Year	March	April	May	June	July	August	September	Total	Mean	%
1981	8,1	45,4	12,7	966,7	624,0	-	-	1656,9	331,4	14,3
1982	9,9	168,0	9,6	58,4	26,3	995,1	7,8	1275,1	182,2	11,0
1983	16,5	55,7	91,7	517,5	609,4	262,0	-	1552,8	258,8	13,4
1984	2,7	12,6	43,2	3,7	1,3	-	-	63,5	12,7	0,5
1985	320,0	442,9	350,8	136,1	358,8	459,6	1,2	2069,4	295,6	17,9
1986	305,4	249,2	18,1	47,3	-	-	-	620,0	155,0	5,4
1987	433,3	572,3	1139,6	1164,9	891,9	117,8	-	4319,8	720,0	37,4
TOTAL	1095,9	1546,1	1665,7	2894,6	2511,7	1834,5	9,0	11557,5		
MEAN	156,6	220,9	238,0	413,5	418,6	458,6	4,5			
%	9,5	13,4	14,4	25,0	21,7	15,9	0,1			

FLUCTUATIONS IN THE CATCHES OF SOME LINEFISH SPECIES OFF SOUTH WEST AFRICA/NAMIBIA, 1964 to 1986

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INTRODUCTION

This paper presents trends in the catches during 1964 to 1986 of the three most important contributors to the handline fishery off Namibia: snoek *Thyrsites atun*, kob *Argyrosomus hololepidotus* and steenbras *Lithognathus aureti*. Data were obtained from catch statistics submitted by local factories and ski boats on a monthly basis. No estimates of fishing effort are available so its effect on interannual variability in the catches cannot be gauged. Mean monthly catches of the three species are presented to highlight seasonal trends in their availability to the handline fisherman.

RESULTS

The highest catches of snoek were made from November to March and those of kob from February to June (Figure 1.37). Catches of steenbras appeared relatively constant throughout the year. The 23-year mean had a minor peak in September.

Annual catches of snoek had a major peak in 1966 to 1967, more than 2 500 metric tons being caught in each of these years (Figure 1.38). Catches then decreased in a fluctuating manner until 1977, before climbing again to a peak of more than 3 300 tons in 1980. After this there was a rapid decrease and the 1986 catch was less than 100 tons.

Catches of kob were low in the late 1960's, but thereafter fluctuated around a level of about 500 tons. The 1981 catch of 1 796 tons was exceptionally high. Catches of steenbras were generally low from 1967 to 1975, after which they improved somewhat.

DISCUSSION

Trends in the overall handline catch have been dominated by trends in the catch of snoek. There is suggestion that, as catches of snoek decreased in the late 1960's and early 1970's, those of kob increased. This is thought to be due to fishermen turning their attention to kob when snoek were scarce. The almost complete failure of snoek during three successive years in the mid 1980's is of interest. Catches of both kob and snoek were poor in 1984, the Benguela Niño year, leading to the lowest line catch on record.

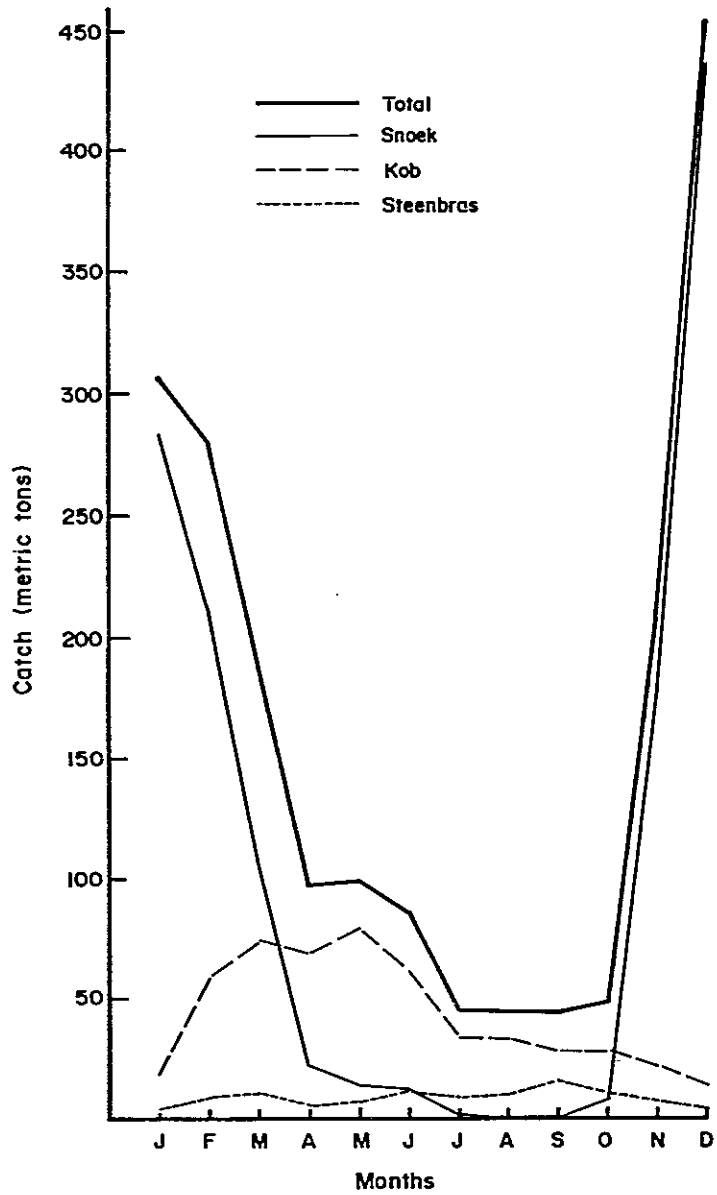

FIGURE 1.37 Average monthly catches of linefish off South West Africa/ Namibia, 1964 to 1986.

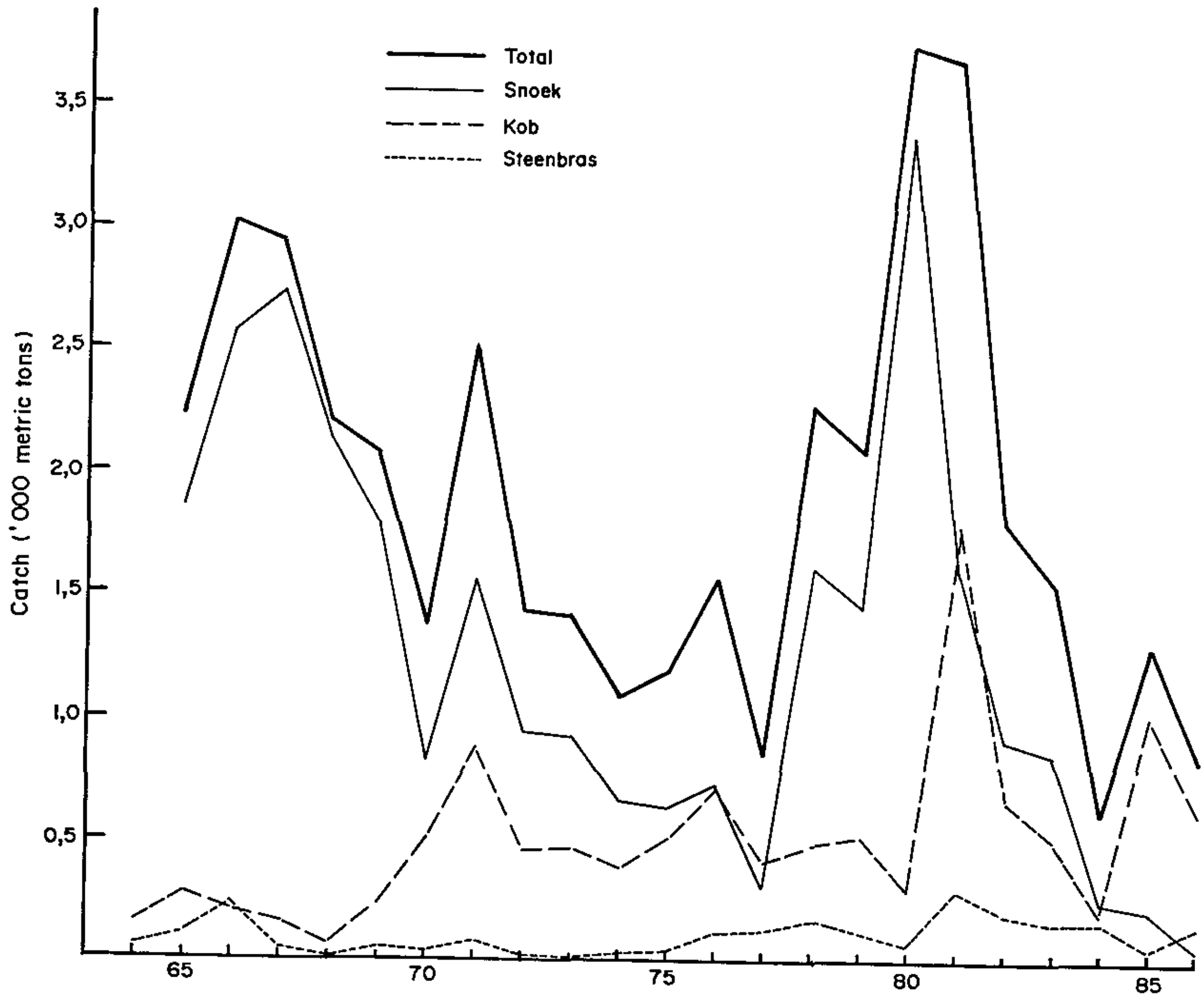

FIGURE 1.38 Commercial linefish catches off South West Africa/Namibia, 1964 to 1986.

PILCHARD CATCH DATA FROM 1950 TO 1985, AND SEA LEVEL, SEA SURFACE TEMPERATURE AND WIND DATA FOR THREE AREAS AROUND THE SOUTH AFRICAN COAST

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Long-term data series are presented for pilchard catches and a number of environmental variables, namely sea surface temperature (SST), sea level and wind. In choosing the variables, a number of factors were taken into consideration, duration and repeatability being the most important. The environmental variables chosen appear to reflect conditions in the ocean that either directly or indirectly influence fish populations both physiologically and ecologically.

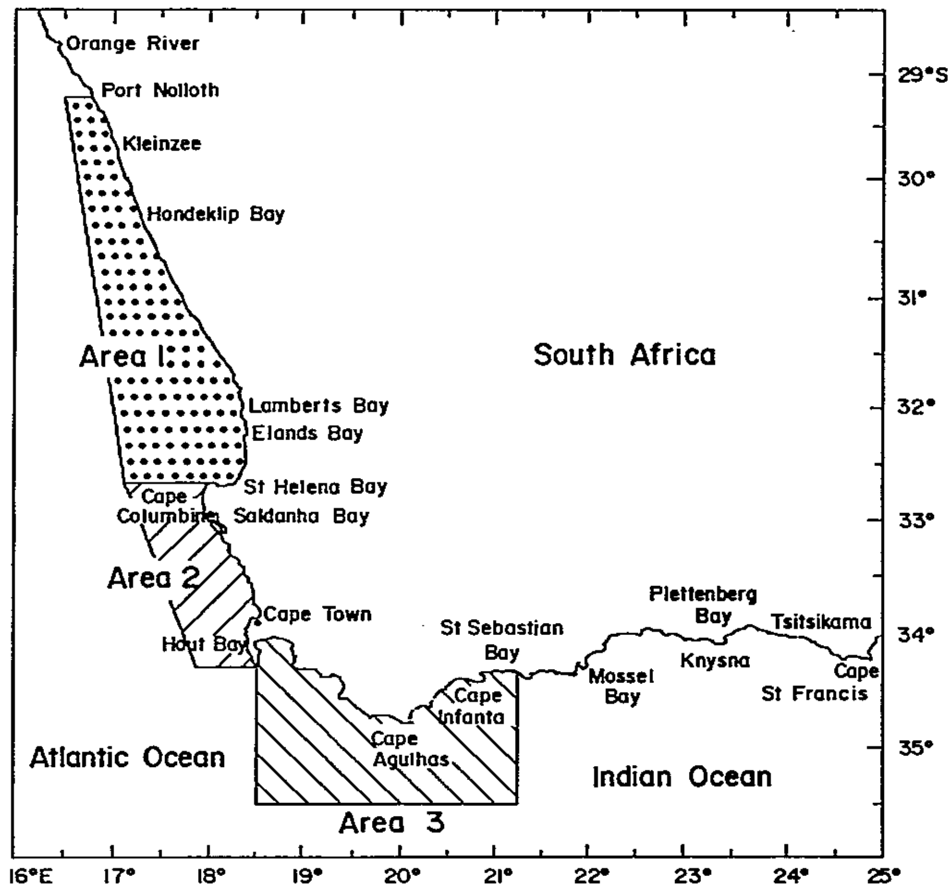

FIGURE 1.39 Map of the three areas of the South African coast used in the analysis.

ENVIRONMENTAL DATA SETS

All the environmental data were consolidated for three main areas off the South African coast, corresponding to the spawning area of adult pilchard, the nursery area of juvenile pilchard and the area of transport of ichthyoplankton between spawning and nursery grounds (Figure 1.39).

Sea level data were reported by Brundrit et al (1987). The data span the period from 1959 to 1985 and were corrected by removing the isostatic effect of air pressure and by filtration of tidal fluctuations. A three-monthly running mean was used to remove short-term effects.

The SST data were obtained from the South African Data Centre for Oceanography (SADCO) and were in excess of 100 000 records. The data for each of the three areas were synthesized into three-monthly running means as in the sea level data.

Wind data were obtained from SADCO for each of the three areas. Wind speeds and directions were decomposed into North-South and East-West wind vectors. Wind estimations appear to be good indirect measures of the upwelling status of the ocean (Hutchings et al this volume). A criterion in terms of minimum number of observations was enforced. Monthly values were excluded from the analysis if fewer than 10 observations were recorded in a month. No exclusions were necessary after 1950.

BIOLOGICAL DATA

Catches were assumed to reflect changes in abundance and were used for the study, owing to either doubt over the validity of other population estimates or their scarcity. Catches also have the longest available record. Annual catches of pilchard *Sardinops ocellatus* from 1950 to 1985 were obtained from Crawford et al (1987). Yearly values were used because it is believed that inter-annual, rather than intra-annual, variability is most important in affecting fish populations.

Simple linear correlations between monthly values of the environmental variables and total annual catches were calculated for each area. In the same way correlations were calculated for environmental variables grouped over a number of months, so as to obtain an idea of the response of the catch to environmental factors affecting seasons and areas of spawning and recruitment. Multiple regressions were also performed using combinations of the same environmental variables.

RESULTS

As can be seen in Table 1.4, there was a consistent response to all four environmental variables in all three areas, the only exceptions being sea surface temperature in areas 1 and 2. This is probably due to the nature of the data and the fact that one-, two-, three- and six-month averages were used, masking sporadic short-term events.

Simple correlations were found between catch and environmental variables in each area. There are very strong negative (for the North-South wind vector) and positive (for the East-West wind vector) correlations with direct catch. With regard to temperature, there is a negative correlation indicating a larger catch with cooler temperatures within the range nine to 20°C. Sea level correlations with catch are also negative, suggesting that a lower sea level, indicative of upwelling, favoured large catches.

TABLE 1.4 Results of simple correlations between four environmental variables (SL = sea level; T = Temperature; NS = North-South wind component; EW = East-West wind component) and catches for the three different areas

	AREA 1				AREA 2				AREA 3			
	SL	T	NS	EW	SL	T	NS	EW	SL	T	NS	EW
Total number of correlations	108	108	108	108	108	108	108	108	108	108	108	108
Dominant sign of correlation	-ve	+ve	-ve	+ve	-ve	+ve	-ve	+ve	-ve	+ve	-ve	+ve
Lag period (years) for highest correlation coefficient	0/1	5	5	5	3/4	0/4/5	5	5	5	2/5	5	5
Sign for highest correlation	-ve	-ve	-ve	+ve	-ve	-ve	-ve	+ve	-ve	-ve	-ve	+ve
Month or period of months with the highest correlation	FEB	JAN	MAR	MAY-JUN	NOV	SEPT	DEC	MAY-JUN	JAN	AUG	FEB	MAY-JUN

Analyses with time-lags appear to have strongest correlations when catches lag temperature and wind vectors by five years (see Figure 1.40 for an example).

Correlations of pilchard catch with sea level do not follow the same pattern as the other environmental variables, but show a tendency to increase with increasing lag time as one goes south and east from area 1 to area 3 (see Figure 1.39). The time-lags (greater than five years) are not presently explained in terms of the pilchard life history.

The above relationships are not as evident in the multiple regression study (Table 1.5). Area 1 had the highest correlation with a one-year lag, area 3 with a five-year lag and area 2 with a lag of around seven years. It is interesting to note, however, that if one assumes a lag period of no longer than five years as reasonable, then the next highest lag correlations for area 2 are consistently centred around three years. The trends of temperature and sea level responses, as shown by the signs of the regression coefficients, remain the same, both being negatively correlated with catch. The East-West wind vector component shows a positive correlation for area 3 (westerlies favourable in the spawning area) but not for the other areas. The North-South vector shows a negative correlation coefficient (northerly winds favourable in all areas). In the multiple regression analyses, as with the simple correlations, there is a tendency for the time lag to increase as one goes from north to south and east.

CONCLUSION

It is generally accepted that coastal upwelling is associated with high primary and secondary production, so one might expect fish abundance, with appropriate lags, to be positively correlated with upwelling intensity.

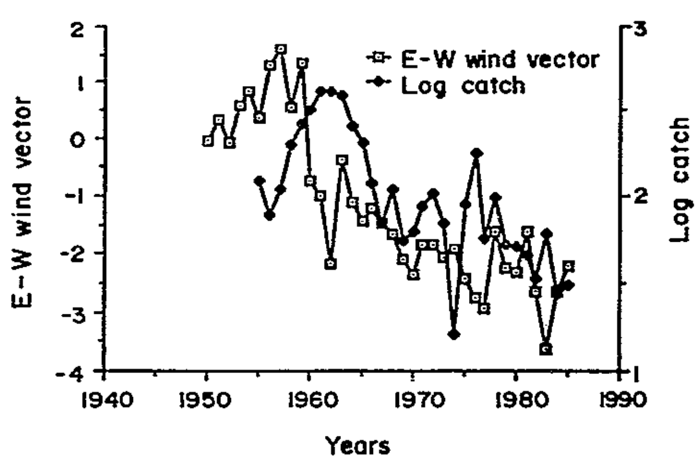

FIGURE 1.40 Five-year lagged catch and East-West wind vector data. The regression coefficient r = 0,8262, n = 31, p < 0,001.

TABLE 1.5 Results of multiple correlations between four environmental variables (SL = sea level; T = Temperature; NS = North-South wind component; EW = East-West wind component) and catches for the three different areas

	AREA 1				AREA 2				AREA 3			
Total number of correlations	1980				1980				1980			
Environmental variables	T	SL	NS	EW	T	SL	NS	EW	T	SL	NS	EW
Sign of highest correlation	+ve	+ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve	+ve
Month or period of months with the highest correlation	February				June				December-February			
Dominant sign of correlation	-ve	-ve	+ve	+ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve	+ve
Lag period (years) for highest correlation coefficient	1				7/9				5			
Lag period (years) with highest correlation coefficient if only first five lags considered	1				3				5			

This trend has been observed by many authors. Belveze and Erzini (1983), for instance, showed a positive correlation between sardine catch and an upwelling index in the eastern North Atlantic. Fiuza et al (1982) found strong positive correlations between the monthly proportions of the annual catch off Portugal and monthly upwelling indices. Bakun and Parrish (1981) demonstrated a positive correlation between mackerel recruitment and an upwelling index in the North-east Pacific. Wooster (in press), however, found that sardine catches off the Iberian peninsula were negatively correlated with spring upwelling for the preceding two to three years.

In the results presented here, the correlations between catch and both sea level and temperature, suggest that there is an increase in catch with decreasing sea level and decreasing temperature, both conditions being related to upwelling. However, correlations of catch with wind data suggest the opposite. A possible explanation for these results might be that north-westerly winds acting locally, would push the fish closer inshore, increasing fish availability rather than causing increased abundance.

If one considers the most frequent signs of all correlations, rather than the signs of the highest correlations (Table 1.4), the picture is somewhat different. The temperature correlations with catch have most frequently a positive sign in Areas 1 and 2, indicating increased pilchard catches with an increase in temperature. The temperature correlations with catch can thus be reconciled with those of wind with catch.

Although the correlations have to be viewed with caution principally due to the strong serial correlation inherent in the data variables, they serve to give an indication of possible mechanisms and provide a good basis for the next stage of the time series analysis.

REFERENCES

Bakun A and Parrish R H 1981. Environmental inputs to fishery population models for eastern boundary current regions. In: G D Sharp (editor) IOC Workshop Report No. 28, Unesco, Paris. pp 67-104.

Belveze H and Erzini K 1983. The influence of hydroclimatic factors on the availability of the sardine (Sardina pilchardus Walbaum) in the Moroccan Atlantic fishery. FAO Fisheries Report 291, 2, 285-327.

Brundrit G B, de Cuevas B A and Shipley A M 1987. Long-term sea level variability in the eastern South Atlantic and a comparison with that in the eastern Pacific. South African Journal of Marine Science 5, 73-78.

Crawford R J M, Shannon L V and Pollock D E 1987. The Benguela Ecosystem 4. The major fish and invertebrate resources. Oceanography and Marine Biology Annual Review 25, 353-505.

Fiuza A F de G, De Macedo M E and Guerreiro M R 1982. Climatological space and time variation of the Portuguese coastal upwelling. Oceanologica Acta 5, 31-40.

Wooster W S (In press). Iberian upwelling and sardine abundance.

CHAPTER 2. MARINE SHELF - SOUTH-EAST COAST

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GROUP MEMBERS: G Cliff, C A de Kock, S F J Dudley and G R Hughes

INTRODUCTION

For present purposes the shelf region of the south-east coast is considered to include the coastal ocean (sensu Schumann 1987) seaward of the surf zone to the 200 m isobath, and the adjoining part of the Agulhas Current, between the Mocambique border and Cape Agulhas. For practical reasons, the Agulhas Bank has been included largely with the south-west coast region in view of its importance to west coast fisheries, particularly those for anchovy *Engraulis japonicus* and pilchard *Sardinops ocellatus*.

The Agulhas Current is a dominant oceanographic feature of the region and undoubtedly is extremely important as a forcing mechanism in environmental and biotic changes along the entire south-east coast. Its ecological significance for this region as a whole has been described by Heydorn et al (1978) and in more detail by Schumann (in press). This south-east shelf has considerable association with the adjoining coastal region, eg in hydrological features, through shared biota such as fish and prawns migrating to and from estuaries, and stranded seabirds and marine mammals found on beaches.

Almost all the data series available for the south-east shelf reflect resource management activities, either in the form of fishery statistics or through angler participation and tourism. The data series are of two types: long-term series assembled specifically for monitoring purposes by institutions with management or conservation objectives, and series which developed from shorter-term projects.

Institutions involved in long-term monitoring in the region include the Sea Fisheries Research Institute (SFRI); the Natal Parks Board; the Oceanographic Research Institute (ORI), Durban; the Natal Sharks Board; the Department of Transport; the Port Elizabeth Museum and the University of Port Elizabeth.

PUBLISHED LITERATURE

Though many data series have been identified, most remain unpublished. Nevertheless a number of significant publications exist and these can be grouped into three categories.

Physical data

The general course of the Agulhas Current was described by Grundlingh (1983), based on an extensive hydrographic data set (period 1969 to 1976, region: shelf and Agulhas Current, St Lucia, Natal, to Port Elizabeth).

The considerable volume of physical data accumulated prior to and during the construction of Richards Bay Harbour, including wind direction and velocities (period 1968 to 1976), current measurements at intervals, wave characteristics (from 1968) and water temperatures (have been summarized in a CSIR report (1980).

Biological data

A number of publications reflect trends in the biota of the region, most directly related to resource utilization. Specifically addressed were demersal handline fisheries of endemic species (period 1965 to 1980, region Agulhas Bank) by Crawford and Crous (1982). Commercial linefish data series were also investigated by Smale and Buxton (1985) and Buxton (1987) (period 1979 to 1980 and 1980 to 1987 respectively, region eastern Cape). Long-term trends in species composition, total catch and catch per unit effort (CPUE) of linefish have been published by van der Elst (in press) (period 1920 to 1983, region Natal shelf). Landings of trawled fish (period 1965 to 1983, region Port Elizabeth) focusing on the kob *Argyrosomus hololepidotus* have been published by Smale (1985). Trends in the monthly recreational linefish catch of the elf *Pomatomus saltatrix* (period 1956 to 1975, region Natal shelf, status ongoing) have been published by van der Elst (1976, in press).

Trends in guano production have been published as indices of seabird abundance and their prey (eg pilchard) by Crawford and Shelton (1978) (period 1950 to 1972, region Algoa Bay) and Bergh (1983) (period 1900 to 1972, region Lamberts Bay and Algoa Bay). More direct assessments of gannet populations have been published by Randall and Ross (1979) and Batchelor and Ross (1984) using aerial photography (period 1956 to 1981, region Bird Island, Algoa Bay).

Changes in the proportions of pilchard *Sardinops ocellatus* and other prey species in the diet of gannets at Bird Island, Algoa Bay have been described by Berruti and Colclough (1987) (period 1978 to 1986, region Eastern Cape, status ongoing).

Extensive records of nesting and hatching rates of loggerhead turtles *Caretta caretta* and leatherback turtles *Dermochelys coriacea* have been published by Hughes (1974b, 1982) (period 1963 to 1981, region Tongaland, status ongoing).

Trends in the annual and monthly rates of capture of large sharks netted by the Natal Sharks Board have been published by Holden (1977) (period 1952 to 1972, region Durban), Wallett (1973, 1978) and van der Elst (1979) (period 1964 to 1978, region Natal, status ongoing).

Historic trends in the exploitation of fin *Balaenoptera physalus*, sei *B borealis* and sperm whales *Physeter macrocephalus* have been published by Gambell (1974) (period 1954 to 1970, region Natal). Patterns in the overexploitation of right whales *Eubalaena glacialis* have been described by Best and Ross (1986) (period 1792 to 1975, region southern Africa). Subsequent recoveries in these right whale populations have been documented by Best (1981) (period 1969 to 1979, region southern Africa). Data for strandings of small cetaceans have been published by Ross (1984) (period 1968 to 1977, region south-east coast, status ongoing).

Other

Levels of nutrients (nitrate, phosphate, silicate) in the waters of the continental shelf of Natal were determined by Carter and D'Aubrey (in press) in an extensive series of offshore transects (period 1970 to 1981, region Natal, status ongoing but more sporadic). No published information is available on long-term trends in parameters such as primary production, plankton or pollution.

NATIONAL MARINE LINEFISH SYSTEM: RECREATIONAL DATA

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INTRODUCTION

For many years the value of recreational fisheries was overshadowed by that of the much larger commercial fisheries. However, dwindling resources, coupled with a fast growing human population, has resulted in a growing demand for marine food. This in turn has given rise to a rapidly increasing amateur linefishery, partly for recreation but largely also to satisfy protein requirements. Present estimates indicate that this demand is growing by at least six per cent annually. Although the value of this fishery is now recognized, it has been difficult to acquire long-term data series, especially because linefishermen are widely dispersed along the entire coast and do not normally report their catches to a central authority. This dilemma was recognized in 1976 by several SANCOR workers who promoted the development of a national data collecting programme. Such a programme commenced in 1980, initially involving the major proportion of South African linefishermen. What appeared to be unattainable goals have almost been achieved and during 1986 a total of 181 000 angler outings were documented.

MATERIALS AND METHODS

Recreational fishing can be divided into a number of facets, and the system adopted here is similar to that of the South African Anglers Union. Hence the following forms of angling have been identified:

a) rock and surf
b) light-tackle boat (estuarine)
c) skiboat
d) spearfishing.

Data collecting systems have been developed for each.

Rock and surf

Angling competition records are made available from the various angling unions in the different provinces, some having commenced in 1956. Approximately 10 000 angler outings are presently being recorded annually.

Data series from nonaffiliated anglers are obtained by two methods:

a) Catch cards are issued at certain controlled access beaches, such as Cape Point, Tsitsikamma and Beachwood. During 1986 a total of 15 571 angler outings were recorded by this technique.

b) Zone officers of the Natal Parks Board (NPB) conduct daily beach patrols during which catch and effort are recorded. This comprehensive "creel" system commenced in 1974 and during 1986 documented 104 415 angler outings.

Estuarine light-tackle boat

Regular tournament records are made available by the clubs involved, and presently amount to about 750 angler outings annually.

Purpose-made catch record cards are issued at a number of resorts, including St Lucia Estuary, Charters Creek and Kosi Bay. This technique yields approximately 13 000 records annually.

Skiboat

Competition records are intermittently made available by clubs or their controlling association, though this amounts to no more than 350 angling outings annually.

A highly productive system is the completion of catch cards on a voluntary basis by various clubs. Up to 40 000 angler outings are processed this way annually.

NPB zone officers check certain launch sites in their zones three times per month on 5th, 15th and 25th. This sampling technique has been operative since 1974 and yields about 450 angler outings annually, including a proportion of commercial fishermen.

Spearfishing

Competition data is sporadically received from underwater clubs, though it represents a very small data source.

Records from nonaffiliated divers are received from two sources:

a) Catch return sheets issued when the spearfishing licences are purchased from the Natal Provincial Administration.

b) Catch record cards filled in by divers at the more popular resorts. Approximately 800 spearfishing outings are recorded this way annually.

RESULTS

The information that is generated by this large data-gathering system is computer processed and made available in two different forms. First, there is a comprehensive system of feedback whereby every boat owner and angling club secretary receives a full analysis of previous years' catches. In addition, nonaffiliated anglers are given handouts at major resorts, each year some 30 000 of these handouts being distributed. The second means of data distribution is to the scientific community, whereby any *bona fide* researcher may request a data report on a specific species or group of fish.

The growth in data acquisition has been most satisfactory and in Figure 2.1 the trend in each facet of recreational angling is given. Unfortunately, the geographic distribution of these records is badly skewed, as more than 90% originate from Natal (Figure 2.2). Serious consideration should be given to promoting data collection in other regions.

The total catch analysed in this programme comprises several hundred species, although some are much more plentiful than others. In Figure 2.3 the percentage composition of all Natal's recreational catches made in 1986 is presented.

CONCLUSION

The National Marine Linefish system is believed to be unique in the world and, with its present level of acquisition, provides an immensely useful basis for investigating fishery-induced as well as natural fluctuations in South Africa's linefishery. Furthermore, it actively promotes involvement of the resource user in a research programme which is considered to facilitate management and ultimately the sustained use of the stock.

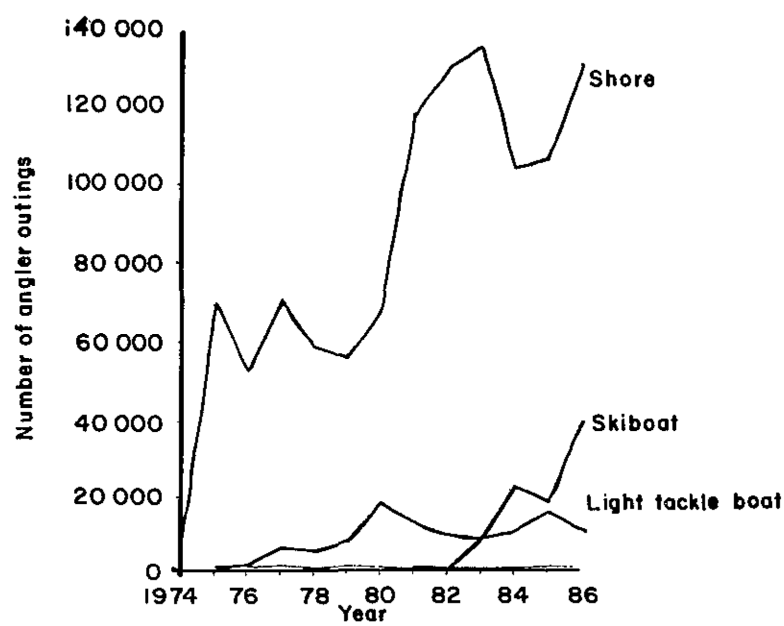

FIGURE 2.1 Growth in the acquisition of data from each facet of South Africa's recreational linefishery.

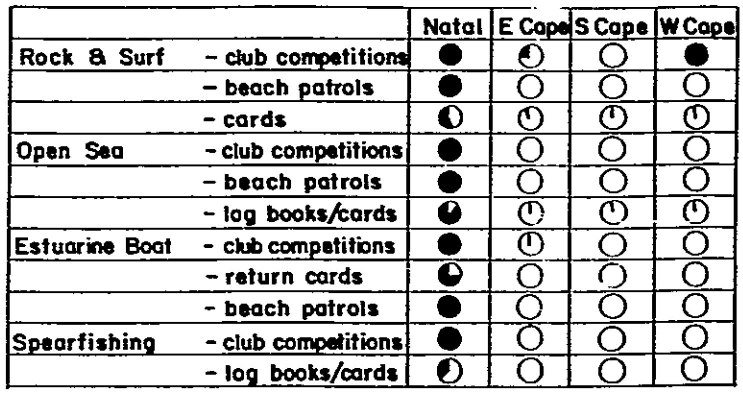

FIGURE 2.2 Pie charts illustrating the relative completeness of linefish catch statistics in South Africa in 1986.

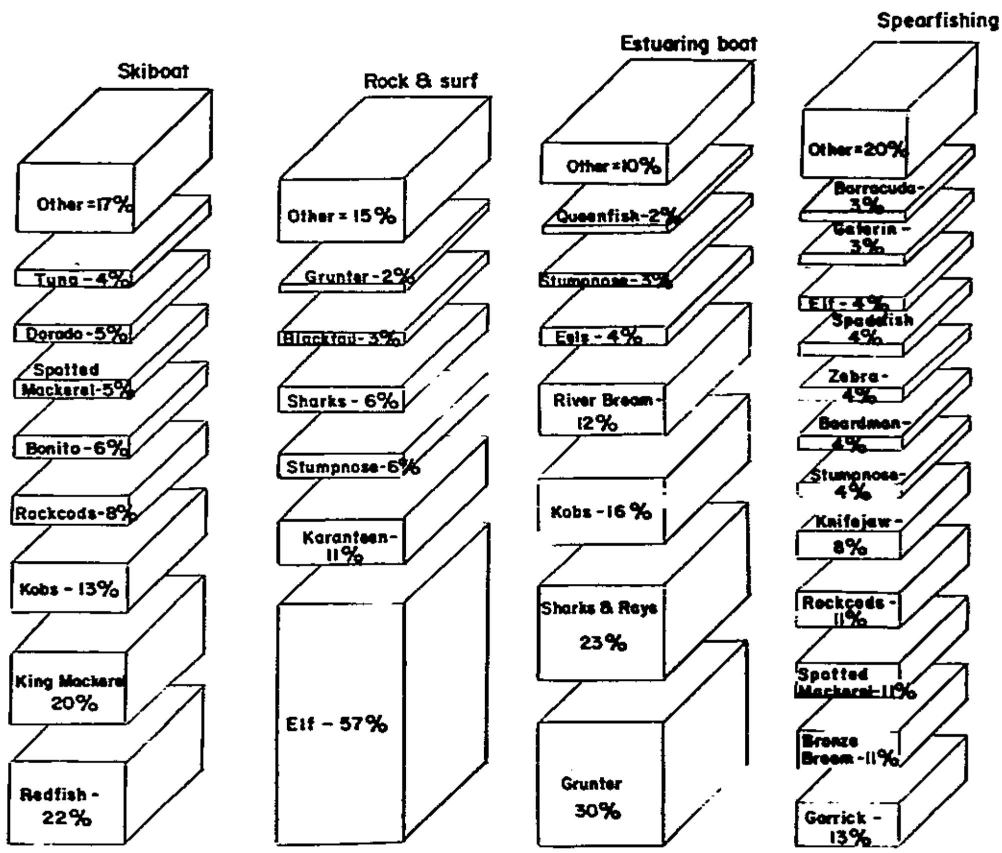

FIGURE 2.3 Species composition of the catches of each component of Natal's recreational linefishery in 1986.

LONG-TERM TRENDS IN NATAL MARINE FISHERIES

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Oceanographic Research Institute

INTRODUCTION

The Natal shelf has sustained a number of fisheries for the past 100 years. Though none rival the total tonnage produced by temperate fisheries of the Cape, the value of the Natal resource and its direct benefit to local communities is considerable.

The fishery comprises a number of distinct facets, which may be grouped in a variety of ways. For the purpose of this presentation the divisions are inshore and offshore, each of which can be further divided into fish and invertebrates. A further overall division that is made concerns the distinction between commercial and recreational fishermen.

All these facets have undergone fluctuations or trends in their landings, some no doubt directly attributable to fishing pressures, but others quite probably a result of natural fluctuations. Clearly long-term data series are needed to investigate these, if only to ensure effective management strategies and optimal resource utilization.

METHODS AND MATERIALS

Since the promulgation of the Natal Fisheries Act in 1880, there have been several attempts to quantify catch and effort from various facets of the fishery. Some of these were successful and some data series presented here originated in 1917. Such records provide a good indication of the original, virtually unexploited status of Natal's renewable marine resources. Recreational fishermen have accurately recorded catches of their shore-based tournaments from 1956 onwards, providing three decades of continuous data.

Since 1974, the Oceanographic Research Institute (ORI) has undertaken the collection of catch and effort statistics, especially those derived from the Natal Fisheries Licensing Board. Furthermore, there are daily censuses on beach patrols by the Natal Parks Board (NPB), catch cards at major fishing sites, as well as onsite censusing by ORI staff.

At present data on catch and effort of the Natal fishery are collected from 0,25 million fishermen outings annually, providing monthly and yearly data sets for several hundred species of linefish, pilchard, prawns, cray-fish, mussel, oyster, redbait, burrowing prawns, molecrab, ghostcrab etc. The database for the recreational fishery has been described by van der Elst and de Freitas (this volume).

RESULTS

Coastal invertebrate fisheries

A considerable diversity of invertebrate biota is harvested from the shores of Natal, both as a source of food and as bait for anglers. The organisms include mostly decapod crustaceans and bivalve molluscs, by far the majority being harvested on a noncommercial basis by almost 35 000 licence holders. The annual number of licences issued and subsamples of catch and effort statistics provide useful insight into long-term trends in the invertebrate resource.

Effort. While the price of and rules relating to licences issued by the Natal Provincial Administration have at times been modified, the overall trend in licences issued is markedly positive. In 1962 a total of 564 so-called 'bait' licences were issued, rising to a total of 4 328 in 1972. Better recording was initiated in 1974, since when the number of licences has escalated from 9 211 to 34 897 in 1986 (Figure 2.4a). The primary reason for this phenomenal increase, amounting to 11% per annum compounded, has been a swing away from traditional use of invertebrates as bait to use of the harvest for high quality seafood, eg mussels and octopus in particular.

Total catch. The total catch in tons of all the organisms harvested during the period 1974 to 1986 shows a steady increase, with a noticeable peak in 1983 (Figure 2.4b). The increase amounts to six per cent per annum, yet further indicating that there have not been major changes in the species composition of catches. The only significant relative change was that of increased landings of octopus and mussel (Figure 2.4c).

Landings of individual species. The total catch comprises a variety of organisms, viz:

Natal rock lobster *Panulirus homarus*
Crabs *Ocypoda ceratophthalmus* and *O ryderi*
Burrowing prawns *Upogebia africana* and *Callianasa kraussi*
Molecrabs *Emerita austroafricana* and *Hippa ovalis*
Octopus *Octopus vulgaris*
Oyster *Striostrea margaritacea*
Mussel *Perna perna*

Individual landings of these species all reveal to a greater or lesser extent, an increasing trend (Figures 2.4d-j).

Considerable interannual variation also occurs, although most data sets indicate some congruency. For instance, 1980 to 1983 and 1986 had higher landings for most species.

Offshore invertebrate fisheries

Without exception, the exploitation of invertebrate stocks over the shelf region is conducted by commercial operators using bottom trawls at various depths, from the shallow Tugela Bank (20 m) to depths of 600 m on the continental slope.

Effort. The Durban based trawler fleet has remained stable since 1973, largely due to management restrictions placed on further licence issue (Figure 2.5a).

Total catch. The total catch of invertebrates landed by Durban based trawlers fluctuates considerably from year to year (Figure 2.5b), although much of this is known to be a result of varying fleet movements in response to political developments in Mozambique. Generally, it can be concluded that from 1973 to 1986 the catch increased by only 8,7%. Significantly, however, the species composition has changed (Figure 2.5c). Prawns remain the most important group, but langoustine and crab have increased considerably.

Landings of individual species. The total catch comprises the following individual species:

Prawns *Penaeus indicus, P monodon, Metapenaeus monoceros* and *Haliporoides triarthrus*
Crab *Geryon macphersoni*
Langoustine *Metanephrops andamanicus*
Crayfish *Palinurus delagoae*
Squid *Loligo reynaudii* plus other species.

Individual landings of these species are reflected in Figures 2.5d-h. Several noteworthy trends emerge, although data are still inadequate to determine if these are natural fluctuations or merely a response to commercial market pressures. The great changes in crayfish landings, for instance, are almost in contrast to those of langoustine and crab. One factor common to all is very poor catches during 1983.

Coastal finfish landings

There are some 60 000 resident anglers in Natal van der Elst (1984) and their numbers are increased considerably by seasonal tourists from inland provinces. These are essentially recreational anglers, the amount of commercialism being negligable.

Effort. Although the absolute number of anglers is difficult to determine because of their wide dispersal, the NPB patrol data provides a good index of angling effort (Figure 2.6a). Clearly there have been marked changes since 1975, with significantly reduced angling effort during 1978 to 1980 and a noticeable peak in 1983.

Total catch. It follows that the total catch of shore-caught finfish should at least partially mirror the trend in total effort. This is only partly true, however, (Figure 2.6b) and it appears that 1977, 1979, 1984 and 1985 are years during which nonanthropogenic factors may have influenced landings. Significantly 1983 again shows a peak, similar to that in coastal invertebrates.

There are approximately 250 species that make up the total catch, though only 10 species constitute 75% of the catch (Figure 2.6c). Based on extensive data, it is clear that there has been a significant change in the composition of the total catch since 1956, notably a drastic increase of cartilaginous fish from six per cent to 52% of the catch. This change has been previously documented (van der Elst 1979) and appears to be persistant in nature. The species that have contributed most to this increase are the dusky shark *Carcharhinus obscurus*, the milkshark *Rhizoprionodon acutus*, the sandsharks *Rhinobatus annulatus* and

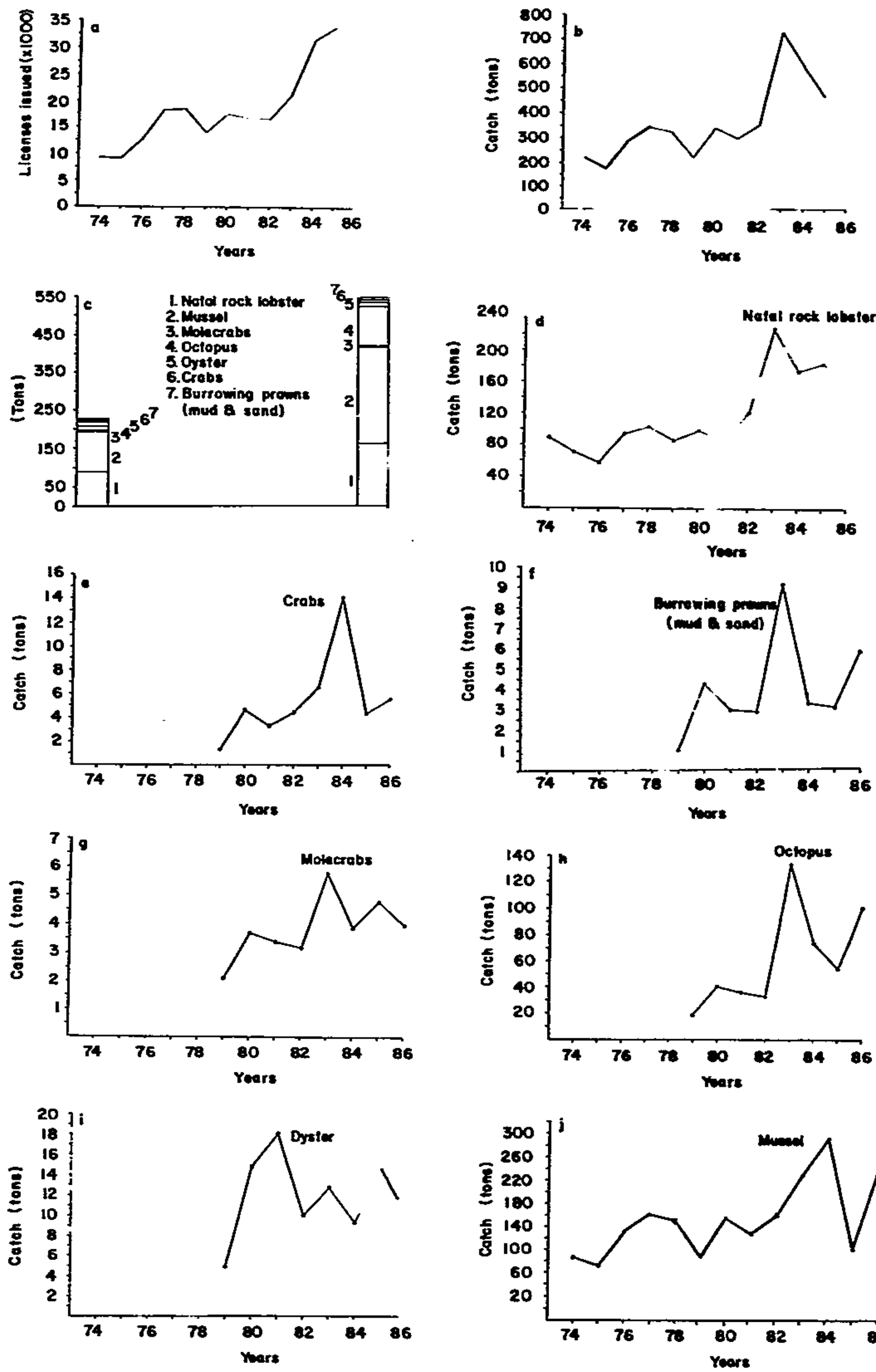

FIGURE 2.4 Data series for Natal's coastal invertebrate fisheries: a) Numbers of licences issued, 1974 to 1986; b) Overall harvests of invertebrate organisms, 1974 to 1986; c) Species compositions of invertebrate organisms harvested in 1974 and 1986; d) Catch of Natal rock lobster, 1974 to 1986; e) Catch of crabs, 1974 to 1986; f) Catch of burrowing prawns, 1974 to 1986; g) Catch of molecrabs, 1974 to 1986; h) Catch of octopus, 1974 to 1986; i) Catch of oyster, 1974 to 1986; j) Catch of mussel, 1974 to 1986.

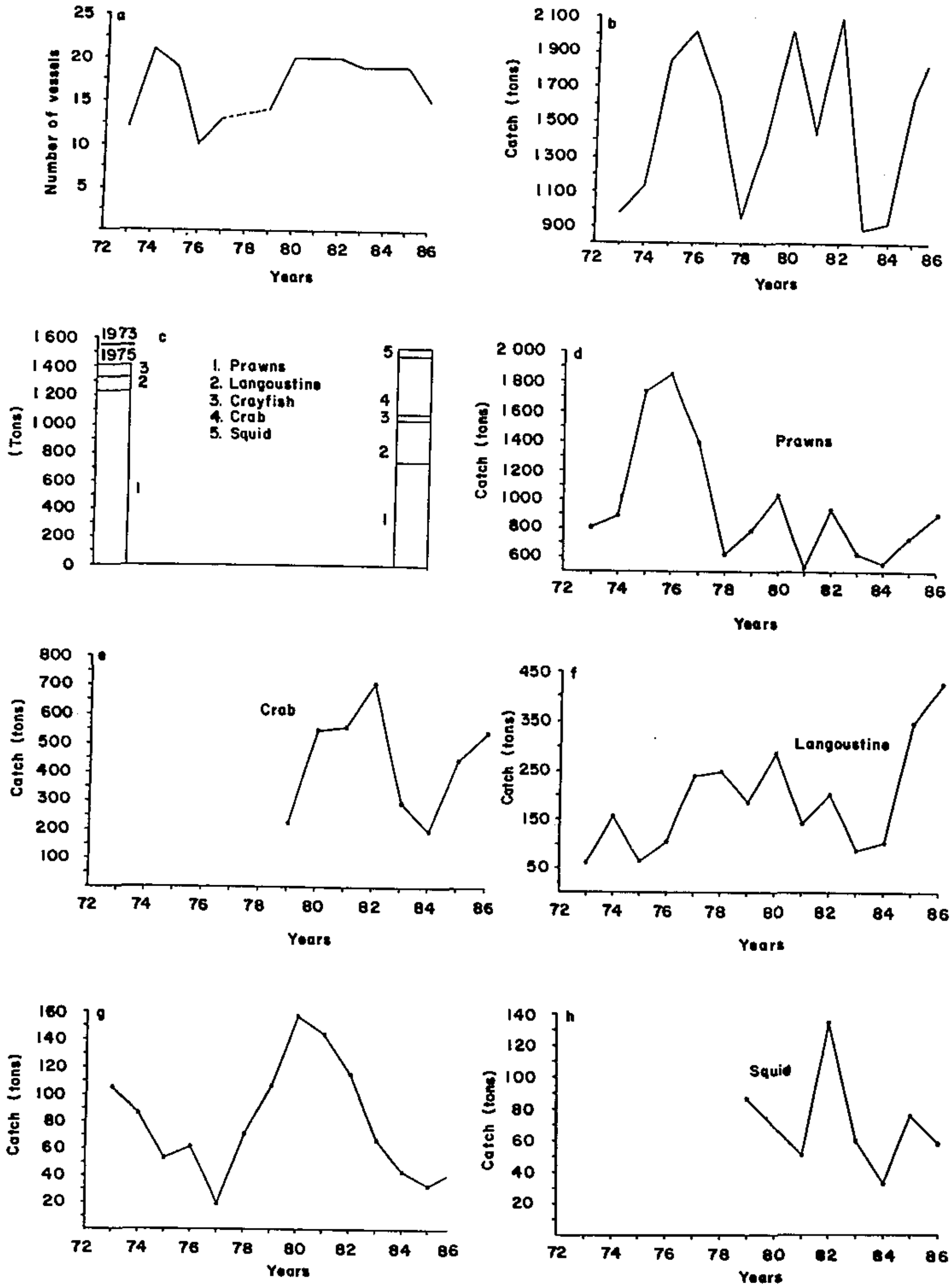

FIGURE 2.5 Data series for Natal's offshore invertebrate fisheries: a) Numbers of prawn trawlers based at Durban, 1973 to 1986; b) Overall catches, 1973 to 1986; c) Species composition of catches in 1973 to 1975 and 1984 to 1986; d) Catch of prawns, 1973 to 1986; e) Catch of crab, 1973 to 1986; f) Catch of langoustine, 1973 to 1986; g) Catch of crayfish, 1973 to 1986; h) Catch of squid, 1973 to 1986.

Rhynchobatus djeddensis and the blue stingray *Dasyatus pastinacus*. In sharp contrast, many of the endemic teleost fishes have decreased in relative abundance.

Landings of individual species. Data series for only two key species are presented, although similar data for catches since 1956 exist for 100 species. Figure 2.6d reveals the increasing trend in abundance of dusky sharks. Since attaining a peak in 1978, there have been fluctuations in the catch that are probably not man- induced, especially the marked change from 1983 to 1984. Another key species, the elf *Pomatomus saltatrix* (Figure 2.6e), was subjected to strict management regulations from 1976 onwards, which interrupted the continuity of historic data sets. Nevertheless, alternative sets were developed and the increasing trend since 1976 is obvious, lending support to the possible effectiveness of the regulations.

Offshore finfish landings

There is a sizeable fleet that exploits linefish over the Natal shelf region, composed of both commercial and recreational fishermen. In addition, but to a much lesser degree, epipelagic fish have been pursued or caught in beach-seine nets.

Effort. When the offshore linefishery first developed, in about 1890, it comprised steam-driven harbour-based vessels. These were later replaced by 15 to 20 diesel-powered lineboats, each with a complement of about 20 fishermen. Since 1950 this has radically changed, however, and during 1987 there was not a single lineboat operating off the Natal coast. Instead there were 1 300 skiboats, each with a crew ranging from two to eight. Not only has the effort in the fishery therefore grown considerably (Figure 2.7a), but it has shifted away from harbour-based operations to beach launching along the entire coast. Much of the increase is attributable to growth in the recreational sector of the skiboat fishery.

The beach-seine fishery for pilchards *Sardinops ocellatus* has fluctuated considerably, though the number of registered netters has remained constant at around 30. Since 1984 a small purse-seiner joined the fishery for pilchards.

Total catch. Despite the considerable change in linefishing effort, it appears that there has not been a corresponding change in the total catch landed (Figure 2.7b). Obviously this infers a lowered catch per individual fisherman. More significant, however, has been the change in species composition (Figure 2.7c). During the years 1922 to 1933 more than 50% of the catch comprised such valuable endemic species as 74 *Polysteganus undulosus*, red steenbras *Petrus rupestris* and poenskop *Cymatoceps nasutus*. By 1983 this component of the catch had dwindled to less than 10%, with other, less desirable nonendemic species replacing them.

The seine-net fishery for pilchards or sardines shows considerable interannual fluctuation (Figure 2.7d). Though these are possibly related to limitations in the data and perhaps also linked to harvesting of pilchards elsewhere, it is nevertheless considered that these data hold promise as an indicator of natural fluctuations in pilchard stocks and their environment.

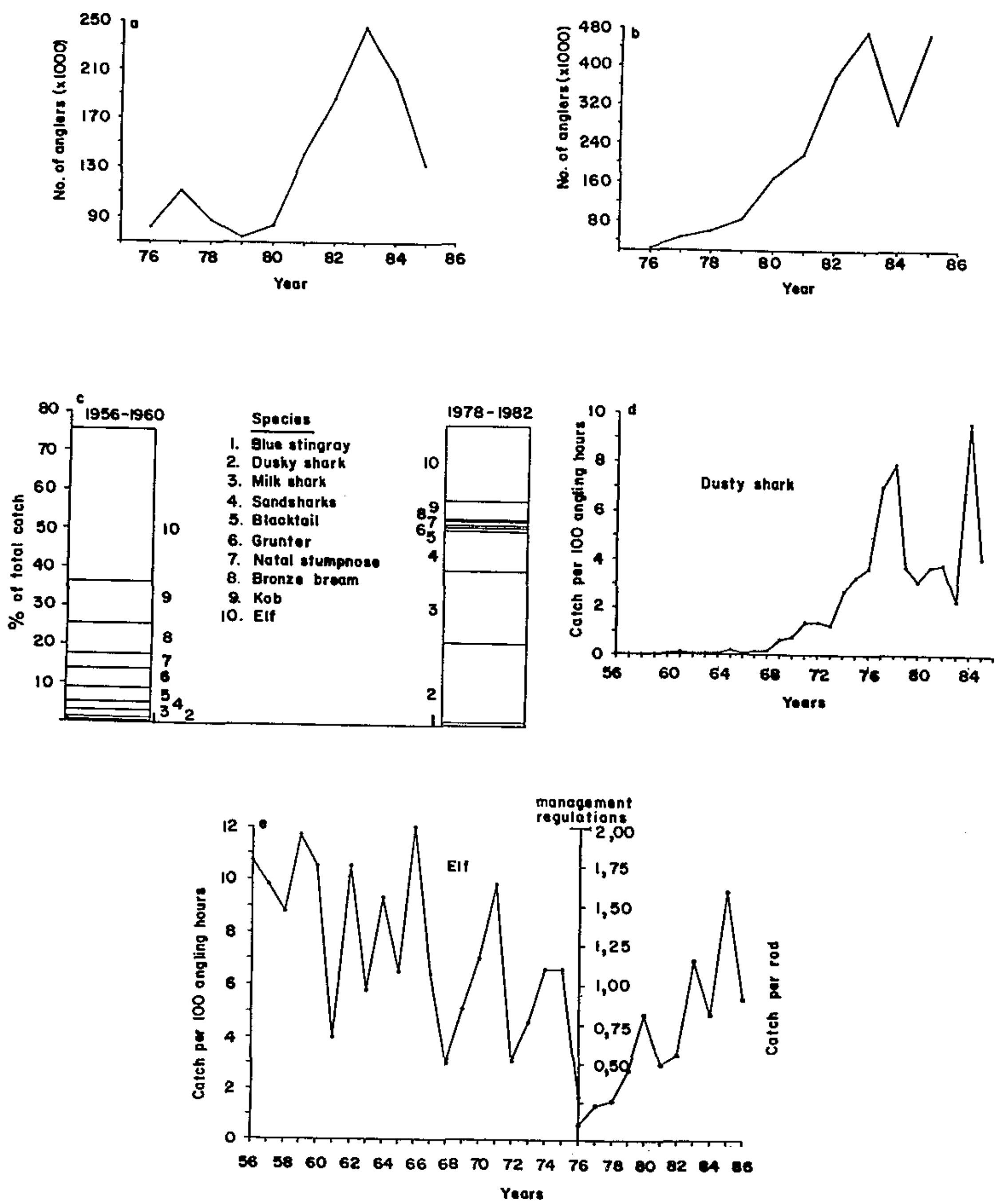

FIGURE 2.6 Data series for Natal's coastal finfish fisheries:
a) Trends in fishing effort expressed as angler outings, 1975 to 1986; b) Overall shore-based linefish catches, 1975 to 1985; c) Relative contribution in 1956 to 1960 and 1978 to 1982 of the top 10 species in the fishery; d) Trends in catch rates of juvenile dusky sharks, 1956 to 1984; e) Trends in catch rates of elf, Natal's top angling fish, 1956 to 1984, before and after implementation of management regulations.

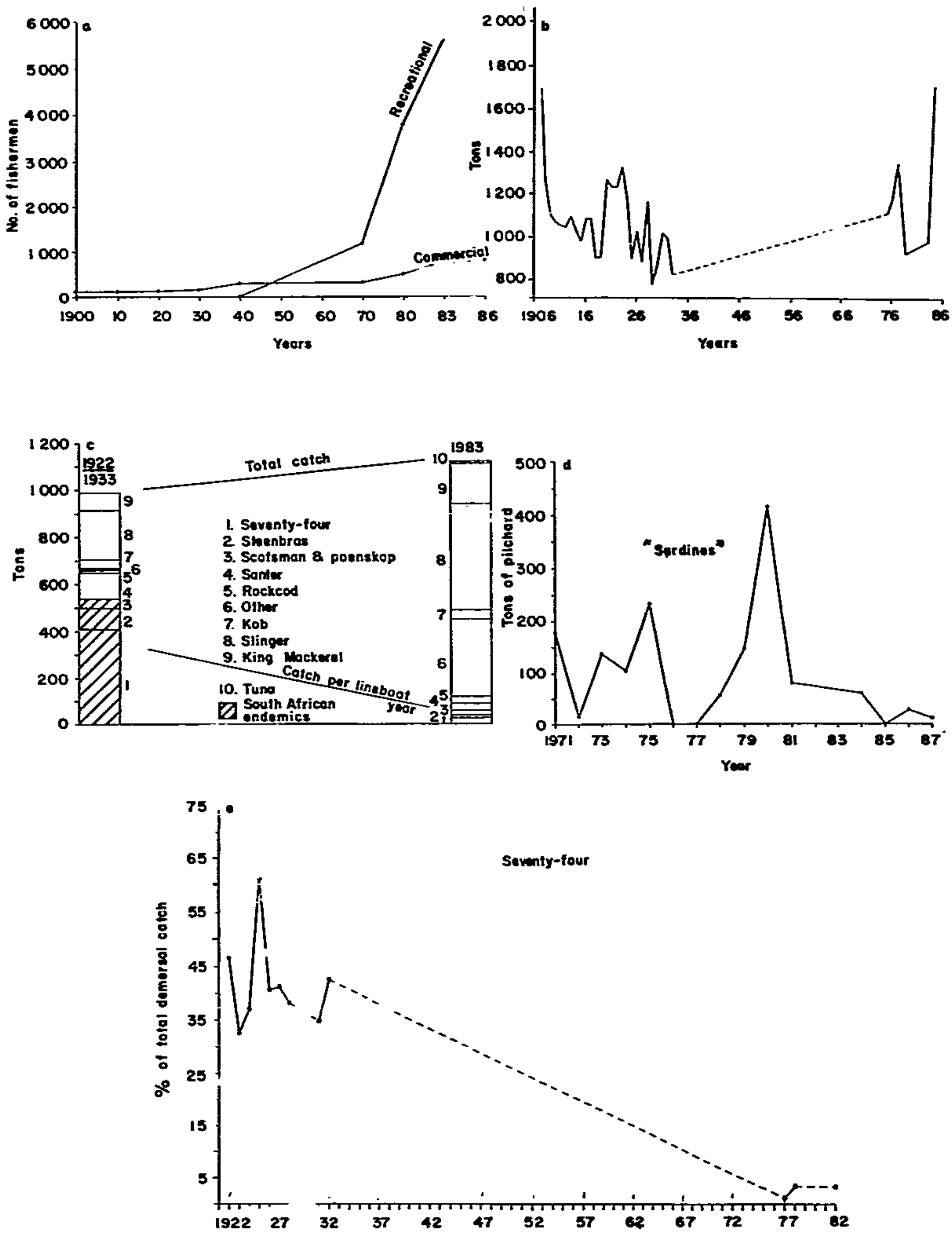

FIGURE 2.7 Data series for Natal's offshore finfish fisheries:
a) Trends in recreational and commercial effort expressed as numbers of participating fishermen, 1900 to 1986; b) Overall linefish catches, 1907 to 1986; c) Species composition of catches in 1922 to 1933 and 1983; d) Landings of pilchard ("sardines") by beach-seine nets, 1971 to 1987; e) Percentage contribution of 74, Natal's top offshore linefish, to the demersal catch, 1922 to 1982.

Landings of individual species. The total catch of linefish comprises some 300 species, for many of which good data sets exist since 1984. Before this date information is patchy, although for several key species quite informative. The 74 is a good example (Figure 2.7e), the lengthy data set clearly showing its declining trend.

CONCLUSIONS

Although the data series provided remain inadequate, it may nevertheless be concluded that these records are suitable for providing insight into the abundance of more than 200 linefish species and about 15 invertebrates. The overall trend that emerges is one of relative constancy in total catch which, when related to growing demand and effort, infers substantial declines in catch per unit effort. Clearly these renewable resources are not likely to sustain the pace of future demand. Furthermore, and perhaps more seriously, the composition of the catch has altered significantly in most cases. While in the case of invertebrates this is in part due to market pressures, for linefish it is a reflection of changes in the ecosystem that have been caused by fishing pressures. It is of concern that endemic species have been most seriously depleted.

Besides these gross trends that can be detected, it would appear that data from widely differing sources often show congruent fluctuations. It was quite apparent, for instance, that 1983 was a year during which major fluctuations occurred. It, therefore, remains an outstanding objective to investigate the data series presented, with a view to detecting natural fluctuations.

ACKNOWLEDGEMENTS

Much of the data represented here has been collected with assistance of Sea Fisheries Research Institute, Natal Parks Board, South African Anglers Union, Natal Fisheries Licensing Board, South Africa Nature Foundation and SANCOR.

AN OVERVIEW OF SHARK CATCHES IN NATAL'S SHARK NETS: 1966 TO 1986

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INTRODUCTION

The gill nets which are used on the Natal coast to protect swimmers from shark attack have provided a unique means of monitoring the populations of large sharks in Natal's nearshore waters. The nets are either 106 m or 212 m in length and six metres in depth, with a mesh size of 25 cm. They are anchored in water 10 to 14 m deep approximately 500 m offshore, where they are serviced on an almost daily basis.

Nets were first installed off Durban's beaches in 1952. The Natal Sharks

Board (NSB) was formed in 1964 when netting operations were extended to other holiday resorts on the Natal coast. The number of nets and netted beaches has since increased considerably (Figure 2.8). Initially the nets were maintained by private meshing contractors who displayed varying degrees of diligence in recording details of sharks caught. Identification, particularly of closely related species, was also a problem. In the mid- and late 1970's staff of the NSB began to assume responsibility for maintaining the net installations. This improved the accuracy of the data collected. By the end of 1982 this transition was complete.

Catch statistics kept by the NSB since 1966 have been used to assess shark catches along Natal's coast, divided into northern and southern regions by Durban. The subdivision of the coast is based on the perceived extent of influence on shark catches of the winter migration of the pilchard *Sardinops ocellatus*. This phenomenon, termed the Natal sardine run, is the greatest single factor contributing to the variability of the annual shark catch.

In those years when the pilchard shoals move close inshore, shark catches during June and July may exceed the total catch for the other 10 months. For this reason sharks caught during the sardine run have been excluded from the analysis. Trends in shark catches in Durban's nets between 1952 and 1972 have been discussed by Holden (1977) and van der Elst (1979), but all Durban data have been excluded from the present analysis.

RESULTS

The total number of nets on the north coast increased by 150% from 24 in 1966 to 60 in 1970, and then by only 35% to 80 in 1986 (Figure 2.9). Despite the large increase in nets between 1966 and 1970, the annual shark catch decreased by 67% and then fluctuated about a mean of 248 ± 76 (SD) sharks per year (Figure 2.10). The major impact of netting occurred during the first five years when catch per unit effort (CPUE) dropped by 87% from 28,3 to 3,7 sharks per 106 m length of net (Figure 2.11). This was followed by a 16-year period of oscillation about a mean of 3,4 ± 1,1 sharks per net per annum. These statistics exclude the isolated installation at Richards Bay (85 km from Zinkwazi) which was established in 1980 and where catches have been extremely high in comparison with those at other north coast beaches.

Trends in total catch on the south coast do not closely match those on the north coast (Figure 2.12). There was an overall decline of only 12% between 1966 and 1970, during which time the number of nets increased by 183% from 54 to 153 (Figure 2.9). Total catch dropped a further 36% in 1971 but subsequent catches showed a slow increase until 1986. The magnitude of the initial drop in CPUE (Figure 2.13) from 9,5 sharks per net in 1966 to 2,9 in 1970 was not as great as that on the north coast. The level of 2,8 ± 0,7 sharks per net attained subsequently was, however, very similar to that of 3,4 for the north coast. These statistics exclude catches at Mzamba, where nets were installed in 1981 and which is five kilometres south of the previously southernmost nets at Port Edward. As at Richards Bay, shark catches at Mzamba have been high in comparison with those at adjacent beaches.

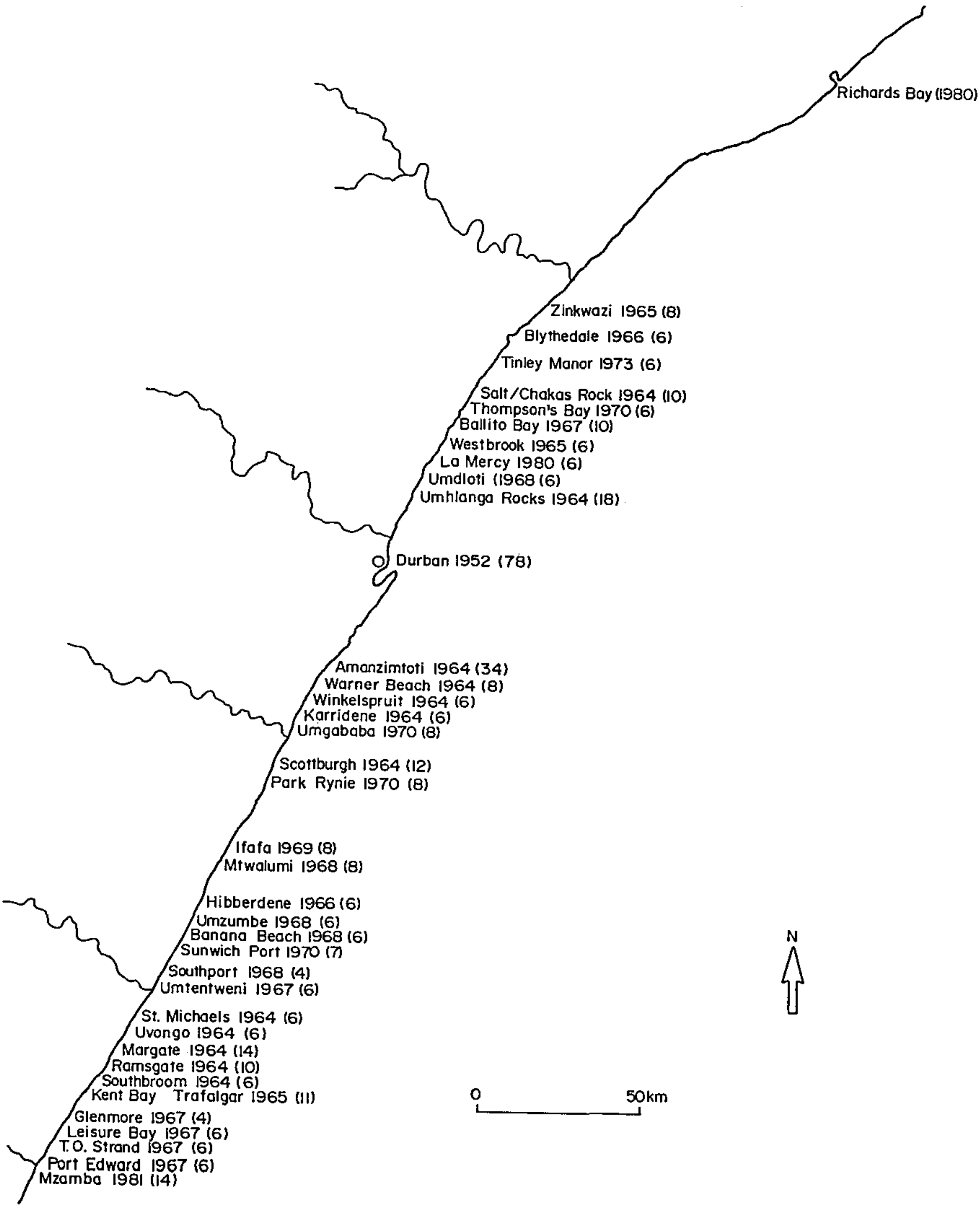

FIGURE 2.8 The Natal coast indicating netted beaches, year of installation of nets and, in parentheses, the current number of 106 m units of net.

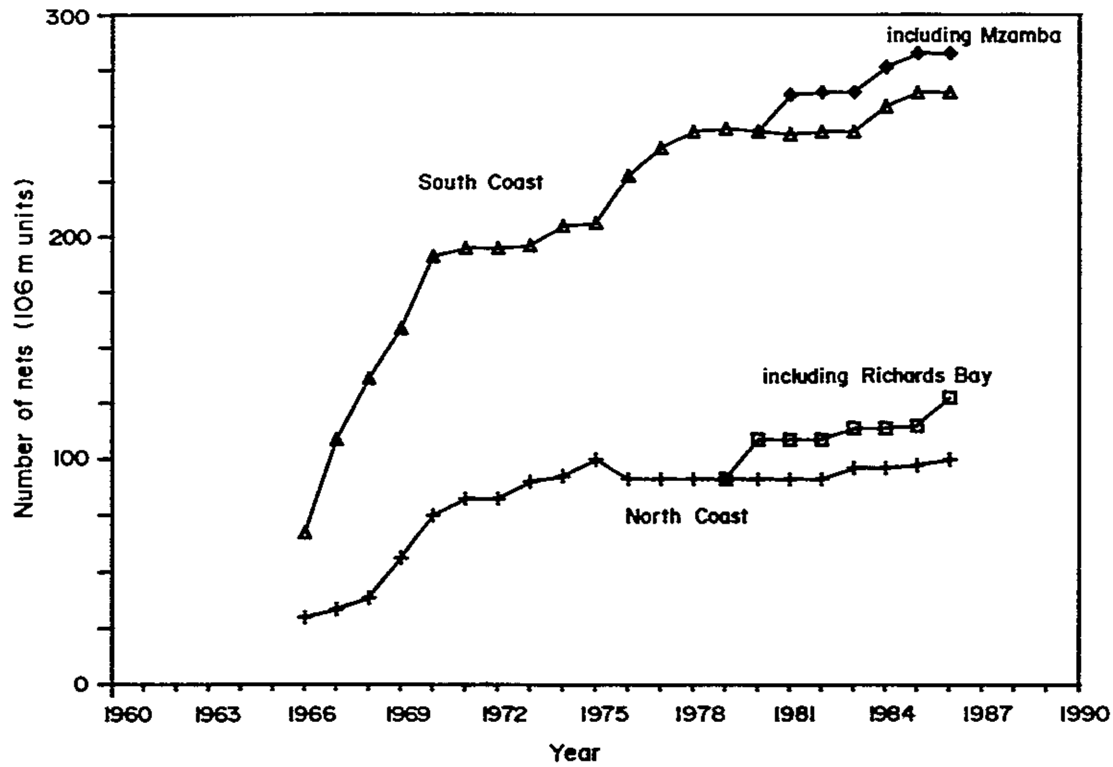

FIGURE 2.9 The number of shark nets at the end of each year on Natal's north coast, excluding and including Richard's Bay, and on Natal's south coast, excluding and including Mzamba.

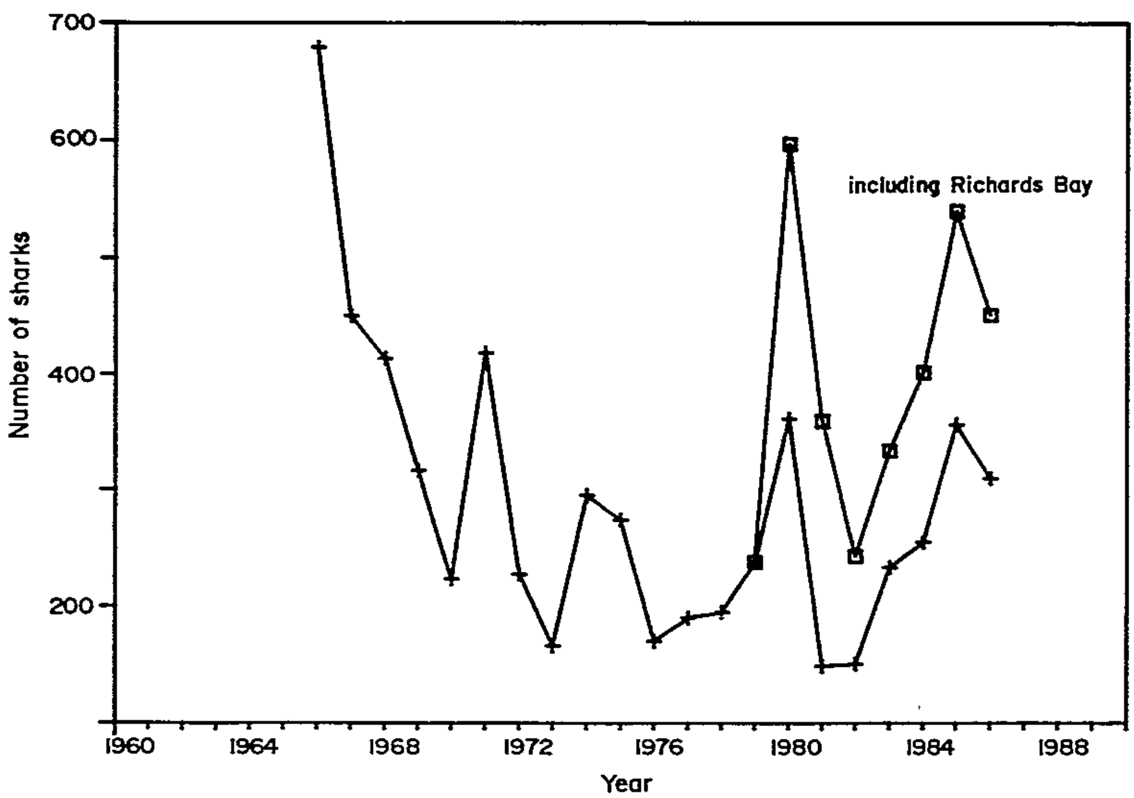

FIGURE 2.10 The total annual shark catch in the shark nets on Natal's north coast, excluding and including Richard's Bay.

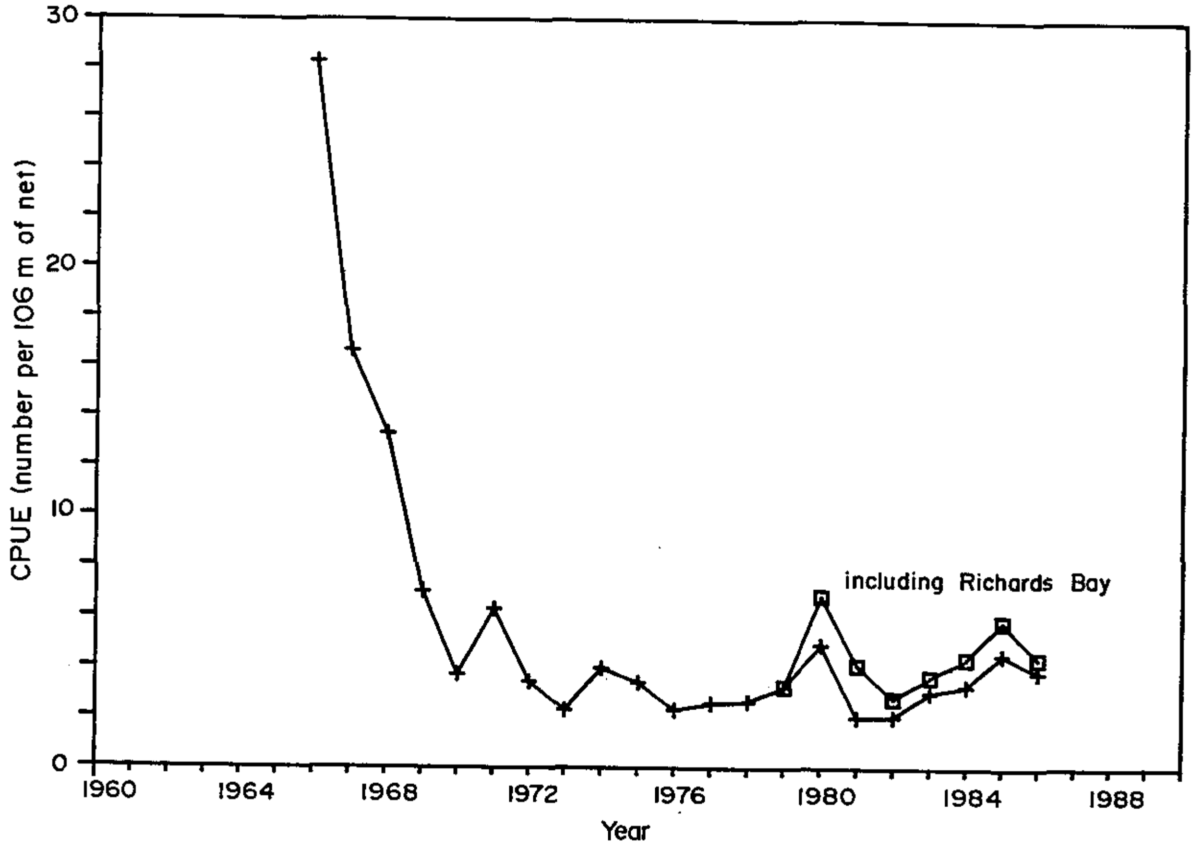

FIGURE 2.11 The total annual shark catch per 106 m length of net on Natal's north coast, excluding and including Richard's Bay.

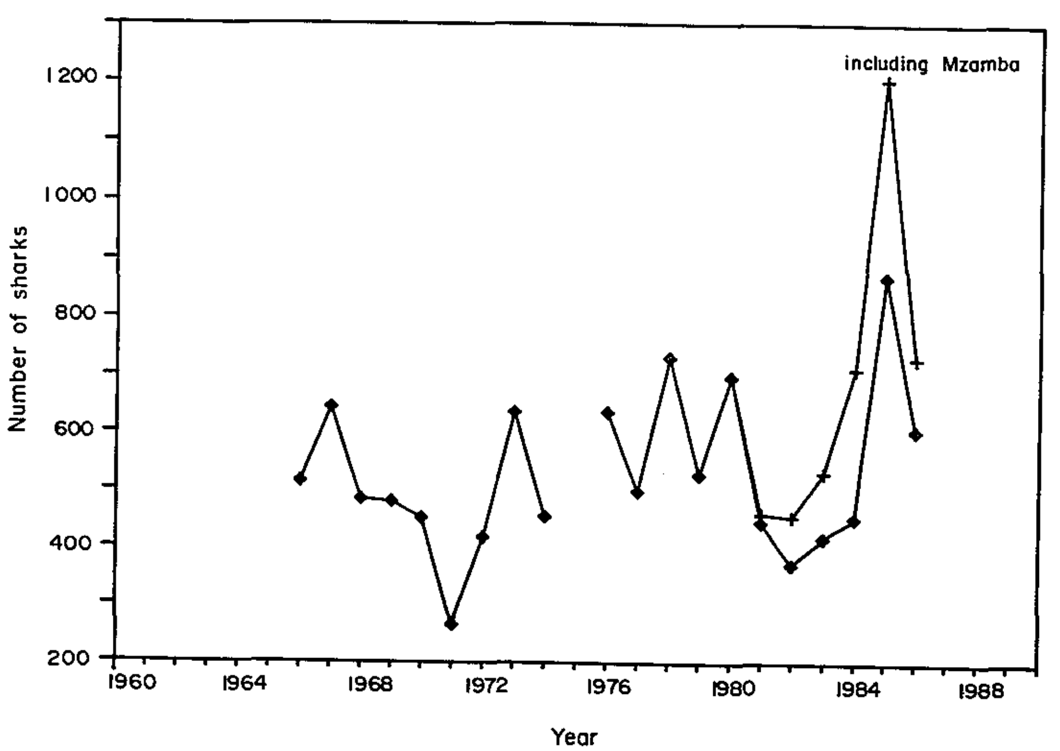

FIGURE 2.12 The total annual shark catch in the shark nets on Natal's south coast, excluding and including Mzamba.

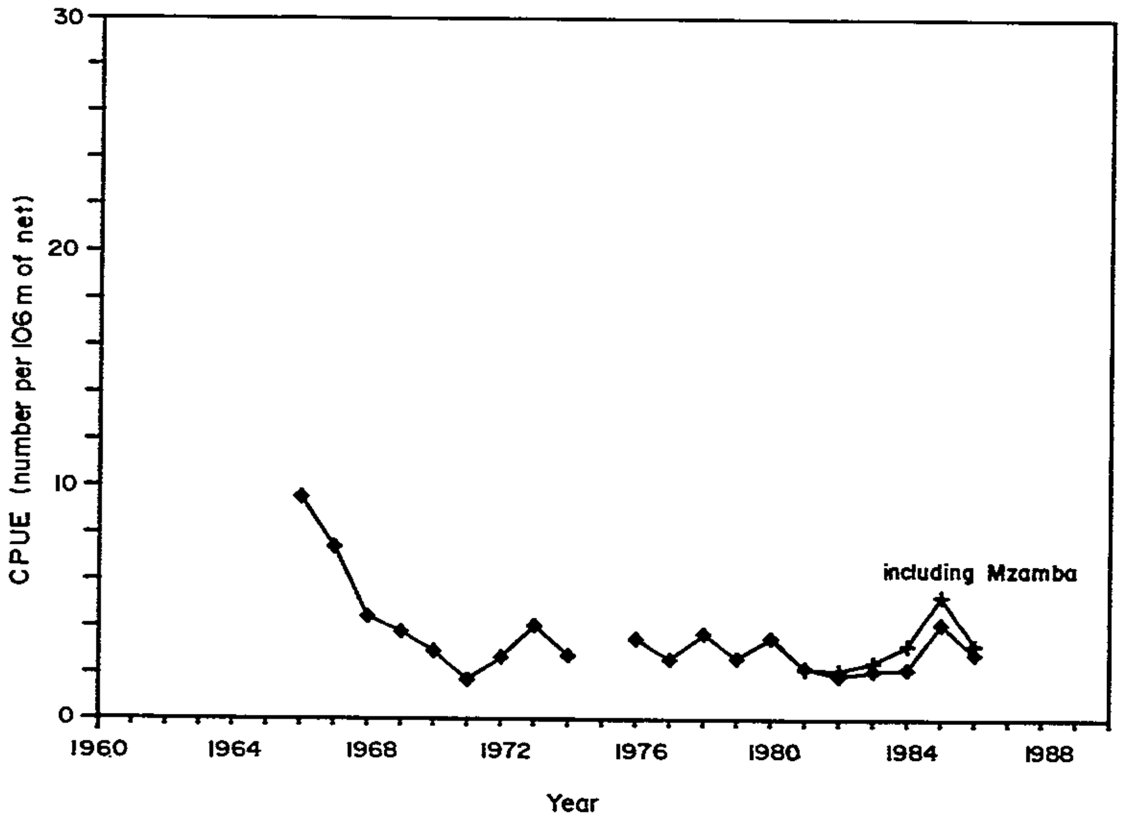

FIGURE 2.13 The annual shark catch per 106 m length of net on Natal's south coast, excluding and including Mzamba.

DISCUSSION

From the initial steep drop in CPUE on the Natal north coast it is apparent that the installation of nets in previously unexploited areas results in a major reduction of the resident shark community. Unfortunately no data are available for 1964 and 1965, the first two years of netting operations. It is probable that had these two years been included, the decline in CPUE would have been even more pronounced. The term resident community is undefined in that it encompasses an unknown number of species of sharks, each with undetermined ranges of movement. Also unknown is whether learned net avoidance reduces captures.

The drop in initial CPUE was less pronounced on the south coast. In general, the early data are regarded as being of a poorer quality than those for the north coast. Infrequent clearances of the nets coupled with poor records may account for the low catches during the early years. Furthermore, by 1966 there were three times as many nets in this region than to the north, and it is possible that a particularly steep decline in CPUE may already have occurred between 1964 and 1966.

Wallett (1973) proposed that once resident sharks are removed by the shark nets, constant catches of migrating sharks will follow. This hypothesis appears reasonable in the light of the essentially constant CPUE level which has been attained in both regions since 1970. Very little is known about the movements and possible territoriality of these large predators, as discussed by Holden (1977), and therefore the extent of the area affected by their removal cannot be defined.

Combining catches of the 14 most common shark species provides a crude method of assessing the effects of the shark nets. No reliable data exist prior to 1978 concerning possible changes in diet, size frequency distribution and age at maturity of each species, as well as in species composition of catches. Such information would have allowed an analysis of the large changes which occurred during the critical first five to seven years after the nets were installed. These data do, however, exist for Richards Bay and Mzamba, but have not yet been examined. Shark catches at these two beaches, which lie beyond the previous limits of the netted coastline, have been depicted separately. These two net installations may be fishing unexploited shark populations, and at this stage their influence on catches at other beaches is undetermined.

The historical failure of a number of shark fisheries has been attributed to the elasmobranch characteristics of slow growth rate, late maturity and a close relationship between stock and recruitment (Bedford 1987). The consistency in CPUE since 1971 is therefore unexpected in the light of elasmobranch susceptibility to overfishing, but is probably due in part to the grouping of all species in this analysis. Further investigation may well reveal a decline in CPUE for certain species.

SEA TURTLES IN MAPUTALAND

G R HUGHES
Natal Parks Board

INTRODUCTION

The Maputaland Sea Turtle Programme started in 1963 and has continued on an annual basis until the present. Objectives are primarily to monitor the success of the Natal Parks Board's conservation effort, and secondly to study within and between season behaviour and movement of nesting females. Two species of sea turtles are involved, the leatherback turtle *Dermochelys coriacea* and the loggerhead turtle *Caretta caretta*. Publications arising from the programme include those of McAllister et al (1965), Hughes et al (1967) and Hughes (1974a,b, 1982).

TECHNIQUES

During the first five years of the 24-year period there was some variation in the monitoring effort, which makes the data for those years slightly, but not much, less reliable than for the last 19 years.

The study area is 56 km long, and is marked out at 400 m intervals for 24 km with the balance in 1 600 m intervals. Nightly foot patrols are undertaken by 12 semiskilled game guards stationed in pairs at six field outposts. Additional nightly patrols are conducted over the 16 km north and south of the Bhanga Nek base by two students during December/January. During the turtle nesting season from 15 October to 15 March, weather permitting the entire 56 km area is patrolled twice nightly by the Officer-in-Charge of the survey using a 4 x 4 vehicle. In addition there are less regular, opportunistic patrols by vehicles south of the survey area. Data recorded from these patrols are not included in figures. All patrolling groups have turtle tags and applicators plus measuring calipers for taking straight line measurements of loggerheads. Leatherbacks turtles are measured over-the-curve.

Plastic tags of various kinds were used from 1963 to 1969 and monel metal tags from 1969 to 1985. Since then titanium tags have been used in an endeavour to reduce tag loss, which was excessive with plastic tags, and of some significance with monel tags. Titanium tags will not corrode in any way and have an improved locking mechanism.

RESULTS

Loggerhead turtles

Within the 56 km study area numbers have increased from an average of 256 nesting females per year in the first 10 years to an average of 350 females per year during the last 10 years. The size of the nesting population ranged from 82 in the incomplete first year to 418 in the 1983/84 season. The highest number recorded for the entire coast is 423. Annual fluctuations in nesting numbers are clearly visible from Figure 2.14.

Nesting patterns and distributions have remained stable over the full 24 years of study, although the beach profiles have varied. Similarly no changes in mean female sizes or clutch sizes have been recorded. The number of remigrants (those females that have been recorded and tagged in more than one season) increased linearly for 12 years to 50,3% of the nesting females in 1975/76 (Table 2.1) and then declined within two years to an average of 33,1% over the past 10 years. This figure is a minimum as some turtles, that have lost their previous tags and the tag scar is either untraceable or overlooked by staff, are certainly retagged.

Long-term recoveries of females tagged in Maputaland cover the east and south-east coasts of Africa from Cape Agulhas to Zanzibar and include Madagascar.

Leatherback turtles

The leatherback turtle is the other species nesting in Maputaland. Monitoring has covered the same 24 years as for loggerheads. Numbers within the 56 km survey have increased from an average of 21 females for the first 10 years to 70 for the last 10, with a range of five (1966/67) to 86 (1986/87). The highest number of females in any one season for the entire coast is 102 (1986/87). No change in nesting patterns and distributions over time are evident. Annual fluctuations in numbers of nesting females are clearly visible from Figure 2.15.

Recorded remigrations have been extremely erratic, especially in the first 12 years as tags were lost in large numbers from fore-flippers. Since tagging on hind flippers began, remigration percentages have stabilized a little. Over the past 10 years the average number of remigrants has been 43,6% of the total number of females nesting in that year (Table 2.2).

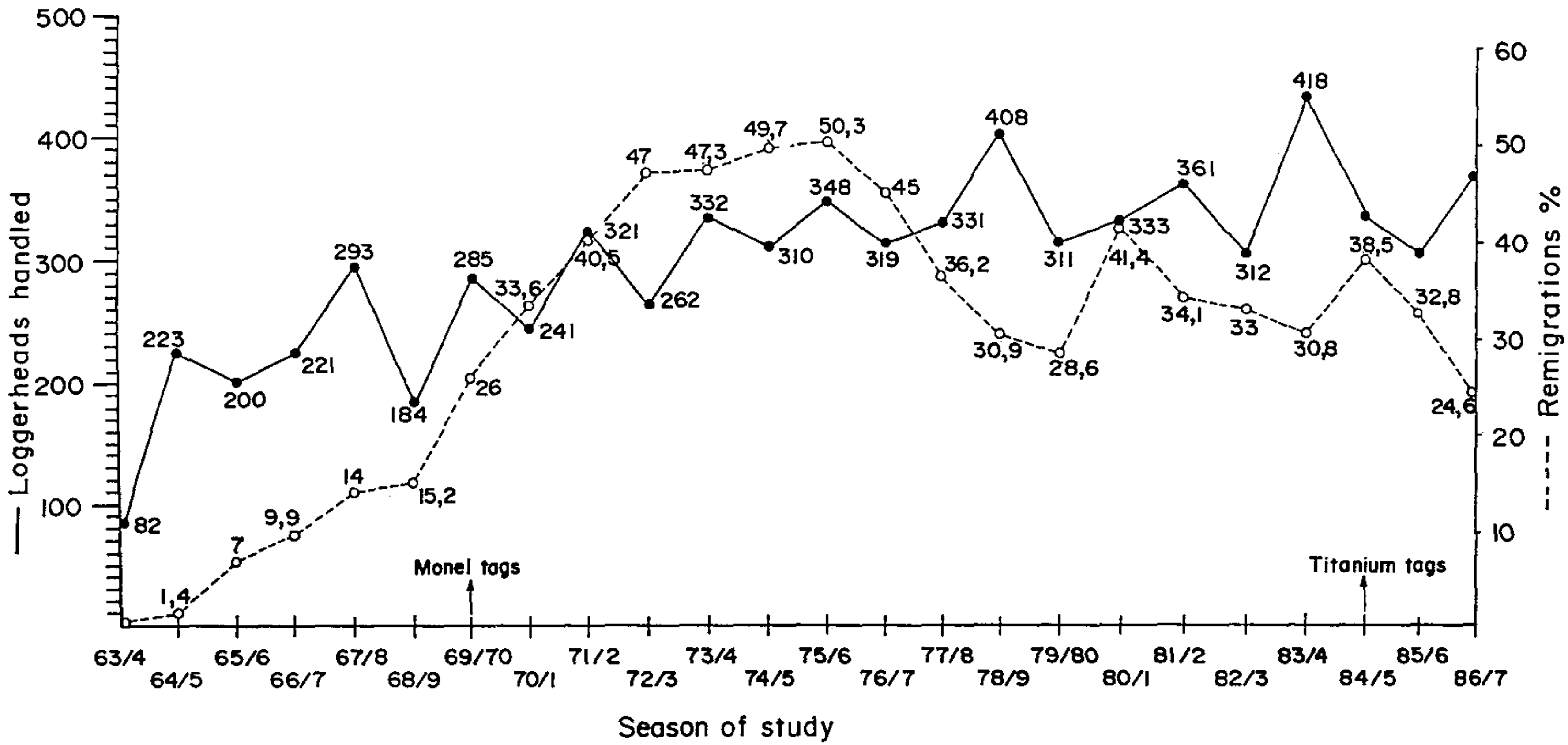

FIGURE 2.14 Loggerhead nesting population numbers and remigration percentages.

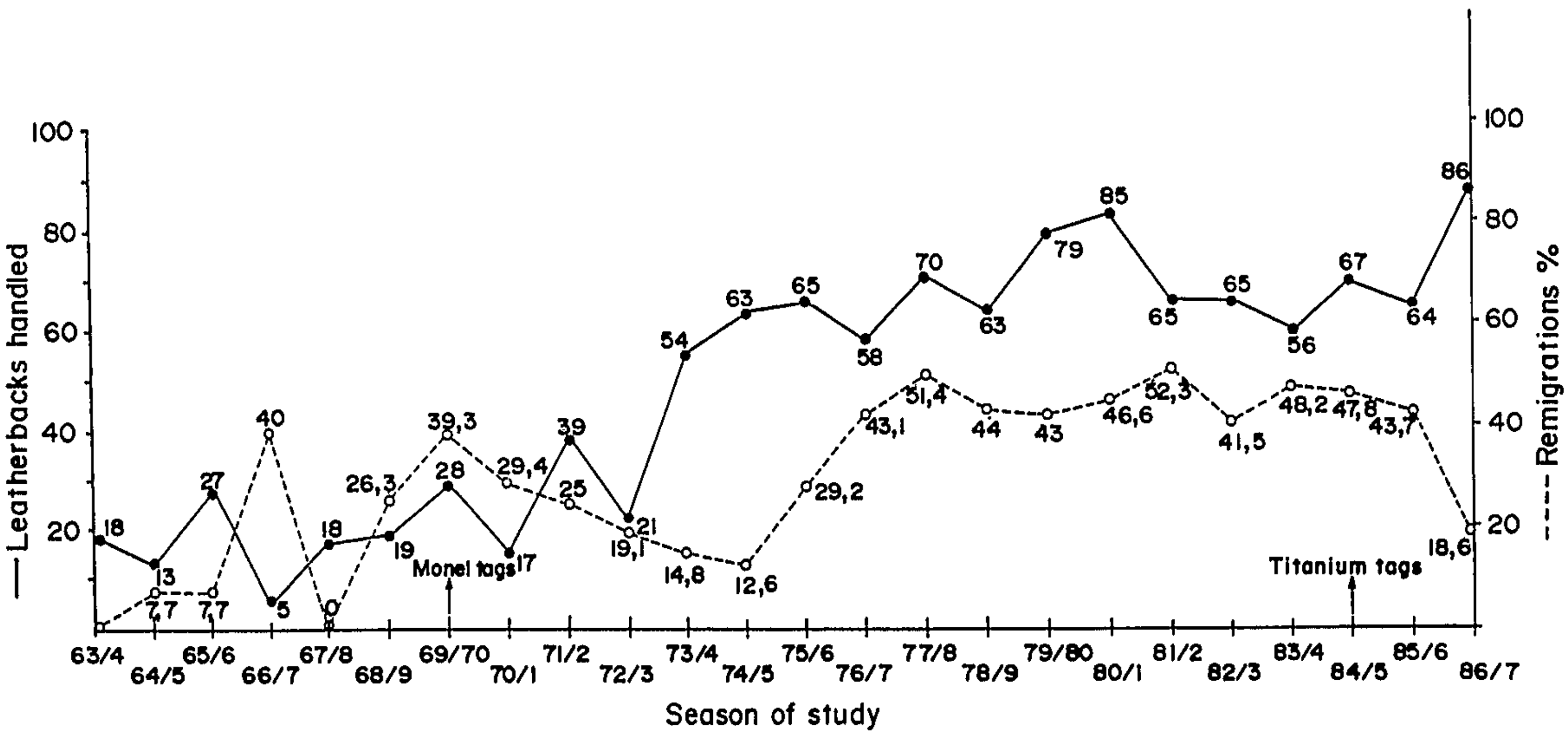

FIGURE 2.15 Leatherback nesting population numbers and remigration percentages.

TABLE 2.1 A summary of loggerhead remigrations to Tongaland, 1963 to 1987

Season	No Turtles	New	%	1yr	%	2yr	%	3yr	%	4yr	%	5yr	%	6yr	%	7yr	%	8yr	%	9yr	%	10yr	%	11yr	%	12yr	%	16yr	%	Call-[1] oused	%	Remi-grations	[Sodwana/Vidal] [New	C.*	Rec][2]
1963/64	82	82	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1964/65	223	220	98,6	3	1,4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1,4%	-	-	-
1965/66	200	186	93	5	2,5	9	4,5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7,0%	-	-	-
1966/67	221	199	90,1	3	1,4	16	7,2	3	1,4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9,9%	-	-	-
1967/68	293	252	86,0	5	1,7	12	4,1	4	1,4	9	3,1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	3,8	14,0%	-	-	-
1968/69	184	156	84,8	-	-	3	1,6	3	1,6	5	2,7	1	0,5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16	8,7	15,2%	-	-	-
1969/70	285	211	74,0	-	-	-	-	-	-	1	0,4	1	0,4	4	1,4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	68	23,9	26,0%	-	-	-
1970/71	241	160	66,4	8	3,3	-	-	-	-	-	-	1	0,4	2	0,8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	70	29,1	33,6%	-	-	-
1971/72	321	191	59,5	10	3,1	18	5,6	-	-	-	-	-	-	1	0,3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	101	31,5	40,5%	-	-	-
1972/73	262	139	53,0	6	2,3	41	15,7	9	3,4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	67	25,6	47,0%	-	-	-
1973/74	332	175	52,7	12	3,6	48	14,5	25	7,5	6	1,8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	66	19,9	47,3%	-	-	-
1974/75	310	156	50,3	17	5,5	35	11,3	27	8,7	13	4,2	3	1,0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	59	19,0	49,7%	-	-	-
1975/76	348	173	49,7	7	2,0	54	15,5	22	6,3	11	3,2	8	2,3	6	1,7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	67	19,3	50,3%	-	-	-
1976/77	319	176	55,0	14	4,4	37	11,6	19	6,0	15	4,7	9	2,8	2	0,6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	47	14,7	45,0%	-	-	-
1977/78	339	216	63,7	12	3,5	38	11,2	11	3,2	17	5,0	7	2,1	1	0,3	2	0,6	1	0,3	-	-	-	-	-	-	-	-	-	-	34	10,0	36,2	-	-	-
1978/79	408	282	69,1	8	2,0	21	5,1	28	6,9	11	2,7	2	0,5	3	0,7	4	1,0	0	0	1	0,2	-	-	-	-	-	-	-	-	48	11,8	30,9%	-	-	-
1979/80	311	222	71,4	7	2,3	29	9,3	18	5,8	8	2,6	2	0,7	4	1,3	3	1,0	1	0,3	-	-	-	-	-	-	-	-	-	-	17	5,5	28,6%	-	-	-
1980/81	333	195	58,6	9	2,7	31	9,3	23	6,9	8	2,4	4	1,2	-	-	3	0,9	2	0,6	-	-	-	-	1	0,3	-	-	-	-	57	17,1	41,4%	-	-	-
1981/82	361	238	65,9	4	1,1	34	9,4	25	6,9	4	1,1	1	0,3	1	0,3	1	0,3	1	0,3	1	0,3	-	-	-	-	-	-	-	-	51	14,1	34,1%	-	-	-
1982/83	312	207	67,0	9	2,9	31	9,9	13	4,2	8	2,6	2	0,6	1	0,3	1	0,3	0	-	1	0,3	-	-	-	-	-	-	-	-	37	11,9	33,0%	-	-	-
1983/84	418	289	69,1	12	2,9	29	6,9	22	5,3	12	2,9	4	1,0	1	0,2	1	0,2	1	0,2	-	-	-	-	1	0,2	-	-	-	-	46	11,0	30,8%	[4	0	1]
1984/85	343	211	61,5	14	4,1	37	10,8	14	4,1	9	2,6	-	-	3	0,9	-	-	-	-	1	0,3	-	-	-	-	-	-	-	-	57	16,6	38,5%	[18	0	0]
1985/86	302	203	67,2	13	4,3	27	8,9	11	3,6	3	1,0	3	1,0	4	1,3	-	-	-	-	-	-	-	-	-	-	-	-	1	-	37	12,3	32,8%	[11	1	0]
1986/87	374	282	75,4	9	2,4	39	10,4	16	4,3	5	1,3	3	0,8	2	0,5	1	0,3	-	-	-	-	-	-	-	-	-	-	-	-	17	4,6	24,6%	[11	0	0]

* Calloused
[1] Anything that has lost a tag
[2] Recovery, recorded outside survey area

TABLE 2.2 A summary of leatherback remigrations to Tongaland, 1963 to 1987

Season	No Turtles	New	%	1yr	%	2yr	%	3yr	%	4yr	%	5yr	%	6yr	%	7yr	%	8yr	%	9yr	%	10yr	%	11yr	%	12yr	%	Call-* oused[1]	%	Remi- grations	[Sodwana/Vidal] [New	C.**	Rec][2]
1963/64	18	18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1964/65	13	12	92,3	1	7,7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7,7%	-	-	-
1965/66	27	25	92,6	-	-	2	7,7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7,7%	-	-	-
1966/67	5	3	60,0	-	-	1	20,0	1	20,0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	40,0%	-	-	-
1967/68	18	18	100,0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1968/69	19	14	73,7	-	-	-	-	4	21,0	1	5,3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	26,3%	-	-	-
1969/70	28	17	60,7	-	-	3	10,7	-	-	2	7,1	1	3,6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	17,9	39,3%	-	-	-
1970/71	17	12	70,6	-	-	3	17,7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	11,8	29,4%	-	-	-
1971/72	39	33	84,6	-	-	3	7,7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	7,7	15,4%	-	-	-
1972/73	21	17	81,0	-	-	1	4,7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	14,3	19,1%	-	-	-
1973/74	54	46	85,2	-	-	4	7,4	2	3,7	-	-	1	1,9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1,9	14,8%	-	-	-
1974/75	63	55	87,2	-	-	3	4,8	1	1,6	2	3,2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	3,2	12,6%	-	-	-
1975/76	65	46	70,8	-	-	13	20,0	2	3,0	-	-	1	1,5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	4,6	29,2%	-	-	-
1976/77	58	33	56,8	1	1,7	11	19,0	8	13,8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	8,6	43,1%	-	-	-
1977/78	70	34	48,6	-	-	12	17,1	23	32,9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1,4	51,4%	-	-	-
1978/79	63	35	55,6	-	-	9	14,3	16	25,4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	4,8	44,4%	-	-	-
1979/80	79	45	57,0	-	-	13	16,5	11	13,9	3	3,8	3	3,8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	5,1	43,0%	-	-	-
1980/81	83	46	55,4	-	-	18	21,7	10	12,1	1	1,2	1	1,2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	8,4	44,6%	-	-	-
1981/82	65	31	47,7	-	-	17	26,2	4	6,2	3	4,6	2	3,1	2	3,1	-	-	-	-	-	-	-	-	-	-	-	-	6	9,2	52,3%	-	-	-
1982/83	65	38	58,5	-	-	17	26,2	8	12,3	1	1,5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	3,0	41,5%	-	-	-
1983/84	56	29	51,8	-	-	13	23,2	5	8,9	3	5,4	-	-	1	1,8	1	1,8	1	1,8	-	-	-	-	-	-	-	-	3	5,4	48,2%	(12)	(6)	-
1984/85	67	35	52,2	-	-	11	16,4	8	11,9	3	4,5	1	1,5	1	1,5	2	3,0	-	-	1	1,5	-	-	-	-	1	1,5	4	6,0	47,8%	(19)	(1)	-
1985/86	64	36	56,3	-	-	9	14,1	6	9,3	4	6,3	2	3,1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	10,9	43,7%	(9)	(2)	-
1986/87	86	70	81,4	-	-	4	4,7	4	4,7	3	3,5	2	2,3	1	1,2	-	-	1	1,2	1	1,2	-	-	-	-	-	-	3	3,5	18,6%	(13)	(-)	(3)

* Very dubious data because of difficulty of recognition
** Calloused
[1] Anything that has lost a tag
[2] Recovery, recorded outside of survey area

Remigration intervals are always at least two years, but are variable after that, so regular cycles are not typical of the population. Long-distance recoveries are poor with only one from Mozambique (Beira) and one from South Africa.

ARTEFACTS

Tags

The reliability of tags is an important aspect of any monitoring programme involving the marking of individuals. In the two seasons following the change from monel tags to titanium tags there was no significant increase in the number of recorded remigrations, recoveries remaining within the range recorded when monel tags were used. This can be seen from recoveries of tagged loggerhead turtles after lapses of one and two years, which are summarized below.

One-year remigrants:

Year	Number of turtles	Tag types	Percentage of cohort
1986/87	9 recoveries	Titanium	2,4%
1985/86	13 recoveries	Titanium	4,3%
1984/85	14 recoveries	Monel	4,1%
1983/84	12 recoveries	Monel	2,9%
1982/83	9 recoveries	Monel	2,9%
Two-year remigrants			
1986/87	39 recoveries	Titanium	10,4%
1985/86	27 recoveries	Monel	8,9%
1984/85	37 recoveries	Monel	10,8%
1983/84	29 recoveries	Monel	6,9%
1982/83	31 recoveries	Monel	9,9%

Patrols

The use of semiskilled staff for monitoring does produce a weakness in the data sets. However, supervision is close and it it is not considered likely that this weakness has significantly affected trends.

POPULATION TRENDS OF CAPE GANNETS ON BIRD ISLAND, ALGOA BAY

G J B ROSS, J H COLCLOUGH and W MARITZ
Port Elizabeth Museum

To gain a better perspective of reasons for the increase in the gannet population at Bird Island (Randall and Ross 1979; Batchelor and Ross 1984), numerous sources of historical data were examined to extend the lengths of relevant data series. Of particular interest were estimates of colony area and guano records. Primary data sources included:

- Cape Parliamentary reports and Government Guano Islands (GGI) Division files in the Cape and Intermediate Archives Depots, Cape Town;
- South African Transport Services files, and photographic records;
- shipping intelligence, Eastern Province Herald, 1871 to 1900;
- unpublished diaries of D B Price, formerly GGI Inspector, 1938 to 1972; and
- unpublished data, numerous photographs and documents made available by lighthouse keepers and members of the public through correspondence and appeals in news media. Data source files are accessioned into the Port Elizabeth Museum library.

METHODS

Series of photographs of the gannet colony at Bird Island, taken from the lighthouse or from the air between 1879 and 1986, were used in conjunction with a ground survey of prominent features to reconstruct plans of the colony for 27 breeding seasons, from which the area of the colony was determined. Guano harvests for the period 1871 to 1897 were estimated at one third of the annual total, based on the practice of mixing one part fresh guano with two parts fossil guano. Annual harvests for the periods 1924 to 1937 and 1938 to 1970 were obtained from original shipping notes and Price's diaries respectively.

RESULTS

As the Bird Island colony is on relatively flat ground, and the maximum recorded nesting density is reasonably constant (circa 2,85 nests per m^2), colony area provided a useful estimate of population size. Changes in colony size are shown in Figure 2.16.

The earliest available photograph (1879) showed that the population had been greatly reduced from an unknown former level, probably through poor management, suggesting that the increase to the post 1912 level reflected a recovery in the population.

At least some of the short-term declines in area from season to season reflect changes in the numbers of breeding adults present in the colony, rather than real changes in population size. This has been observed in successive breeding seasons from 1980. Thus from about 1912 to 1950 the maximum colony size of about 10 000 to 11 000 m^2 may represent a period of comparative stability in population size.

From about 1953 onwards the population increased rapidly at about three per cent per annum to 1978. It is suggested that this increase was due to better nesting conditions, partly through the addition of nesting material in the form of phosphatic sand or "phosphate" spread over the nesting area, and an increased food supply through reduction by fishing of predators competing for the same prey. Such predators would include kob *Argyrosomus hololepidotus*, yellowtail *Seriola lalandi*, hake *Merluccius capensis*, santer *Cheimerius nufar* and 74 *Polysteganus undulosus*.

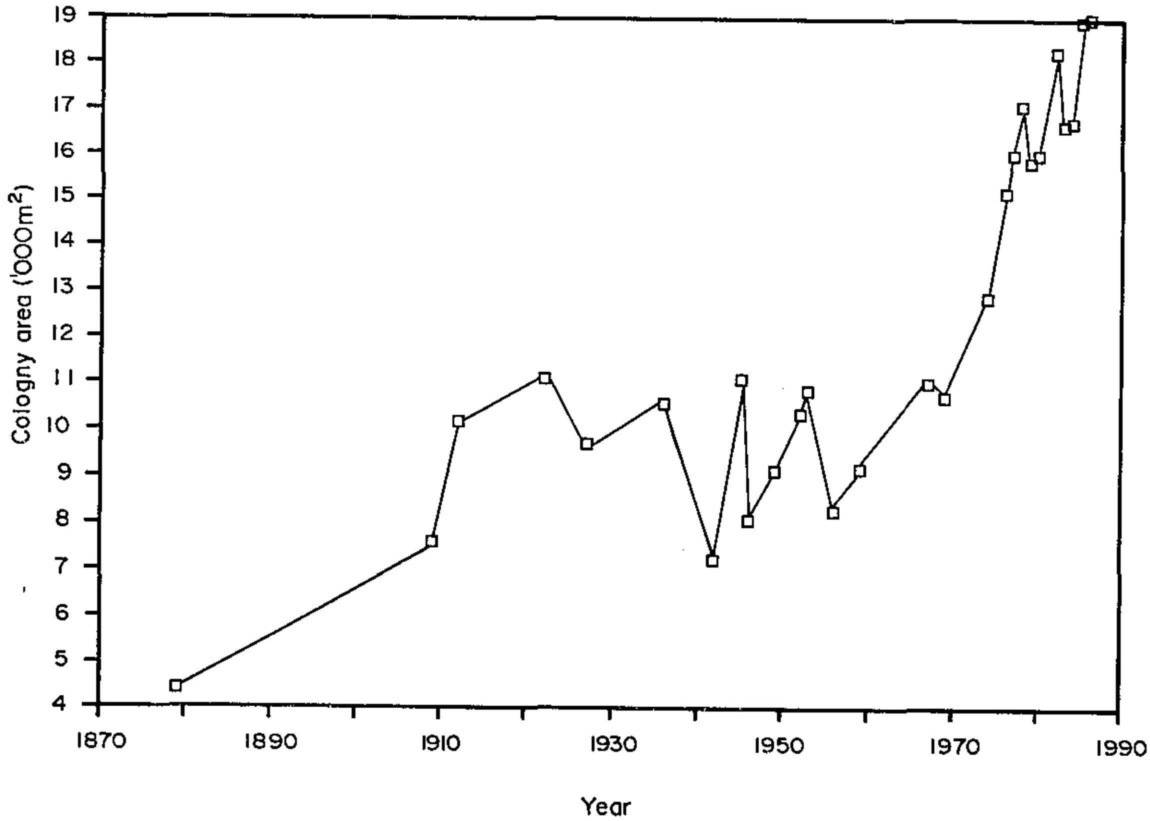

FIGURE 2.16 Estimated area (m²) of the Bird Island gannet colony, 1879 to 1987 during the breeding season.

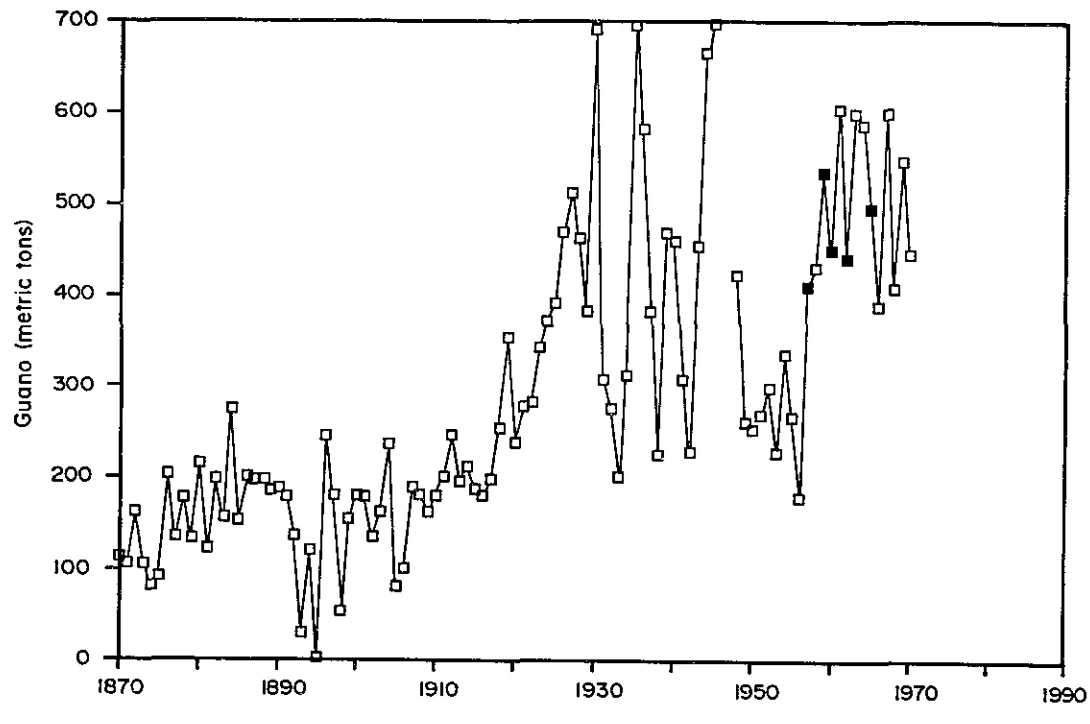

FIGURE 2.17 Annual guano harvest on Bird Island, 1871 to 1970. Closed squares indicate harvests preceded by deposition of phosphate.

Though the data are sparse, the proportion of immature birds and early breeders in the colony appears to have increased after about 1950, as evidenced by the numbers of birds showing black secondary coverts. Such increases probably reflect better feeding conditions, and lend support to the suggestion of increased food availability.

Guano harvest figures (Figure 2.17) complement the trend in colony area. Of concern, however, are the rapid excursions in the amounts collected between 1930 and 1950. Loss through rainfall does not account for the variation. The peak values in the guano series differ from other values when expressed as guano/area indices. One of these peak values (1959) occurs in the period when phosphate was added. Three of the others (1927, 1936 and 1945) precede a decline in the guano yield. We suggest that these peak values represent overzealousness on the part of the collectors, resulting in reduced breeding success in succeeding seasons. From 1957 onwards the effect of adding phosphate to the colony is clear in the elevated guano figures. The estimated quantities of phosphate added prior to the 1958, 1960, 1961, 1963 and 1966 guano harvests were 500, 132, 160, 250 and 86 tons respectively. Without this addition the guano figures would probably have shown an increase comparable to the trend in colony area for this period.

"PHOSPHATE" AND SOUTHERN AFRICAN GUANO HARVESTS

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Figures for annual guano harvests are potentially useful indices of population size in seabirds, particularly in evaluation of historical trends (eg Siegfried and Crawford 1978) and population responses to changes in prey availability (Crawford and Shelton 1978). Various factors affect the reliability of these figures. Thus rainfall may wash guano away or make it difficult to collect, or the size of the available labour force and the motivation of the headman who oversees the work may affect the size of the harvest (Randall and Ross 1979).

An additional factor directly affecting the size of guano harvests from southern African islands was the practice of replacing nesting material at gannet colonies with phosphatic sand, termed "phosphate", from Dassen Island, since some or all of this material would be subject to removal with the succeeding year's harvest. Apart from a brief comment that phosphate was deposited on Bird Island, Algoa Bay (Rand 1963), there is no published record on the frequency of this practice, or which gannetries and quantities of phosphate were involved.

In this paper we describe the collection, quantities and subsequent fate of phosphate removed from Dassen Island. Annual totals for quantities deposited at various islands are tabled to place them on record.

METHODS

The description of phosphate collection and its use is derived from correspondence between Mr D B Price, formerly Chief Inspector, Government Guano Islands (GGI) Division, 1938 to 1972, and GJBR (January 1985 to February 1986; in Bird Island source files, Port Elizabeth Museum library). Quantities, dates, times taken to load and land the phosphate, and destinations of phosphate were obtained from detailed entries and memoranda in Price's daily diaries for the period 1938 to 1967, excepting for 1950. Bound photocopies of all entries relating to Bird Island, Algoa Bay, and all phosphate collection or deposition have been accessioned into the Port Elizabeth Museum library.

On the few occasions that quantities of phosphate loaded at Dassen Island were not recorded, they could be determined from the amount landed on the same voyage and vice versa, or estimated from times taken to load or land the phosphate. Regressions of the number of bags of phosphate loaded or landed against time are:

a) Dassen Island:	$Y = 405{,}3\ X^{0.83}$	($r^2 = 0{,}75$; $n = 33$)
b) Malgas Island:	$Y = 67{,}0\ X^{1.44}$	($r^2 = 0{,}67$; $n = 19$)
c) Bird Island, Lambert's Bay	$Y = 291{,}3\ X^{0.79}$	($r^2 = 0{,}55$; $n = 4$)

where Y = number of bags loaded (a) or landed (b,c), and
X = time (hr).

RESULTS AND DISCUSSION

Penguin guano was collected at Dassen Island for many years prior to 1938, when Price joined the guano islands inspectorate. This consisted of a mixture of sand and guano kicked out of the the burrow by the penguin during nest building. The presence of sand reduced the quality of penguin guano, which was subsequently mixed with gannet and cormorant guano at the Cape Town depot. Collection of penguin guano at Dassen Island ceased when a new Superintendant was appointed (inferred from the correspondence to Mr J H C Hewitt 1936), who felt that the mixing of guano was an unfair practice.

Phosphate was identical to penguin guano in all but name, and was dug or scraped in an even layer from the surface of the penguin colony. It was collected by the boatmen and trimmers (stevedores) landed on Dassen Island from the GGI vessel while the latter proceeded to Cape Town to discharge guano loaded at other islands. The times of phosphate collection reflect the schedules of such voyages. Almost all phosphate was taken from the large colony at Lighthouse Bay eastward of the lighthouse (marked colony B in Rand 1963, plate 4).

Quantities of phosphate loaded at Dassen Island are given in Table 2.3. There is no evidence that phosphate was loaded prior to 1941. The last recorded collection was made in November 1967 and shipped to Malgas Island. On 10 May 1968 Price noted a request from the headman on Malgas Island for another load of phosphate, but made no mention of collecting or delivering it.

Phosphate collection may have affected the penguin population in Lighthouse Bay through increased disturbance during the sensitive nest building and incubation periods. According to Price, phosphate was collected at the same time as penguin eggs, though by different teams. Dates in Table 2.3 support this, showing that collection occurred in January, February, March, May, June and November in one, six, three, five, one and one of 15 years respectively, coinciding closely with the harvesting of penguin eggs from March to June (Siegfried and Crawford 1978).

TABLE 2.3 Quantities of phosphate (bags) loaded at Dassen Island

Date	Quantities	Comments
1941	7560*	Estimated crop. Three loadings. Added to guano in Cape Town.
1942	2258	Noted as 14 bags per ton.
16-20 May 1943	3000	
19-20 Jun 1943	3140	
8-9 Feb 1944	4280	
19-20 Feb 1944	3258	
23-25 Feb 1944	3335	
2 Feb 1945	2517	
14 Feb 1945	2418	
18 Feb 1945	3110	
21 Feb 1945	2533	Estimate from subsequent landings.
6-8 May 1948	6775	500 bags dumped overboard 21 May
3 Feb 1951	4000	
9-10 Feb 1951	3000	
26-28 Mar 1953	7260	
7 May 1953	2015	Destination unknown. Evidently not Bird Island, Algoa Bay.
1954	7238	Included with guano allotment in Cape Town.
14-16 Jan 1955	7755	300 tons included with guano allotment.
5-6 Mar 1956	8406	443 tons discharged 8 Mar at unknown destination.
10-12 May 1956	8495	4262 bags noted as approx 250 tons (= 17 bags per ton).
6-9 Mar 1957	16108	
24-27 Feb 1959	7350	
13-23 Feb 1961	10830	
2 May 1962	13000	
24 Feb 1965	1200	
15-18 Nov 1967	5270	

* converted from tons at 14 bags per ton.

It seems unlikely that the physical removal of their nesting substrate through phosphate collection would have affected the penguins' ability to burrow deeply enough for protection from the elements. At approximately 14 bags per ton, the total amount of phosphate collected from Dassen Island from 1941 to 1967 was about 10 437 tons. Assuming a specific gravity of 1,56, based on that of similar material at Bird Island, Algoa Bay (Ross unpublished), and a surface area of 65 350 m for the Lighthouse Bay colony (estimated from Rand 1963), phosphate removal would have lowered the colony surface only some 10 cm, with minimal effect.

The destinations of phosphate shipments are listed in Table 2.4. These were made between 1943 and 1967 to five of the six extant gannet colonies in southern Africa, the exception being Mercury Island.

Price noted that the phosphate was spread evenly over the gannet colonies after guano scraping to replace the birds' nesting material. This practice would have had two important implications for studies of population trends in these colonies.

The first of these is the probability of improved breeding success following phosphate deposition, as Jarvis (1970) has shown that gannets provided with abundant nesting material in the form of guano had a lower chick mortality than those with little nesting material. Further, he suggested that the former birds laid earlier than the latter, potentially allowing for earlier fledging and resultant improved post fledging survival (Jarvis 1970; Oatley et al unpublished).

A second important consideration is the effect of phosphate deposition on the interpretation of guano harvests, for clearly this material became an integral part of the harvest in the following year. The effects of this addition were substantial in particular periods. At Malgas Island, 24 285 bags of phosphate were deposited between May 1943 and February 1945. Equivalent to 1 735 tons (at 14 bags per ton), this material exceeded the total guano harvest of 1 411 tons from this island in the period 1944 to 1946 (guano data from Sea Fisheries Research Institute). At Lambert's Bay an estimated 1 024 tons of phosphate were deposited between February 1945 and February 1952, amounting to some 52% of the total guano collected from 1946 through 1953. The deposition of some 643 tons of phosphate on Malgas Island and 500 tons on Bird Island, Algoa Bay, in early 1957 exceeded the respective guano harvests of 1958 by 192 tons and 133 tons, indicating that a substantial part of the phosphate remained to be included in one or more subsequent harvests.

Until techniques can be developed to correct these effects, interpretations of historical trends in gannet populations (particularly those based on guano harvests) and their relationship to environmental factors are open to doubt, and should be used cautiously.

ACKNOWLEDGEMENTS

We thank Mr D B Price for his invaluable advice and comments on phosphate deposition, and Dr R J M Crawford for provision of guano harvest figures for each island.

TABLE 2.4 Quantities of phosphate (bags) landed at southern African islands

Date	Malagas Is	Bird Is Lamb's Bay	Possession Is	Ichaboe Is	Bird Is Algoa Bay
18-20 May 1943	3000				
21-23 Jun 1943	3140				
10-11 Feb 1944	4280				
21-22 Feb 1944	3258				
25-27 Feb 1944	3335				
7 Feb 1945	1500				
15-17 Feb 1945		3435			
19-20 Feb 1945	3110				
22-23 Feb 1945	2662[1]				
10-14 May 1948		3995[2]			
19-20 May 1948	1855[3]				
6-7 Feb 1951		3900			
9 Feb 1951			100		
11-12 Feb 1952		3000			
4 Apr 1955			2800[4]	770-1400[4]	
14-16 May 1956			??[5]		
22-23 May 1956			6912[6]	1582[6]	
16-17 Jul 1956			??[5]		
10-12 Mar 1957	c 9000				
12-14 Apr 1957					c 7000
28 Feb-2 Mar 1957	5500				
25-27 May 1959					1850
20-21 Feb 1960	6000				
19-24 Apr 1961					c 2233
15-17 May 1961				2820	
6-7 May 1962	9500				
26 Aug-2 Sep 1962					3500
Feb 1965					1200[7]
19 Nov 1967	5470				

[1] 997 bags estimated.
[2] 975 bags estimated.
[3] 1455 bags estimated.
[4] Inferred from mass collected, at 14 bags per ton.
[5] Unknown quantity landed at Possession Island.
[6] Proportions of total estimated from time.
[7] Notes imply Bird Island as destination.

CHLORINATED HYDROCARBON RESIDUES IN MARINE ORGANISMS

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INTRODUCTION

It is now well accepted that the benefits of many synthetic organic chemicals in use are partially offset by deletereous side effects. This is particularly true of the synthetic chlorinated hydrocarbon group of chemicals, which include pesticides such as DDT (and its major metabolites DDE and DDD), the cyclodienes (chlordane, dieldrin) and lindane (hexachloro-cyclohexane), frequently referred to as BHC (benzene-hexachloride), as well as the polychlorinated biphenyls (PCB's) which are used for many industrial purposes.

The synthetic chlorinated hydrocarbons have a low water solubility, a high lipid/water partition coefficient and do not readily undergo metabolic transformation. Such chemical and biochemical properties result in the accumulation of these compounds in various biological systems of the global marine environment, including the Antarctic and Arctic, particularly in the lipid tissue of organisms. This process of accumulation is far more rapid (orders of magnitude) than the process of elimination.

The transfer of synthetic chlorinated hydrocarbons among various compartments in the marine environment is controlled by their chemical and biochemical properties, as well as by the nature (physical, chemical) of the environment concerned. Identification of lipid tissue as a major sink for chlorinated hydrocarbons should allow for the monitoring of concentrations in this one compartment to provide information about actual exposure levels, as well as about changes in exposure levels with time. This generalized model is fairly well accepted, although very few of the transfer processes involved have been described in any more than qualitative terms. In addition, it should be noted that there are some differences in properties among the chlorinated hydrocarbons. The PCB's have been produced in the form of several technical mixtures with different mass-percentages of chlorine. Structural differences between PCB components cause differences in their physiochemical and biochemical behaviour. These differences can be used to shed light on the 'length of time' that an organism has been exposed, and also, how long that compound has been in the environment.

DATA SET

The measurement of the chlorinated hydrocarbon residues in sediment and various marine organisms has been undertaken in South Africa since 1974. Samples include fish, mussels, oysters, tissue and eggs from coastal bird species, and cetacean blubber. The data presented here are believed to represent the bulk of those available. The largest set of data available has been loaded into the SADCO (South African Data Centre for Oceanography) database. Data not yet loaded into this data base was obtained from various publications and unpublished reports (NIWR 1982; Gardner et al 1983; Henry and Best 1983; de Kock and Randall 1984; de Kock 1985; de Kock and Boshoff 1987; V A Cockcroft personal communication).

REVIEW OF DATA

Sediments

Although some low levels for t-DDT and dieldrin were reported in sediments for the period 1974 to 1976 no residues were found to be present in sediments mainly from the south-east coast in the ensuing years, the exception being low residues for t-DDT during 1980 (0,001 to 0,004). Sediments can be used successfully to reflect the history of chlorinated hydrocarbon fluxes to the sea floor, provided there exists a regular net deposition and sediments are not eroded. Chlorinated hydrocarbons are normally associated with fine sediments (less than 60 microns) and with sediments having a high organic carbon content. These parameters should always be measured when sediment residues are determined.

Biota

The biota in this context refers to marine organisms in general and includes fish, oysters, and mussels. In the data summary no distinction has been made between pelagic or benthic organisms. There is much individual variation in the residues within species as well as amongst different species from the same area. This is ascribed to differences in lipid content, as well as differences in feeding habits, and spawning and migration patterns. A relationship between total lipid content and residue levels for some selected species has been reported elsewhere (Stout 1980; Gadbois and Maney 1983). This relationship was not investigated in these studies.

It is worth noting that, for edible sea foods, recommendations by the National Academy of Science (USA) and the Canadian Council of Resource and Environment Ministers are that whole-body residues in fish muscle (edible portion), expressed on a wet mass basis, should not exceed 1,0 μg/g for t-DDT, 0,5 μg/g for PCBs or 0,1 μg/g for dieldrin, aldrin and chlordane, either singly or together. These levels were exceeded by some specimens taken from the Swartkops River, the Wilderness Lakes and the Nahoon Rivers. Overall, however, the coastal areas investigated indicate a low biota contamination level which in turn suggests a relatively low level of contaminant contribution to the coastal ocean of southern Africa with moderate contamination occurring at specific sites.

Bird eggs and tissue

Although some eggs of the African Marsh Harrier *Circus ranivorus* nesting along the Wilderness Lakes had residue levels of 5 μg/g t-DDT, there was no evidence of poor reproduction in this population. Tissue samples of coastal bird species from the Wilderness Lakes had low residue levels, but there was an inverse relationship between residue levels and the extent to which a species feeds in the marine environment, showing that the open sea is less polluted than coastal waters. For example, grey-headed gulls *Larus cirrocephalus* feeding away from the sea in estuaries (and rubbish dumps) had the highest mean residue levels. There is little continuity of data and no clear trend for residue levels to decrease or increase with time.

Cetacean blubber

No PCB residues were found in whale blubber in 1974. The largest single source of residue data for cetaceans is that obtained from samples of dolphin blubber. For data interpretation the animals were divided into the following classes; juveniles (<8 GLG's), mature males (>8 GLG's), lactating females, pregnant females and quiescent mature females. The results show that as males increase in age so the concentrations of both 5-DDT and PCB's in blubber increase at an estimated rate of 0,22 μ g/g yr^{-1}. Females, however, show a marked, rapid decline in concentrations of both t-DDT and PCB residues at about eight GLG's, approximately the age of sexual maturity. Lactating females have significantly lower ($P < 0,05$) blubber levels of both t-DDT and PCB's than all other classes excluding pregnant females. Of particular interest is the contrast in levels shown by females before and subsequent to their first or second ovulations. About 80% of a female common dolphin's total PCB and t-DDT load is transferred to her calf during lactation. No conclusion as to changes in residue levels with time in dolphin tissue can be made, due to the relatively short period of time (1982 to 1986) for which sufficient data exist.

CONCLUSION

The data are unfortunately insufficient to determine whether any change in residue levels in marine organisms has occurred with time. Virtually no data on 'uncontaminated' systems exist. There is a reasonable data set only for the post 1980 era, by which time many contaminants had come under more controlled use and disposal. The only data set of significant value is that on chlorinated hydrocarbon residues in cetacean blubber where it can be shown that males accumulate residue with age and females transfer about 80% of their residue load to their calves during lactation. Although the fragmented data set has indicated no cases of massive and consistent overload in the marine environment, there are sufficient isolated cases of high levels to warrant concern.

ADDITIONAL DATA SERIES

PHYSICAL DATA

Much of the information on which Grundlingh (1983) based his paper is unpublished. It comprises data from some 6 000 hydrographic stations along 307 sections, to depths of 500 m, between St Lucia (28°30 S) and Port Elizabeth (34°S) (period 1969 to 1976). Data source: National Research Institute for Oceanology.

Hydrographic data from additional cruises. These data are not in continuous series, but may be useful for selected parameters. A cursory survey of cruise tracks illustrated by Lutjeharms (1972) suggests that the area between Cape Agulhas and Algoa Bay was sampled consistently over several years (period 1960 to 1969), but further east sampling was inconsistent. Data source: South African Data Centre for Oceanography (SADCO).

Hydrographic data, including sea condition, currents and sea temperature (period 1968-ongoing), and micropalaeontological series (period Tertiary - Recent), primarily for the region offshore of the coast between Port Alfred and Cape Agulhas. Data source: Southern Oil Exploration Corporation (SOEKOR), National Research Institute for Oceanology (NRIO); Marine Geoscience Unit, University of Cape Town.

Wave height and period off Richards Bay (period 1979 to 1986) and a block of 17 closely spaced stations on the Agulhas Bank (period 1978 to 1986). Data source: L Coetzee, NRIO.

Daily wind direction and strength, in lighthouse keeper units, Bird Island, Algoa Bay (periods 1852 to 1857, 1911 to 1934, 1944 to 1967). Data source: Weather Bureau, Department of Transport.

Continuous monitoring of weather and sea temperature at Bird Island, Algoa Bay (period 1984-ongoing), and Cape Recife (1986-ongoing) and of sea temperature on a reef two kilometres offshore of Port Elizabeth (1986-ongoing). Data source: Department of Oceanography, University of Port Elizabeth.

Measured sea temperature, and estimated water visibility and swell height for about 19 days per month at 44 shark net installations, between Mzamba, Transkei and Richards Bay, Natal (period 1977-ongoing). Data source: Natal Sharks Board, Umhlanga Rocks.

Archived satellite imagery (period 1978-ongoing). Data source: CSIR Satellite Data Centre; SADCO.

BIOLOGICAL DATA

Extensive long-term data are available on catch and effort in the linefishery, both offshore and shore-based. These data are captured and can be retrieved through the National Marine Linefish System (NMLFS). There are two broad divisions within these data, viz commercial and recreational. The first commercial statistics are available for the period 1907 to 1933 for the Natal coast (source: ORI). Subsequent records date from 1985 and provide countrywide coverage of the commercial linefishery (source: NMLFS, SFRI). Information on the recreational linefishery - primarily for Natal, is available from 1956 for shore-based fishing and 1983 for offshore fishing. Though only initiated in 1984, the nationwide marine linefish tagging programme provides an ongoing data set of species composition of catches by the linefishery and also variations in the annual mortality rates of some 230 linefish species (source: ORI).

Other fish resources for which long-term data series exist are few - with the exception of the Natal sardine (pilchard) run for which total landings and CPUE along the Natal coast exist since 1971 (source: ORI).

Trends in the invertebrate fishery have been reasonably recorded, though largely unpublished. The trends in species composition and weight of the trawled catch of Natal's offshore crustaceans (prawn *Haliporoides triarthrus*, langoustine *Metanephrops andamanieus*, rock lobster *Palinurus delagoae* and crab *Geryon macphersoni*) are available since 1973 (source: SFRI, ORI). Similarly medium- to long-term data are available on the landings of squid (*Loligo reynaudii*) off the eastern Cape. Data collection has intensified considerably since 1985 (source: SFRI). Reliable long-term records on the resource utilization of coastal invertebrates off Natal, such as the Natal rock lobster *Panulirus homarus* and a range of littoral species see Chapter 3) are available since 1974. These data are based on catch returns submitted by noncommercial licence holders and comprise a large catch and effort data base (source: ORI).

Routine two-monthly surveys of jackass penguin colonies (*Spheniscus demersus*) at St Croix Island, Algoa Bay, for the period 1973 to 1986 were made (source: University of Port Elizabeth, Port Elizabeth Museum) providing data on population size and interannual variation in breeding success. Data on gannet diet from Bird Island, Algoa Bay, have been collected at frequent intervals since 1978 (source: Port Elizabeth Museum and SFRI). They provide a valuable indication of interannual variation in the availability of pilchard and other epipelagic fish stocks in the eastern Cape.

Bird-ringing programmes also provide valuable long-term data series (source: South African Bird Ringing Unit (SAFRING), University of Cape Town). For example, the survival rates of gannet fledglings ringed at Bird Island in 1983 declined to less than 10% of those in 1980, following the 1982/83 "Warm Event" (source: SAFRING; Port Elizabeth Museum; period 1979-ongoing).

A system of monthly beachwalks initiated at Cape Recife (source: South African Museum; Eastern Cape Wild Bird Society, period 1977-ongoing) provides qualitative abundance data for stranded seabirds and marine mammals (see G Avery this volume). Similarly, marine mammals, turtles and several large fish species are periodically captured in Natal's shark nets, providing some measure of their variability in abundance, for which data have been recorded with improving accuracy from 1966 (source: NSB).

Data on the oil content and blubber thickness of whales taken at the now defunct Natal whaling stations may indicate interannual variation in body condition of balaenopterid whale stocks, reflecting food availability in the Southern Ocean (source: International Whaling Commission; South African Museum).

OTHER SERIES

Museum collections can offer valuable distributional and other supplementary data, eg on molluscs, fishes, seabirds and marine mammals (examples of sources: Natal Museum (Pietermaritzburg), Durban Museum, East London Museum, J L B Smith Institute of Ichthyology (Grahamstown), Port Elizabeth Museum and South African Museum (Cape Town)).

The fossil guano deposit, Bird Island, Algoa Bay (source: Port Elizabeth Museum; period possibly 8 000 yr BP to present) is a structured, well stratified deposit, containing numerous fine alternating cream and brown layers. These alternations in the guano probably represent environmental changes, perhaps through fluctuations in the size of the gannet colony or changes in wind direction.

A most valuable source of long-term data series is the annual yearbook of fisheries statistics published by the FAO. Dating from 1947 (in which volume loadings by some countries are traced back to 1930) this detailed document of marine landings is probably the most comprehensive overview of exploitation of the world's marine renewable resources.

TENTATIVE CONCLUSIONS ON TRENDS

The biota of the south-east coast shelf generally reveal an intimate relationship with the Agulhas Current. In the short term, lifecycles of prawns, rock lobsters, sharks, bony fishes, turtles, birds, cetaceans and others have been shown to respond to seasonal fluctuations of the current (Heydorn et al 1978; Ross 1984; Schumann in press). Fluctuations are a dominant feature of this ecosystem, a fact most clearly reflected in the various fisheries. The Natal sardine run is perhaps one of the most dramatic events of this nature, though many more examples exist.

From the above it could be concluded reasonably that the Agulhas Current should also influence longer-term trends within the ecosystem and that these, too, may then be reflected in the data sets. Several of the data series available for certain fisheries show considerable interannual fluctuations that do not appear to be directly related to fishing. Certainly the large amplitude of elf catches, shark landings, gannet counts and turtle nestings may indicate fluctuating levels of recruitment, which are likely to be linked to environmental parameters within the Agulhas Current's influence. For example, annual catches of elf off Natal have been shown to fluctuate inversely with coastal rainfall, thought to be related to the frequency of atmospheric coastal lows (van der Elst 1976). Other as yet unstudied relationships may exist, and the possibility that trends in turtle nesting relate to sea surface temperature in the non-nesting areas to the north seems worthy of further consideration.

Some caution should be expressed, however, when relating fluctuations of fish, turtle and bird records to the Agulhas Current and physical influences, because in many cases there is likely to be a lag which is related to the growth rate and age at recruitment of the individual organism. Physical changes in the environment are most likely to influence phases of early life history such as fertilization, embryonic growth and larval survival. These may only manifest themselves in adult populations some years later.

While many of the data sets available reflect trends in fisheries, there are several important long-term series that are not directly (but often indirectly) influenced by fishing activities.

The continuing increase in the gannet population on Bird Island, Algoa Bay, from the mid-1950's is of interest as a probable reflection of changes in the community of predators on epipelagic fish, particularly through reduction of bony fishes. This interpretation is in keeping with changes in fish communities observed in Natal over the same period, as described below. The direct assessments of gannet population size, based on colony area, also provide an important reference for evaluation of the guano harvests. Such comparisons and other forms of validation, for example allowing for deposition of phosphates, are essential before data on guano harvests can realize their full potential.

Results obtained from 24 years of intense research on sea turtle nesting in Maputaland reveal a remarkably stable trend in nesting behaviour and frequency, after an initial increase resulting from habitat protection and resource management. It is important to note that these reptiles are not exploited within South African waters, though elsewhere in their West Indian Ocean range they are known to be exploited by peasant fishermen. These trends are observed in both loggerhead and leatherback turtles and, significantly, do not appear to be related to fluctuations in beach condition such as sand grain size and beach profile.

Most of the data sets reflect fishery-induced trends, some of which date from the turn of the century. Several important conclusions can be reached from these data in general. Foremost is the clear and persistent trend for drastic declines in the relative proportion of the catch of endemic fishes (van der Elst and de Freitas this volume).

This disturbing phenomenon has been reported for virtually every line-fishery studied along the east coast, and is usually associated with a corresponding increase of less desirable species. This can be clearly seen in the offshore linefishery of Natal, where the endemic 74 *Polysteganus undulosus*, poenskop *Cymatoceps nasutus*, Scotsman *P praeorbitalis* and red steenbras *Petrus rupestris* historically constituted at least 50% of the total catch. Today these species contribute no more than five per cent of total landings, the rest being composed of slinger *Chrysoblephus puniceus*, canter *Cheimerius nufar*, barbel *Galeichthys feliceps*, smaller kob-like fishes and a wide range of small and more widely distributed demersal fishes.

The shore-based linefishery reveals similar trends. Here the endemic components of musselcracker *Sporodon durbanensis*, bronze bream *Pachymetopon grande*, stumpnose *Rhabdosargus* species, and blacktail *Diplodus sargus* have been seriously reduced. This reduction has been matched by a marked increase in the proportion of cartilaginous fishes, especially guitar-fishes, dusky shark, milkshark and stingrays. Thus these species increased in angling competitions from less than six per cent of the catch in the period 1956 to 1965 to more than 50% of the 1972 to 1982 landings.

Most, if not all, of these declines in endemic species are associated with overfishing, as a result of targeting by fishermen (Smale and Buxton 1985; Buxton 1987) in the trawl fishery, and the inshore and offshore components of the linefishery (van der Elst and de Freitas this volume). Species showing the greatest declines are those associated with the nearshore ecosystem and especially estuaries. It is possible that the negative trend in the contribution of estuarine-associated species is an indicator of the overall condition of east coast estuaries, especially in their role as juvenile nursery areas.

Trends in shark catches following the installation of protective nets off bathing beaches in Natal from the mid-1960's indicated an initial, major reduction in the resident community of larger sharks, with a relatively constant smaller catch rate of immigrant sharks in subsequent years.

Taken together, these trends indicate that major changes have occurred in the structure of fish communities in the coastal waters of Natal, initiated anthropogenically and probably influenced by the effects of increased niche space for members of the present community, coupled with reduced predation.

The monthly and annual landings of pilchards in the Natal sardine run offer a potentially valuable indicator of the shelf ecosystem (van der Elst and de Freitas this volume). Numerous other organisms are known to be associated with this annual run, including copper sharks *Carcharinus brachyurus* (Cliff et al this volume), gannets (Batchelor and Ross 1984) and common dolphins *Delphinus delphis* (Ross 1984).

Generally the total landings of the invertebrate fisheries are comparatively stable, no doubt influenced by the relatively slow rate of increase in fishing effort. There are clear changes in the species composition of the catch, though CPUE studies do not suggest overexploitation, but rather a change in targeting due to market pressures.

DIRECTIONS FOR FUTURE RESEARCH

The lack of detailed information on long-term physical trends for the Agulhas Current presents a major limitation to the interpretation of variations in biotal components. The intensive data set collected between 1969 and 1976, much of which is unpublished, demonstrated considerable variability according to Grundlingh (1983) who specifically excluded unusual events to obtain appropriate average values. It is recommended that analysis of these data and publication of the results should be undertaken as a priority.

In view of the high costs of undertaking further ship-based, long-term surveys of the Agulhas Current, it is essential that monitoring of the inshore environment with automatic weather and hydrographic stations should continue. Where feasible these should be expanded into a network of stations along the entire south-east coast, operated on a cooperative basis. Integrated with satellite imagery, such stations could provide considerable insight into long-term variability in the Agulhas Current and the coastal ocean inshore of the current.

Specific components of the biota, in addition to those affected by anthropogenic effects, should be selected for monitoring, to investigate the influence of environmental effects. Thus comparison of variation in landings of pilchard during the Natal sardine run with environmental data may provide insight into movements of this key species along the south-east coast. Variation in amount of pilchard landed in Natal would reflect changes in the amount of pilchard nearing the coast and thus available for catch - an environmental effect. The influence of exploitation elsewhere is less likely to affect the strength of the run or could be accounted for. Continuation of projects for which data series already exist is most important, eg interannual variation in diet and post-fledging mortality in Cape gannets at Bird Island, Algoa Bay. Continued monitoring for management or conservation purposes, eg recording of commercial and recreational fish catches and numbers of nesting turtles, is also strongly supported, particularly as many of the data sets are of long standing. Collection of data on chlorinated hydrocarbons and other contaminants should be maintained to monitor trends in levels of these compounds in top predators known to carry contaminant loads (eg dolphins) or to have minimal loads at present (eg gannets).

The coastal data collection systems operating in Natal have been vital in establishing the database for resource management. In view of their value, it is proposed that such systems should be extended to other parts of the region, including relatively pristine areas such as the Transkei and Ciskei. At the same time, the continuity and development of surveys such as beach walks for seabirds and marine mammals to cover much larger stretches of coast should be encouraged to investigate the effects of the environment on pelagic predators.

Long-term data series can benefit greatly from historical research that extends the series back in time and validates existing data. Such research could be of use for further evaluation of population changes in seabirds and seals and variations in guano harvests at the southern African islands, particularly prior to the large-scale exploitation of epipelagic fish. It depends on unpublished documents, photographs or verbal evidence. It is recommended that the collection, archiving and analysis of such data for all regions should be initiated urgently before the data are lost forever.

CONCLUSIONS

Few conclusions can be drawn about forcing mechanisms other than anthropogenic ones, though some tentative suggestions have been made above. Several reasons account for this situation. In particular, the lack of analysed long-term hydrological data, with which biological data could be compared, was most restrictive. Although there was a considerable number of biological series, most were unpublished. Also, most data series were initiated to monitor anthropogenic effects on resources, with less regard for more subtle environmental effects.

REFERENCES

Batchelor A L and Ross G J B 1984. The diet and implications of dietary change of Cape gannets on Bird Island, Algoa Bay. Ostrich 55, 45-63.

Bedford D 1987. Shark management: a case history - the California pelagic shark and swordfish fishery. In: Cook S (editor) Sharks an enquiry into biology, behaviour, fisheries, and use. Oregon State University Extension Service. pp 161-171.

Bergh M O 1983. Modelling in the Benguela ecosystem with emphasis on pilchard and anchovy biomass estimates. Internal Report of the Benguela Ecology Programme 5, 1-152.

Berruti A and Colclough J 1987. Comparison of the abundance of pilchard in Cape gannet diet and commercial catches off the western Cape, South Africa. South African Journal of Marine Science 5, 863-869.

Best P B 1981. The status of right whales (Eubalaena glacialis) off South Africa, 1969-1979. Investigational Report Sea Fisheries Institute South Africa 123, 1-44.

Best P B and Ross G J B 1986. Catches of right whales from shore-based establishments in southern Africa, 1792-1975. In: Brownell R L, Best P B and Prescott J H (editors) Right Whales: Past and Present Status. Reports of the International Whaling Commission Special Issue 10. pp 275-289.

Buxton C D 1987. Life history changes of two reef fish species in exploited and unexploited marine environments in South Africa. PhD Thesis, Rhodes University, Grahamstown.

Carter R A and D'Aubrey J (In press). Inorganic nutrients in Natal coastal shelf waters. In: Schumann E H (editor) Coastal ocean studies off Natal, South Africa. Lecture Notes in Coastal and Estuarine Studies Series 26. Springer Verlag, New York.

Crawford R J M and Shelton P A 1978. Pelagic fish and seabird interrelationships off the coasts of South West and South Africa. Biological Conservation 14, 85-109.

Crawford R J M and Crous H B 1982. Trends in commercial handline catches of redfishes along the southern Cape coast, Republic of South Africa. Koedoe 25, 13-31.

CSIR Report C/SEA 8036 1980. Richards Bay Ocean Outfall. NRIO, Stellenbosch, 1-21.

De Kock A C 1985. Polychlorinated biphenyls and organochlorine compounds in marine and estuarine systems. MSc Thesis, University of Port Elizabeth, Port Elizabeth.

De Kock A C and Randall R M 1984. Organochlorine insecticide and polychlorinated biphenyl residues in eggs of coastal birds from the eastern Cape, South Africa. Environmental Pollution Series A 35, 193-201.

De Kock A C and Boshoff A F 1987. PCB's and chlorinated hydrocarbon insecticide residues in birds and fish from the Wilderness Lakes System, South Africa. Marine Pollution Bulletin 18, 413-416.

Gadbois D F and Maney R S 1983. Survey of polychlorinated biphenyls in selected finfish species from United States coastal waters. Fishery Bulletin 81, 389-396.

Gambell R 1974. A. The fin and sei whale stocks off Durban. B. Sperm whales off Durban. In: Schevill W E (editor) The whale problem. A status report. Harvard University Press, Cambridge. pp 82-96.

Gardner B D, Connell A D, Eagle G A, Moldan A G S, Oliff W D, Orren M J and Watling R J 1983. South African marine pollution survey report 1976-1979. South African National Scientific Programmes Report No 73. CSIR, Pretoria. 105 pp.

Grundlingh M L 1983. On the course of the Agulhas Current. South African Geographical Journal 65, 49-57.

Henry J and Best P B 1983. Organochlorine residues in whales landed at Durban, South Africa. Marine Pollution Bulletin 14, 223-227.

Heydorn A E F, Pearce A F, Bang N D, Flemming B W, Carter R, Schleyer M, Berry P F, Hughes G R, Bass A J, Wallace J H, van der Elst R P, Crawford R J M and Shelton P A 1978. Ecology of the Agulhas Current region: an assessment of biological responses to environmental parameters in the south-west Indian Ocean. Transactions of the Royal Society of South Africa 43(2), 179-183.

Holden M J 1977. Elasmobranchs. In: Gulland J A (editor) Fish population dynamics. John Wiley, London. pp 187-215.

Hughes G R 1974a. The sea turtles of South East Africa I. Status, morphology and distributions. Investigational Report, Oceanographic Research Institute 35, 1-144.

Hughes G R 1974b. The sea turtles of south-east Africa II. The biology of the Tongaland loggerhead turtle Caretta caretta L with comments on the leatherback turtle Dermochelys coriacea L and the green turtle Chelonia mydas L in the study region. Investigational Report, Oceanographic Research Institute Durban 36, 1-96.

Hughes G R 1982. Nesting cycles in sea turtles - typical or atypical? In: Bjorndal K (editor) Proceedings on the biology and conservation of sea turtles, Smithsonian Institution, 26-30 November 1979. pp 81-89.

Hughes G R, Bass A J and Mentis M T 1967. Further studies on marine turtles in Tongaland I. Lammergeyer 7, 1-55.

Jarvis M F J 1970. Interaction between man and the South African gannet Sula capensis. Ostrich, Supplement 8, 497-513.

Lutjeharms J R E 1972. A guide to research done concerning ocean currents and water masses in the south-west Indian Ocean. Department of Oceanography, University of Cape Town.

McAllister H J, Bass A J and Van Schoor H J 1965. Marine turtles on the coast of Tongaland, Natal. Lammergeyer 3(2), 10-40.

NIWR 1982. National Marine Pollution Surveys. East coast section. Annual Report.

Rand R W 1963. The biology of guano-producing seabirds. 4. Composition of colonies on the Cape Islands. Investigational report, Division of Fisheries, South Africa 43, 1-32.

Randall R M and Ross G J B 1979. Increase in the Cape Gannet population on Bird Island, Algoa Bay, and its present status. Ostrich 50, 168-175.

Ross G J B 1984. The smaller cetacea of the south-east coast of southern Africa. Annals of the Cape Provincial Museums (Natural History) 15, 173-410.

Schumann E H 1987. The Coastal Ocean off the east coast of South Africa. Transactions of the Royal Society of South Africa 46, 215-229.

Schumann E H (editor) (In press). Coastal ocean studies off Natal, South Africa. Lecture Notes in Coastal and Estuarine Studies Series 26. Springer Verlag, New York.

Siegfried W R and Crawford R J M 1978. Jackass penguins, eggs and guano: diminishing resources at Dassen Island. South African Journal of Science 74, 389-390.

Smale M J 1985. Aspects of the biology of Argyrosomus hololepidotus and Atractoscion aequidens (Osteichthyes: Sciaenidae) in waters of the south-eastern Cape, South Africa. South African Journal of Marine Science 3, 63-75.

Smale M J and Buxton C D 1985. Aspects of the recreational ski-boat fishery off the eastern Cape, South Africa. South African Journal of Marine Science 3, 131-144.

Stout V F 1980. Organochlorine residues in fishes from the north-west Atlantic Ocean and Gulf of Mexico. Fishery Bulletin 78, 51-58.

Van der Elst R 1976. Gamefish of the east coast of southern Africa. I. The biology of the elf, Pomatomus saltatrix (Linnaeus), in the coastal waters of Natal. Investigational Report, Oceanographic Research Institute 44, 1-59.

Van der Elst R P 1979. A proliferation of small sharks in the shore-based Natal sport fishery. Environmental Biology of Fishes 4, 349-362.

Van der Elst R P 1984. Marine sport fishing in South Africa: an up-to-date evaluation. South African Journal for Research in Sport, Physical Education and Recreation 7(1), 59-69.

Van der Elst R P (In press). Shelf ichthyofauna of Natal. In: Schumann E H (editor) Coastal ocean studies off Natal, South Africa. Lecture Notes in Coastal and Estuarine Studies Series 26. Springer Verlag, New York.

Wallett T S 1973. Analysis of shark meshing returns off the Natal coast. MSc Thesis, University of Natal, Durban.

Wallett T S 1978. Shark attack and treatment of victims in southern African waters. Purnell, Cape Town.

CHAPTER 3. THE INTERTIDAL AND SUBTIDAL ECOSYSTEMS OF SOUTHERN AFRICA

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INTRODUCTION

This chapter is concerned with the coastal zone, the ecotone between the fully terrestrial environment and the marine shelf, and which may comprise rocky shore, sandy beach or mixed shore. We define the terrestrial boundary as the upper limit of storm wave action. Interactions across this boundary occur, particularly between sandy coastlines and their adjacent dune fields. The seaward limit is more difficult to define as there are no clear boundaries. McLachlan (1981) defined the nearshore zone on sandy beaches as the outer limit of surf-circulation cells at approximately 500 m offshore and a depth of four to five metres. The outer limit of the coastal zone can also be defined as the point at which waves cease to interact with the substratum, a depth of about 15 m (Swart 1983) or on rocky shores as the seaward limit of attached macrophytes.

Coastal ecosystems possess unique features which may complicate monitoring programmes. The first of these is their shape, as they may be thousands of unbroken kilometres in length, but as little as a few metres in width. This means that boundary effects may have an overriding influence. Enormous physical variation may also be evident over minute spatial scales, especially in the vertical plane. Organisms may thus be able to compensate for marked variations in physical conditions by migrating over very small distances.

The physical forcing factors controlling rocky-shore and sandy beach systems are different. Being unconsolidated, beach sediments are highly mobile, and changes in wave action and beach morphology have a pronounced influence on the distribution and abundance of the biota. On mixed shores, sand scour and smothering are also of critical importance. By contrast, rocky shore communities are more strongly influenced by biotic interactions, such as predation and competition for limited resources of space or food.

The data considered in this chapter can be categorized into physical and biological data series. Physical data include sea level, water temperatures, wave action and beach morphodynamics. Biological series relate primarily to human exploitation of coastal species, to population dynamics and also to microbiological monitoring. Community analyses are notable by their absence.

Despite its ready accessibility and long history of human exploitation, few data series from coastal habitats in South Africa date back more than 30 years. As might be expected the longest series are those relating to sea level (because of its significance for harbour access) and to exploitable stocks or resources. The currently available data series are summarized below.

PHYSICAL DATA SETS

Sea level

Sea level data are obtained from tide gauges in harbours. By filtering out tidal and event-scale fluctuations it is possible to observe long-term trends, which may be correlated with other physical or biological variables. There exists a long-term trend in these data indicating an increase in sea level of 15 cm per century.

Sea level records for 1959 to 1975 have been reported on by Brundrit (1984), those over the period of the 1983 to 1984 warm event by Brundrit et al (1984), and the extended data series 1959 to 1985 by Brundrit et al (1987). The records show periods of persistently higher than average sea level and periods of persistently lower levels, together with anomalous high events. The high events of 1963, possibly 1974, and 1984 appear to correlate with periods of elevated sea surface temperature, or "Benguela Niños", as identified by Shannon et al (1986).

These data are dealt with in detail in Chapter 1 of this volume.

Temperature

Several data series are available, the longest being a 26-year series from Table Bay Harbour (Walker et al 1984). It shows a persistent warm-water period in 1959 to 1964. Abnormal temperature minima were noted in 1967 to 1968 and 1970 to 1971, and another high in 1972 to 1974. The authors suggest that the 1959 to 1964 anomaly may have been associated with the pilchard *Sardinops ocellata* collapse over the same period.

A second data series is that of Lutjeharms et al (this volume) for the subantarctic islands of Tristan da Cunha, Gough and Marion. The main feature of the Marion Island data is a prolonged period of above-average values during 1981 to 1983, since when values have been below normal. Maximum deviation occurred in 1982, a full year prior to the warm event observed elsewhere.

Wave action

Although of a short-term nature, daily wave records from a site at Koeberg Nuclear Power Station are available since 1979 and are reported on in part by Branch and Griffiths (in press). Periods of extreme wave action apparent in these records may have an effect on coastal communities.

BIOLOGICAL DATA SERIES

A large proportion of the long-term biological data refers to the yields of exploited resources, although populations of birds have also been extensively monitored. There is a notable lack of long-term community studies, although coastal ecosystems are known to vary considerably in species composition over time (eg Berry 1982).

Seals

Cape fur seal *Arctocephalus pusillus pusillus* populations, which were reduced to low levels by the beginning of the twentieth century as a result of exploitation, have subsequently undergone a dramatic recovery. There was an increase in seal populations in the 1930's, resulting in an estimated pup population of 155 500 in 1940. This rose further to 196 000 in 1971 and 310 000 in 1983 (Butterworth et al 1987). These increases have occurred despite the collapse of pilchard and horse mackerel *Trachurus capensis* resources off South Africa and the pilchard resource off Namibia, the seals having switched to feeding mainly on anchovy and hake in South Africa and pelagic goby *Sufflogobius bibarbatus* in Namibia. Major factors responsible for population recovery are a recent low exploitation level and the establishment of mainland breeding colonies. The elimination of top predators by man may have facilitated mainland breeding. There is no indication that seal populations are resource limited at their present levels.

Whales

Coastal surveys of southern right whales *Eubalaena glacialis* have been carried out annually since 1969. The surveys, which cover the area from False Bay to Algoa Bay, show a steady growth in the population at a rate of some seven per cent per annum, from 60 in 1969 to 274 in 1986 (Anonymous 1986). This recovery follows more than a century of intense exploitation, which took place all over the southern ocean and around the South African coast. Since recovery is occurring from a low base and the whales spend much of the year distant from the South African coast, population densities are unlikely to be linked to any of the environmental parameters recorded locally.

Seabirds

Historical trends in seabird densities at offshore islands have been estimated both directly and by extrapolation from annual guano harvests. The guano data are considered by Shelton and Crawford (this volume).

Direct counts are available for a number of seabird species. Cape gannet *Morus capensis* populations declined from 150 000 breeding pairs in 1956 to 100 000 pairs in 1980 (Crawford et al 1983) and those of jackass penguins *Spheniscus demersus* from 300 000 pairs in 1956 to 130 000 pairs in the late 1970's (Shelton et al 1984). Both these declines are thought to be related to reduction of the pilchard resources (Crawford and Shelton 1981). The decline in jackass penguins may, however, merely represent part of a longer-term trend (from a population of approximately 2,5 million in 1900), associated with habitat degradation due to removal of the guano within which the penguins constructed their nest burrows and to intense exploitation of eggs in the early part of the century. Some species, notably the bank cormorant *Phalacrocorax neglectus* have shown an increase in numbers over the same period. In the region between Walvis Bay and Lüderitz decreases in gannet numbers and simultaneous increase in bank cormorant numbers appear to be linked to changes in food availability, numbers of pilchards (eaten by gannets) having declined and those of pelagic goby (eaten by bank cormorants) having increased (Crawford et al 1985).

Further evidence on the status of seabird populations comes from records of strandings of dead birds (Avery this volume) and of wader numbers at Langebaan Lagoon (Underhill this volume).

Sand Mussels

Birkett and Cook (1987) monitored the *Donax serra* population at Ou Skip in the western Cape over a five-year period. In the eastern Cape, *D serra* has been sampled at irregular intervals, in 1973 to 1974 by McLachlan and Hanekom (1979), in 1976 by McLachlan (1977), in 1983 by A D Ansell and A McLachlan (unpublished) and in 1985 by Donn (1987).

TRENDS IN THE CATCH PER UNIT EFFORT OF SHORE ANGLERS, 1938 to 1986

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INTRODUCTION

A number of angling clubs in the south-western Cape organize regular angling competitions in False Bay and maintain detailed records of man-hours fished and of species and mass of each fish weighed in at the end of the day. In some cases records dating back several decades are still in existence. These data are available for several clubs for the period since about 1970, while one, the Liesbeek Park Angling Club, was able to provide a time series dating back to 1938, with only a short break during the 1940's.

RESULTS

Results are presented as catch per unit effort (CPUE), expressed as numbers of fish caught per man-hour fished. Separate analyses were carried out for each of the nine species most frequently caught by rock and surf anglers in the south-western Cape. Trends in catches suggest that records fall into three groups as detailed below.

The first group, comprising four species, white stumpnose *Rhabdosargus globiceps*, red stumpnose *Chrysoblephus gibbiceps*, roman *Chrysoblephus laticeps*, and yellowtail *Seriola lalandi*, all show an irregularly declining trend in CPUE over time (Figure 3.1).

A second group, comprising white steenbras *Lithognathus lithognathus*, kob *Argyrosomus hololepidotus*, and baardman *Umbrina capensis*, were poorly represented in the catches prior to 1960 and show a progressive increase in CPUE thereafter (Figure 3.2).

The third group, comprising dassie *Diplodus sargus* and galjoen *Coracinus capensis*, show irregular fluctuations in CPUE (Figure 3.3).

DISCUSSION

Initial examination of these results suggests that fish in group 1 have been overfished and that those in group 3 may have increased in abundance over time. More detailed examination of club records, however, indicates

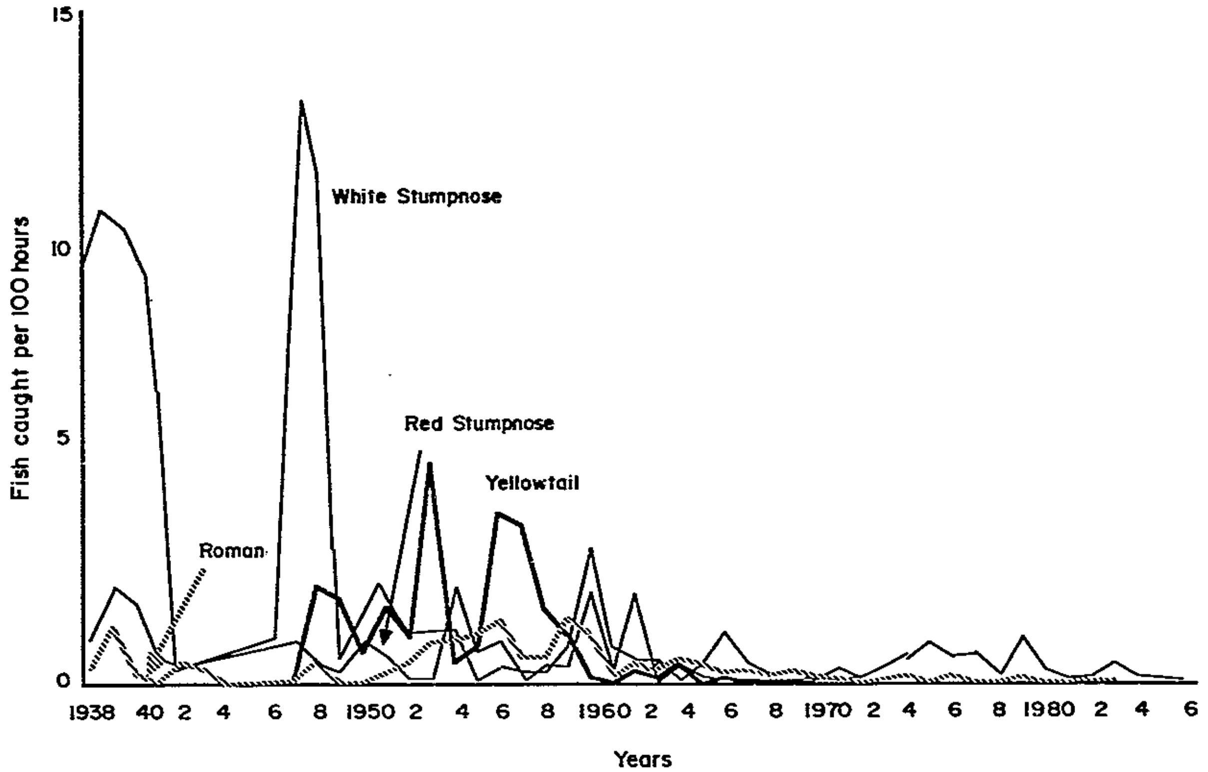

FIGURE 3.1 Catch per unit effort for angling species that have shown a decline over time.

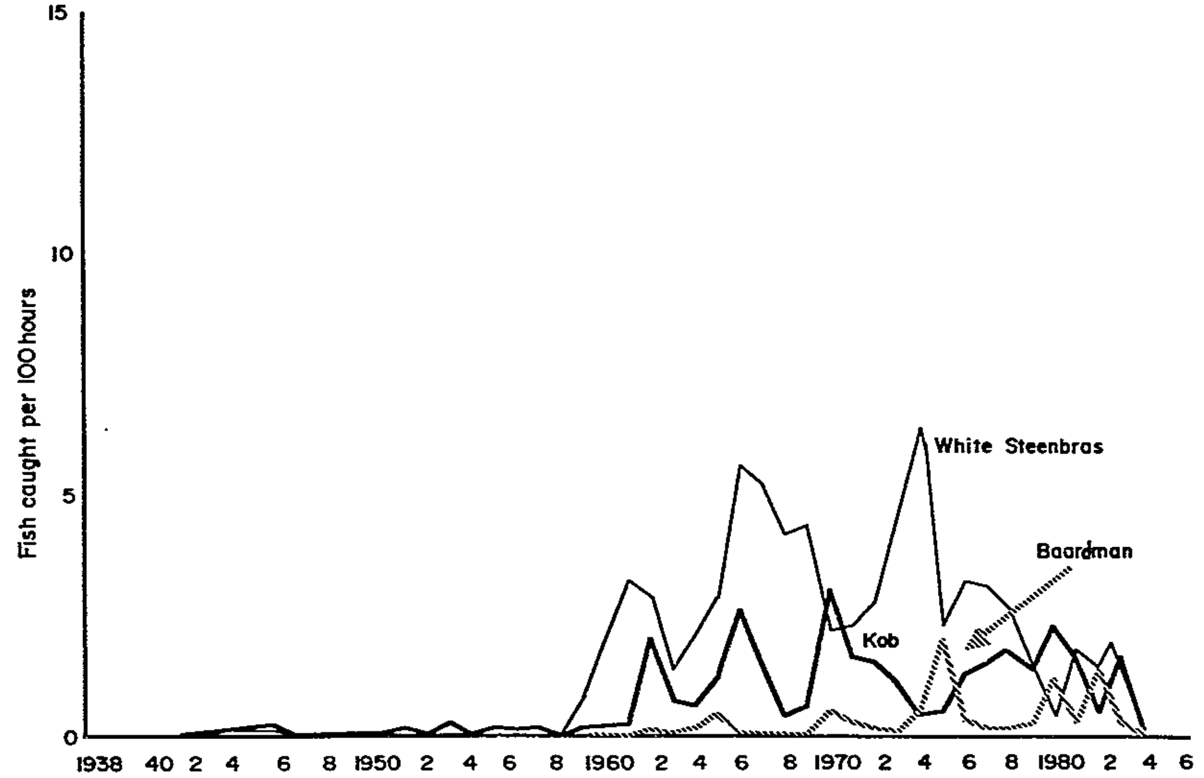

FIGURE 3.2 Catch per unit effort for angling species that have shown an increase over time.

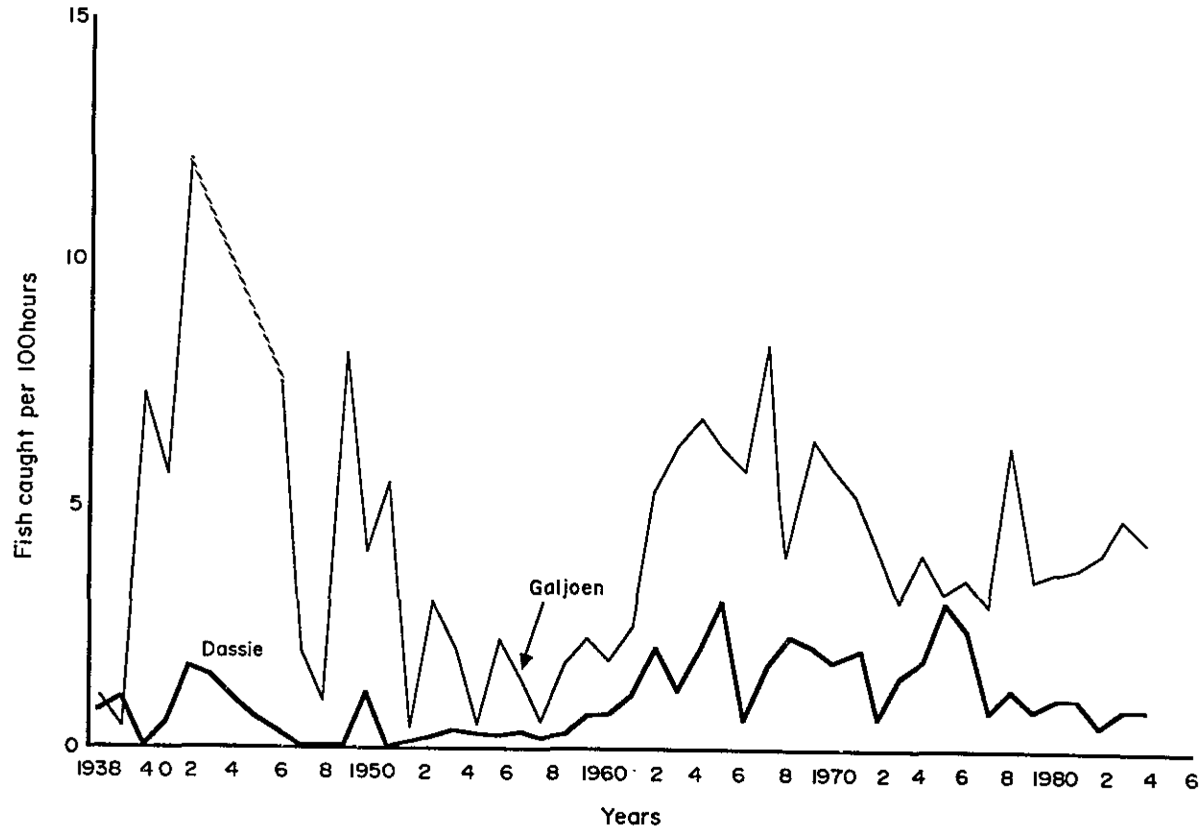

FIGURE 3.3 Catch per unit effort for angling species that have shown fluctuating catches over time.

that catch trends may, to a large extent, reflect the habits of the fishermen, in particular changes in the localities of fishing competitions.

Prior to 1950, competitions were held either on the west coast of the Cape Peninsula or between Simon's Town and Partridge Point on the east coast. Catches at these sites comprised mainly white stumpnose and galjoen, together with some red stumpnose and roman. From 1950 to 1960, competitions were held mainly at Rooikrans or Rooiels, where deep water is accessible from the shore. Such areas are unsuitable for galjoen and white stumpnose, leading to a decrease in catches of these species, but favour species such as yellowtail and roman, which were caught most frequently during this period. After 1960, competitors were offered the option to fish almost anywhere on the Cape Peninsula or False Bay coastlines. This resulted in an increase in fishing effort in beach or mixed rock and sand habitats, favoured by species such as kob, white steenbras and baardman. These species thus show an increased CPUE towards the latter part of the time series (Figure 3.3). Transfer of effort away from deep water sites simultaneously resulted in a decline in catches of red stumpnose, yellowtail and roman, all of which are poorly reflected in catches subsequent to 1960.

It appears therefore that these records, while they provide an interesting insight into changing fishing habits and catch patterns, and refute the common claim amongst fishermen that catches have declined systematically over time, are of little use as indicators of temporal changes in fish abundance. The changes in behaviour patterns of fishermen highlighted here appear to be associated with transportation facilities, in particular the move from public transport to private vehicles, the opening up of new sites through road development, and availability of off-road vehicles.

LIMPET RECRUITMENT AND DENSITY 1972 TO 1986

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INTRODUCTION

As part of a study on the population dynamics of limpets, densities and recruitment patterns of a number of species have been monitored at Dalebrook, in False Bay, at Kommetjie, on the west coast of the Cape Peninsula and at Marcus Island, in Saldanha Bay. Both total numbers and the proportion of first-year recruits in the population were recorded. The species monitored were *Patella cochlear, P granularis* and *P oculus*.

RESULTS

Patella cochlear exhibits a high and extremely stable density pattern (Figure 3.4), a function of its territorial behaviour, apparently regular recruitment regime and longevity of 20 to 30 years (Branch 1984a, 1985). The ratio of recruits to adults in this population in fact remained remarkably stable at between 0,12 and 0,22 juveniles to each adult over the 14-year study period at Dalebrook. *Patella granularis*, which has an intermediate longevity of approximately five to seven years, showed

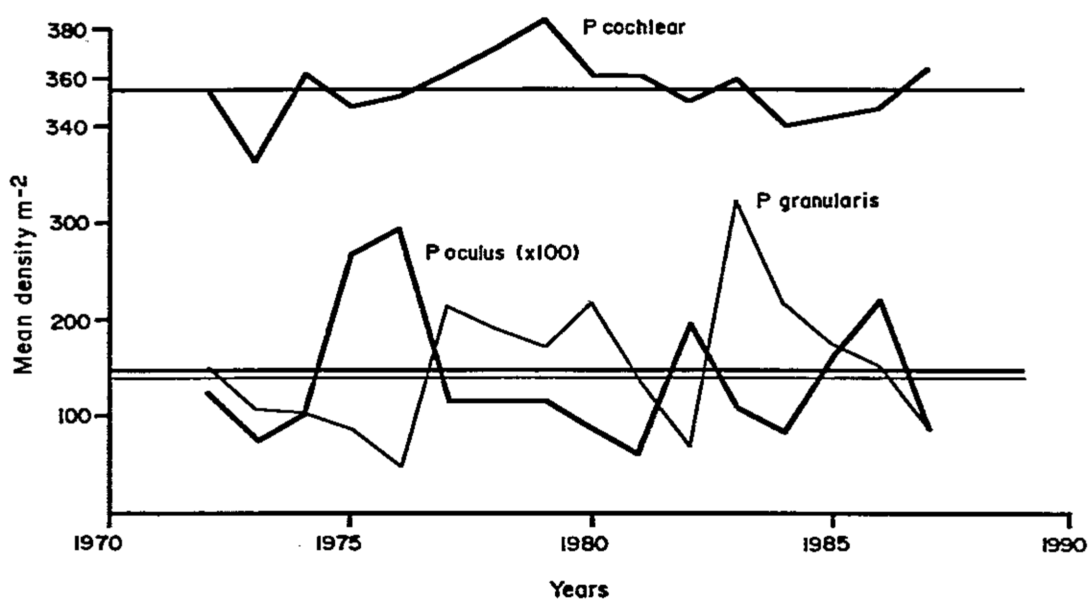

FIGURE 3.4 Densities of three species of limpets at Dalebrook in False Bay 1972 to 1987.

greater fluctuations in density (Figure 3.4). These could largely be attributed to more erratic recruitment, the number of juveniles varying between 0,09 and 0,52 for each adult in the population. Particularly strong recruitment occurred in 1972, 1977, 1980 and 1983, and is associated with peaks in overall density. Since the adults live for several years, above-average recruitment influences the population for several years. *Patella oculus*, which lives for only approximately two years, shows dramatic interannual variations in density, which occur despite an apparently stable input of recruits relative to the adult stocks (see below). These are attributable to the high adult mortality rate in this species.

Recruitment of *P oculus* at Dalebrook remained remarkably constant, with an average of 1,93 recruits for every animal in older size classes. At Kommetjie recruitment was more erratic, with a noticeable peak in the proportion of juveniles in 1983. At Marcus Island recruitment was very irregular, and there was a lower overall ratio of recruits to adults (1,43) than at the other sites. Peaks of recruitment were evident in 1976/77, 1980 and, most dramatically, in 1983 (Figure 3.5).

DISCUSSION

Variations in the population densities of three limpet species at Dalebrook appear to be functions of their life history and behavioural patterns. The long-lived, territorial *P cochlear* maintains extremely constant densities, whereas the shorter lived *P granularis* and *P oculus* exhibit progressively more irregular population densities. In the case of *P granularis* changes in density are largely a function of irregular recruitment, possibly associated with warm water incursions from around Cape Point, but in *P oculus* large variations in adult mortality rate are a more important factor.

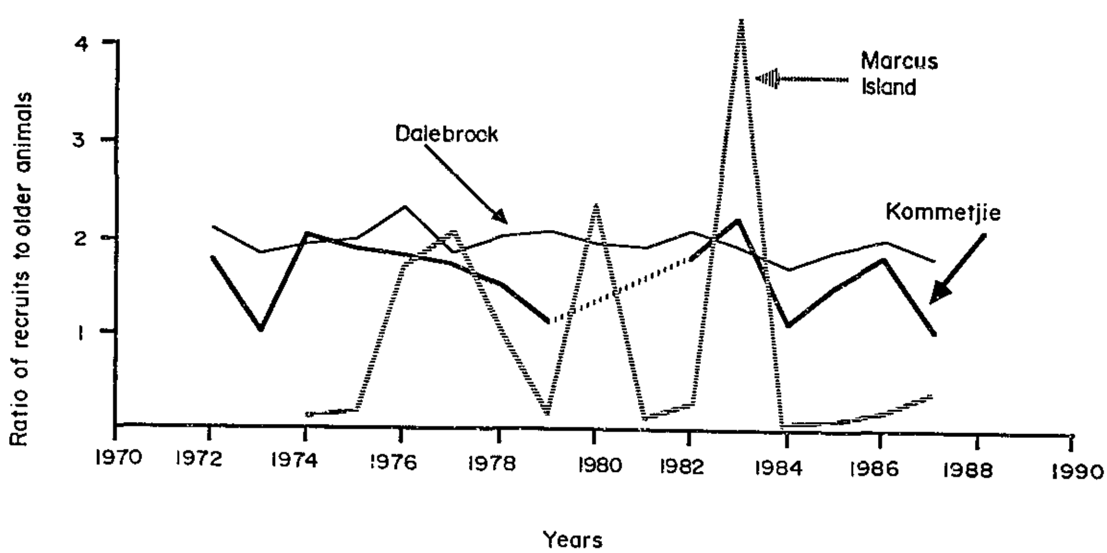

FIGURE 3.5 Numbers of first year recruits entering the population per year for each adult present in *Patella oculus* from three study sites: Dalebrook, in False Bay; Kommetjie, on the west coast of the Cape Peninsula and Marcus Island, in Saldanha Bay.

Recruitment patterns in *P oculus* at the three study sites are linked more clearly to environmental parameters. Conditions are always favourable for this warm water species in False Bay, resulting in regular recruitment. On the west coast recruitment is probably only associated with the incursion of warmer water (Branch 1984b). This is particularly evident in the data for Marcus Island, where the recruitment peaks, at least in 1976 to 1977 and in 1983, can be linked to warm events of 1976 and 1982/83.

LONG-TERM DATA ON EXPLOITATION OF THE MUSSEL *PERNA PERNA* IN NATAL

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INTRODUCTION

The harvesting of intertidal and subtidal invertebrates in Natal is regulated by a Provincial Ordinance and is controlled by the Natal Parks Board. Collectors are obliged to hold a licence issued by the Natal Fisheries Licencing Board and are required to submit catch-return forms annually to the Oceanographic Research Institute. On these forms collectors are expected to state the number of days per month spent collecting and the number of organisms removed.

Analysis of these returns gives an indication of the total annual catch and, although they must clearly be underestimates, have served to demonstrate the increasing intensity of exploitation of the intertidal rock organisms from 1974 to 1986.

RESULTS

The demand for licences is a measure of the demand for a particular species. The analysis of the requests for licences from 1974 to 1986 shows that the brown mussel *Perna perna* is the most sought after species. The demand for this organism has increased at a rate of 22,7% yr^{-1} over the period.

The number of mussel licences issued increased from 627 in 1974 to 7 306 in 1986 representing a gross increase of 1 065%. Mussels may also be taken by holders of a general bait licence, and the numbers taken by holders of this licence can be expressed in terms of full mussel licences. The effective number of mussel licences therefore increased from 1 012 in 1974 to 10 686 in 1986 (Figure 3.6). The lack of increase in numbers of licences issued between 1977 and 1978 and the decrease in 1981 result from the Fisheries Licencing Board imposing a maximum on the number of licences to be issued.

Catches increased from 105,45 tons in 1974 to 317,46 tons in 1986 (Figure 3.7). The unexpectedly low catches between 1978 and 1982 cannot be explained, but do not seem to be related to limits placed on the licences issued. The value of the mussels harvested in 1986 is placed around R1 000 000.

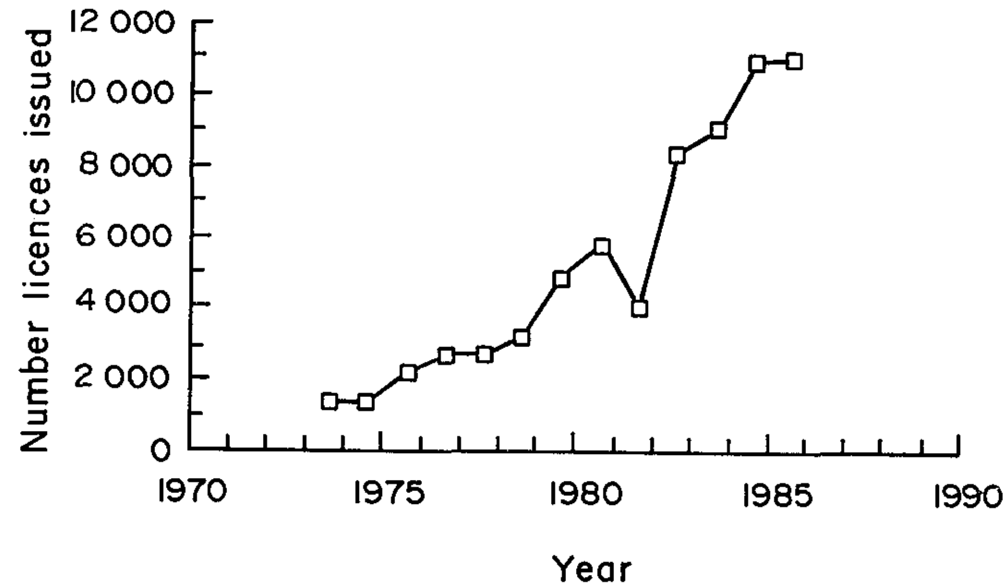

FIGURE 3.6 Total effective number of mussel licences issued in Natal over the years 1974 to 1986.

CONCLUSIONS

The demand for mussels has increased more rapidly than that for the other exploitable species such as octopus which increased by 18,3% yr^{-1}, crab by 15,2% yr^{-1} and crayfish by 12,7% yr^{-1}. In gross terms, the effective number of licences issued increased by an order of magnitude over the 13 years of this data set. Catches, on the other hand increased three-fold.

The present catch-return forms permit only a rough estimate to be made of the exploitation level. To improve the quantity and quality of data, 100 volunteer mussel licence holders, who are trustworthy and conservation-minded, have been chosen and have been issued with forms requesting more detailed information on the harvesting practice. Also they have each been supplied with a measuring board and are furnishing valuable data on the size range of mussels being collected. This project has only been running for 18 months but will be continued in the future.

In conjunction with the monitoring of mussel catches, surveys at a number of localities are being undertaken to establish baseline information on the population structure of the mussels at these points. It is hoped that through subsequent surveys, harvest- and environment-related changes in distribution and demography will be able to be detected.

In addition to the applied management objectives for this continuous data acquisition, these data series provide an opportunity to document and investigate long-term natural fluctuations such as the alleged total disappearance of mussels in 1906 and unprecedented high density settlement event which was observed to have taken place in October 1976.

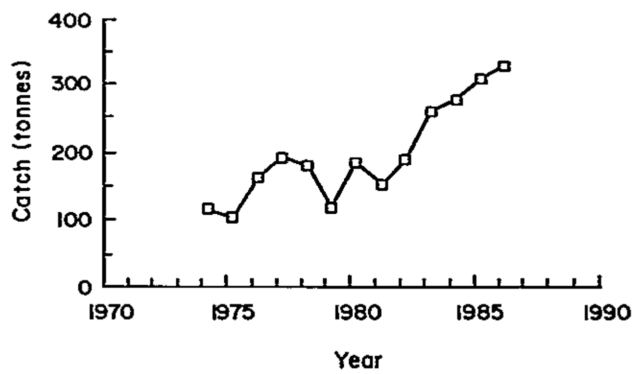

FIGURE 3.7 Total annual catch of mussels in Natal in tons over the period 1974 to 1986.

SEA WATER TEMPERATURES AT EIGHT METRES ON THE CAPE PENINSULA 1974 TO 1987

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INTRODUCTION

Sea water temperatures have been continuously recorded by thermoscript recorders anchored at eight metres depth at Oudekraal (1974 to 1987), on the west coast of the Cape Peninsula and at Betty's Bay (1980 to 1987), further east along the southern Cape coast. An additional recorder was installed in False Bay in 1984. All the data series are the product of present monitoring programmes. Portions of the records have been published previously eg Velimirov et al (1977), Dieckmann (1980), Anderson and Bolton (1985) and Anderson and Hay (1986), but the complete series for Oudekraal is presented here for the first time.

RESULTS

Two aspects of the data series are presented. Figure 3.8 illustrates daily fluctuations in temperature over two years at the Oudekraal and Betty's Bay sites. Both records illustrate the rapid fluctuations in temperature that occur over a time scale of a few days, as a result of upwelling events. Monthly mean values, superimposed on the daily records, smooth out many of these extremes, so that events of biological significance may easily be obscured. Nevertheless the monthly means reveal seasonal cycles which are reversed at the two sites. At Betty's Bay maximum temperatures occur in summer and minima in winter (although on the daily record annual temperature minima can occur at any time of year). At Oudekraal the reverse pattern is evident, with lowest temperatures in summer, the season of maximum offshore wind stress and hence most intense upwelling. Mean annual temperatures at Oudekraal are about three degrees Centigrade colder than those at Betty's Bay.

The complete time series for Oudekraal is shown in Figure 3.9 and illustrates the regularity of the annual cycles. The main features evident from the time series are apparent warm events in mid-1980 and 1984, when temperature maxima exceeded 15°C. Particularly low winter temperatures are evident in 1979 and 1983. A period of unusually low temperatures occurred in November/December 1979, when temperatures fell to below eight degrees Centigrade. The period November 1979 to May 1980 was thus one of extreme variation, with both the lowest and highest recordings of the entire series.

DISCUSSION

These recordings appear to reveal the same long-term temperature anomalies recorded elsewhere. In particular the minima of 1979 and positive anomaly that followed it are evident in the recordings from Table Bay presented by Walker et al (1984). The 1983 anomaly has been widely reported elsewhere (eg Branch 1984 and other articles in that volume). The main value of these particular records, however, lies in their continuous nature. This reveals pronounced short-term temperature fluctuations, not only on a day to day basis, but also on even finer time scales of hours or minutes. These are thought to occur when thermoclines lie close to the sites of the recorders, such that they are alternately exposed to warm and cool layers in response to tides, or even as individual swells move overhead.

This leads to a situation where short-term variations in temperature equal or exceed the amplitude of variations over longer time periods. The biological inferences which may be drawn from such data are, therefore, limited, without an appreciation of the consequences of short-term fluctuations in temperature on the behaviour and physiology of affected species.

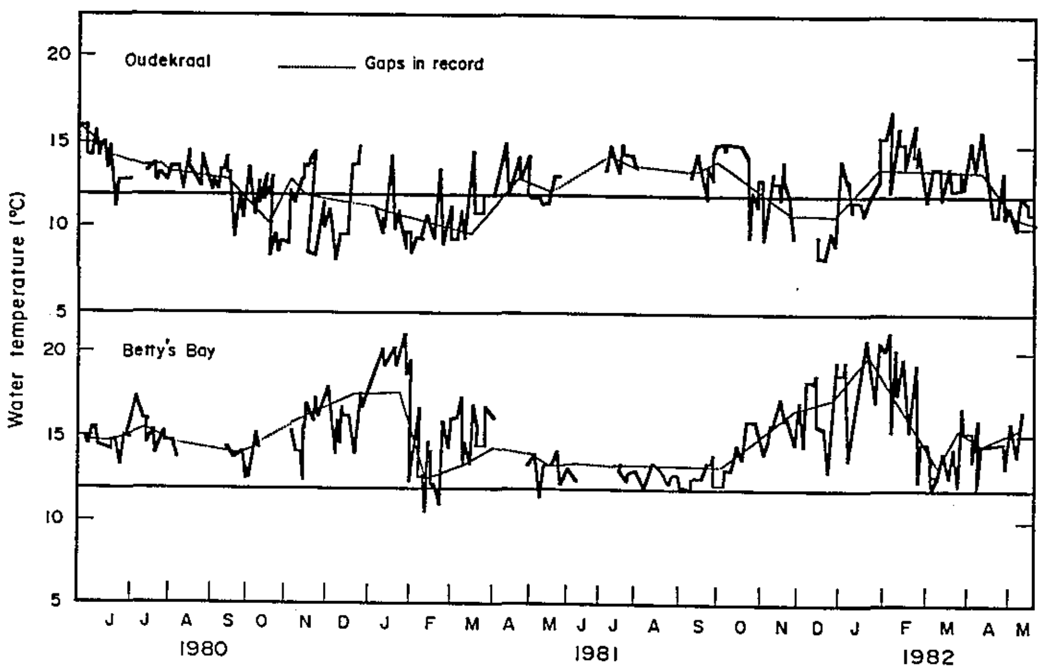

FIGURE 3.8 Daily temperature fluctuations at two sites in the south-western Cape, 1980 to 1982.

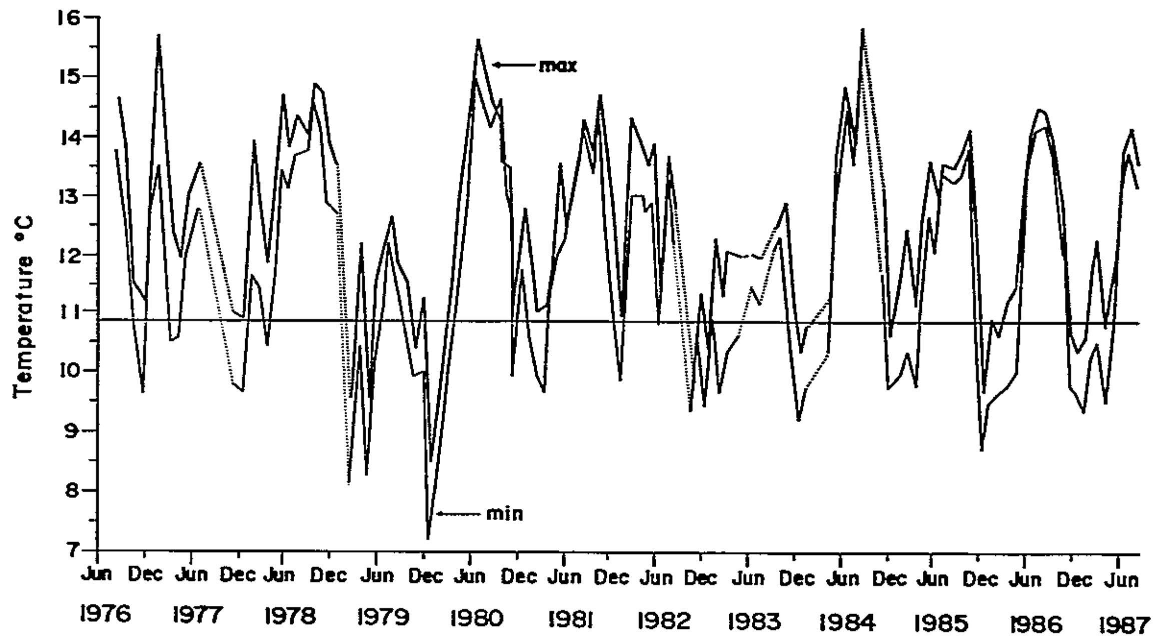

FIGURE 3.9 Mean monthly maximum and minimum temperatures at eight metre depth at Oudekraal on the Cape Peninsula.

SEAWEED EXPLOITATION ON THE WEST COAST OF SOUTH AFRICA 1964 to 1986

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INTRODUCTION

The kelps, *Ecklonia maxima* and to a lesser extent *Laminaria pallida* and *L schinzii*, and the alga *Gracilaria verrucosa (= G confervoides)* are commercially exploited along the west coast of South Africa. These are used for the extraction of alginic acid utilized extensively as an emulsion stabilizer in industry or for the production of agar.

Kelp beds are the dominant communities on rocky sublittoral reefs from about Cape Agulhas to Luderitz. Total kelp standing stock between Cape Point and Cape Columbine (220 km) has been estimated at 554 330 tons wet mass, of which 39% is *Laminaria* and 61% is *Ecklonia* (Jarman and Carter 1981).

Gracilaria verrucosa grows loosely attached to the substratum in shallow water in sheltered lagoons. A small industry has been in existence in Saldanha Bay since at least the 1950's (Isaac 1956).

Records of the tonnage of both kelp and *Gracilaria* collected and exported each year are given in the Sea Fisheries Annual Reports and are based on monthly returns by the concession holders concerned. The data reported on below are all derived from that source. In the case of kelps only beach-cast material has been included. *Gracilaria* figures are for Saldanha Bay only, although Lüderitz has recently developed into a centre for the *Gracilaria* industry.

RESULTS

Total commercial harvests of kelp are shown in Figure 3.10. Gradual expansion was experienced in the early 1970's, after which a collapse in the world kelp market was accompanied by a dramatic decline in collection. A recovery of the industry in the early 1980's, was followed by a second decline in 1986, largely attributable to a political boycott of the South African product. At present there is a very unpredictable export market for South African kelp, although some is still being used locally as an organic fertilizer and for stabilization and reseeding of road embankments.

The history of the *Gracilaria* industry is depicted in Figure 3.11. A relatively stable crop of some 500 to 1 000 tons yr^{-1} was collected until 1973, following which the industry experienced a dramatic collapse, with a negligible return two years later. The demise of the industry can apparently be attributed to construction of the new harbour facilities in Saldanha Bay in the 1970's, possibly because current patterns were altered so that the *Gracilaria* was no longer cast up on the beaches, or because the suspended silt content of the water increased to such an extent that light penetration was reduced. There has been a slight increase in the crop over the past two years, although it is not yet clear whether this will be sustained.

DISCUSSION

Temporal fluctuations in both the kelp and *Gracilaria* data sets appear to be driven more by human activities than by long-term environmental factors. The size of the kelp crop is determined almost entirely by the world price, the sustainable yield of economically recoverable kelp being at least 5 000 tons, a figure that was only realized in the "boom-years" from 1973 to 1977.

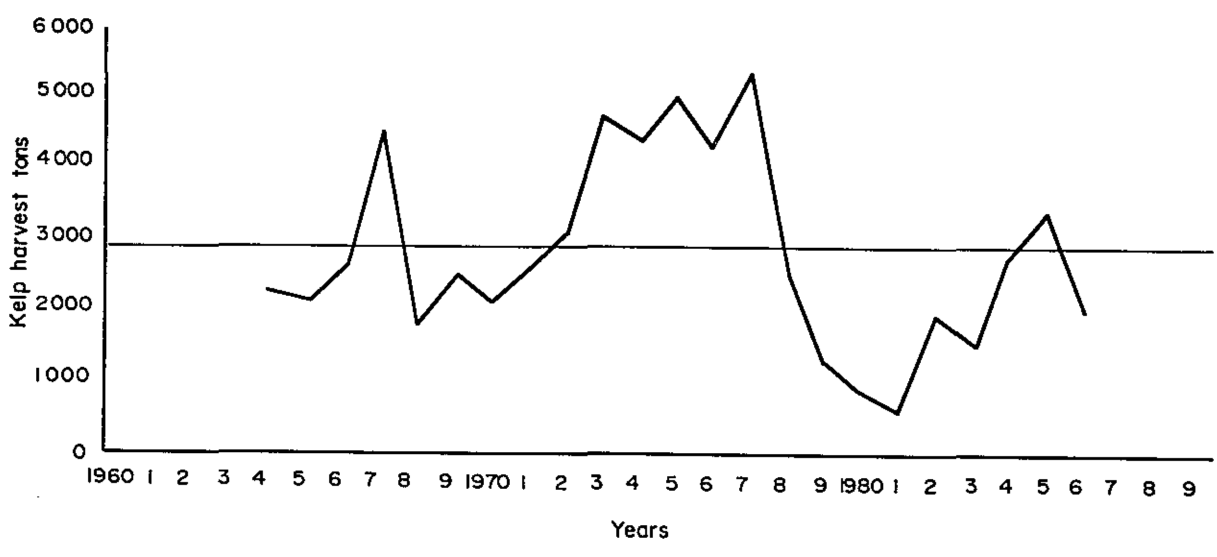

FIGURE 3.10 Total commercial kelp harvests as derived from Sea Fisheries Annual Reports.

Gracilaria production may be representative of total beached biomass up to 1973, but subsequent returns have been severely disrupted by human impacts on the environment. It is not clear whether the decrease in *Gracilaria* production is as severe as the returns indicate, or whether the plants are merely not being cast up on the shore as was previously the case and hence remain inaccessible.

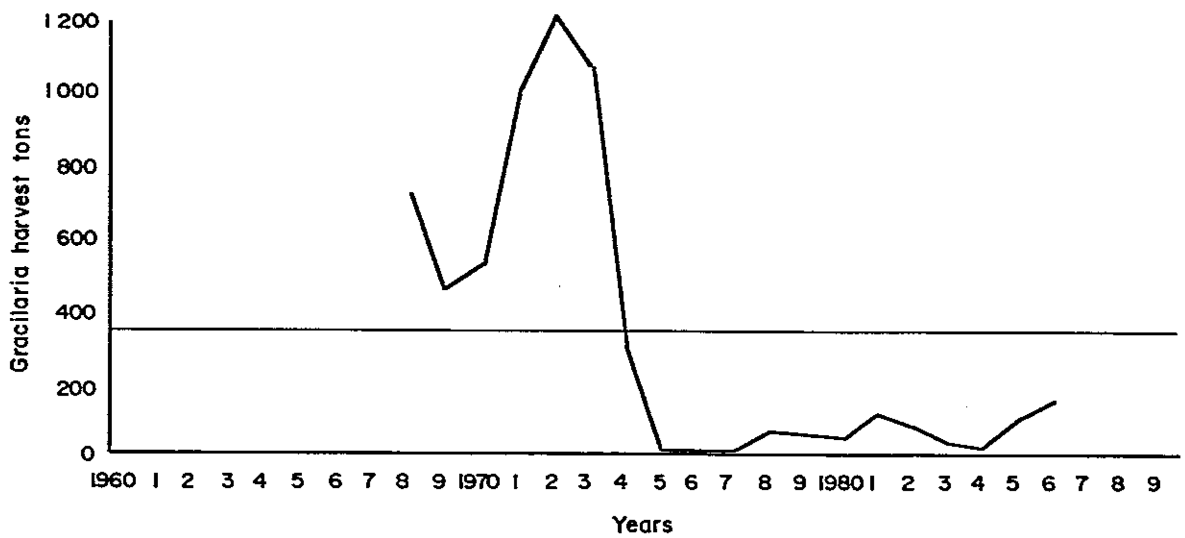

FIGURE 3.11 *Gracilaria* harvests for the west coast of South Africa, mainly Saldanha Bay, as extracted from Sea Fisheries Annual Reports.

ROCK-LOBSTER CATCHES, SEA SURFACE TEMPERATURES AND SHELF WATER CHARACTERISTICS IN THE CENTRAL BENGUELA 1950 TO 1984

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INTRODUCTION

Recent findings have suggested a link between fluctuations in rock-lobster production and fishery yields in the central Benguela region (Namaqualand coast and southern Namibia) and changes in upwelling (Pollock 1987; Pollock and Shannon 1987). This paper presents time series of sea surface temperature (SST) anomalies in the South-east Atlantic, rock-lobster catches in the central Benguela and temperature sections on the Walvis Bay shelf, from which a marked degree of coherence is noted between cool periods and declines in productivity and yields of rock-lobster (Figure 3.12). Rock lobster catch statistics and SST data are derived from Pollock and Shannon (1987), whereas the temperature sections are reported on elsewhere in this volume.

DISCUSSION

Walker (1987) and Taunton-Clark and Shannon (in press) have highlighted coherence between changes in SST over much of the South Atlantic and variations (on a quasi-decadal time scale) in SST at an offshore five-degree square west of Lüderitz. The latter variations are fairly typical of both the oceanic and the coastal regions. Variations in SST of West Coast shelf waters are caused mainly by changes in equatorward (upwelling-favourable) wind stress and changes in the advection of surface and bottom layers. Cool periods in the central Benguela region result from increased upwelling wind stress and/or increased advection of cold "bottom" water onto the shelf, and are associated with increased nutrient supplies which favour enhanced primary production. The eutrophication of shelf water causes formation of oxygen-deficient bottom waters, which in turn leads to shallow-water overcrowding of rock-lobsters. (Lobsters move inshore to avoid low dissolved oxygen concentrations further offshore - Pollock and Shannon 1987).

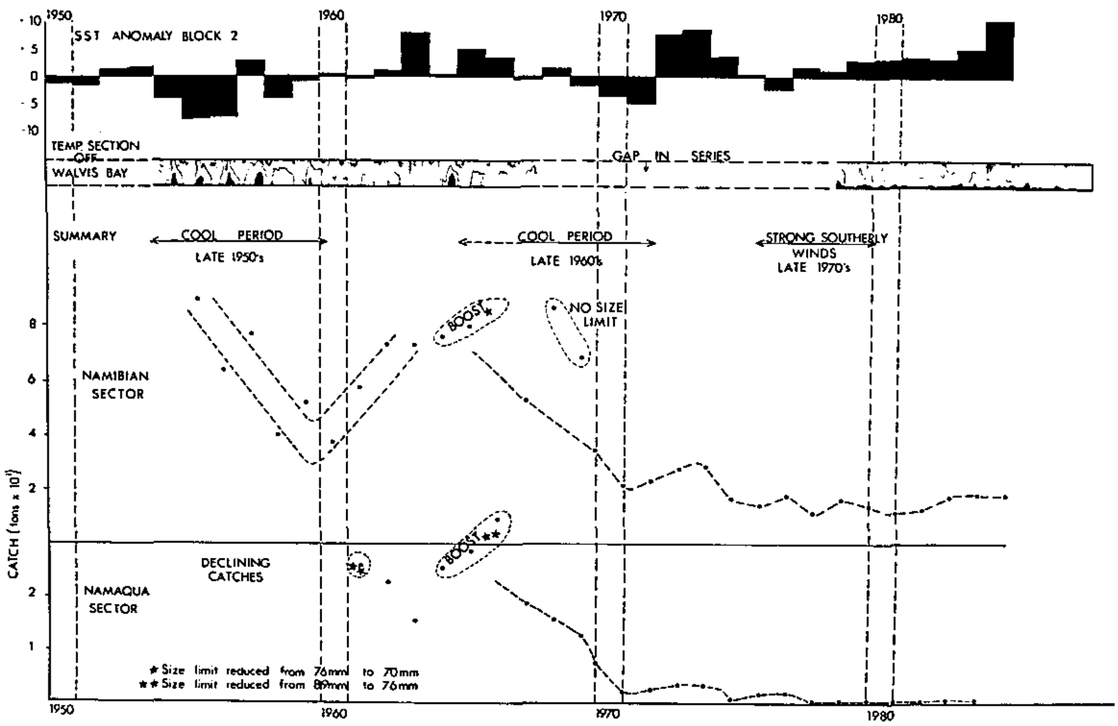

FIGURE 3.12 Time series of SST in South-east Atlantic, thermal stratification on the Walvis Bay shelf (bold shading indicates water cooler than 11°C) and rock lobster catches in the Namaqualand and Namibian regions of the Benguela, from 1950 to 1984.

Of interest in the data series shown in Figure 3.12, is the abnormally prolonged advection of cold, bottom water onto the shelf during the late 1950's. Marked declines in catches of rock-lobsters during the late 1950's and late 1960's may have resulted from the resultant oxygen depletion. It is thought that lobsters were forced to occupy a much reduced, shallow-water habitat, causing reduced growth and survival, together with an increased vulnerability to fishing. Rock-lobster stocks in the central Benguela have shown no significant recovery since the major "collapse" of the late 1960's, suggesting that the system is currently locked into a comparatively stable condition of low productivity.

POPULATION TRENDS OF *TURBO SARMATICUS* IN THE TSITSIKAMMA COASTAL NATIONAL PARK

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INTRODUCTION

Turbo sarmaticus, the alikreukel, is endemic to South Africa and is collected for food and bait on the rocky coasts of the southern Cape. Although protected, little is known about this mollusc and its conservation status. The Tsitsikamma Coastal National Park, a stretch of steep and rugged rocky shore of about 60 km in the southern Cape, was proclaimed in 1964 as the first coastal national park in Africa (Tietz and Robinson 1974; Toerien 1976). From 1967 onwards a total prohibition was enforced on the removal of any organism from the shore, making this area near the centre of the range of *T sarmaticus* an ideal reference area for a long-term study of the species' population dynamics.

The numbers and sizes of individuals of *T sarmaticus* occurring on a fixed transect in the littoral near the Storms River mouth in the Tsitsikamma Coastal National Park have been recorded on a regular basis since 1972. Trends perceived from the data are firstly the influence of man, and secondly the influence of environmental factors, possibly related to cold water upwellings. These influences are reflected in fluctuating population density and recruitment (Tietz and Robinson 1974; Lombard 1977; McLachlan and Lombard 1981).

METHODS

Two intersecting transects were marked out at Swartrif near the Storms River mouth, one transect (62 m) parallel to the shore, and the other (95 m) perpendicular to the shore. The size and position of all *T sarmaticus* within one metre of the transect lines have been recorded periodically since 1972.

Between July 1977 and March 1979 an exploitation experiment was conducted by removing all *T sarmaticus* within five metres of the perpendicular transect every time sampling was done.

RESULTS AND DISCUSSION

The *T sarmaticus* in the transect area cannot be considered representative of the total population, mainly because larvae are not represented, juveniles and smaller animals are not fully represented, (hence larger size classes are possibly overrepresented), and the sublittoral part of the population was not sampled. This situation is a classic sampling problem and was compensated by keeping the sampling method and area constant.

The deviation of the long-term mean number of *T sarmaticus* occurring in the combined transect areas, smoothed by calculating a running mean over a period of twelve months, was plotted against time as a measure of changes in abundance (Figure 3.13). Similarly, deviations of the long-term mean shell length and of biomass, smoothed as described, were plotted against time as indices of population structure (Figures 3.14 and 3.15).

After exploitation ceased, density, mean size and biomass all increased (Figures 3.13 and 3.15). However, there is evidence that, even when afforded eight years of protection, the population has not recovered to the pre-exploitation condition. Whether this is due solely to the exploitation, or is a phenomenon compounded by environmental factors, cannot yet be determined. It was thought that the population may be affected by changes in water temperature. However a 15-year series of water temperature measurements (Figure 3.16) shows no trend or pattern obviously correlated with fluctuations in the *T sarmaticus* population.

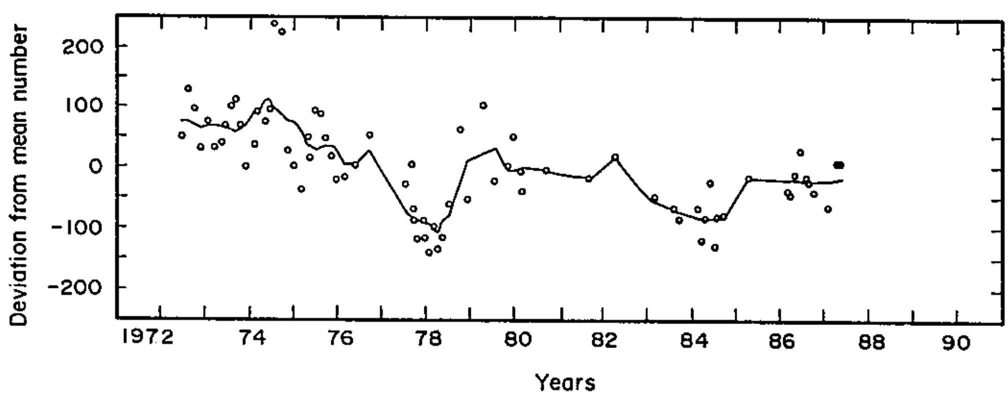

FIGURE 3.13 Deviations of the twelve month running mean number of *Turbo sarmaticus* from the long-term mean. Actual numbers sampled are indicated as circles (long-term mean number sampled = 178,0).

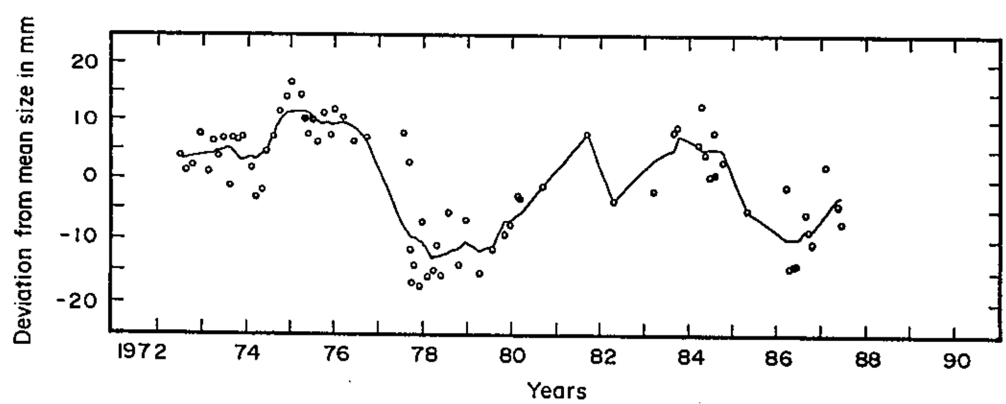

FIGURE 3.14 Deviation of a twelve month running mean length of *Turbo sarmaticus* from the long-term mean length. Actual mean lengths for each sample are indicated as circles (sizes in millimetres, long-term mean length = 49,782).

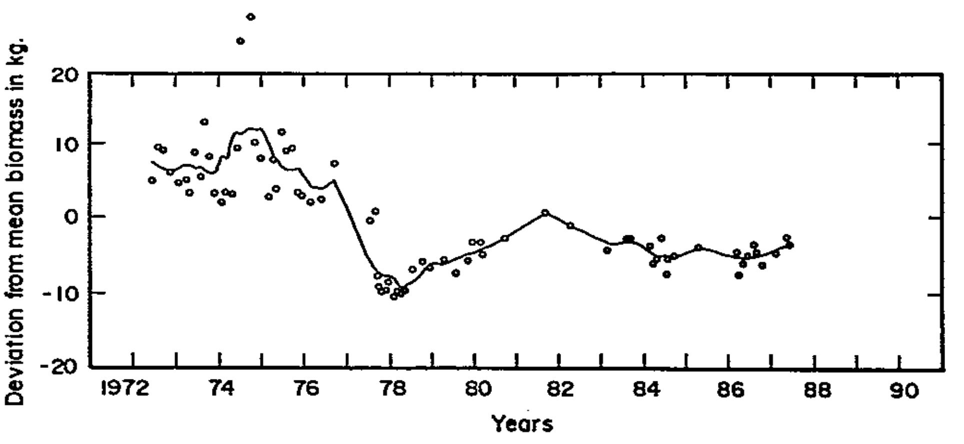

FIGURE 3.15 Deviation of the twelve month running mean biomass of *Turbo sarmaticus* from the long-term mean biomass. Actual biomass sampled is indicated as circles (long-term mean biomass = 11,182 kg).

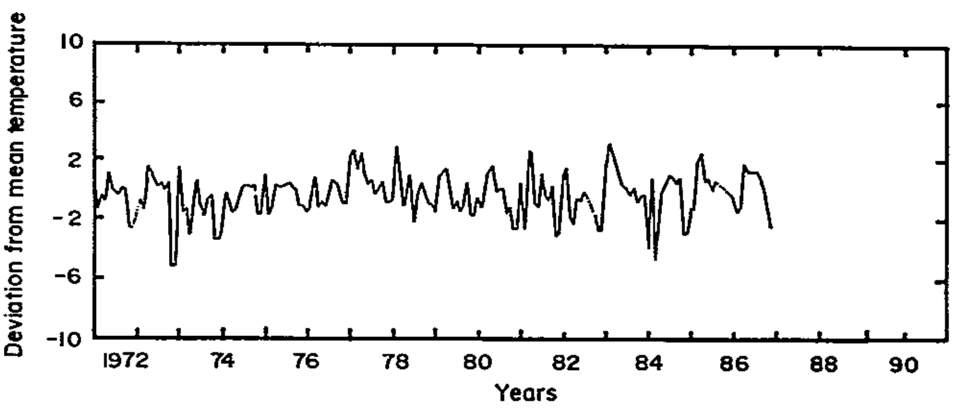

FIGURE 3.16 Deviation of the monthly mean temperature from the long-term monthly mean recorded at Storms River Mouth (temperature in degrees Centigrade).

OTHER POTENTIAL DATA SOURCES

Other long-term biological data sets which are being collected relate to subtidal community structure in the vicinity of the Richards Bay pipeline (National Research Institute for Oceanology (NRIO) Durban, SADCO), and the bacteriological quality of waters on Durban beaches (NRIO Durban, SADCO) and at Port Elizabeth Harbour (Port Elizabeth Municipality).

Profile data along 25 transects on Durban beaches are available, on a monthly basis from 1973 to 1987 and along an additional six transects from 1978 to the present but have not been worked up (NRIO Stellenbosch, SADCO). Data on beach profiles in the vicintiy of the Richards Bay Harbour (two kilometres south to five kilometres north) have been collected by the South African Transport Services Harbour Authority on a quarterly basis since 1980 and fowarded to NRIO Stellenbosch for analysis.

Archaeological records collected by Professor J Parkington and others (Archeology Department, University of Cape Town) document the species and size distributions of marine invertebrates utilized by man in the Elandsbaai region from 12 000 BP. Although there are long gaps in the record, a decreasing trend in the size of limpets collected over time is evident. These changes are unlikely to be the result of overexploitation, recent research having shown that limpet growth rates, and hence size distributions, are strongly influenced by nutrient levels (Bosman and Hockey 1986; Bosman et al 1987).

Long-term photographic monitoring of fixed quadrats in protected and exploited areas of the rocky intertidal in the Transkei is being conducted by Professor A Dye (Zoology Department, UNITRA). These records should provide data on the effects of both human exploitation and conservation measures on the status of exploited species, notably the mussel *Perna perna*, and unexploited but space-dominating ones, such as barnacles.

Further data pertaining to the coastal zone, but for which we were unable to obtain details, may include:

- Fossil records. For example species such as *Fissurrella ? robusta* and *Concholepas* species have become extinct in this area, but remain dominant in the south Pacific, while limpets have undergone strong speciation.

- Strandloper deposits in Natal (T Maggs, Natal Museum)

- Periodic aerial surveys of the South African Coastline (Department of Survey and Mapping).

- Periodic hydrographic surveys (NRIO, Marine Geology, University of Cape Town).

- Marine pollution records (NRIO, Department Transport).

- Fishing/boat license statistics (Sea Fisheries Research Institute).

- Demographic/urbanization statistics (Provincial Administrations).

- Continuous low-level environmental observations (H Swart, NRIO).

- Dune stabilization/vegetation records (NRIO, Directorate of Forestry).

- Mining activities in the coastal zone (Department of Mineral and Energy Affairs).

- River outflows and sediment transport (Department of Water Affairs).

- Beach utilization patterns in Natal (Beach Facilities Committee of Natal Provincial Administration).

CONCLUSIONS AND RECOMMENDATIONS

The demands placed on southern Africa's coastal resources will increase as human population size and the demand for recreational activities increase. Therefore, it is imperative that we gain a better understanding of the physical and biological dynamics of coastal ecosystems. Key species and communities, whether defined ecologically or economically, must be monitored to assess their responses to environmental fluctuations and to separate these responses from the effects of human exploitation. The studies on *Perna perna*, *Patella* species and *Turbo sarmaticus* reported on in this chapter provide an insight into the usefulness of this approach.

The coastal zone consists of two main habitat types, rocky shores and sandy beaches. While the physical structure of rocky shores does not change readily, sandy beaches are very dynamic, changing on time scales ranging from a few hours to years. Beaches have been shown to respond to changes in wave energy, tidal inundations, sea level variations and weather patterns (Inman and Filloux 1960; Eliot and Clarke 1982; Clarke and Eliot 1983; Aubrey 1983). Fortunately the macrofaunal communities of sandy beaches comprise relatively few mobile species (normally 10 to 20 species per beach - Donn unpublished) of which one or two are often highly dominant. Monitoring of these few species may thus be undertaken at a variety of sites without excessive manpower requirements.

The situation on rocky shores is far more complex. Species diversity is almost invariably great, and the communities differ dramatically in biomass and composition both over time and over small spatial scales. These variations result from microclimatic differences and differences in the history of individual patches. The net result is that the monitoring of rocky shore communities requires far more effort than is the case in many other ecosystems and is difficult to justify unless other motives for the work exist (eg monitoring of exploitation, national parks etc).

Despite this reservation it should be stressed that there remains a pressing need for long-term monitoring programmes that are independent of fishery statistics. In particular, it is necessary for these to discriminate the effects of human exploitation from the pronounced fluctuations that may take place in natural undisturbed systems. The studies of Dye and Branch (see above) exemplify this approach.

REFERENCES

Anderson R J and Bolton J J 1985. Suitability of the agarophyte *Suhria vittata* (L) J Ag (Rhodophyta : Gelidiaceae) for mariculture: geographical distribution, reproductive phenology and growth of sporlings in culture in relation to light and temperature. South African Journal of Marine Science 3, 169-178.

Anderson R J and Hay C H 1986. Seasonal production of *Desmarestia firma* (C Ag) Skottsb (Phaeophyceae, Desmarestiales) in a kelp bed on the west of the Cape Peninsula, South Africa. Botanica Marina 24, 523-531.

Anonymous 1986. The South African right whale census, 1986. African Wildlife 40, 256-257.

Aubrey D G 1983. Beach changes on coasts with different wave climates. In: McLachlan A and Erasmus T (editors) Sandy Beaches as Ecosystems. W Junk, The Hague. pp 63-86.

Berry P F 1982. Biomass and density of detritivores on a littoral rocky reef on the Natal coast, with an estimate of population production for the ascidian *Pyura stolonifera*. Investigational report of the Oceanographic Research Institute, Durban 53, 1-15.

Birkett D and Cook P A 1987. Effect of the Benguela temperature anomaly 1982 to 1983 on the breeding cycle of *Donax serra* Roding. South African Journal of Marine Science 5, 191-196.

Bosman A L and Hockey P A R 1986. Seabird guano as a determinant of rocky intertidal community structure. Marine Ecology Progress Series 32, 247-257.

Bosman A L, Hockey P A R and Siegfried W R 1987. The influence of coastal upwelling on the functional structure of rocky intertidal communities. Oecologia 72, 226-232.

Branch G M 1984a. Ecology of Patella Linnaeus from the Cape Peninsula, South Africa, 3. Growth rates. Transactions of the Royal Society of South Africa 4, 161-193.

Branch G M 1984b. Changes in intertidal and shallow-water communities of the south and west coasts of South Africa during the 1982/1983 temperature anomaly. South African Journal of Science 80, 61-65.

Branch G M 1985. Intraspecific competition in Patella cochlear Born. Journal of Animal Ecology 44, 263-282.

Branch G M and Griffiths C L (In press). The Benguela Ecosystem 5. The Coastal Zone. Oceanography and Marine Biology. An Annual Review.

Brundrit G B 1984. Monthly mean sea level variability along the West coast of southern Africa. South African Journal of Marine Science 2, 195-203.

Brundrit G B, de Cuevas B A and Shipley A M 1984. Significant sea-level variations along the west coast of southern Africa 1979-1983. South African Journal of Science 80, 80-82.

Brundrit G B, de Cuevas B A and Shipley A M 1987. Long-term sea level variability in the eastern South Atlantic and a comparison with that in the eastern Pacific. South African Journal of Marine Science 5, 73-78.

Butterworth D S, David J H M, Rickett L H and Zulu S 1987. Modelling the population dynamics of the Cape fur seal (Arctocephalus pusillus pusillus). In: Croxall J P and Gentry R L (editors) The status, biology and ecology of fur seals. NOAA Technical Report NMFS 51. pp 141-164.

Clarke D J and Eliot I G 1983. Mean sea level variations and beach width fluctuation at Scarborough, Western Australia. Marine Geology 51, 251-262.

Crawford R J M and Shelton P A 1978. Pelagic fish and seabird interrelationships off the coasts of South West and South Africa. Biological Conservation 14, 85-109.

Crawford R J M and Shelton P A 1981. Population trends for some southern African seabirds related to fish availability. In: Cooper J (editor) Proceedings of the symposium on birds of the Sea and Shore. Cape Town, African Seabird Group.

Crawford R J M, Shelton P A, Cooper J and Brooke R K 1983. Distribution, population size and conservation of the Cape Gannet Morus capensis. South African Journal of Marine Science 1, 153-174.

Crawford R J M, Cruickshank R A, Shelton P A and Kruger I 1985. Partitioning of a goby resource amongst four avian predators and evidence for altered trophic flow in the pelagic community of an intense perennial upwelling system. South African Journal of Marine Science 3, 215-228.

Dieckmann G S 1980. Aspects of the ecology of Laminaria pallida (Grev) J Ag off the Cape Peninsula (South Africa). I. Seasonal growth. Botanica Marina 23, 579-583.

Donn T E Jr 1987. Longshore distribution of Donax serra in two log-spiral bays in the eastern Cape, South Africa. Marine Ecology Progress Series 35, 217-222.

Eliot I G and Clarke D J 1982. Periodic variation in subaerial beach sediment volume on the south coast of New South Wales. Search 13, 205-207.

Inman D L and Filloux J 1960. Beach cycles related to tide and local wind wave regime. Journal of Geology 68, 225-231.

Isaac W E 1956. The ecology of Gracilaria confervoides (L) Grev in South Africa with special reference to its ecology in the Saldanha-Langebaan Lagoon. In: T Braand and N A Sorenson (editors) Proceedings of the 2nd International Seaweed Symposium, Trondheim 1955. Pergamon Press, London. pp 173-185.

Jarman N G and R A Carter 1981. The primary producers of the inshore regions of the Benguela. Transactions of the Royal Society of South Africa 44, 321-326.

Lombard H W 1977. Die bevolkingsdinamika en energievloei deur Turbo sarmaticus op twee rotsstrande in die Oos-Kaap. Unpublished MSc Thesis, Department of Zoology, University of Port Elizabeth, Port Elizabeth.

McLachlan A 1977. Composition, distribution, abundance and biomass of the macrofauna and meiofauna of four sandy beaches. Zoologica Africana 12, 279-306.

McLachlan A 1981. Exposed sandy beaches as semi-closed ecosystems. Marine Environmental Research 4, 59-63.

McLachlan A and Hanekom N 1979. Aspects of the biology, ecology and seasonal fluctuations in biochemical composition of Donax serra in the East Cape. South African Journal of Zoology 14, 183-193.

McLachlan A and Lombard H W 1981. Growth and production in exploited and unexploited populations of a rocky shore gastropod, Turbo sarmaticus. Veliger 23(3), 221-229.

Pollock D E 1987. Simulation models of rock-lobster populations from areas of widely divergent yields off the Cape west coast. South African Journal of Marine Science 5, 531-546.

Pollock D E and Shannon L V 1987. Response of rock-lobster populations in the Benguela ecosystem to environmental change - a hypothesis. South African Journal of Marine Science 5, 887-900.

Shannon L V, Boyd A J, Brundrit G B and Taunton-Clark J 1986. On the existance of an El Niño type phenomenon in the Benguela system. Journal of Marine Research 44, 495-520.

Shelton P A, Crawford R J M, Cooper J and Brooke R K 1984. Distribution, population size and conservation of the jackass penguin Spheniscus demersus. South African Journal of Marine Science 2, 217-257.

Swart D H 1983. Physical aspects of sandy beaches - a review. In: McLachlan A and Erasmus T (editors) Sandy Beaches as Ecosystems. W Junk, The Hague. pp 5-44.

Taunton-Clark J and Shannon L V (In press). Annual and interannual variability in the South-east Atlantic during the 20th century. South African Journal of Marine Science.

Tietz R M and Robinson G A 1974. Tsitsikamma shore. National Parks Board of Trustees, Pretoria. 111 pp.

Toerien D K 1976. Geologie van die Tsitsikammakusstrook. Koedoe 19, 31-41.

Velimirov B, Field J G, Griffiths C L and Zoutendyk P 1977. The ecology of kelp bed communities in the Benguela upwelling system. Helgolander wissenshaftlische Meeresuntersuchungen 30, 495-518.

Walker N D 1987. Interannual sea surface temperature variability and associated atmospheric forcing within the Benguela system. In: Payne A I L, Gulland J A and Brink K H (editors) The Benguela and Comparable Ecosystems. South African Journal of Marine Science 5, 121-132.

Walker N, Taunton-Clark J and Pugh J 1984. Sea temperatures off the South African west coast as indicators of Benguela warm events. South African Journal of Science 80, 72-77.

CHAPTER 4. SOUTHERN AFRICAN INLAND WATER ECOSYSTEMS

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INTRODUCTION

This chapter covers data series on the physical, chemical and biotic components of inland water ecosystems, including rivers, impoundments, wetlands and nonestuarine coastal lakes. The topic is a diffuse one, dealing as it does with a variety of ecosystems throughout the subcontinent, subject to a number of climatic and anthropogenic forces and situated in different catchments.

Two separate pairs of issues need to be examined: long-term changes in physical and chemical factors on the one hand and in the biota on the other, and changes in each of these as a result of climatic variability as opposed to human alteration of the environment. In the context of this chapter, determination of the effect of 'natural' climatic cycles is of greater academic interest but of less practical importance than the effect on our inland waters of anthropogenic perturbations such as interbasin water transfers, impoundment and pollution.

The combination of seasonal and interannual unpredictability and geographically inequitable distribution of rainfall, plus the consequent harnessing of much of South Africa's available water, means that there are at present few entirely natural inland waters to examine. Thus it is not easy to determine the effects of climatic changes taking place over decades or centuries on the chemistry or the biota of such ecosystems. It is, of course, possible to examine historical and prehistorical changes by means of palaeolimnological techniques, although, except for Martin's (1968) work on Groenvlei, no published data of this sort exist for southern Africa.

Furthermore, with the few exceptions mentioned in Table 4.1, there are virtually no long-term data sets that provide information on the effects of natural climatic fluctuations on natural ecosystems. Some information is available on anthropogenic effects, however. Studies by Chutter (1968) and de Moor (1982, 1986a,b) document the man-induced increases in the numbers of *Simulium chutteri* in the Vaal River. Cambray and Jubb (1977) and O'Keefe and de Moor (1988) show that the modified flow-regime in the Great Fish River has resulted in translocations of fish species and changes in invertebrate community structure.

Owing to the structure of research funding in this country, many papers (eg King et al 1987a,b) are able to examine trends over no more than three or four years, although such data should form the basis of valuable long-term studies. In contrast, hundreds of data sets attest to the alterations in the water quality of many of our larger, and some of our smaller, systems, although few of these sets of data have been synthesized (but see van Vliet and Nell 1987) and even fewer have been analysed for long-term trends.

Acid rain is of major global concern. Thus far it has not been identified as a serious problem in most of southern Africa (eg Böhm 1985), although this is certainly not the case in the eastern Transvaal. Research programmes funded by the Water Research Commission, the Department of Water Affairs and ESCOM are presently examining the effects of atmospheric pollution on precipitation chemistry and the consequences for rivers in the north-eastern parts of South Africa (Louw 1984).

We consider that the length of a data series that can be used to demonstrate long-term changes will depend on the stability and predictability of the system under examination, the resilience of the biota and the sort of changes that are being sought. For example, a change in temperature of one degree Centigrade may only become manifest in the biota over millenia, whereas 10 years may be more than adequate to reflect increases in salinity; similarly the biota adapted to very constant and predictable conditions may become recognizably different within a year or two of a minor change, while those of a highly fluctuating system might not react perceptibly over many generations.

REVIEW OF LONG-TERM DATA SETS

Non-South African data

It is remarkable how few long-term studies have been carried out and analysed in inland water ecosystems worldwide. Nonetheless, one of the most famous long-term studies of all, that of the Hubbard Brook Experimental Catchment in New Hampshire, USA, by G E Likens and his coworkers (see Likens 1984 and several hundred other papers emerging from this work between 1963 and the present), incorporates a good deal of limnological information. These workers have been able to show long-term variations in acid precipitation (eg Oehlert 1984), and were some of the first to be able to do so because of their long database. Long-term palaeolimnological data on natural acidification in Cumbria in England have recently been analysed by Pennington (1984). Syntheses of more specific data sets include one on nine years of data on the phytoplankton of Loch Leven (Bailey-Watts 1978) and one on 20 years of data by Macan (1977) on the fauna, particularly the corixid hemipterans, of a moorland fishpond in England.

Previously published southern African data

The longest and by far the most complete sets of limnological data in South Africa are those on various lentic ecosystems examined by Allanson and coworkers from the Institute for Freshwater Studies at Rhodes University between 1965 and 1986. These data include values for physical, chemical and macrobiological variables for Lake Sibaya (Allanson 1979), for Lake Le Roux (Allanson and Jackson 1983), for Swartvlei (Allanson and Howard-Williams 1984) and for the Touw River estuary/Wilderness lakes (Allanson and Whitfield 1983).

Elsewhere in southern Africa, there is the admirable synthesis of the effects of drought and subsequent recovery on Lake Chilwa, Malawi (Kalk et al 1979); the work of Balon and Coche (1974) that described the filling

TABLE 4.1 Published long-term data series on southern African waterbodies

	Locality	Data available	Length (years)	Authority
Physical and Chemical	Lake Sibaya	Water chemistry	1965-1979	Allanson 1979
	Lake le Roux	"	1974-1982	Allanson and Jackson 1983
	Lake Chilwa	"	1949-1976	Kalk et al 1979
	Lake Kariba	"	1956-1963	Balon and Coche 1974
	Lake McIlwaine	"	1963-1979	Thornton 1982
	Lake Midmar	"	(intermittent)	Breen 1983
	Wuras Dam	"	1974-1982	Pieterse and Keulder 1982
	Lake Verwoerd	"	1972-1982	van Zinderen Bakker 1974
	Hartbeespoort Dam	"	1928-1985 (intermittent)	NIWR 1985
Biological	Lake Sibaya	Fish	1965-1979	Allanson 1979
	Lake le Roux	"	1974-1982	Tomasson et al 1984
		Zooplankton	1976-198	Allanson and Jackson 1983
	Lake Verwoerd	Fish	1970-1980	Hamman 1980
	Lake Kariba	Fish	1956-1963	Balon and Coche 1974
	Lake McIlwaine	Zooplankton, Benthic fauna, Fish Bacteria, Algae	1963-1979	Thornton 1982
	Pongola River	Fish, Macrophytes	1929-1976	Breen and Heeg 1982
	Touw River	Macrophytes	1979-1983	Allanson and Whitfield 1983
	Buffalo River		1975-1982	Hart 1982
	Hartbeespoort Dam	Fish, Zooplankton, Bacteria, Algae	1980-1985	NIWR 1985
	Swartvlei	Macrophytes, benthos fish	1975-1987	Allanson and Howard-Williams 1984
	Vaal River	Zoobenthos, Zooplankton	1958-1981 (intermittent)	Chutter 1971 de Moor 1986b
	Tugela River	Zoobenthos	1959-1964	Oliff et al 1965
Pre/Post Impoundment	Lake Cahora Bassa	Macrophytes, Water quality	1973-1975	Davies et al 1975; Hall et al 1977
	Lake Robertson	Water quality	1975-1979	Cotterill and Thornton 1985
	Lake Kariba	Macrophytes, Fish, Water quality	1956-1963	Balon and Coche 1974
	Orange-Fish Transfer Scheme	Water quality, Benthic Fauna	1964-1985 (intermittent)	O'Keeffe and de Moor 1988
	Kafue	Macrophytes	1974-1976	Magadza 1977
	Lake Verwoerd	Water quality	1972-1974	Van Zinderen Bakker 1974
River Water Quality	South Africa	Synthesis		O'Keeffe 1986
Eutrophication Surveys	South Africa	21 man-made lakes	1977-1979	Walmsley and Butty 1980
	Zimbabwe	33 natural and man-made lakes	1976-1979 (intermittent)	Thornton 1980

phase and attainment of stability in Lake Kariba, Zambia/Zimbabwe; and the summary of Thornton (1982) of the eutrophication and recovery of Lake McIlwaine, Zimbabwe.

Recently, programmes of several years duration have been undertaken on a number of South African impoundments and some river systems. These studies, and those mentioned above, are summarized in Table 4.1. Not surprisingly, in view of the fact that the studies have been done at different times and have examined different attributes of the ecosystems studied, they have not been used to provide an overview of long-term climatic trends and anthropogenic influences for the country as a whole.

PREVIOUSLY UNPUBLISHED DATA

Change as a consequence of human perturbations of aquatic ecosystems is occasionally documented in partly synthesized form in internal reports to various local and state authorities, but most data (largely chemical, although some physical and microbiological data are also available) are still unsynthesized. There are thousands of such data sets throughout the country, some extending over more than 20 years. The quality is variable, in that the chemicals or species analysed, the sampling points, times and techniques, and the analytical methods applied, vary with time and from data set to data set, while not all samples were adequately preserved prior to analyses. Nonetheless some very valuable information is available from these sources. The entire data set from the Department of Water Affairs is now computerized and thus more readily accessible than are similar sets from most local authorities.

The few long-term series of macrobiological records that are available but not analysed are listed in Table 4.2.

SYMPOSIUM PRESENTATIONS

Data series presented in this document (Table 4.3) examine changes in physical, chemical and biotic attributes of South African inland waters.

Allanson et al (this volume), illustrating the relationship between water transparency and inflow to Swartvlei, point out that data of this type can be used as an index of catchment deterioration.

The chemical analysis of precipitation in mountain fynbos catchments over a 15-year period (van Wyk this volume) illustrates the role of climate in determining the magnitude of chemical input to rivers and streams. In addition, the influences of environmental and anthropogenic factors are discussed.

A number of presentations deal with fluctuations in populations of water birds in wetlands (Heÿl; Morgan; Snook et al this volume). These data series cover a variety of time spans, and refer to a number of species, but all show that bird abundance is regulated by habitat availability. This in turn is largely dependent on climate, but is also artificially modified, eg by eutrophication (Heÿl this volume) or water level manipulation (Snook et al this volume). Suitability of habitat is determined largely by food supply, itself dependent on climate and local

TABLE 4.2 Unpublished biological data series of potential value

	Locality	Data available	Length years	No of sites	Authority
Biological	Municipal areas	Usually faecal coliforms	variable	hundreds	Local authorities
	Rondevlei	Macrophytes and water bird	1952-present	1	Western Cape Regional Services Council
	South Africa	Fish catches	since 1920's	many	Angling clubs
	Wilderness-Sedgefield and other Cape areas	Water birds	1980-1984	3	CDNEC*
	Lake Kariba	Fish catches	1956-present	variable	Lake Kariba Fisheries Research Institute
	Lake Verwoerd	Fish	1970-present		CDNEC*
	Lake le Roux	Fish	1974-present	variable	CDNEC*
	Pongolo Floodplain	Fish	1978-present	variable	Natal Parks Board
Remote sensing	Variable	Satellite data and aerial photographs	variable	many	--

* CDNEC (Cape Department of Nature and Environmental Conservation)

TABLE 4.3 Data series presented at this conference

	Locality	Data available	Length years	No of sites	Authority
Biological	Rocher Pan	Water birds	1968-1987	1	Heÿl
	SW Cape Wetlands	Water birds	1979-present	6	Heÿl
	Rondevlei	Birds	1952-present	1	Snook, Semmelink and Langley
	Whole country	Museum specimens	10-100y+	many	see Cambray and de Moor
	Barberspan	Waterfowl and some environmental data	1954-present	1	Morgan
Physical and Chemical	Mountain fynbos	Precipitation chemistry	1971-present	several	van Wyk
	Hartbeespoort Dam	Lake water chemistry	1928-present (intermittent until 1980)	1	Ashton and Thornton

conditions. The relationships described by these data sets provide a starting point, although no long-term trends are identified.

Ashton and Thornton (this volume) address the issue of the time scales in sampling necessary to establish trends in data series. Depending on the biotic component being monitored, up to five orders of magnitude may be involved. The frequency of sampling needs to tie in closely with biotic events such as growth and reproductive cycles. Further, in assessing changes in populations or movements in or along an aquatic system, monitoring should perhaps coincide with a particular inflow or flow-volume rather than occurring at regular time intervals.

Cambray and de Moor (this volume) highlight the importance of museum collections as cryptic long-term data series. The value of these data series lies in the fact that species identification can be verified. Furthermore, old material can be re-examined to look for long-term changes in morphology or sometimes even in community composition.

TRENDS AND CYCLES

Major industrial and urban developments have occurred in southern Africa since the mid-1940's; most of these have not been located near a convenient and reliable source of water. As the demand for potable water grew, it became necessary to develop weirs, and later major dams, to supply adequate water for inhabitants. Likewise, the demand for food led to the creation of areas of intensive agriculture, watered by irrigation schemes. These developments have led to anthropogenic problems such as eutrophication, erosion and salinization. In view of this trend, long-term cycles of the biota in inland water ecosystems have often been obscured, but usually reflect the deterioration of habitats as a result of these anthropogenic interferences.

Figure 4.1 uses data on phosphate concentration and chloride content in Hartbeespoort Dam, South Africa, to illustrate diagrammatically the relative scales of the influence of human and natural events on water quality cycles and trends. Figure 4.1a shows the apparent long-term sinusoidal fluctuations in the hydrological cycle. The droughts of the 1930's and 1950's are shown as peaks in this cycle (the decrease in water volume would lead to the evaporative increase in phosphate and chloride concentration in the lake water). Developments since 1945 led to an increase in phosphate concentration, ultimately two orders of magnitude greater than the concentration of 5 $\mu g l^{-1}$ measured by Hutchinson et al (1932). This trend is indicated by the 50 $\mu g l^{-1}$ phosphate concentration measured by Allanson and Gieskes (1961). The abundance of data during recent years has allowed some resolution of seasonal biogeochemical cycles. These are shown superimposed on the long-term cycle between 1980 and the present. In addition, a second anthropogenic discontinuity subsequent to 1985 is apparent as the result of limiting the phosphate concentrations of effluents from the catchment.

Figure 4.1b shows the chloride data superimposed on the same long-term cycle and also clearly shows the effect of the post-war man-made changes in the catchment of the lake. In addition, the recent (1980 to 1985) data show the relative intensity of a natural perturbation, drought, which caused elevated chloride concentrations between 1983 and 1984. These periodic natural discontinuities can cause short-lived deviations in the

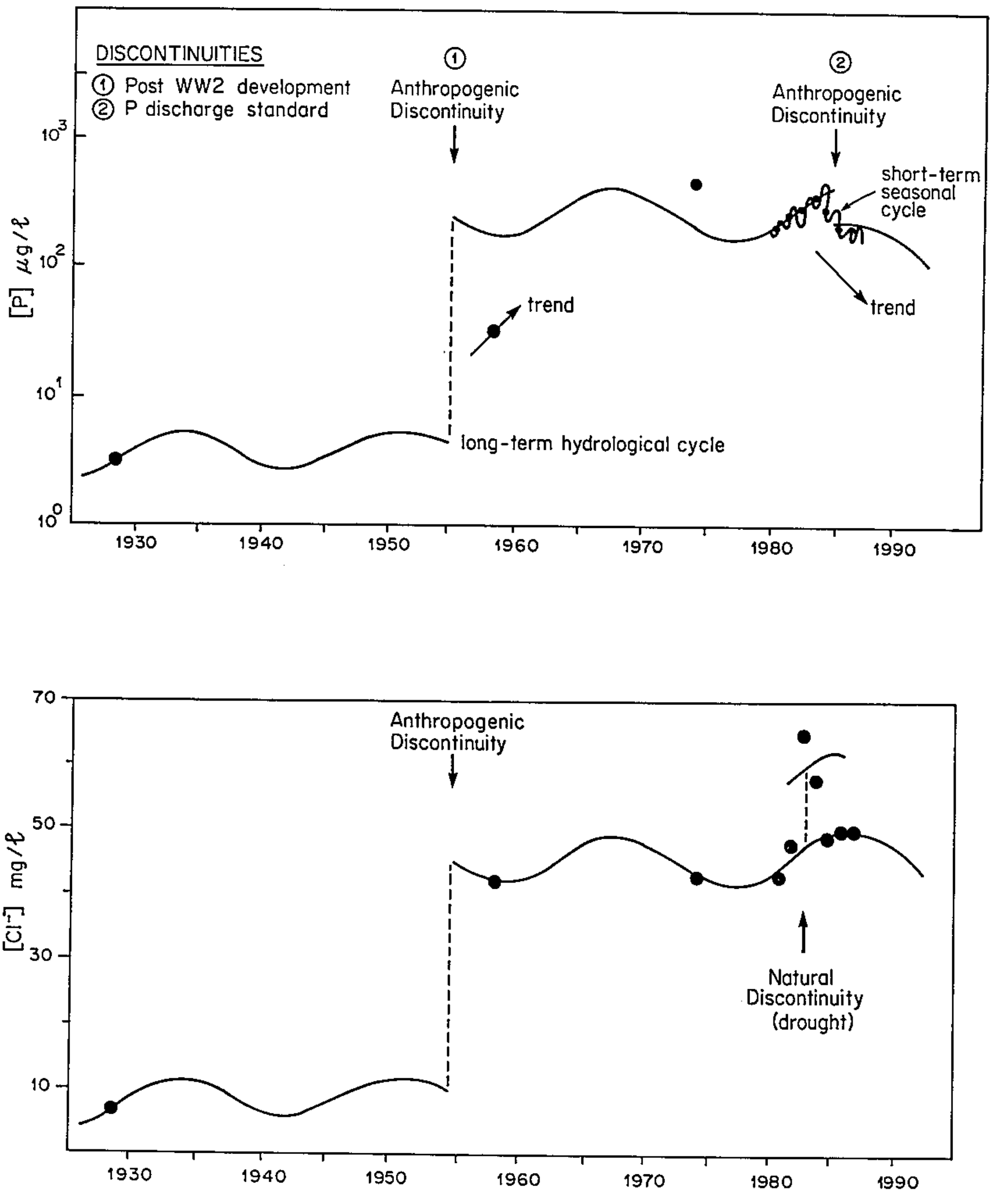

FIGURE 4.1 Diagrammatic representation of the relative effects of natural and anthropogenic interference on the concentrations of (a) phosphate and (b) chloride in the surface waters of Hartebeespoort Dam. Data from Ashton and Thornton (this volume).

chemical record of an order at least as great as anthropogenic changes such as the implementation of an effluent phosphate standard. Thus, while we commonly find that change due to anthropogenic interferences exceeds that due to natural annual events, natural catastrophic events can alter the aquatic environment to a similar degree.

Similar trends have been shown for other highly manipulated catchments in southern Africa, such as the one feeding Lake McIlwaine in Zimbabwe (Thornton 1982).

The changes that man has induced in inland water ecosystems have not always been acceptable to him. The South African public has generally been considered to be much less concerned, and certainly much less vocal, about environmental pollution than their Northern Hemisphere contemporaries. However, the extent and deleterious nature of anthropogenic interferences in aquatic ecosystems, resulting in extreme hypertrophy as in the case of Hartbeespoort Dam, have begun to disturb this complacency. A recent CSIR survey designed to test public perceptions of water pollution has shown that 98% of respondents considered water pollution to be a matter of concern in South Africa. This concern was expressed not only in the definition of desirable water quality but also in a commitment to carry the financial burden implicit in the reversal of deleterious anthropogenic influences (Thornton 1987). We therefore forecast a continued trend towards improved water quality in South Africa, as depicted in Figure 4.1a, but recognize that this trend will be unlikely to eliminate completely anthropogenic influences on inland waters in the foreseeable future.

The continuing demographic movement toward conurbations, and the increasing economic development of southern Africa, will necessitate continued anthropogenic interference in inland waterbodies. Such trends make it essential that a holistic, systems approach be adopted as a matter of priority, not only in data gathering networks but also in the conservation and management of inland water systems.

WHERE DO WE GO FROM HERE?

Some of the questions that need to be answered

If we are to plan for a changing environment, then we must be able to predict both the causes and the consequences of such changes. In order to do this, a number of questions must be addressed. The answers to some can be found by analysis and synthesis of the data discussed above, while answers to others will require specific research programmes. Some of the questions are:

i) What are the periods and amplitudes of long-term changes in the physical, chemical and biological features of natural aquatic ecosystems?

ii) Are these changes the result of long-term climatic changes, natural changes in the catchment, and/or anthropogenic manipulations?

iii) Are long-term changes in the biota obscured by fluctuations in rainfall?

iv) Are anthropogenic changes more rapid in time, and more or less severe in consequences, than natural ones?

v) Can we separate the influence of anthropogenic perturbations from the influence of climatic change and stochastic natural events?

vi) What effects do large natural perturbations (episodic events such as drought, fire etc) have on long-term trends, and is this effect greater or smaller in disturbed ecosystems?

vii) What magnitude and period of external change is required for alterations in:
- community structure and habitat diversity?
- species composition; diversity; and interactions?
- evolutionary trends?
- genetic variations?
- nutrient dynamics?
- physical and chemical elements?

viii) Which biotic and abiotic factors respond most rapidly and/or quantitatively to a changing environment?

ix) How do aquatic ecosystems vary in response to changing environments?

x) If we accept that anthropogenic and climatic perturbations (including alterations in rainfall, temperature and radiation) are the major forces driving change in aquatic ecosystems, and that the primary driving forces are precipitation and temperature, but that runoff patterns (and therefore temperatures) are modified in regulated systems, then what are the effects on lotic and lentic systems of:
- increased or decreased annual rainfall?
- increased or decreased variability in seasonal or annual rainfall?
- increased temperature or decreased temperature?
- increased or decreased variability in seasonal or annual temperatures?

xi) There is no doubt that pollutants of various kinds are also critical in determining the species composition, and hence the functioning, of aquatic ecosystems. Thus the effects of the following pollutants (or results of pollution) need to be followed by long-term monitoring:
- suspended and dissolved solids
- increased or decreased pH
- increased or decreased temperature
- increased or decreased levels of dissolved oxygen
- nutrients
- heavy metals
- organic pollutants
- pesticides

We might also point out that, with the exception of the intensive five-year programme on Hartbeespoort Dam (NIWR 1985), virtually nothing is known about the responses of the aquatic microbiota to change.

Future requirements for monitoring change in these systems

Not all of the questions listed above can be answered by analysis of existing data series, and future trends can only be identified by consistent, reliable, long-term monitoring. This is an expensive operation, so it is necessary to determine the minimal number of sites and variables, with the largest possible inter-sampling period that need to be analysed in order to provide an adequate database for determining trends and predicting change. The lists below indicate the minimal number of systems, sites and measurements needed to provide adequate coverage of the whole country. Variables appearing in square brackets are useful ancillaries but are less important than the others. Asterisks indicate variables that might be worth examining in some systems but not others.

Systems

Pristine mountain stream
Unregulated section of a river
Man-made lake
Wetland

Sites

Winter rainfall area
Summer rainfall area
Area of aseasonal rainfall

Physical data

Rainfall (continuous if possible)
Discharge (continuous if possible)
Temperature (continuous if possible)
Variations in water level
Turbidity*
[Solar radiation]
[Cloud cover]
[Windspeed]
[Evaporation rate]
[Soil moisture]

Chemical data

TDS, conductivity or salinity
pH)
Dissolved oxygen) only valuable if measured in situ
Chloride*
Sulphate*
Total nitrogen*)
Total phosphorus*) only valuable if samples are adequately preserved
Potassium*
[Major ions]
[Biological oxygen demand]
[Chemical oxygen demand]

Frequency of sampling will vary with the extent of knowledge of the system, and its inherent variability. We recommend that sampling is carried out at least twice a year (eg wettest and driest, or warmest and coolest periods) as well as more frequently after major disturbances, natural or anthropogenic.

We consider it essential that analytical methods are uniform for all systems, that they and the sampling methods are described in detail and that methods are kept simple wherever possible.

Biotic factors to be monitored should include estimates of primary production (eg algal blooms, or even percentage cover), decomposition rate and biomass of invertebrates, fish and birds. It might save a good deal of routine counting and weighing of invertebrates to establish which are key species or communities in the ecosystem and later to concentrate on estimating these alone. In other words, familiarity with the system should allow the identification of those key factors (which might also be physical or chemical) that respond most noticeably to change and therefore have greatest predictive value.

We recognize that certain specific kinds of data are sadly lacking in South Africa. The most obvious are the lack of information on rivers before and after regulation (particularly by interbasin transfers), and on palaeolimnology.

CONCLUSIONS

We conclude that the major force driving change in almost all of southern Africa's aquatic ecosystems is anthropogenic. The magnitude of such change is overwhelmingly greater than that of the major natural driving force, the hydrological regime. We are of the opinion that, since the degree of short-term variability in precipitation is so vast, it would be extremely difficult to detect changes due to a superimposed long-term trend in climate as reflected, for instance, by small changes in mean annual rainfall.

REFERENCES

Allanson B R (editor) 1979. Lake Sibaya. Monographiae Biologicae Vol 36. W Junk, The Hague.

Allanson B R and Gieskes J M T M 1961. Investigations into the ecology of polluted inland waters in the Transvaal. Part II. An introduction to the limnology of Hartebeespoort Dam with special reference to the effect of industrial and domestic pollution. Hydrobiologia 18, 78-94.

Allanson B R and Jackson P B N (editors) 1983. Limnology and fisheries potential of Lake Le Roux. South African National Scientific Programmes Report No 77. CSIR, Pretoria. 182 pp.

Allanson B R and Whitfield A K 1983. The limnology of the Touw River Floodplain. South African National Scientific Programmes Report No 79. CSIR, Pretoria. 35 pp.

Allanson B R and Howard-Williams C 1984. A contribution to the physico-chemical limnology of Swartvlei. Archiv für Hydrobiologie 99, 133-159.

Bailey-Watts A E 1978. A nine-year study of the phytoplankton of the eutrophic and non-stratifying Loch Leven (Kinross, Scotland). Journal of Ecology 66, 741-771.

Balon E K and Coche A G 1974. Lake Kariba: a man-made tropical ecosystem in central Africa. Monographiae Biologicae 24. W Junk, The Hague.

Böhm M 1985. Rain acidity in Stellenbosch. South African Journal of Science 81, 652-653.

Breen C M 1983. Limnology of Lake Midmar. South African National Scientific Programmes Report No 78. CSIR, Pretoria. 140 pp.

Breen C M and Heeg J 1982. Man and the Pongola Floodplain. South African National Scientific Programmes Report No 56. CSIR, Pretoria. 117 pp.

Cambray J A and Jubb R A 1977. Dispersal of fishes via the Orange-Fish Tunnel, South Africa. Journal of the Limnological Society of Southern Africa 3, 33-35.

Chutter F M 1968. On the ecology of the fauna of stones in the current in a South African river supporting a very large Simulium (Diptera) population. Journal of Applied Ecology 5, 531-561.

Chutter F M 1971. Hydrobiological studies in the catchment of Vaal Dam, South Africa. Part 2. The effects of stream contamination on the fauna of stones-in-current and marginal vegetation biotopes. Internationale Revue der Gesammelde Hydrobiologie 56, 227-240.

Cotterill M G and Thornton J A 1985. Hydroclimate development following impoundment in a tropical African man-made lake (Lake Robertson, Zimbabwe). Journal of the Limnological Society of Southern Africa 11, 54-61.

Davies B R, Hall A and Jackson P B N 1975. Some ecological aspects of the Cabora Bassa Dam. Biological Conservation 8, 189-201.

De Moor F C 1982. A community of Simulium species in the Vaal River near Warrenton. PhD Thesis, University of the Witwatersrand, Johannesburg. Volumes I and II. 317 pp.

De Moor F C 1986a. Invertebrate communities in the Vaal River near Warrenton, with emphasis on the Simuliidae. In: Davies B R and Walker K F (editors) The ecology of river systems. Monographiae Biologicae Volume 60. W Junk, Dordrecht. pp 135-142.

De Moor F C 1986b. Blackfly problems in and along the Vaal River. In: R D Walmsley and K H Rogers (editors) The Vaal River Ecosystem: status and problems. Proceedings of a joint symposium convened by the Foundation for Research Development and the Vaal River Catchment Association. Occasional Report No 5, FRD, CSIR, Pretoria. pp 158-174.

Hall A, Davies B R and Valente I M C B S 1977. The Zambezi River in Mocambique: the physico-chemical status of the Middle and Lower Zambezi prior to the closure of the Cabora Bassa Dam. Freshwater Biology 7, 187-206.

Hamman K C D 1980. Post-impoundment trends in the Hendrik Verwoerd Dam fish populations. Journal of the Limnological Society of Southern Africa 6, 101-108.

Hart R C 1982. Water quality in the Buffalo River catchment. A synthesis. Rhodes University Press, Grahamstown.

Hutchinson G E, Pickford G E and Schuurman J F M 1932. A contribution to the hydrobiology of pans and other inland waters of South Africa. Archiv für Hydrobiologie 24, 1-154.

Kalk M, McLachlan A J G and Howard-Williams C (editors) 1979. Lake Chilwa. Studies on change in a tropical ecosystem. Monographiae Biologicae Vol 35. W Junk, The Hague. 462 pp.

King J M, Henshall-Howard M P, Day J A and Davies B R 1987a. Leaf pack dynamics in a South African mountain stream. Freshwater Biology 18, 325-340.

King J M, Day J A, Davies B R and Henshall-Howard M P 1987b. Particulate organic matter in a mountain stream in the south-western Cape, South Africa. Hydrobiologia 154, 165-187.

Likens G E (editor) 1984. An ecosystem approach to aquatic ecology: Mirror Lake and its environs. Springer-Verlag, New York.

Louw C W 1984. National Programme for Weather, Climate and Atmosphere Research. Annual Report. South African National Scientific Programmes Report No 95. CSIR, Pretoria. 28 pp.

Macan T T 1977. A twenty-year study of the fauna in the vegetation of a moorland fishpond. Archiv für Hydrobiologie 81, 1-24.

Magadza C H D 1977. Observations on the behaviour of macrophytes following the impoundment of the Kafue River at Kafue Gorge (1974-1976). Transactions of the Rhodesian Scientific Association 58, 17-23.

Martin A R H 1968. Pollen analysis of Groenvlei Lake sediments, Knysna (South Africa). Review of Palaeobotany and Palynology 7, 107-144.

NIWR (National Institute for Water Research) 1985. The limnology of Hartbeespoort Dam. South African National Scientific Programmes Report No 110. CSIR, Pretoria. 269 pp.

Oehlert G W 1984. A statistical analysis of the trends in the Hubbard Brook bulk precipitation chemical data-base. Department of Statistics, Princeton University, Technical Report No 260, Series 2. 11 pp.

O'Keefe J H 1986. Ecological Research on South African rivers - a preliminary synthesis. South African National Scientific Programmes Report No 121. CSIR, Pretoria. 121 pp.

O'Keefe J H and de Moor F C 1988. Changes in the physico-chemistry and benthic invertebrates of the Great Fish River, South Africa, following an interbasin transfer of water. Regulated Rivers Research and Management 2, 39-55.

Oliff W D, Kemp P H and King J L 1965. Hydrobiological studies on the Tugela River System. Part 5. The Sundays River. Hydrobiologia 26, 189-202.

Pennington W 1984. Long-term natural acidification of upland sites in Cumbria: evidence from post-glacial lake sediments. Freshwater Biological Association Annual Report 52, 28-46.

Pieterse A J H and Keulder P C 1982. The limnology of a shallow turbid impoundment, Wuras Dam. University of the Orange Free State Press, Bloemfontein.

Thomassen T, Cambray J A and Jackson P B N 1984. Reproductive biology of four large riverine fishes (Cyprinidae) in a man-made lake, Orange River, South Africa. Hydrobiologia 112, 179-195.

Thornton J A 1980. A review of limnology in Zimbabwe 1959-1979. National Water Quality Survey. Report No 1, Government Printer, Causeway, Zimbabwe.

Thornton J A 1982. Lake McIlwaine: the eutrophication and recovery of a tropical man-made lake. Monographiae Biologicae Volume 49, W Junk, The Hague. 251 pp.

Thornton J A 1987. Public perspectives of water quality in Hartbeespoort Dam, South Africa. In: Thornton J A and Walmsley R D (editors) Hartbeespoort Dam 'quo vadis'? Occasional Report No 25. FRD, CSIR, Pretoria. pp 117-128.

Van Vliet H and Nell U 1987. Surface water quality of South Africa. The Vaal River Catchment: 1979-1983. Department of Water Affairs Technical Report 131, Pretoria. 208 pp.

Van Zinderen Bakker E M 1974. The Orange River: progress report. University of the Orange Free State Press, Bloemfontein.

Walmsley R D and Butty M (editors) 1980. The limnological characteristics of twenty-one South Africa impoundments. Final contract report to the Water Research Commission, Pretoria.

THE INFLUENCE OF RUNOFF UPON LAKE TRANSPARENCY AND LIGHT ATTENUATION BETWEEN 1974 and 1984 IN SWARTVLEI, CAPE

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Variation in Secchi disk depth is a sensitive indicator of change in lake transparency. Consequently it could become a useful index of deterioriation in Table Mountain Sandstone catchments, the waters from which are normally clear and stained with humic substances.

This possibility was examined for Swartvlei, a coastal lake in the southern Cape. Secchi disk depths and total runoff from the montane catchments of the Outeniqua mountains were correlated for the decade 1974 to 1984.

The changes in transparency which occurred during 1979/80/81 coupled with total runoff are reported in Figure 4.2. It was during this period, particularly the end of 1979, that the dense beds of *Potamogeton pectinatus* which fringed the littoral of the lake collapsed.

A polynomial regression of secchi disk depth against total runoff for the decade is given in Figure 4.3.

The regression explained between 74 and 94% of the variance. The observed bimodality in transparency against runoff suggests that not all river catchments influent to Swartvlei were equally destructive of lake transparency. Simultaneous studies by C Howard-Williams and his team during this period on the ecological structure of the littoral established that inflow from the Diep Wolwe and Klein Wolwe Rivers were responsible for the major decrease in lake transparency.

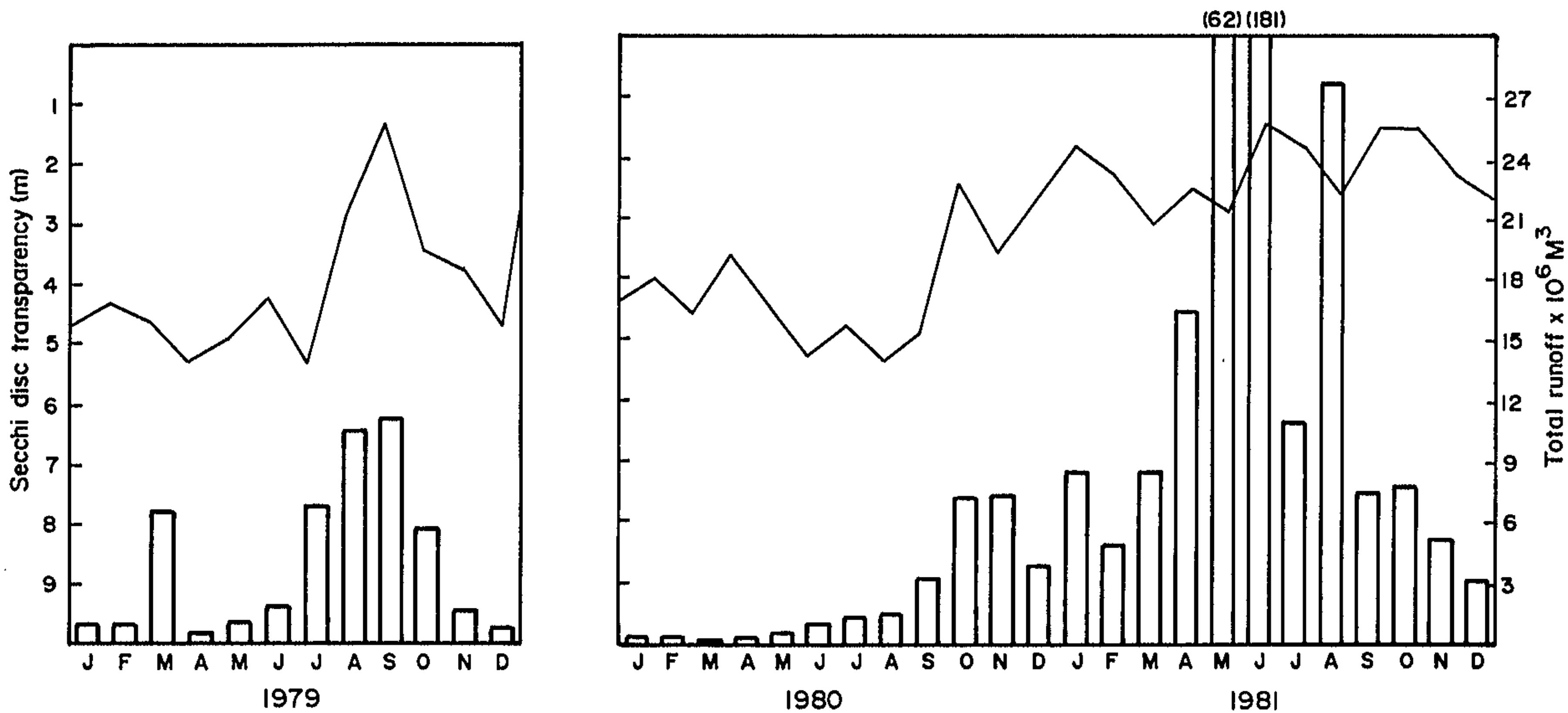

FIGURE 4.2 The change in Secchi disk transparency measurements made in Swartvlei and the records of total monthly runoff from the Outeniqua Mountains, 1979 to 1981.

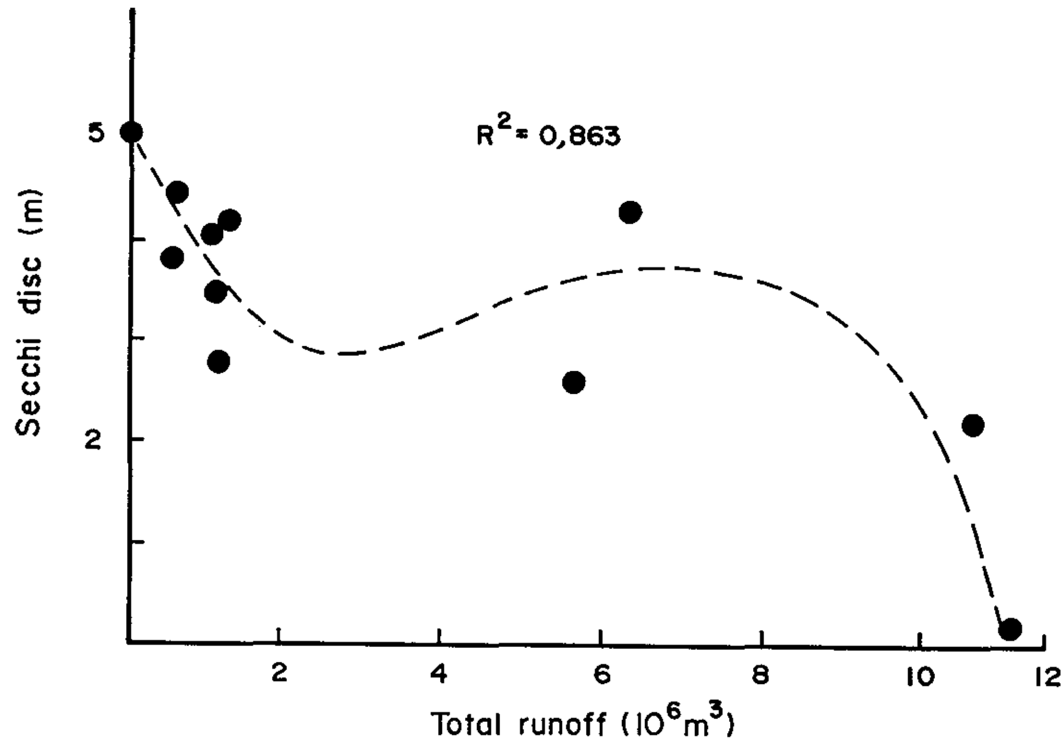

FIGURE 4.3 Polynominal regression between Secchi disk transparency measurements in Swartvlei and the total annual runoff from the Outeniqua Mountains for the decade 1974 to 1984.

TABLE 4.4 Variation in mean attentuation coefficient (km^{-1}) for PAR in Swartvlei. n = the number of measurements

Period	1974-76	1977-79	1980-84
km^{-1}	0,60	0,78	0,56
n	37	37	42

The increase in the photosynthetically active radiation (PAR) attenuation coefficient (k) paralleled the overall decrease in transparency during 1975 to 1979. Mean values of the attenuation coefficient are given in Table 4.4. These values are understandably high due to the marked attenuation afforded by the peat staining of the water. It is the change in k which is important. The increase in k reported represents some 30% increase in PAR attenuation.

We argue that the suspensoid load of influent rivers increased as a result of catchment deterioration during the decade under review. Swartvlei acted as a mirror reflecting the change in its catchment. Accordingly we recommend that coastal lakes should be included in current programmes for low level monitoring of estuaries and coastal wetlands. In this way they will provide timeous warning of substantial change in montane and upland catchments.

We thank Dr D A Hughes for making his runoff data available to us.

LONG-TERM DATA SERIES IN RESERVOIR LIMNOLOGY: PROBLEMS OF SCALE

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As the basis for a comprehensive limnological study of Hartbeespoort Dam, the National Institute for Water Research has compiled a detailed database relating to the physics, chemistry and biology of this excessively enriched man-made lake (NIWR 1985). Routine collection of comprehensive limnological data from the reservoir commenced in October 1980 and has continued, at weekly intervals, until the present. Concurrently, daily values of river flows, nutrient chemistry and climatic variables have also been obtained. The climatic data included continuous records of solar radiation, wind speed, air temperature and humidity. Chemical parameters for the inflowing rivers, dam and outflow and lake water include major anions (chloride, sulphate and carbonate), cations (calcium, magnesium, potassium and sodium) and macronutrients (nitrogen and phosphorus). Biological studies have focused on phytoplankton species composition and productivity, bacterial activity, zooplankton biomass and grazing activity, and fish population dynamics. Physical measurements include water temperature and density, from which values for lake stability, heat content and wind work have been derived.

The present study has coincided with a progressively worsening drought which has partially masked the effects of increased urbanization and development within the catchment. Prior to this study, limited biological and chemical data are available from 1928 (Hutchinson et al 1932), 1958 (Allanson and Gieskes 1961) and 1973 to 1976 (Scott et al 1977). From these data, it is clear that the chemical and biological quality of the impounded water has deteriorated steadily since the dam was constructed in 1925 (Figure 4.4).

In multidisciplinary studies of this nature there are inevitable problems due to differences in the time scales associated with all components of the ecosystem. These differences span at least five orders of magnitude (Allanson 1985). This has obvious implications for the frequency and duration of the sampling programme and complicates analysis of any long-term trends. For example, a six-year record of short-lived bacteria constitutes an extremely long record, while a similar length of record relating to fish or hydrological processes is hardly long term.

Nevertheless, the rapidly changing bacterial population lives in an environment that is subjected to changes that result from long-term weather patterns as well as from short-term anthropogenic management patterns such as seasonal demands for irrigation water or the phased implementation of the effluent phosphate standard in the catchment. These long- and short-term changes in the physical and chemical environment can benefit or inhibit the growth and population size of future generations of bacteria, as well as organisms at other levels of the food web. Such interactions, spanning these several orders of magnitude, have led Allanson (1985) to conclude that "we must break away from the rigidity of a sampling pattern which has confounded our efforts to interpret events in aquatic systems wisely to the satisfaction not only of ourselves, but also of our colleagues, the water engineers!"

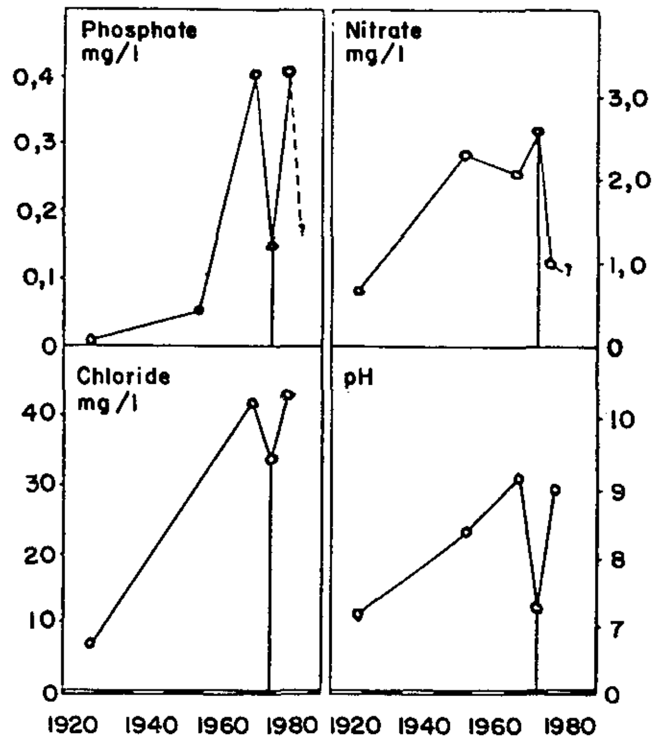

FIGURE 4.4 Concentrations of phosphorus, nitrogen, chloride and pH in Hartbeespoort Dam between 1925 and 1985 (Vertical line shows period of hyacinth control programme; ? shows the forecast effect of the effluent phosphate standard). (After Thornton and Fenn 1985).

REFERENCES

Allanson B R 1985. Thermal characteristics: Chairman's summary. Hydrobiologia 125, 71-73.

Allanson B R and Gieskes J T 1961. Investigations into the ecology of polluted waters in the Transvaal. Part II. An introduction to the limnology of Hartbeespoort Dam with special reference to the effect of industrial and domestic pollution. Hydrobiologia 18, 77-94.

Hutchinson G E, Pickford G E and Schuurman J F 1932. A contribution to the hydrobiology of pans and other inland waters of South Africa. Archiv für Hydrobiologia 24, 1-154.

NIWR 1985. The limnology of Hartbeespoort Dam. South African National Scientific Programmes Report No 110. CSIR, Pretoria. 269 pp.

Scott W E, Seaman M T, Connell A D, Kohlmeyer S I and Toerien D F 1977. The limnology of some South African impoundments. I. The physico-chemical limnology of Hartbeespoort Dam. Journal of the Limnological Society of southern Africa 3, 43-58.

Thornton J A and Fenn T A 1985. Chemical water quality of Hartbeespoort Dam. Water Report 2, 15-16.

THE ALBANY MUSEUM AS A SOURCE OF DATA ON LONG-TERM ENVIRONMENTAL AND RESOURCE CHANGES

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INTRODUCTION

Natural History museums are by their nature repositories of collections of plant and animal material. They are information banks with a long-term commitment to the acquisition, care, understanding and use of their collections. Museum collections contain the information held by the real things or objects themselves and in this respect are unique repositories of long-term information stored in its most unbiased way.

MUSEUMS AND THEIR COLLECTIONS

Brinkhurst (1985) points out that large collections are frequently made and are often well stored and preserved by Environmental Impact Agencies (EIA). As staff cycle rapidly in such organizations, and even the continued existence of such companies is uncertain over the long term, valuable collections may be lost unless they are stored in suitable repositories. Government agencies may also store old collections but all too often they suffer from inadequate storage and curation facilities, and the agencies also have periodic management reorganizations which may result in the disposal of valuable material. Museums are at present the only institutions with the basic core skills and facilities to undertake the task of acquiring and maintaining collections adequately, but unfortunately their funding and resources for processing large quantities of material are limiting (Brinkhurst 1985).

The importance of museum holdings will increase with time as countless habitats and even entire ecosystems change, diminish or even vanish. Collections of objects, housed in a museum for safe-keeping, record data no longer obtainable and also provide an enormous trove of undiscovered information awaiting the imaginative inquisitiveness of future scholars. A good example from the Northern Hemisphere was demonstrated when the need arose to examine egg shell thickness to evaluate the potential effects of DDT on bird reproduction. In this case, museum collections were used in a study of considerable significance to mankind (Ratcliffe 1970). Natural history collections are as basic to research in organismal biology as compounds are to a chemist (Berry 1985). Systematically organized collections will always be at the cutting edge of biological research, for if you do not name an organism correctly, you cannot know what you are talking about (Edwards 1985).

The use of aquatic invertebrates in environmental impact assessments is a widely recognized use of museum collections (Hynes 1963; Brinkhurst 1985). Museums house valuable collections which can be used as baseline information on how the environment and the renewable natural resources have changed over the historical time period. Natural history collections at the Albany Museum (see Cambray et al 1987 for a full description of these collections) have provided valuable material for assessing the impact of interbasin transfers (eg Cambray and Jubb 1977; O'Keeffe and de Moor 1988).

THE ALBANY MUSEUM FRESHWATER FISH COLLECTION

The freshwater fish collection at the Albany Museum is a storehouse of data waiting to be further evaluated and used. Collections date back to 1875 and include specimens from areas which have or will be altered by man or natural forces. For example, there is a collection of the endangered minnow *Oreodaimon quathlambae* from Lesotho. The Lesotho Highlands Water Project will flood three populations of this fish species. The collections in the Museum provide valuable records of this species' existence before its habitats were altered. The Museum also houses and records the occurrence and impact of invasive species such as *Micropterus salmoides* (bass) and *Parasalmo mykiss* (trout). Researchers are therefore able to determine if indigenous species have been eliminated by these exotic predators. Cambray (1984) suggested that the regulated flow in the lower Orange River has created more habitats for the endangered minnow, *Barbus hospes*. Collections lodged at the Albany Museum may show changes in single species such as morphological and physiological changes, or else changes in community structure in this highly regulated river system.

The collection also houses specimens of *Barbus anoplus* and *Labeo umbratus* collected from the Great Fish River prior to the interbasin transfer of separate gene-pools of these two species from the Orange River. Future research might be able to assess the impact of this introduction on fish species which have been isolated for thousands of years. The fish collection also houses records of Orange River species, such as *Barbus aeneus* and *Labeo capensis* which have been able to pass successfully through the Orange-Fish Tunnel (Cambray and Jubb 1977).

The freshwater fish collection is now fully computerized, and automated data retrieval permits the Museum to keep all the fish records readily available for use by other institutions. The collection has over 11 000 accessions representing some 250 000 specimens from a wide range of localities, including those from Mocambique, Botswana, Swaziland, Malawi, South West Africa/Namibia, the Cape, Orange Free State, Natal and Transvaal.

Fish collections at the Albany Museum have also been used by parasitologists. Old collections as well as recent ones were examined for parasites, and having these collections at the Museum saved the researchers both time and money in that they did not have to travel to the sites and collect for themselves. In the case of highly endangered species such as *Clarias cavernicola*, available collections can be used by workers in many fields. The most information can then be gathered from a limited number of specimens.

THE ALBANY MUSEUM'S FRESHWATER INVERTEBRATE COLLECTION

The donation of aquatic invertebrates collected during the NIWR's extensive surveys of South African rivers, combined with the large collection of aquatic beetles collected by Prof and Mrs J Omer-Cooper, formed a core collection of freshwater invertebrates (Scott 1972). The freshwater invertebrates and freshwater fish collections together with the amphibian collection make the Albany Museum's collection of freshwater organisms the most comprehensive in the country.

The freshwater invertebrate collection comprises in excess of one million specimens stored separately in glass vials in 80% ethanol, or pinned in insect cabinets. The accessions are recorded in 65 separate catalogues, each one referring to a unique collector, locality or series of medium- to long-term collections. Catalogues record four collections with data records exceeding 20 years, seven with data records in excess of 10 years, 10 with records exceeding five years and 44 having records of shorter duration than five years. The Omer-Cooper aquatic Coleoptera collections (JOC), for example, date from 1935 to 1968 and material in this collection covers the entire Afrotropical region. The extensive collections of invertebrates from the Great Berg, Vaal and Tugela Rivers, and their tributaries, are all housed in the Albany Museum, and a large number of publications refer to this material. A detailed list of the catalogues is available on request from the Curator of Freshwater Invertebrates at the Albany Museum.

Aquatic invertebrates were collected in the Great Fish River system in the late 1960's (Scott et al 1972) and the material was lodged at the Albany Museum. O'Keeffe and de Moor (1988) were able to compare these samples with recently collected material, and with available published data to assess the impact of the modified flow regime in the Great Fish River after the interbasin transfer of Orange River water began.

This study revealed that one of the major impacts of the interbasin water transfer was the change in water quantity and quality. The invertebrate community structure had changed and was now dominated by *Simulium chutteri*, a known mammalophilic blackfly. The trichopterary, *Cheumatopsyche afra*, a species not found in the Great Fish River prior to the interbasin transfer, is now quite common. This reveals that silt loads are low enough for extended periods of time to have enabled this species to colonize this river successfully. Such assessments would not have been possible if specimens collected prior to the interbasin transfer had not been available.

CONCLUSION

Natural history museums, such as the Albany Museum, store data covering a time span of over 100 years in some collections. These collections may be drawn upon for a broad spectrum of studies such as: systematics, ecological and biogeographic research, evolutionary concepts, ethology, environmental impact assessment, life history studies, ecomorphology and paleobiology. Museums house examples of extinct species and voucher specimens from ecological studies which can be re-examined. As well as these actual uses, the collections have potential uses as yet not known. In the future, new techniques, new theories and fresh eyes and minds will prove the collections' worth as man continues to alter his environment (Cambray et al 1987).

REFERENCES

Berry M B M 1985. The significance of type specimens and old collections to research in the biological sciences. In: E H Miller (editor) Museum collections: their roles and future in biological research. Occasional Papers of the British Columbia Provincial Museum 25, 23-28. British Columbia Provincial Museum.

Brinkhurst R O 1985. Museum collections and aquatic invertebrate environmental research. In: E H Miller (editor) Museum collections: their roles and future in biological research. Occasional Papers of the British Columbia Provincial Museum 25, 163-168. British Columbia Provincial Museum.

Cambray J A 1984. Fish populations in the middle and lower Orange River, with special reference to the effects of stream regulation. Journal of the Limnological Society of southern Africa 10, 37-49.

Cambray J A and Jubb R A 1977. Dispersal of fishes via the Orange-Fish Tunnel, South Africa. Journal of the Limnological Society of southern Africa 3, 33-36.

Cambray J A, de Moor F C, Holleman W H and Wilmot B C 1987. Albany Museum: A Guide to its Resources for Research Scientists. Albany Museum, Grahamstown.

Edwards R Y 1985. Research: A Museum Cornerstone. In: E H Miller (editor) Museum collections: their roles and future in biological research. Occasional Papers of the British Columbia Provincial Museum 25, 1-11. British Columbia Provincial Museum.

Hynes H B N 1963. The Biology of Polluted Water. University of Liverpool Press, Liverpool.

O'Keeffe J H and de Moor F C 1988. Changes in the physico-chemistry and benthic invertebrates of the Great Fish River, South Africa, following an interbasin transfer of water. Regulated Rivers Research and Management 2, 39-55.

Ratcliffe D A 1970. Changes attributable to pesticides in egg breakage frequency and egg shell thickness in some birds. Journal of Applied Ecology 7, 67-116.

Scott K M F 1972. The Albany Museum collection of freshwater organisms. Newsletter of the Limnological Society of southern Africa 9, 30-36.

Scott K M F, Allanson B R and Chutter F M 1972. Orange River Project working group for hydrobiology of the Fish and Sundays Rivers. CSIR Research Report 306, Pretoria.

WATERBIRD NUMBERS FROM ROCHER PAN, SOUTH-WESTERN CAPE

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Cape Provincial Administration

INTRODUCTION

Rocher Pan is a seasonal brackish to freshwater vlei on the Cape west coast. The vlei is included in the Rocher Pan Nature Reserve, which was established in 1968 as a waterfowl sanctuary. Waterbird counts, which were started in 1968, included taxa such as the white pelican *Pelecanus onocrotalus*, flamingoes *Phoenicopterus* species, ducks (Anatidae) and the redknobbed coot *Fulica cristata*. Total counts were made with binoculars up to 1977, and thereafter a combination of a 15-45x telescope and binoculars were used. Bird counts were made mostly at weekly intervals up to 1978. The data series for the first six years, however, is incomplete. From 1979 the birds were counted monthly. Where more than one data set was available per month, only the one closest to the middle of the month was used in this study.

Searches for duck nests, aimed at determining the total breeding effort, were started in 1976. Duck nesting data are now available for 11 years. Water levels and salinities were recorded from 1981 onwards and 1982 onwards respectively. Rainfall data from the two weather stations closest to the catchment area, Redelinghuys (5441) and Kliphoek (5429), are available from 1936 and 1969 respectively.

RESULTS

White pelicans frequented Rocher Pan more regularly and in larger numbers during the first half of the study period. Numbers in the region appear stable, and it is therefore possible that feeding conditions in Rocher Pan have deteriorated. (At Rocher Pan this species probably feeds only on the clawed toad *Xenopus laevis*).

Flamingo numbers show a strong upward trend over the past decade (Figure 4.5). The lower numbers for 1986 could, however, be the start of a reverse trend. Both species use the vlei, but the invertebrate-feeding greater flamingo *P ruber* occurs more abundantly.

The spurwinged goose *Plectropterus gambensis* and Egyptian goose *Alopochen aegyptiacus* feed mainly outside the study area and use the vlei mostly for roosting. Numbers often fluctuate widely throughout the season, depending on the presence or absence of terrestrially feeding groups during the counts. There seems to have been an increase in numbers of these species during, and for some time after, the high rainfall years of 1974 to 1977.

The numbers of invertebrate-feeding ducks fluctuate from season to season, but do not show any clear long-term trends. The maximum numbers recorded during below average, average and above average rainfall years were not significantly different ($P>0,10$).

Populations of herbivorous ducks show an upward trend to a peak in 1976, after which numbers steadily declined until 1982; over the past five years, small numbers have usually been recorded (Figure 4.6). The peak numbers observed in 1976 were mainly the result of large numbers of redbilled teal *Anas erythrorhyncha*, a nomadic species which does not usually occur abundantly in the south-western Cape.

The redknobbed coot was not censused in 1977 and 1978. Before this period numbers never exceeded 1 400 (Figure 4.7). From 1979, however, populations were significantly larger, except in 1982 and 1986. Coot numbers for 1986 were the lowest recorded over the study period. The seasonal rainfall for 1986 was close to the 19-year average recorded at the Redelinghuys/ Kliphoek weather stations, water levels were above the average recorded during 1981 to 1986, and salinity of the water followed the normal pattern, increasing throughout the season. For most of the 1986 season, however, planktonic algae occurred abundantly, possibly suppressing the growth of submerged macrophytes, the primary food source of the coot.

The number of duck nests recorded per season was positively correlated with seasonal rainfall ($r=0,75$; $P<0,01$). Little breeding occurred during years of below average rainfall, but the breeding effort for years of average and above average rainfall was similar.

DISCUSSION

Coetzer (1981, 1987) reported recent increases in the levels of orthophosphates and suspended solids, as well as changes in the zooplankton community, that indicated eutrophication. This could be related to agricultural activities, such as the use of fertilizers and increased leaching from cultivated fields, in the catchment area. The processes of eutrophication may also have been accelerated by present-day management of this closed wetland system; the cessation of livestock grazing in approximately 1970, together with the trampling effect, has probably resulted in increased stands of emergent littoral vegetation. At the same time a source of nutrient export was eliminated by removal of these animals.

Waterbird numbers reported here also indicate long-term changes in environmental conditions in the vlei. The numerical status of some taxonomic groups (eg white pelican and herbivorous ducks) has deteriorated, while populations of others (eg flamingoes and coot) have increased in later years. However, even for those taxa showing increased numbers, the most recent data indicate that such trends could be temporary and that numbers could already be declining again.

Management action was started in 1987 by removing the top sediment of a section of the vlei, aimed at reducing nutrient levels. Rotational cropping of littoral vegetation such as *Scirpus martimus* and *Phragmites australis* is also being implemented. Monitoring of the full spectrum of waterbirds is being continued to determine the effects of management.

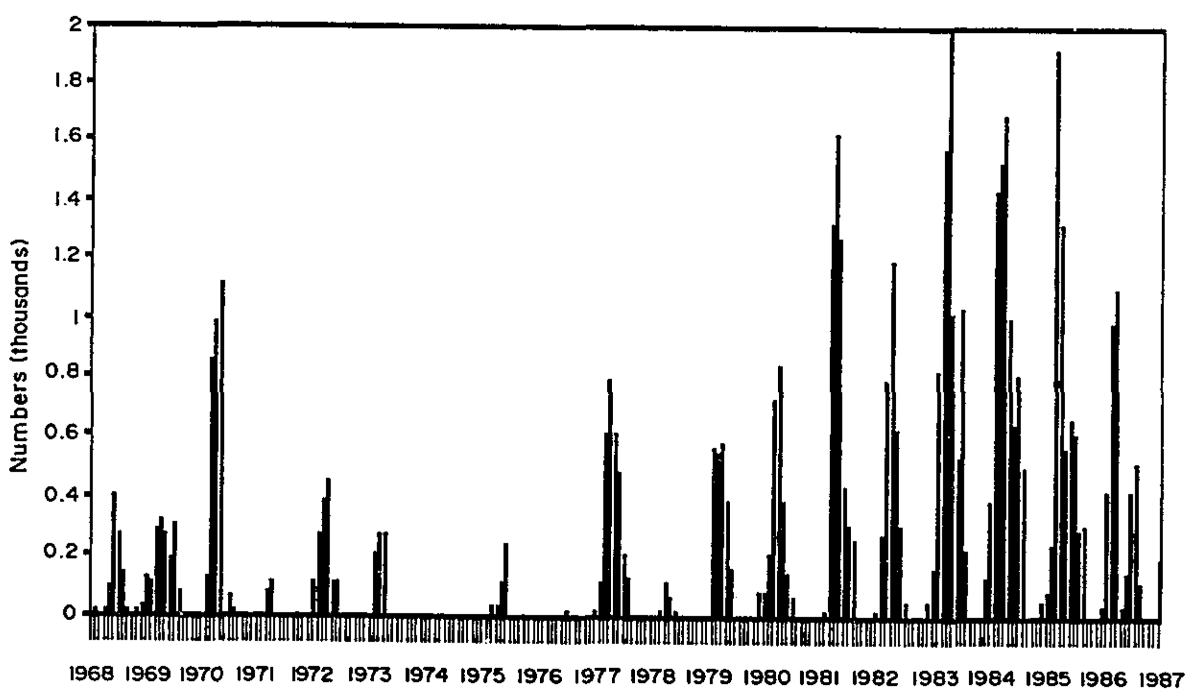

FIGURE 4.5 Monthly numbers of flamingoes on Rocher Pan.

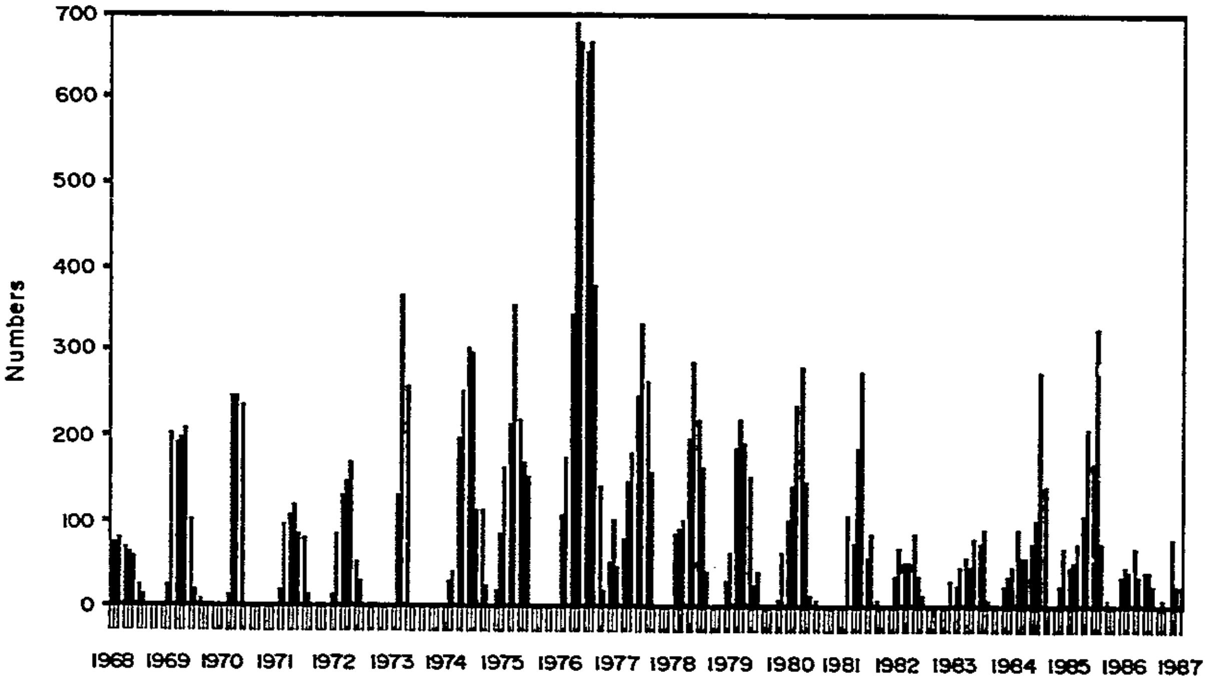

FIGURE 4.6 Monthly numbers of herbivorous ducks on Rocher Pan.

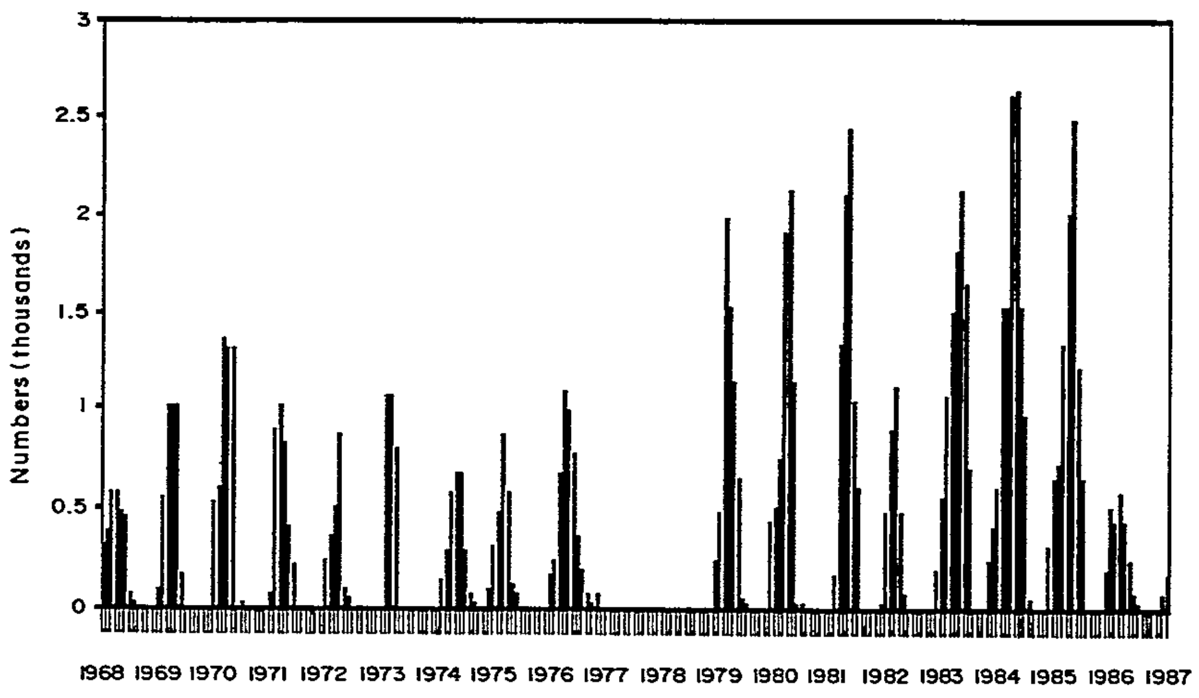

FIGURE 4.7 Monthly numbers of the redknobbed coot on Rocher Pan (no data for 1977/78).

REFERENCES

Coetzer A H 1981. Some limnological observations of a temporary west coast pan in southern Africa: Rocher Pan. Hydrobiologia 78, 161-167.

Coetzer A H 1987. Succession in zooplankton and hydrophytes of a seasonal waterbody on the west coast of South Africa. Hydrobiologia 148, 193-210.

VARIATIONS IN WATERBIRD NUMBERS FROM SOME WETLANDS IN THE SOUTH-WESTERN CAPE

C W HEŸL
Cape Provincial Administration

INTRODUCTION

Monthly population counts of certain waterbird taxa were started in 1979 and are being continued for several important waterbird habitats in the south-western Cape. The study areas include two coastal lakes (De Hoop Vlei and a section of Verloren Vlei), three estuaries (Botriviervlei, Berg River and Wadrif Salt Pan), and one sewage works (Strandfontein). Total population sizes are determined, usually by counting the birds individually. However, large concentrations of a species are estimated by extrapolation from 100 to 200 individually counted birds. For a particular wetland the same census techniques have been used throughout the study. Data for three of the numerically dominant taxa are discussed, namely two flamingo species *Phoenicopterus* species, all ducks (Anatidae), and the redknobbed coot *Fulica cristata*.

RESULTS

Waterbird numbers from De Hoop Vlei oscillate, with peaks every two to five years, as exemplified by the results for coot (Figure 4.8). Fluctuations in the numbers of ducks and coot usually correspond, but peaks in flamingo numbers tend to occur later, during periods of low water levels. Notably the numbers of ducks vary seasonally with summer peaks, which is related to the birds' use of the coastal lake as a dry-season refuge and moulting area. Oscillations in bird numbers appear to be largely related to fluctuating physical and chemical conditions of the water. Floods occur irregularly, followed by extended drydown phases during which salinity can increase from four to 58 parts per thousand ($^o/_{oo}$). The bird-life during a period of 10 years following extensive flooding in 1957 was described by Uys and Macleod (1967).

Waterbird numbers from the western section of Verloren Vlei show that the area is used largely as a dry season refuge. Seasonal fluctuations, however, do not obscure a longer-term (six to eight years) oscillation. Physical and chemical conditions in the water appear to be stable from year to year, with a seasonal variation in salinity from 1-2$^o/_{oo}$ in winter to 3-6$^o/_{oo}$ in summer. *Myriophyllum spicatum*, the dominant submerged macrophyte, declined from 1980 and recovered from 1983 (Sinclair et al 1986) to the extent that most of the shallow areas were covered by 1986/87. Coot (Figure 4.9) and duck numbers seem to reflect changes in the biomass of this macrophyte.

Peak bird populations were observed on Botriviervlei during a period (late 1970's and early 1980's) when the estuary had been closed off from the sea for three to four years (Figure 4.10). However, breaching of the sand bar normally occurs every year or two. The subsequent low water levels and high salinities probably have a prolonged negative effect on submerged macrophytes (*Potamogeton*, *Ruppia* and *Chara* species), which form important feeding areas for ducks and coot (Heÿl and Currie 1985). The planktonic-feeding flamingoes occur abundantly when water levels are low, albeit as a result of breaching or a slow drydown.

The Berg River Estuary is subject to regular seasonal changes in environmental conditions, with salinities of the water dropping as low as $1^{o}/_{oo}$ as a result of winter flooding, and increasing to $36^{o}/_{oo}$ in summer. Bird populations reach a maximum in summer, with peak numbers of flamingo being followed by peak numbers of coot. The data suggest that longer-term oscillations (about six years) might occur.

Although defined as an estuary, Wadrif Salt Pan was closed-off from the sea throughout the study period. It is a permanent wetland, but physical and chemical conditions fluctuate widely. Bird numbers are correlated closely with the surface area of the water, and peak numbers occur in the early summer. The area is of major importance to flamingoes, whose numbers appear to have increased over the study period.

Bird populations from the Strandfontein Sewage Works fluctuate seasonally with peak numbers in summer. The largest numbers were recorded at the end of 1980 and beginning of 1981, and populations of all three taxa thereafter declined throughout the study period . It is possible that the birds reacted to changed environmental conditions, caused by a large purification plant which was put into operation in 1980. Flamingo numbers from Strandfontein and Wadrif Salt Pan (the two major south-western Cape flamingo habitats included in the study) appear to be negatively correlated.

DISCUSSION

The distribution and abundance of waterbird food organisms, such as submerged macrophytes and their associated faunas, are probably the major factors determining habitat suitability and waterbird population sizes. The availability of food organisms is again dependent on physical and chemical water conditions, which change continually as a result of floods and drydown phases. Being highly mobile, waterbirds can react quickly to habitat changes, as is shown by the results of this study. Waterbirds could therefore be useful indicators of changing environmental conditions.

Waterbird population changes could, however, also be induced by biological cycles such as breeding and moulting. For instance, there is generally a rainfall-induced dispersal to temporary wetlands, which are used for breeding. Waterbird numbers on permanent wetlands therefore often fluctuate seasonally, as was found for most of the study areas.

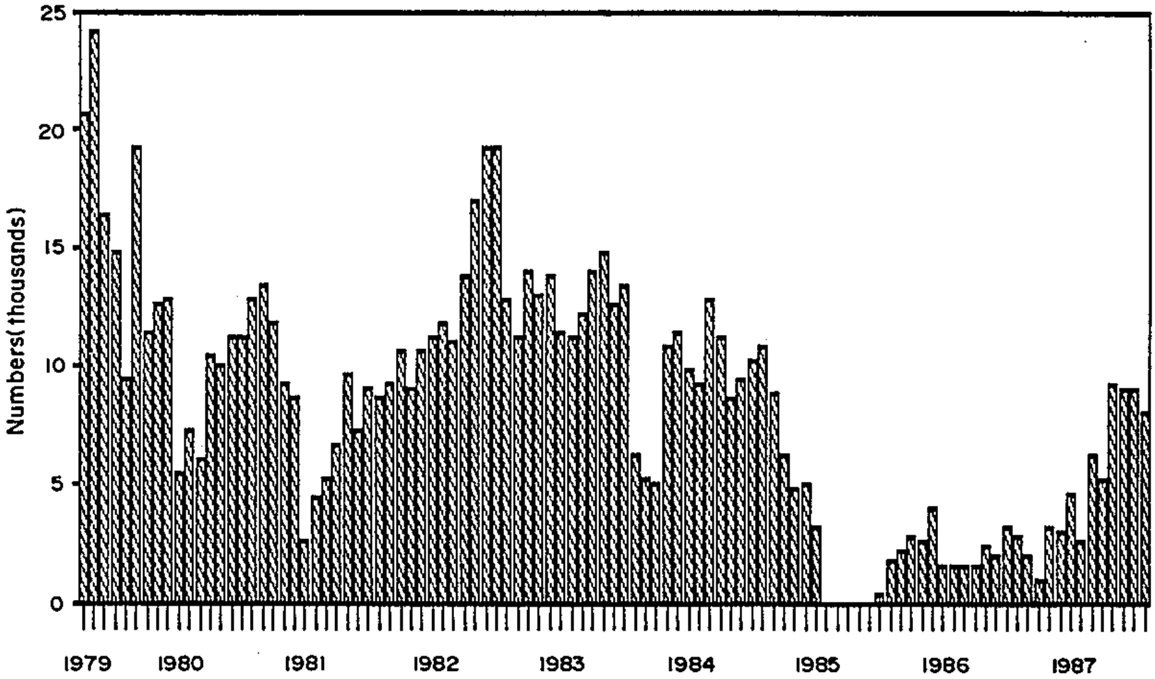

FIGURE 4.8 Monthly numbers of the redknobbed coot on De Hoop Vlei.

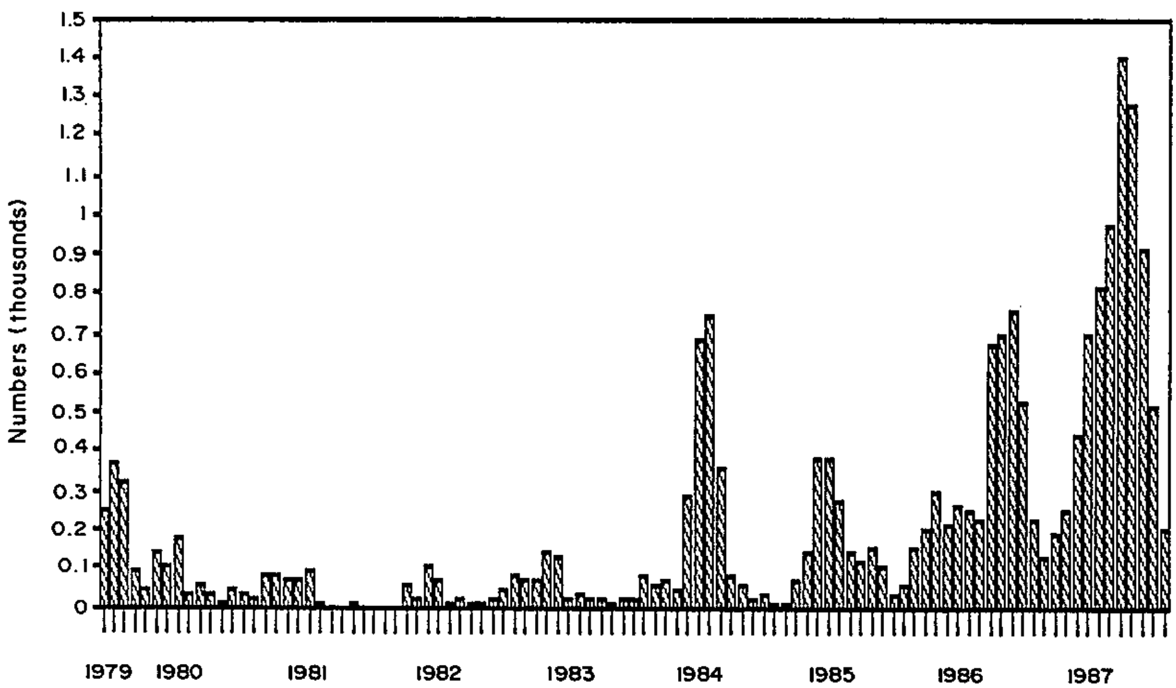

FIGURE 4.9 Monthly numbers of the redknobbed coot on the western section of Verloren Vlei.

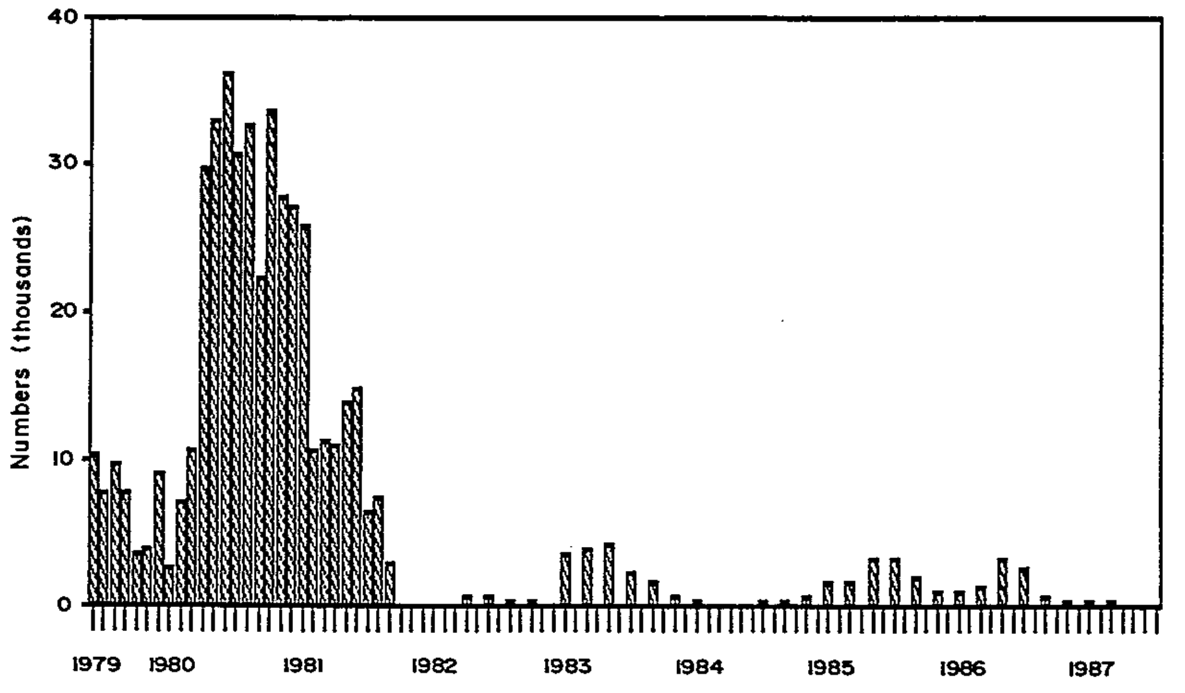

FIGURE 4.10 Monthly and two-monthly numbers of the redknobbed coot on Botriviervlei.

REFERENCES

Heÿl C W and Currie M H 1985. Variations in the use of the Bot River estuary by waterbirds. Transactions of the Royal Society of South Africa 45, 397-417.

Sinclair S A, Lane S B and Grindley J R 1986. Verlorenvlei (CW 13). In: Heydorn A E F and Grindley J R (editors) Estuaries of the Cape. Part II: Synopses of available information on individual systems. Report No 32. Research Report of the South African Council for Scientific and Industrial Research 431, 1-9.

Uys C J and Macleod J G R 1967. The birds of the De Hoop Vlei region, Bredasdorp, and the effect of the 1957 inundation over a 10-year period (1957-1966) on the distribution of species, bird numbers and breeding. Ostrich 38, 233-254.

AN OVERVIEW OF BARBERSPAN, A BIRD OBSERVATORY IN THE WESTERN TRANSVAAL

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INTRODUCTION

Barberspan is a large pan in the western Transvaal. An ornithological research station was established on the pan by the Transvaal Provincial Administration's Division of Nature Conservation in 1955. The characteristics and history of the pan have been summarized by Milstein (1975).

THE DYNAMICS OF THE BARBERSPAN SYSTEM

Barberspan is the largest of the pans in the bed of the fossil Harts River and in the Delareyville/Geysdorp series. It cannot be studied in isolation since it depends on inflow from the Harts catchment area. Except at very high water levels, waterfowl look for breeding to the lands around and between the two fossil rivers, where small pans and the vleis comprise five to 20% of the area.

Good rains (or a flash flood) in the catchment area raise the water level. Local rain does little to raise this water level but it does fill the temporary water bodies, along with the other large pans of the series. A moving average of rainfall recorded at the pan since 1960 agrees closely with the 20-year cycle predicted by Tyson and Dyer (1978).

Waterfowl populations build up in the winter months and 'crash' after rains, when birds are attracted away from Barberspan to highly productive breeding areas provided by temporary pans nearby or farther afield. Any sharp rise in the pan level submerges the *Potamogeton* beds, making food temporarily hard to get (Skead and Dean 1977a,b).

DISTURBANCE

Before 1980/81 the greater part of the pan was in private hands and open to fishing, boating and other recreational activities. This does not seem to have affected the waterfowl much because it was during this period that the most prolific populations were recorded. Currently disturbance is limited to the recreational area.

THE CURRENT SITUATION (OCTOBER 1987)

For the first time since 1966 the water level has dropped below six metres. The normal growth of *Potamogeton* and other water plants has disappeared.

The last inflow was in 1980. With water level below four metres the total dissolved salts has risen from <800 to >4 000 parts per million. Fish (*Labeo* species) have died in numbers.

AN EXAMPLE OF AN AVIAN DATA SERIES

Barberspan has a shoreline (ignoring inlets) of not less than 18 km. Counts of waterfowl must be made by boat so that one team can cover the whole area expeditiously.

TABLE 4.5 Census figures for redknobbed coot *Fulica cristata* on Barberspan, 1955 to 1987

Year	Water Depth m	Rain mm	Food	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Shewell (1959)															
1955										3000	3000	3000	3000	3000	3000
1956				3500	3500	4000	4000	4000	3500	3500	3500	4000	4000	4000	4000
1957				4000	5000	5000	5000	5000							
Farkas (1962)															
1959				)											
1960				) Total number counted Sep 1959 to Sep 1960----- 432 -----											
Milstein (1975)															
1968	9,65	557			17791	19813		19500		8300	8368	12610	9666		
1969	8,84	620				16088		25984	9700	10999					
1970	7,42	409		11157			5179	3340							
Skead and Dean (1977a)															
1971	7,50	489	Poor		1817	4855	5876	3278	3454	3735	4328	4812	6348	6006	3262
1972	9,70	838	Flood	1685	966	956	681	1318	2462	3720	5128	6392	8464	9235	12185
1973	8,38	436	Good	17276	19183	18807	14912	14133	13559	13619	9575	6792	5939	5949	5741
1974	11,05	897	Flood	5553	580	314	182	482	2132	3491	5442	8435	11037	11284	11338
1975	11,16	932	Good	10619	6014	6222	11634	14943	19761	22803	26189	23469	22910	25991	18106
Morgan (Unpublished)															
1984	7,56	289	Poor												264
1985	6,05	332	None		1407		573			101		47		104	
1986	4,69	416	None	421		174	103		127	52	36			41	
1987	4,10	541	None		159		192								

Successive ornithologists at the Station have allocated time and available resources to this work for discrete periods and have published their results (Shewell 1959; Farkas 1962; Milstein 1975; Skead and Dean 1977a,b).

Data are available for all the waterfowl. A schedule of figures for the redknobbed coot *Fulica cristata* is presented as Table 4.5 as an example. It shows sources and periods for which counts were made.

CONCLUSIONS

Rainfall is the key to the state of the reserve. The severe drought of the last six years sharply emphasizes the cyclical nature of the pan's ecology as induced by climatic fluctuations. The pan will need several years of good rainfall to recover its state as recorded at the end of the high rainfall period experienced in the mid-1970's.

REFERENCES

Farkas T 1962. Contribution to the bird fauna of Barberspan. Ostrich Supplement 4, 1-39.

Milstein P le S 1975. The biology of Barberspan, with special reference to the avifauna. Ostrich Supplement 10, 1-74.

Shewell E L 1959. The waterfowl of Barberspan. Ostrich Supplement 3, 160-179.

Skead D M and Dean W R J 1977a. Status of the Barberspan Avifauna, 1971-1975. Ostrich Supplement 12, 3-42.

Skead D M and Dean W R J 1977b. Seasonal abundance of Anatidae at Barberspan. Ostrich Supplement 12, 49-64.

Tyson P D and Dyer T G J 1978. The predicted above normal rainfall of the seventies and the likelihood of droughts in the eighties in South Africa. South African Journal of Science 74, 372-377.

SOME ASPECTS OF THE LONG-TERM DATA SERIES FROM RONDEVLEI BIRD SANCTUARY

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[1]University of Cape Town and [2]Rondevlei Bird Sanctuary

INTRODUCTION

The Rondevlei Bird Sanctuary provides food, shelter and breeding grounds for approximately 222 species of birds, making it an important conservation area within the developed suburbs of Cape Town. Bird counts and fluctuations in some environmental variables (water depth, Secchi disc transparency, surface water temperature, wind speed and direction, water chemistry) have been recorded systematically since the creation of the sanctuary in 1952. This has resulted in an important data set spanning 35 years. The large number of birds, and the problems associated with disturbing breeding birds, make it impossible to make accurate counts of birds present in large flocks (eg flamingos), although the reliability of the data are enhanced by the fact that they have been collected by only

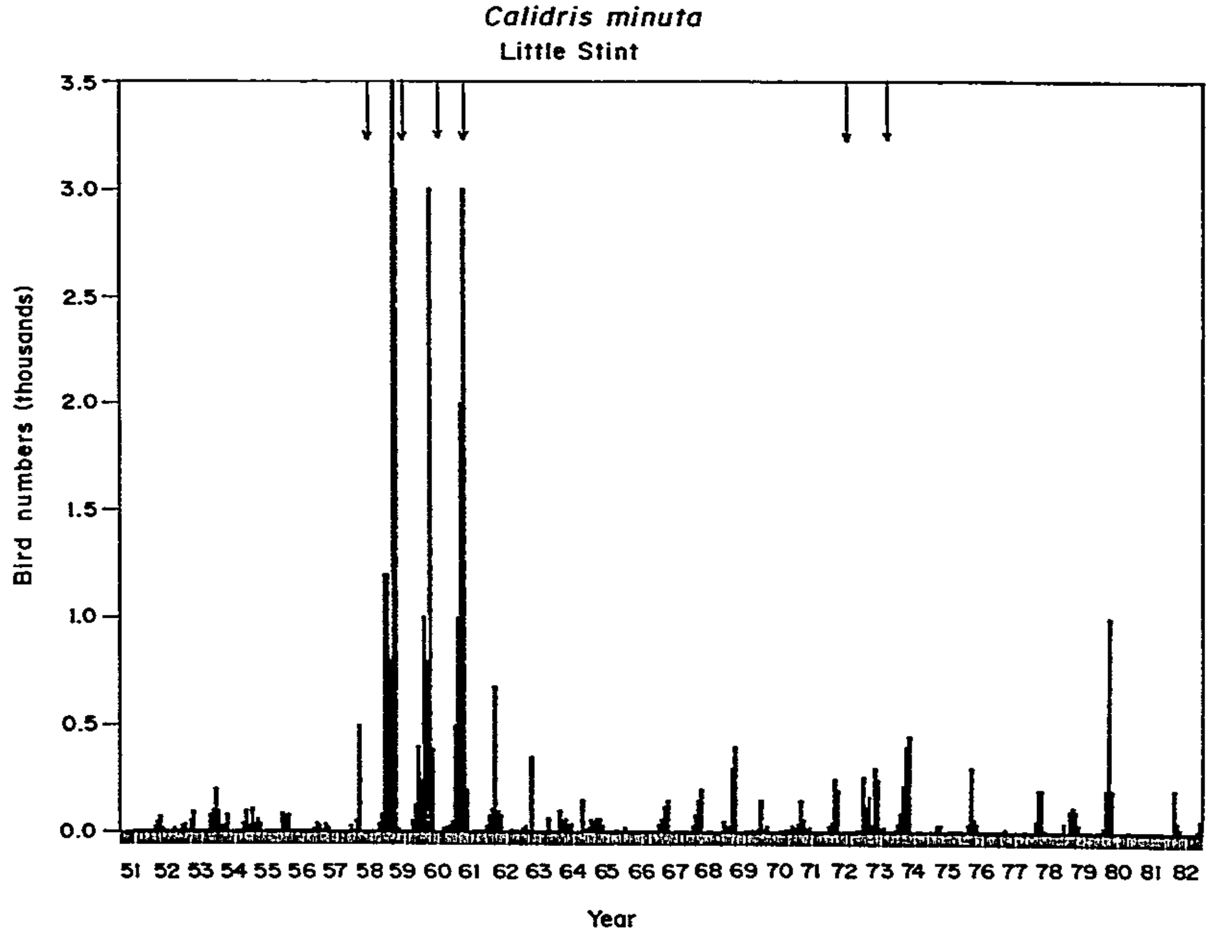

FIGURE 4.11 Monthly maximum number of little stint *Calidris minuta* recorded in Rondevlei. Arrows indicate periods of low water (see text for details).

two people (Messrs E Middlemiss and C H Langley), who used the same methods. The importance of the data set as one of the longest available in South Africa and one of the few dealing with birds in a virtually undisturbed environment, make it imperative that the data be utilized to a greater degree than at present.

DYNAMICS OF THE RONDEVLEI SYSTEM

Previous work on the water birds of the sanctuary suggested that habitat availability, which fluctuates with water level, is the most important variable regulating both wader and swimmer abundance (Banks 1980; Guillet and Crowe 1987). This relationship is most obvious when examining the abundance of waders like the little stint *Calidris minuta*, curlew sandpiper *C ferruginea* and African spoonbill *Platalea alba*. The number of little stints and curlew sandpipers increased dramatically

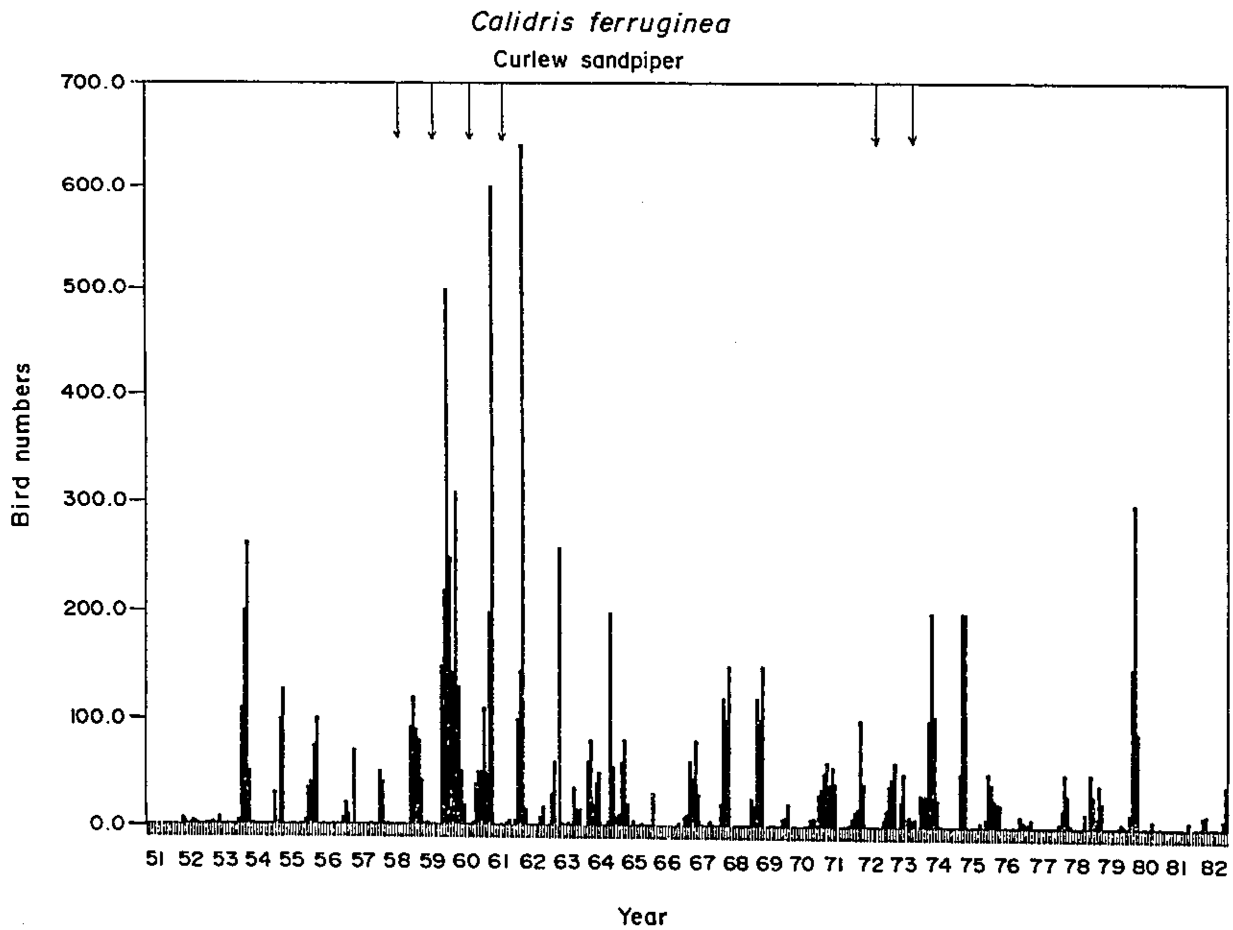

FIGURE 4.12 Monthly maximum number of curlew sandpiper *Calidris ferruginea* recorded in Rondevlei. Arrows indicate periods of low water (see text for details).

during the period 1958 to 1960 (Figures 4.11 and 4.12), when the level of the vlei was artificially lowered for the purpose of increasing wader abundance and species richness (Middlemiss 1974). There was a smaller increase in both species and spoonbills when the vlei dried up, leaving only a small pool of standing water, during the 1972 to 1973 drought (Figures 4.11, 4.12, 4.13 and 4.14). Conversely, the abundance of swimmers, such as the southern pochard *Netta erythrophthalma*, increased when the vlei filled (Figure 4.15).

However, Guillet and Crow (1987) have shown that the availability of wader habitat is increased significantly only when the water level falls below 4,45 m above mean sea level. Water level data show that the water was this shallow for long periods only from 1958 to 1961 and 1972 to 1973 (though always falling below it during summer), and is likely to remain relatively deep as it is now regulated by a weir. Furthermore, even when the water level falls, the exposed shore is colonized by terrestrial

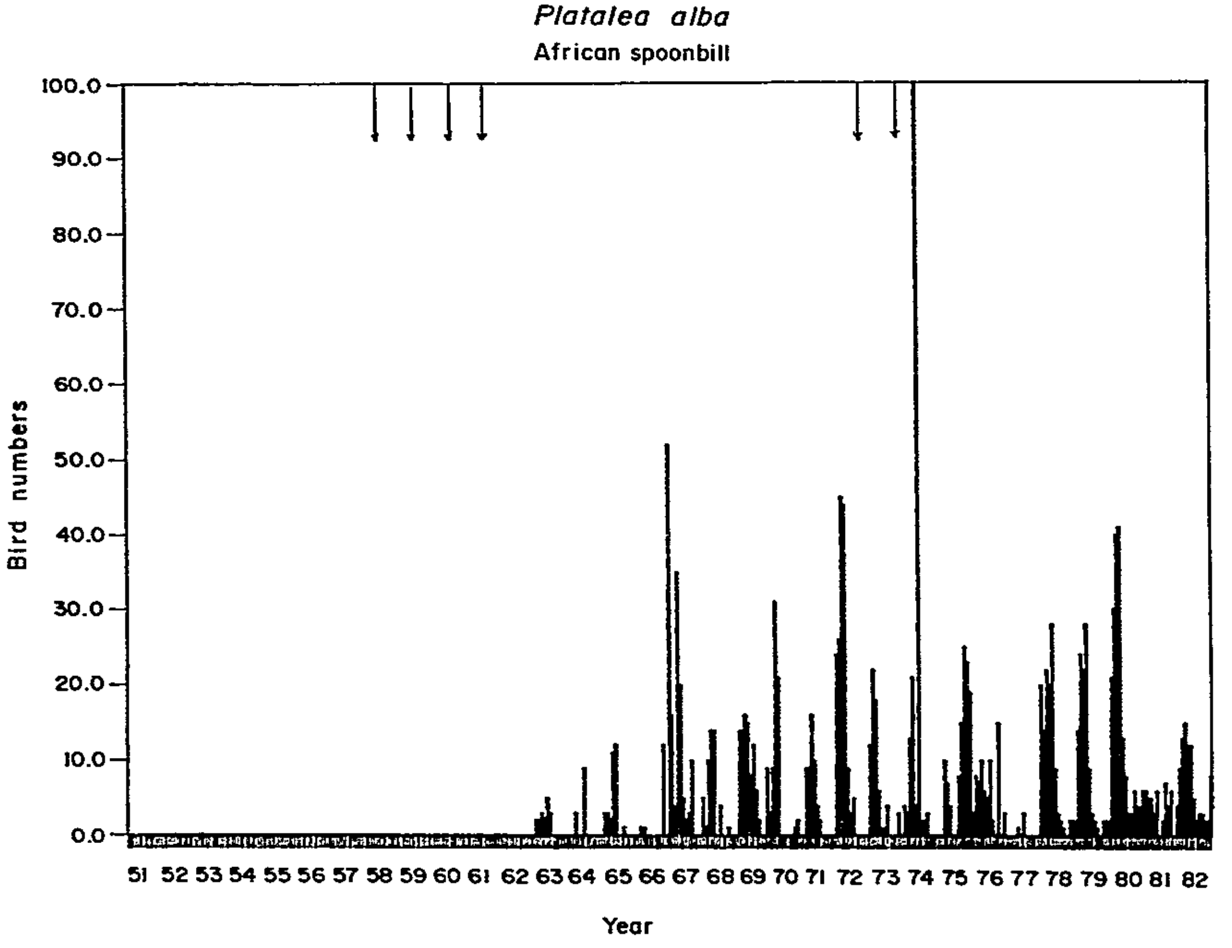

FIGURE 4.13 Monthly maximum number of African spoonbill *Platalea alba* recorded in Rondevlei. Arrows indicate periods of low water (see text for details).

grasses such as *Paspalum vaginatum* and the bulrush *Typha latifolia*. These conditions are unsuitable for waders, although suitable for other birds. Thus, water level alone cannot be used as a measure of habitat availability.

When the water level is above the critical point the relationship between the number of birds and water temperature is significant (Guillet and Crowe 1987). They suggested that this relationship was an indirect one, reflecting the relationship between bird abundance and food supply. Unfortunately there are no quantitative records of food abundance in the sanctuary, although the Annual Reports do mention changes in vegetation of the vlei and its shores. From these, it is possible to estimate the fluctuations in abundance of invertebrates, phytoplankton and submerged macrophytes, especially *Potamogeton pectinatus*. Changes in numbers of redknobbed coot *Fulica cristata* can be related to the presence or absence of *P pectinatus* (Figure 4.16), while the number of Cape

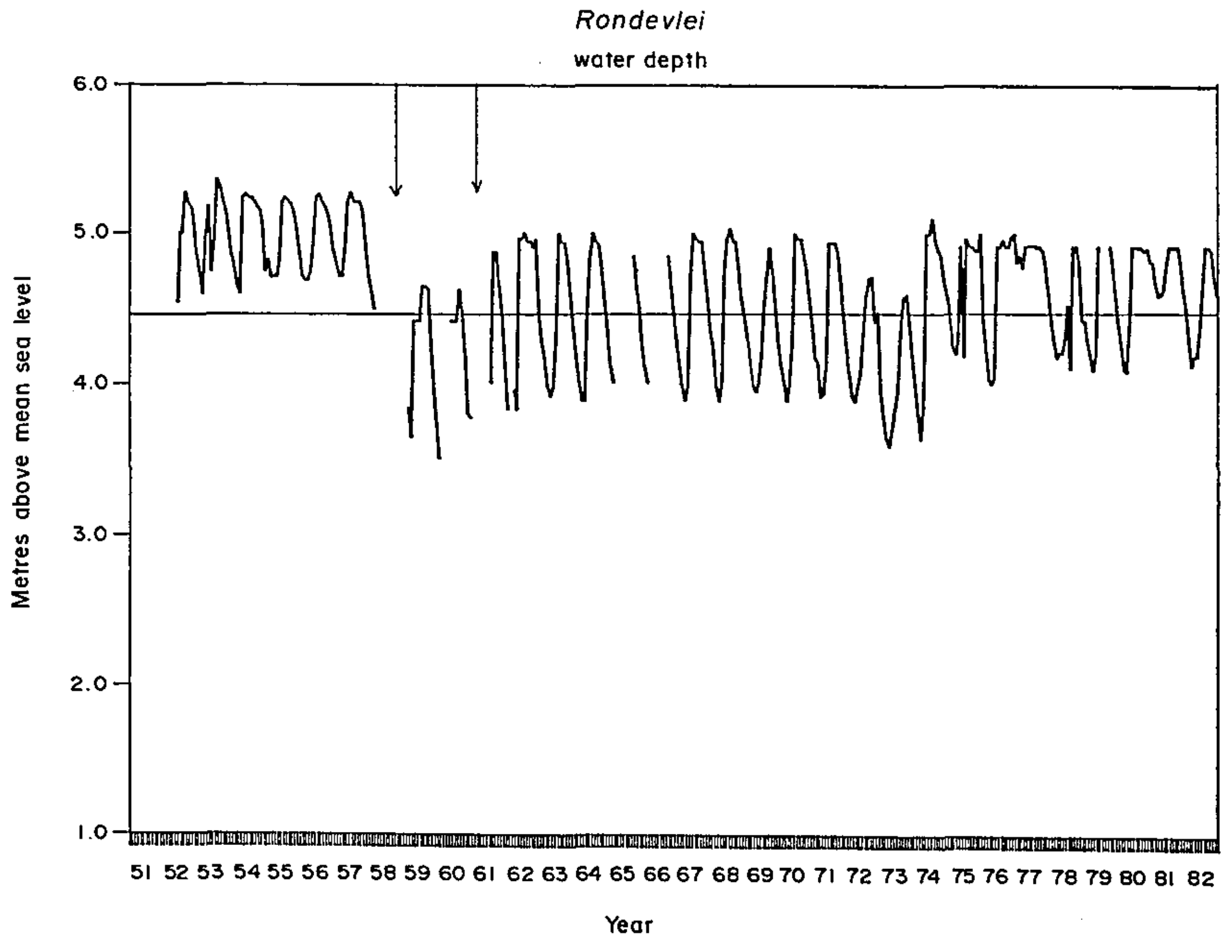

FIGURE 4.14 Monthly maximum water level recorded at the Rondevlei weir.

shovellers *Anas smithii* increased during periods when the submerged macrophytes were absent (Figure 4.17), a phenomenon usually associated with high plankton density (Middlemiss 1974). In addition, there seems to be a positive relationship between the abundance of macrophytes and the numbers of waders such as the greater flamingo *Phoenicopterus ruber*, feeding on invertebrates (Figure 4.18).

Despite being able to explain some of the major trends in bird numbers recorded in the sanctuary using local information, it is impossible to negate the role of external factors, particulary when examining the changes in migrant numbers. For example, the number and population age structure of curlew sandpipers in South Africa appears to be related to the abundance of lemmings in Siberia (Underhill 1987). This relationship may modify the abundance of waders in Rondevlei, but the effect will be superimposed on those factors which are of local importance. It is also necessary to recognize that the factors important in regulating bird numbers, even of resident species such as the blacksmith plover *Vanellus armatus* (Figure 4.19), are not always obvious. Nevertheless, these records could fill an important gap in understanding the biology of aquatic birds in the western Cape, if they are fully utilized.

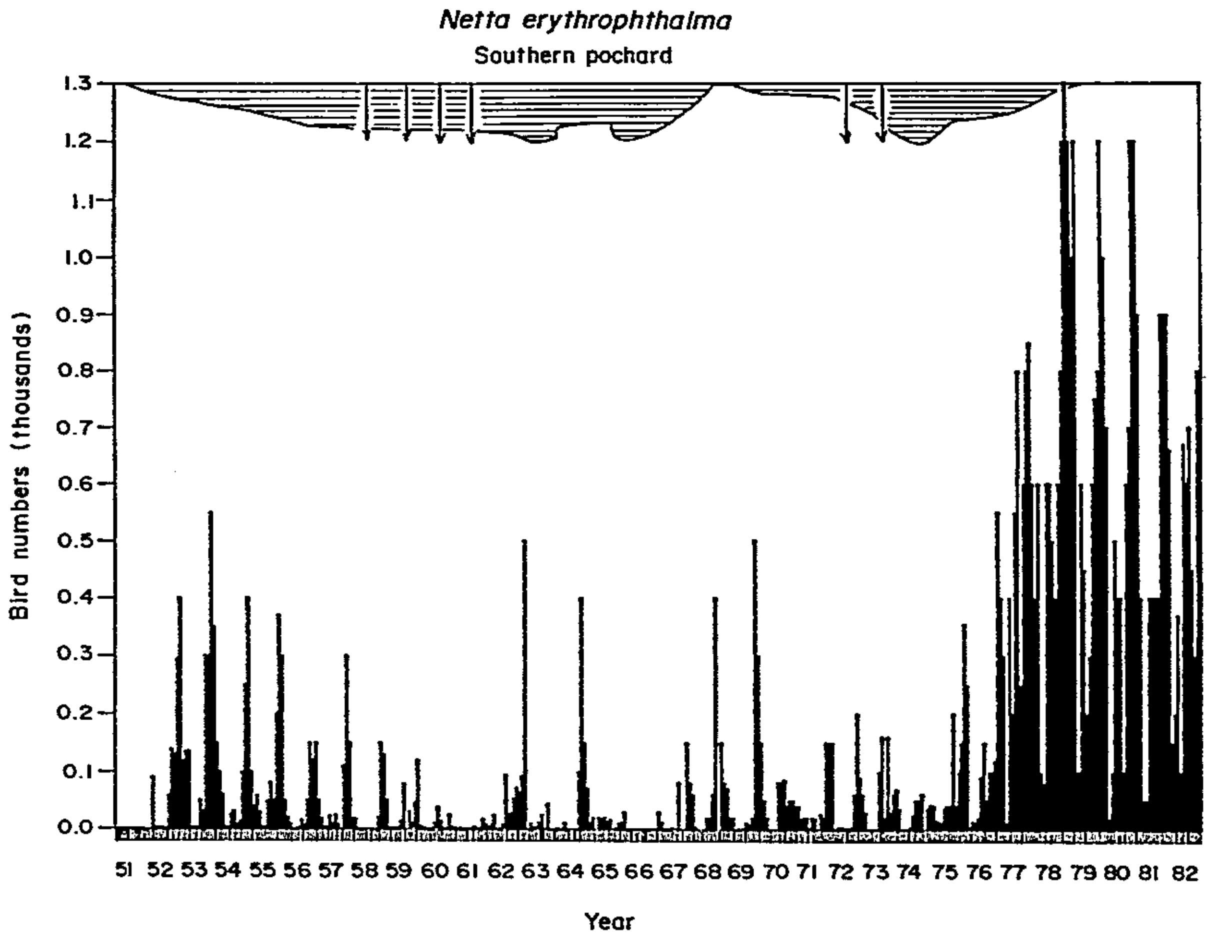

FIGURE 4.15 Monthly maximum number of southern pochard *Netta erythrophthalma* recorded in Rondevlei. Arrows indicate periods of low water and shaded area changes in abundance of *Potamogeton pectinatus* (see text for details).

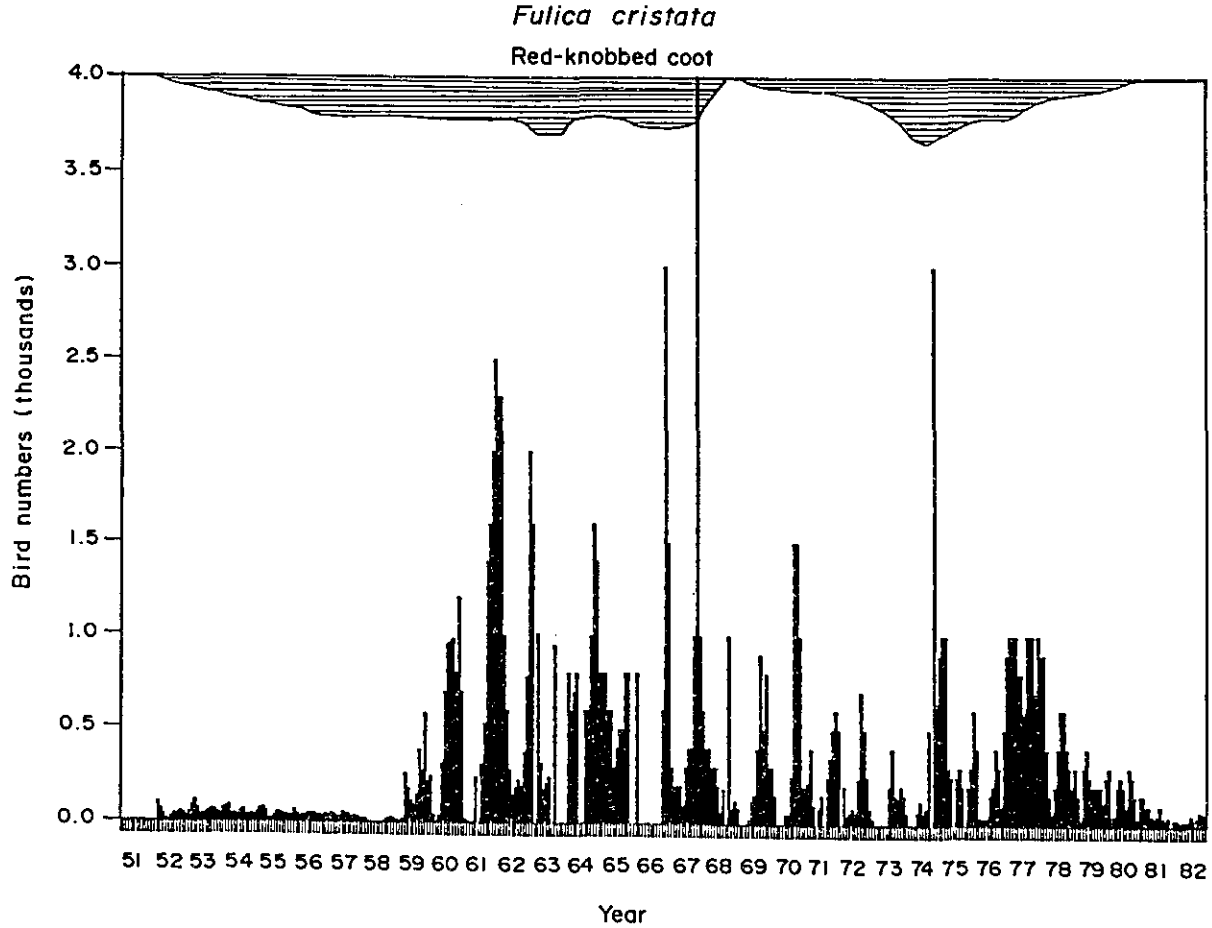

FIGURE 4.16 Monthly maximum number of redknobbed coot *Fulica cristata* recorded in Rondevlei. Shaded area indicates changes in abundance of *Potamogeton pectinatus* (see text for details).

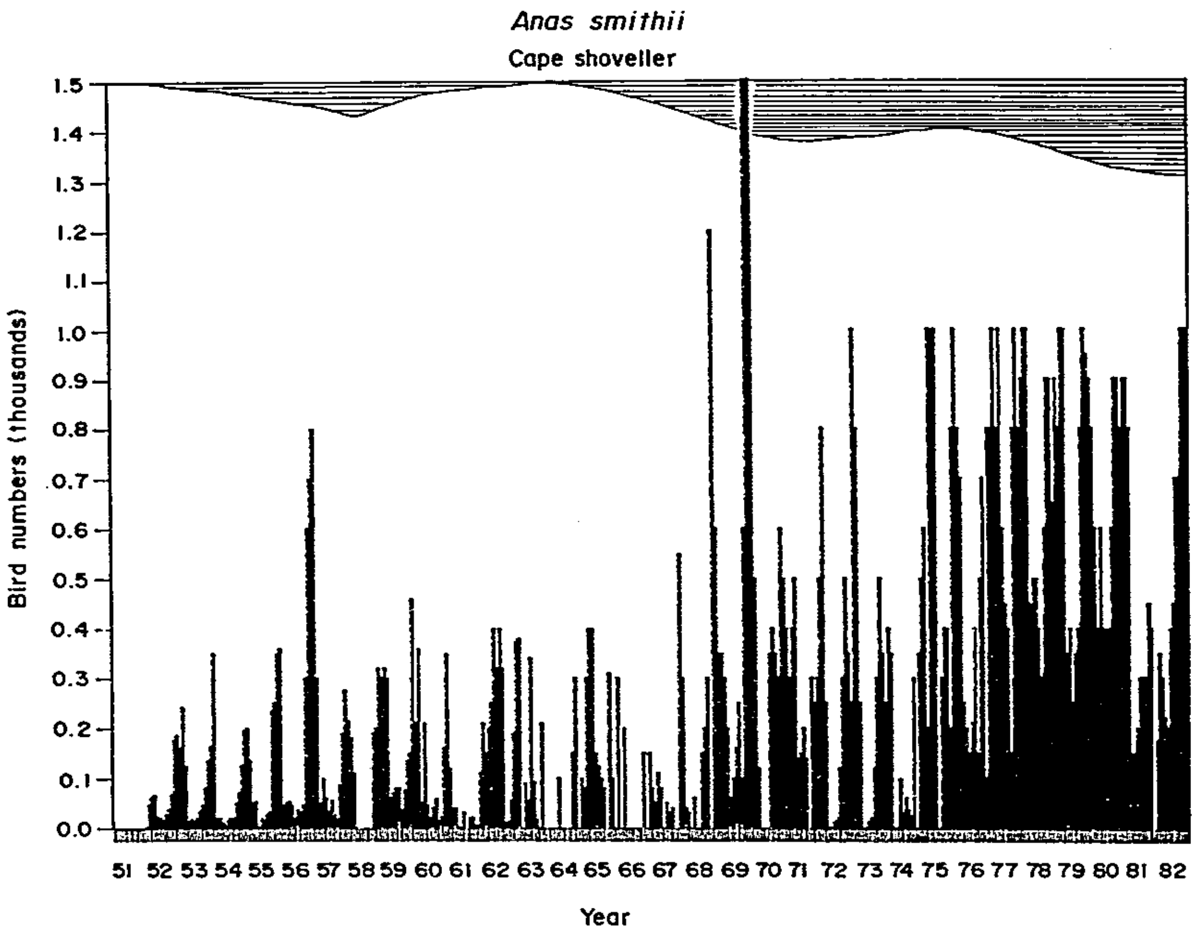

FIGURE 4.17 Monthly maximum number of Cape shoveller *Anas smithii* recorded in Rondevlei. Shaded area indicates changes in phytoplankton abundance (see text for details).

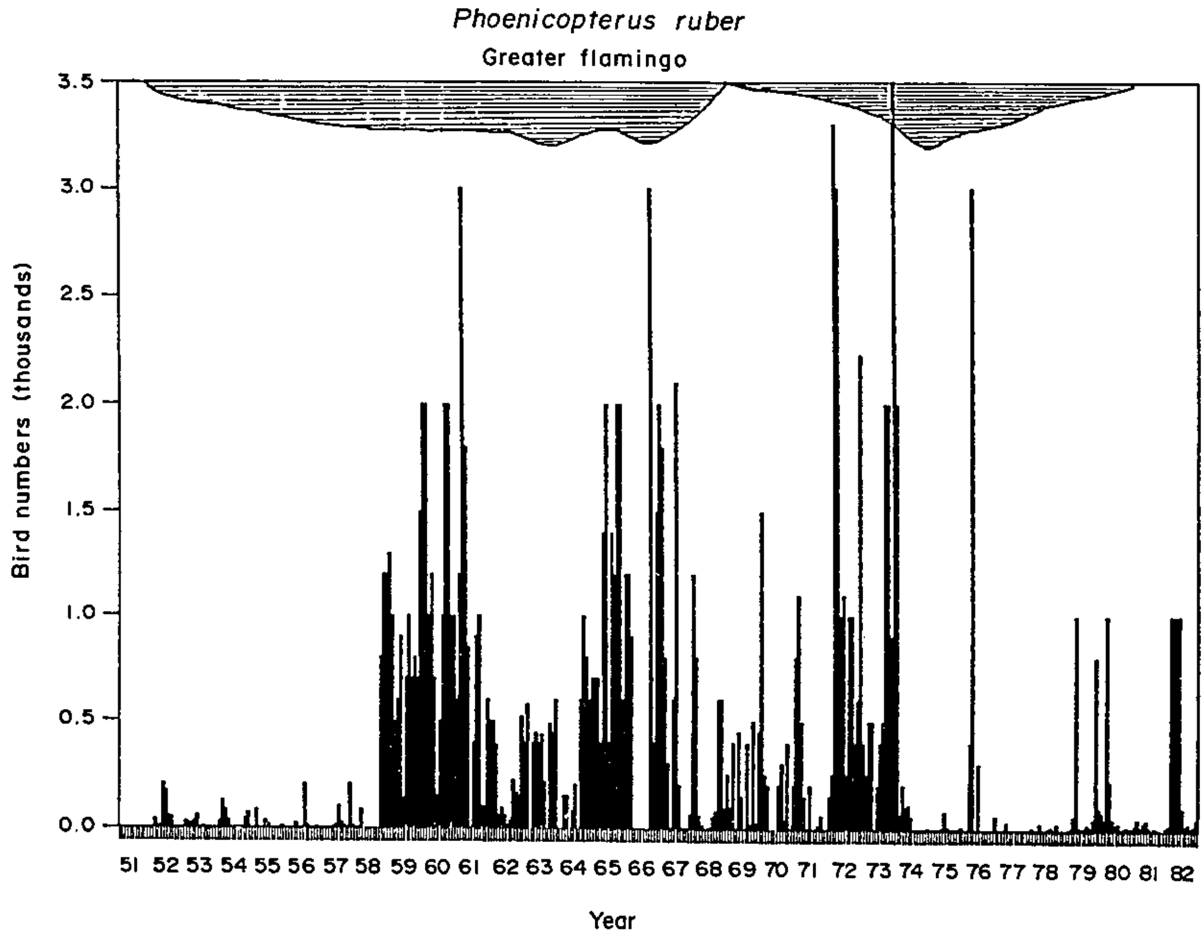

FIGURE 4.18 Monthly maximum number of greater flamingo *Phoenicopterus ruber* recorded in Rondevlei. Shaded area indicates changes in macrophyte abundance (see text for details).

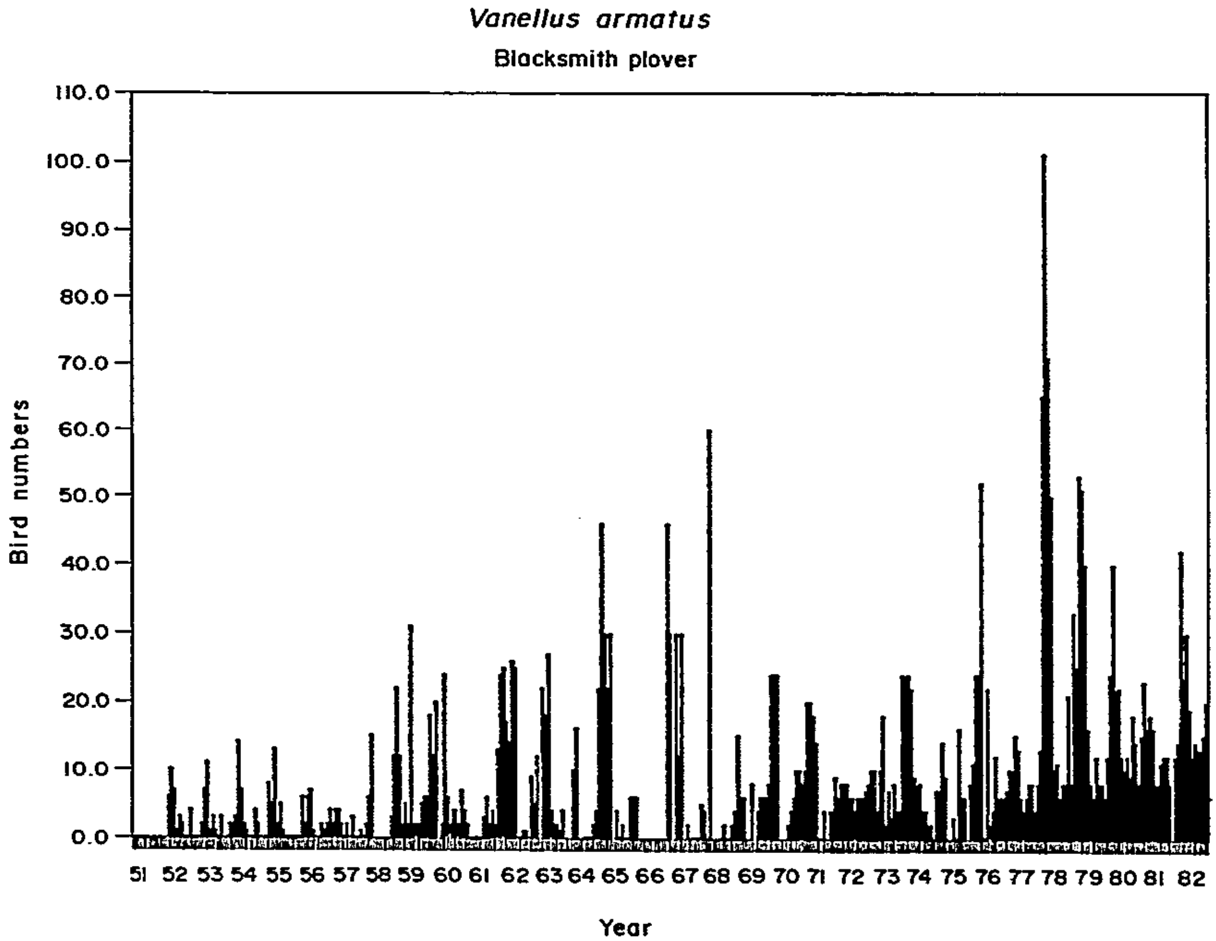

FIGURE 4.19 Monthly maximum number of blacksmith plover *Vanellus armatus* recorded in Rondevlei over a period of 30 years.

REFERENCES

Banks D J 1980. Use of habitats by waterbirds within a fluctuating environment. MSc Thesis, University of Cape Town, Cape Town.

Guillet A and Crowe T M 1987. Monthly and seasonal changes in the aquatic avifauna at Rondevlei Bird Sanctuary (Cape Province, South Africa). Avocetta 11, 1-16.

Middlemiss E 1974. The Rondevlei Bird Sanctuary. A record of the environment, 1952-1974. Divisional Council of the Cape, Cape Town.

Underhill L G 1987. Changes in the age structure of Curlew Sandpiper populations at Langebaan Lagoon, South Africa, in relation to lemming cycles in Siberia. Transactions of the Royal Society of South Africa 46, 209-214.

PRECIPITATION CHEMISTRY IN MOUNTAIN FYNBOS CATCHMENTS

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INTRODUCTION

Sampling of atmospheric deposition in the mountain catchments of the western Cape was initiated in 1971 at the Zachariashoek research area in the Klein Drakenstein mountains near Paarl. This sampling was extended in 1979 to Jonkershoek near Stellenbosch and in 1982 to Jakkalsrivier in the Groenland mountains near Grabouw. The main reason for the initiation of this sampling was to calculate nutrient budgets which are used to determine the effect of fire on nutrient exports and water quality in fynbos catchments. Atmospheric deposition will continue to be monitored over the long term at three sites in the mountains of the western Cape.

Wet and dry precipitation sampling has been carried out since 1971 by means of an inert sampler (van Wyk 1980). In 1985 an Aerochem-metrics wet/dry precipitation sampler was erected at Jonkershoek. The samples were chemically analysed for pH, conductance, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, HCO_3^-, NO_3^-, PO_4^{3}-P, NH_4^+-N, Kjeldahl nitrogen, total phosphorus and silicate. For the period 1971 to 1981 the samples were analysed by the National Institute for Water Research of the CSIR in Bellville. Since 1981 the samples have been analysed by the Hydrological Research Institute.

RESULTS

Results indicate that ion inputs exceed exports by 29% (van Wyk 1981, 1984). The total inputs at Zachariashoek range from 64 to 566 $kg.ha^{-1}a^{-1}$ over the period 1971 to 1986. Years with extremely high nutrient inputs correspond with high-rainfall years. In the wet season or during big rainstorms the total concentrations of ions in wet precipitation in the western Cape is much lower than during the dry summers. The high total annual input during the year 1977 can be ascribed to a high precipitation volume (Figure 4.20). Mean annual concentrations of total dissolved solids (TDS) calculated using 16 years of data range from nine to 21 $mg.l^{-1}$ (van Wyk 1987) with a yearly mean of 15,2 $mg.l^{-1}$. The concentrations of wet deposition for individual rainstorms range from two to 60 $mg.l^{-1}$ (van Wyk 1984).

The calculated dry deposition is about eight per cent of the total deposition (van Wyk 1984). For the year 1986 the results obtained at Jonkershoek showed that dry deposition made up 17% of total deposition, indicating some variability in the ratio of wet to dry deposition (van Wyk 1987).

The ionic input varies considerably over the study area. The main constituents in atmospheric deposition at Zachariashoek in the Drakenstein mountains near Paarl are Na^+ (Figure 4.21), Cl^- (Figure 4.22), HCO_3^- and SO_4^{2-}, while in the Groenland mountain near Grabouw they consist mainly of Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-} and HCO_3^-.

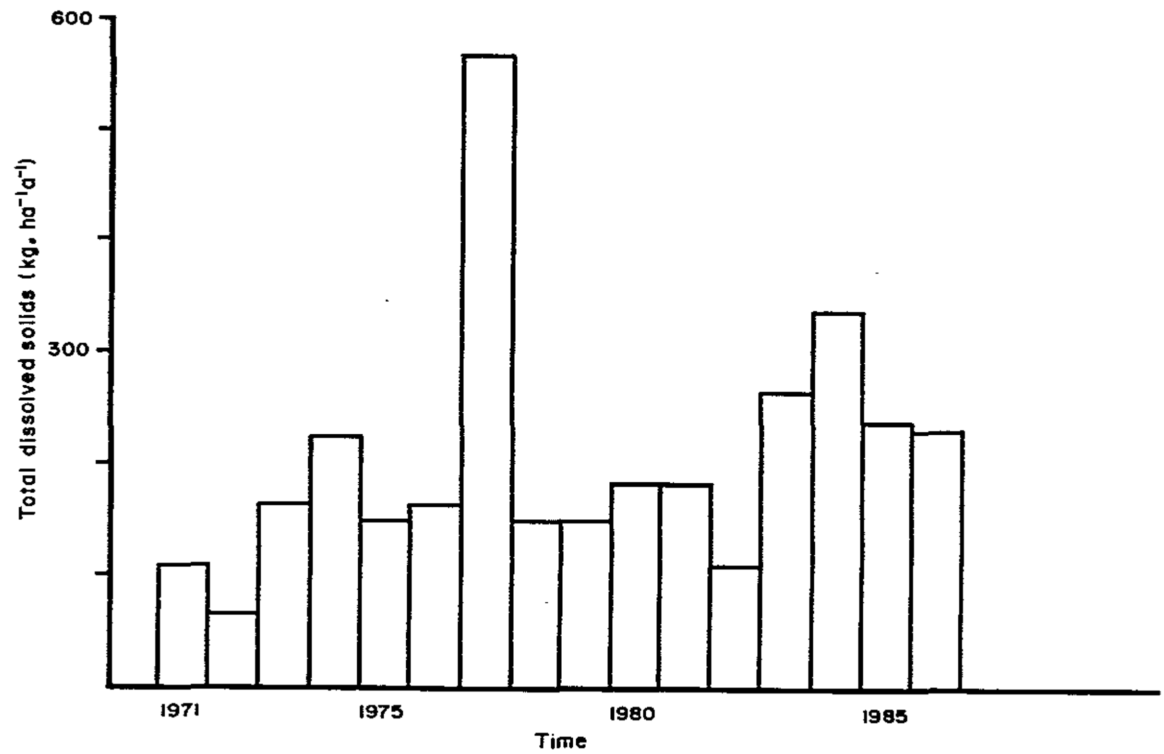

FIGURE 4.20 Total atmospheric deposition of dissolved solids ($kg.ha^{-1}a^{-1}$) at the Kasteelkloof sampling site in the Zachariashoek research area.

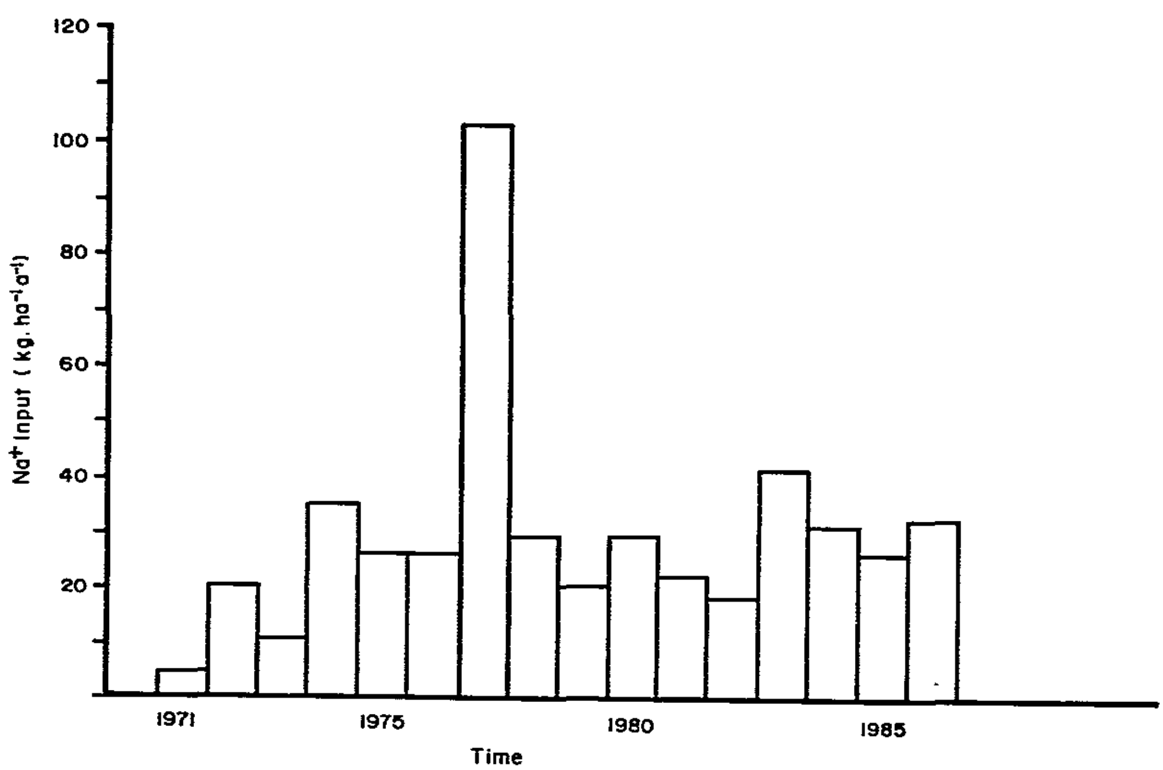

FIGURE 4.21 Total atmospheric deposition of sodium ($kg.ha^{-1}a^{-1}$) at the Kasteelkloof sampling site in the Zachariashoek research area.

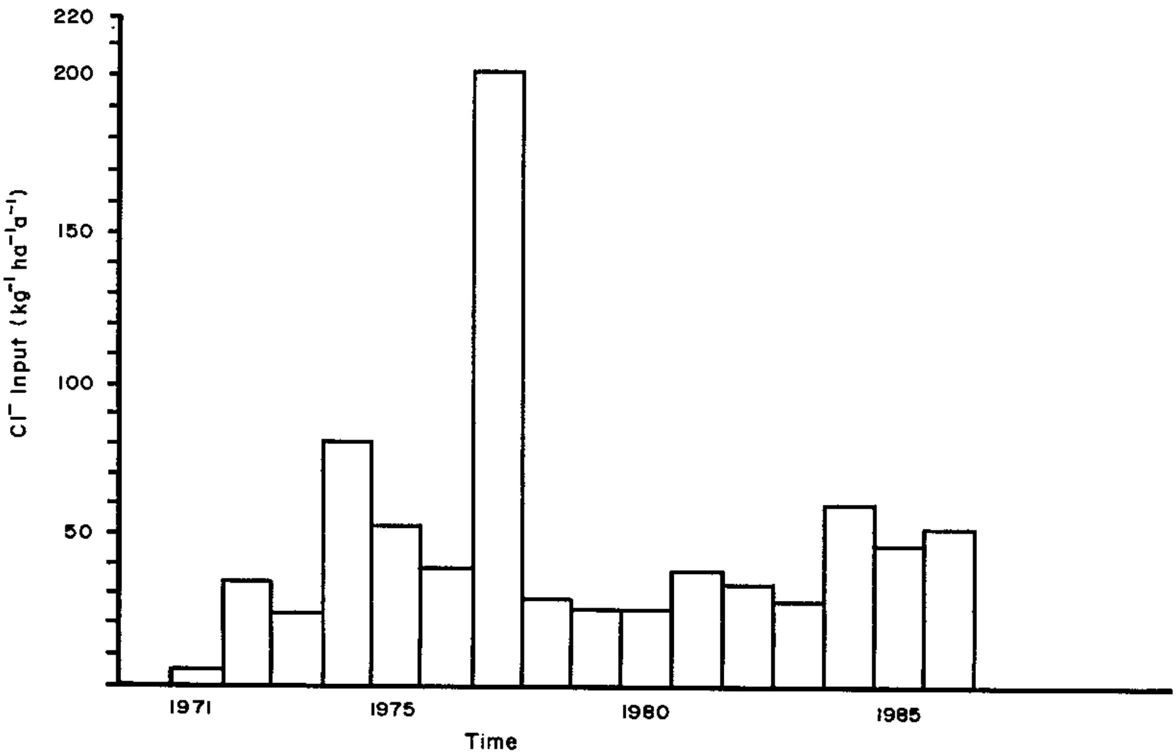

FIGURE 4.22 Total atmospheric deposition of chloride ($kg.ha^{-1}a^{-1}$) at the Kasteelkloof sampling site in the Zachariashoek research area.

The long-term mean annual levels of the specific ions in the fynbos mountain catchments in $kg.ha^{-1}a^{-1}$ are: Na^+ (22,9), K^+ (6,2), Ca^{2+} (6,3), Mg^{2+} (3,5), Cl^- (42,6), SO_4^{2-} (30,1), NO_3^--N (1,2), HCO_3^- (55,2), NH_4^+-N (0,89), KN (2,76), TP (0,13) and PO_4^{3-}-P (0,03) (van Wyk 1987). The ionic ratios show that the effect of the sea is much stronger in the Zachariashoek area than at Jonkershoek. A site-specific and clearly marked seasonal variation in atmospheric deposition exists for each of the different mountain catchments. The Groenland mountains, for example, receive high inputs from both the north-west and the south-east while the main source of atmospheric deposition in the Jonkershoek and Klein Drakenstein mountains is from the north-west. As the winds blow from different directions at different seasons of the year this results in seasonal patterns of deposition.

The mean volume-weighted pH of precipitation for the year 1986 also varies between Zachariashoek (with a pH of 4,89), Jonkershoek (with a pH of 5,09) and Jakkalsrivier (with a pH of 4,64). These values are much higher than those for catchments in the Drakensberg and the eastern Transvaal (van Wyk 1986, 1987).

DISCUSSION

The variability in the composition of the atmospheric deposition suggests that the Zachariashoek and Jakkalsrivier areas are influenced by the sea. Relative to Jonkershoek, the higher inputs of Cl^-, Na^+ and Mg^{2+}

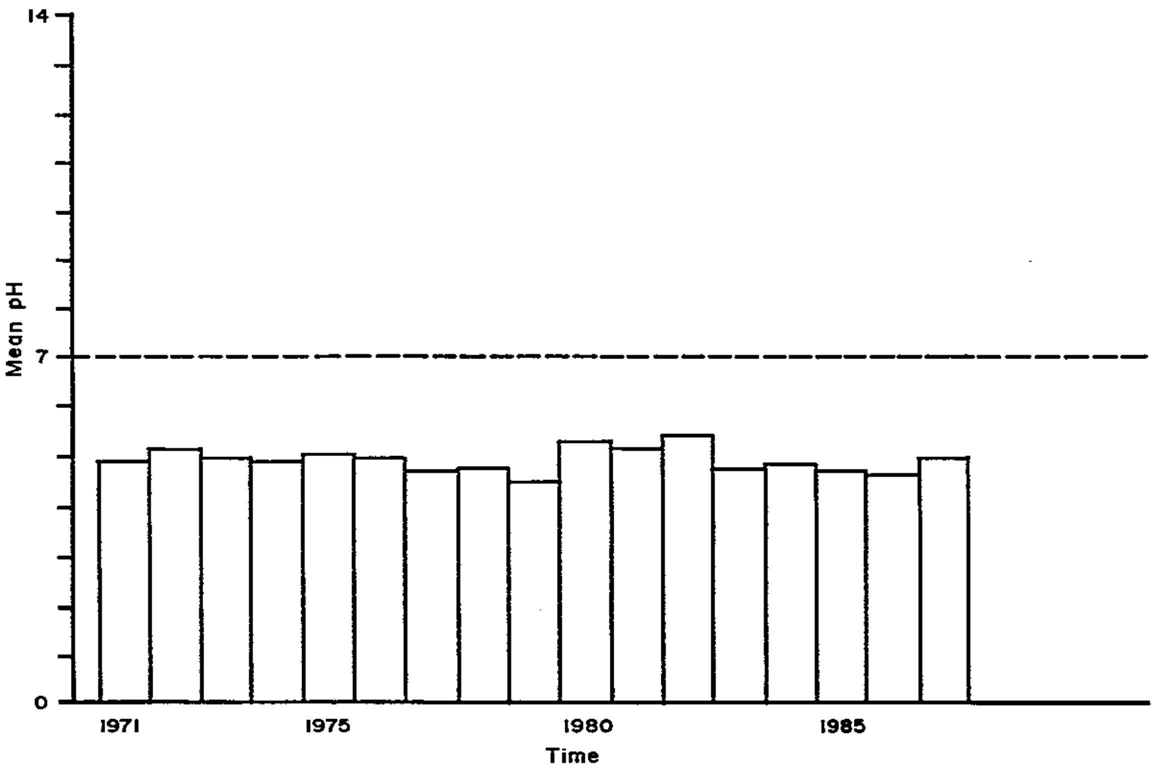

FIGURE 4.23 Volume weighted mean pH of wet atmospheric deposition at Kasteelkloof.

indicate that the majority of atmospheric deposition in these catchments is of marine origin (Bowen 1979).

The apparent increased input of SO_4^{2-} and NO_3^- in the Groenland mountains may be the result of pollution from the greater metropolitan area of Cape Town (van Wyk 1984). The lower pH, combined with the higher inputs of SO_4^{2-}, Cl^- and NO_3^-, (Bowen 1979) indicates that the rain is more acid in Jakkalsrivier than at Jonkershoek or Zachariashoek (van Wyk 1984).

The climate, especially the frontal systems, play an important role in the amount and composition of atmospheric deposition in the mountain catchments of the western Cape.

REFERENCES

Bowen H J M 1979. Environmental chemistry of the elements. Department of Chemistry, The University of Reading. Academic Press.

Van Wyk D B 1980. Water quality of manipulated mountain catchments in the western Cape. In: H Maaren (editor) Proceedings of the National Workshop on the effects of rural landuse and catchment management on water resources. Report TR113, Department of Water Affairs, Forestry and Environmental Conservation, Pretoria.

Van Wyk D B 1981. The influence of prescribed burning on nutrient budgets of mountain fynbos catchments in the south-west Cape, Republic of South Africa, Proceedings of an international symposium on Dynamics and Management of Mediterranean-type Ecosystems held at San Diego University, California, USA in June 1981.

Van Wyk D B 1984. Ioon-invoere en pH van reënval in die bergopvangebiede in die Wes-Kaap. Opsomming van seminaar in verband met atmosferiese interaksies deur die WNNR, Kaapstad.

CHAPTER 5. RIVER FLOWS AND ESTUARIES

SURFACE WATER HYDROLOGY

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INTRODUCTION

Surface water hydrology, in the context of this chapter, is the study of the processes and phenomena of the terrestrial hydrological system. As such it examines the interrelationships of rainfall, evapotranspiration, land use, soil and topography with reference to streamflow from catchment areas, in terms of the quantity and quality of water.

While the hydrological system is "driven" largely by climatic variables, it also acts as the primary driving force of inland aquatic systems and estuaries.

This chapter reviews the availability and adequacy of long-term data sets pertinent to the hydrological system as a prelude to assessing the existence of possible trends and cycles in southern Africa and outlining areas of research deemed necessary in the future. In this paper South Africa refers to the Republic of South Africa (RSA) and the National States while southern Africa is taken to include the RSA, the National States and the Kingdoms of Swaziland and Lesotho.

AVAILABILITY OF LONG-TERM HYDROLOGICAL DATA SETS IN SOUTHERN AFRICA

Length of records

Rainfall. The lengths of rainfall data sets in South Africa are summarized in Table 5.1. Years with incomplete records have been omitted and the data period extends to 1984.

The spatial distribution of stations with record lengths exceeding 50 years is depicted in Figure 5.1. It would appear that in terms of rainfall, the major input variable to hydrological response, southern Africa has adequately long records in most regions. It is, however, in certain critical areas such as Lesotho (a major source of future water resources) and the National States (where rural development schemes require planning) that there is a dearth of stations with records long enough to detect trends or oscillations.

Pan Evaporation. The measurement of evaporation from the standard American Class A pan (and formerly the Symon's pan), while riddled with inherent conceptual and recording problems, is the simplest direct means of estimating potential evaporation. Midgley et al (1983) provide statistics on the availability of long-term data sets for pan evaporation in South Africa for the period up to 1980 (Table 5.2).

TABLE 5.1 Number of stations with various lengths of years of rainfall records. (Source: Computing Centre for Water Research 1987)

	>100	75-100	50-74	<50
Cape Province	5	88	407	3500+
Transvaal	0	1	207	2493
Natal	1	4	92	926
Orange Free State	0	0	155	1355
Totals	6	93	861	8274+

TABLE 5.2 Number of stations with various lengths (years) of data sets for pan evaporation (source: Midgley et al 1983)

Length of record (yrs)	50-74	25-49	<25
Number of stations	9	61	>300

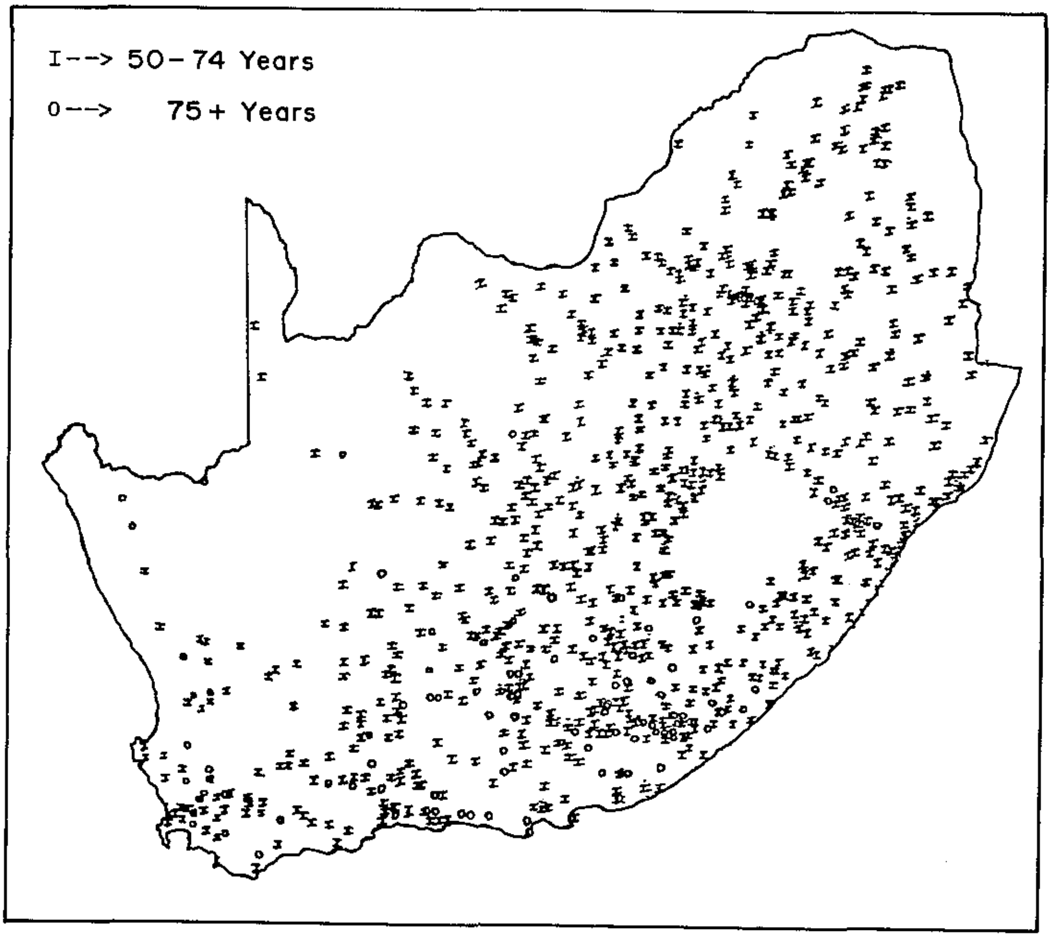

FIGURE 5.1 The distribution of long-term rainfall gauging stations.

The distribution of the 70 stations with the longest records is shown in Figure 5.2. While pan evaporation is a more conservative regional climatic variable than, say, rainfall or streamflow, the pan network is considered inadequate, being concentrated around irrigated and more densely farmed agricultural areas. It should be noted that the pan evaporation network is least adequate where evaporation is likely to be highest, viz in the arid and semi-arid zones.

<u>Streamflow</u>. From an inventory of the Department of Water Affairs' Division of Hydrology (1981) information was compiled on the number of stations recording streamflow in operation in 1980 for catchments of differing size (Table 5.3).

From Table 5.3 it may be gleaned that there are relatively few sets of streamflow data of long duration (ie >75 years), significantly none being in the Cape Province. Of the 215 streamflow gauging stations with record lengths exceeding 25 years, only 25 are from small (<10 km²) catchments whilst 67 are from very large (>1 000 km²) catchments.

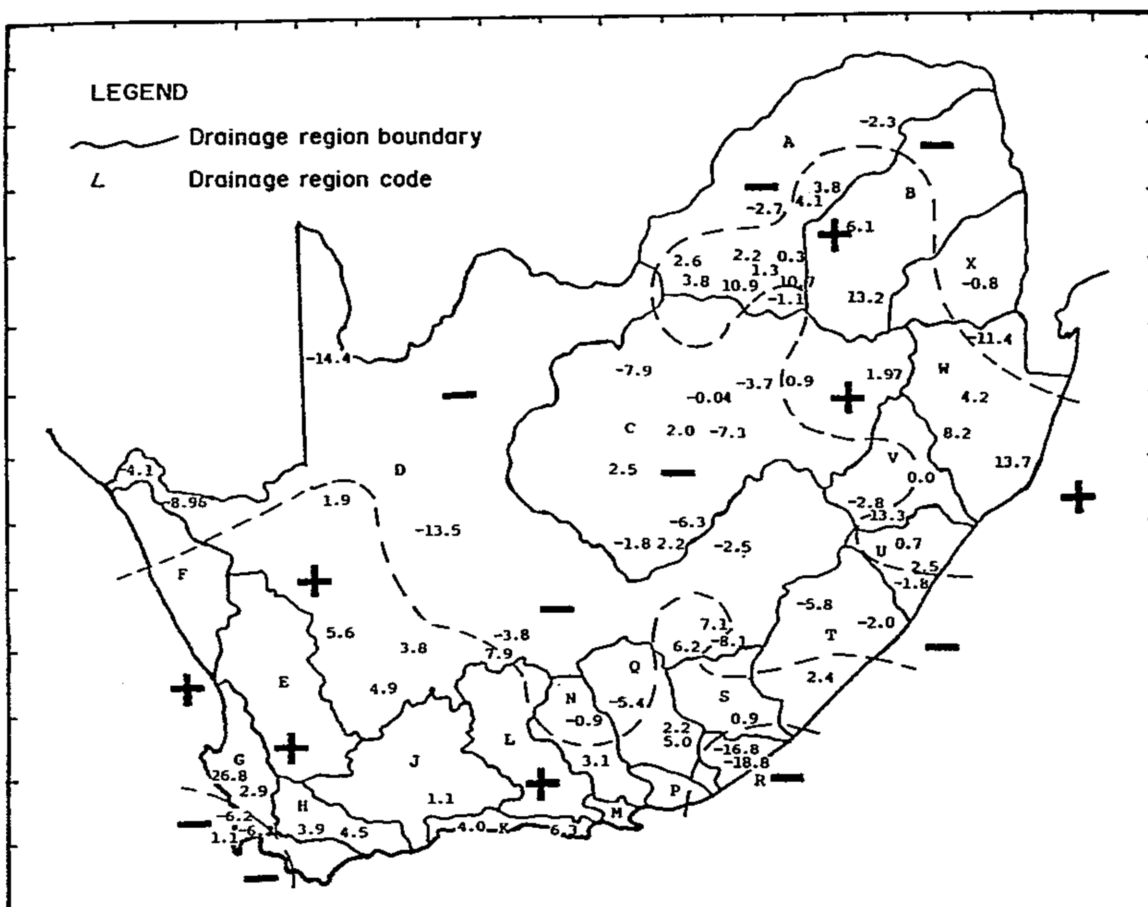

FIGURE 5.2 Possible trends in annual pan evaporation shown by split data figures from stations with better than 50 years of record. The positive or negative change in evaporation (mm) over the second half of the record is plotted at the appropriate station location.

TABLE 5.3 Number of stations with various lengths (years) of streamflow data sets for catchments in different size categories

	Area (km²)	Length of record (years) >75		50-74		25-49		<25	
Cape Province	<10	0		0		9		14	
	10-100	0		1		21		38	
	101-1000	0	0	3	13	15	52	48	124
	>1000	0		9		7		24	
Transvaal	<10	1		0		3		3	
	10-100	0		2		8		24	
	101-1000	1	3	3	8	29	58	21	59
	>1000	1		3		18		11	
Natal	<10	0		0		11		2	
	10-100	0		0		3		5	
	101-1000	1	1	2	2	22	48	10	35
	>1000	0		0		12		10	
Orange Free State	<10	0		0		1		1	
	10-100	0		0		3		0	
	101-1000	0	3	3	13	6	14	9	21
	>1000	3		10		4		11	
Total			7		36		172		239

Water quality. The Department of Water Affairs now takes weekly or monthly samples for water quality at approximately 800 stations. The majority of stations were started in the early 1970's with few records extending longer than 20 years. Many data records are incomplete.

Problems with existing data sets

Precipitation.

1) There are limited long-term data from mountain catchment areas, many of which are main sources of water for industrial/ irrigation areas. These areas cover only 11,8% of southern Africa but yield 53,1% of its mean annual runoff.

2) There are gaps in the spatial distribution of the long-term record, eg the arid regions, Lesotho, north-east Zululand, the National States and homelands and the Kruger National Park.

3) Problems associated with short-term data sets in southern Africa have recently been partially overcome by the facility to generate synthetic rainfall data sets from a 12-parameter model developed by Adamson (1986). These generated data sets preserve certain critical statistics very well, rendering them highly useful for long-term planning related to water resources. It must, however, be pointed out that synthetic data do not necessarily reproduce time series or

trends in the sequence they occurred historically. As synthetic data generation assumes stationarity they are not a substitute for real, long-term data, which are needed for the study of trends and cycles.

Evaporation

1) The use of evaporation pans is a surrogate for the measurement of potential evaporation, and as such is subject to several criticisms.

2) Nonuniformity of evaporation pan installation can cause errors of up to 20%.

3) Historically, Symons pans were installed but there has been a gradual change since the 1960's to the American Class A pan. Although regional and seasonal coefficients exist for the conversion of Symons to A-pan equivalents, the change has complicated the data set by introducing an additional factor of uncertainty.

4) The ground cover and/or surrounding vegetation around evaporation pans has, in cases, been changed without this having been recorded, rendering application of the historical record difficult in assessing long-term trends because evaporation records are highly sensitive to surrounding microclimates.

5) The spatial distribution of the evaporation pan network is, like that of precipitation, uneven.

6) Missing evaporation data have in many cases not been synthesized into the record, and have sometimes been recorded as zero events, resulting in an underestimation of pan evaporation.

Streamflow

There are few catchments with long-term measurements of streamflow whose records may be considered stationary and/or homogeneous. Typical problems found in streamflow data sets are (van Biljon et al 1987):

- damming upstream of streamflow gauging stations;
- irrigation and other abstractions (eg interbasin transfers) reducing natural streamflow;
- return flows to stream from overirrigation practices boosting flows;
- siltation of gauging weirs; and
- faulty or inaccurate weirs (eg leaks, submergence when in flood), gauges or rating tables (eg need for recalibration).

Furthermore, many catchments are dynamic in that they have undergone major changes in land use or management (see Figure 5.3) such as urbanization, soil conservation, multiple construction of farm dams, agricultural intensification on afforestation which affect streamflow response to rainfall.

Few records of abstractions upstream of gauging stations have been kept, though annual abstractions may be over 50% of the annual streamflow. Furthermore, many of the gauging weirs constructed before the late 1950's had as their main aim good measurements of low flows, with resultant poor

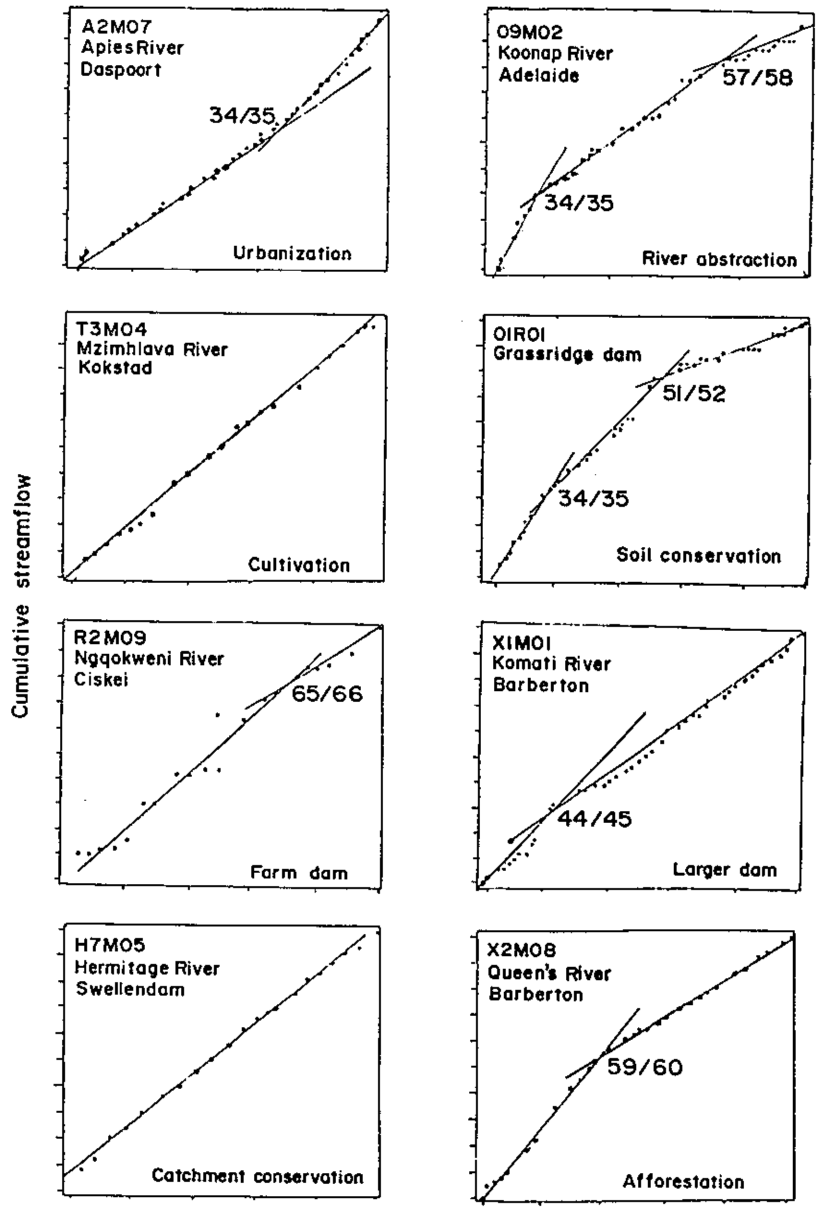

FIGURE 5.3 Plots of cumulative streamflow against cumulative rainfall showing the possible effects of various developments or land uses in the catchments (source: Braune and Wessels 1981).

accuracy and reliability at high discharges. At some gauging weirs continuous recording of streamflow replaced single daily readings. Single daily readings may or may not have missed individual flood peaks, thereby biasing the estimate of total flow. Smaller catchments are generally sampled more poorly than larger areas in the national streamflow network (Table 5.3).

The above problems imply that unadjusted historical data sets are frequently inappropriate for identifying or forecasting possible cycles or even for assessing water resources.

<u>Are southern Africa's hydrometeorological records long enough for analyses of trends and cycles?</u>

In order to answer this question, it is important to distinguish between some commonly used terms in the analysis of data series of long duration. A population sample of (say) annual rainfall or streamflow has a mean, which is assumed to be a long-term and statistically stable measure of the central tendency of the sample. About this mean, interannual variability occurs. This variability is not to be confused with periodicity or cyclicity, which is an expression of a more or less regular oscillatory pattern about a long-term mean with a more or less regular amplitude and wavelength. A trend, on the other hand, signals a long-term and directional change in the mean, such that it tends either to be increasing or decreasing from its original regular pattern.

In a hydrological context Lynch and Dent (1987) have shown that the length of record necessary to establish an index of stability in the value of mean annual rainfall varies from region to region within southern Africa, with moister areas requiring only 15, but drier areas requiring over 30 years of annual data to ensure an estimate within 10% of the long-term mean in 90% of years (Figure 5.4).

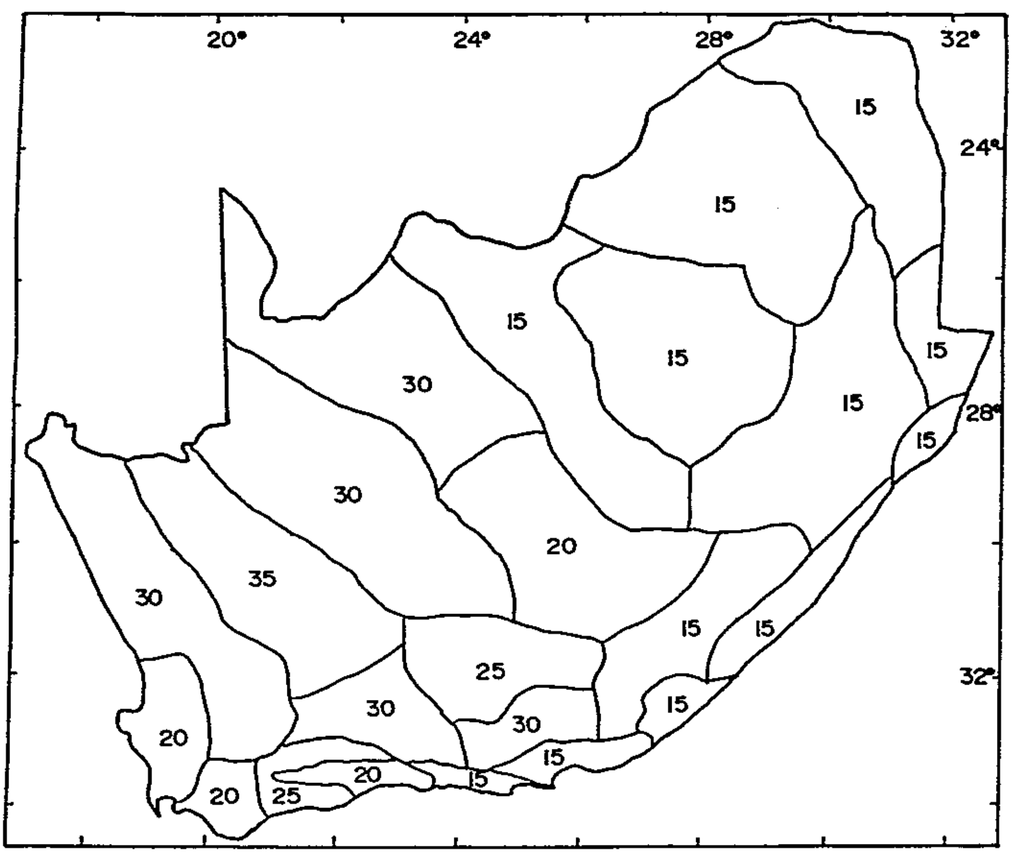

FIGURE 5.4 Record lengths required to ensure that the mean of annual rainfall estimates falls within 10% of the long-term mean, 90% of the time (source: Lynch and Dent 1987).

Streamflow, however, is a complex interaction of rainfall, evapotranspiration, topography, soil and human intervention, which responds curvilinearly (but with much variation interannually and between catchments) to rainfall, as Figure 5.5 illustrates. Considerably longer records of streamflow will therefore be required to obtain reliable estimates of long-term means and deviations, let alone establish any possible existence of quasi-periodic "cycles".

The problem of variability of streamflow in southern Africa has recently been highlighted by McMahon et al (1987), who have illustrated, inter alia, that for a given latitude the variability of both annual rainfall and corresponding streamflow are considerably higher in southern Africa and Australia than in the rest of the world (Figure 5.6). Furthermore, if an index of peak flood discharge is plotted against catchment area, southern Africa again is shown to experience far more devastating flood peaks for a given catchment size than elsewhere in the world, particularly in larger catchments (Figure 5.7).

These examples underline that considerable caution has to be exercised in predicting possible trends and/or cycles of streamflows in southern Africa.

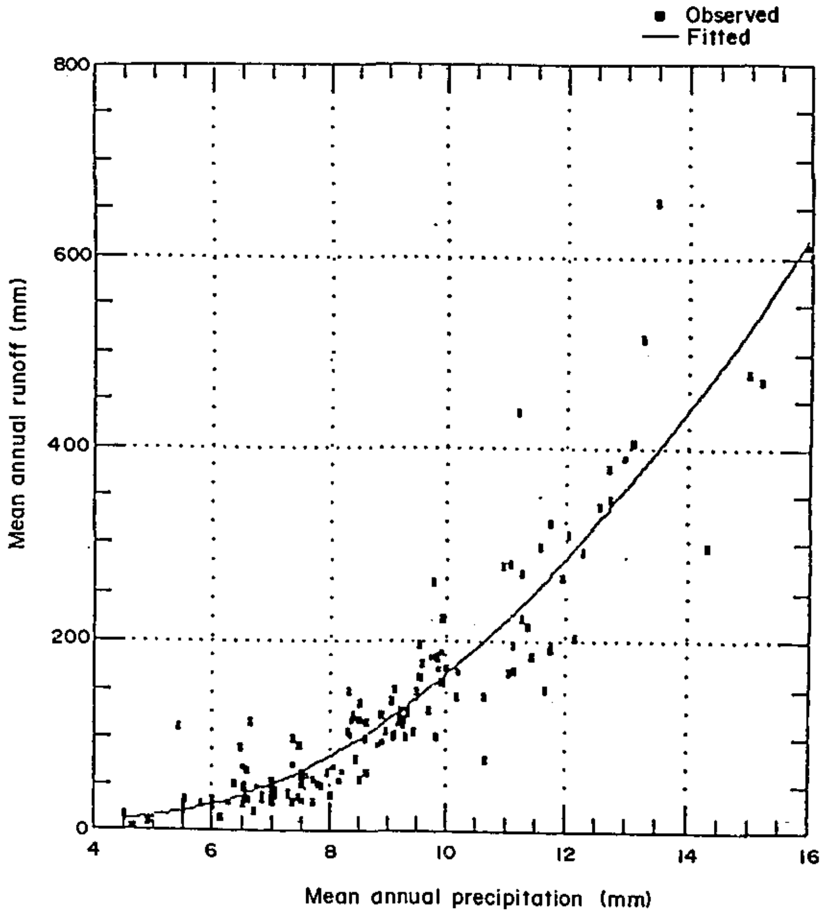

FIGURE 5.5 Relationship between rainfall and runoff for 126 catchments in northern and eastern South Africa (source: van Biljon et al 1987).

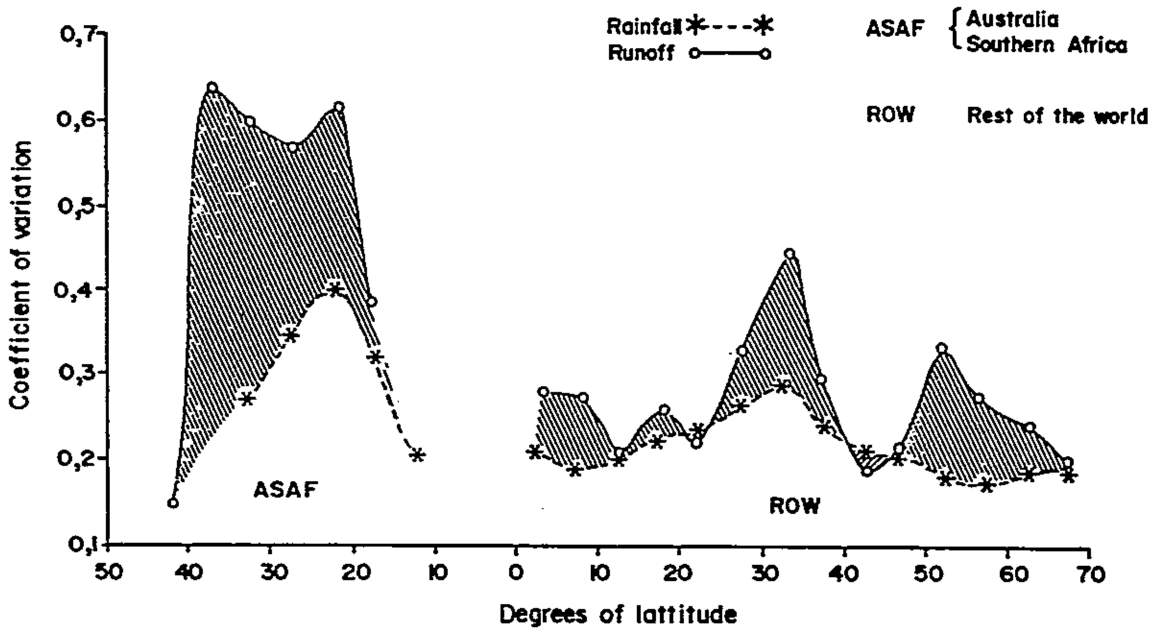

FIGURE 5.6 The distribution of variability of rainfall and runoff by latitude (source: McMahon et al 1987).

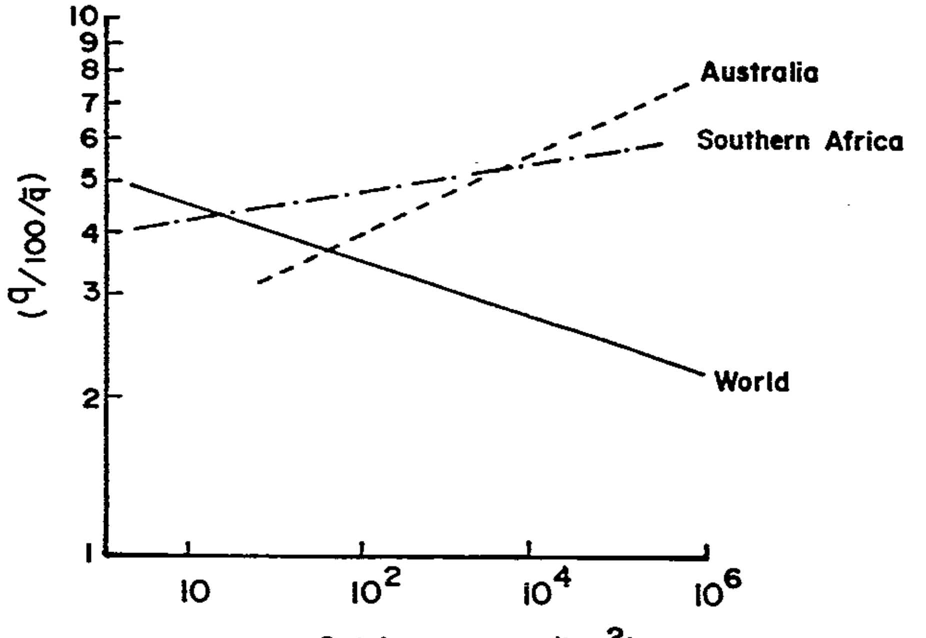

FIGURE 5.7 Relationship between an index of variability of annual peak flows and catchment area for southern Africa, Australia and the world (after McMahon et al 1987).

SOURCES OF HYDROLOGICAL DATA FOR SOUTHERN AFRICA

General comments on data availability

The major rain gauge network in southern Africa is operated by the South African Weather Bureau, whereas the hydrological network (streamflow, reservoir status, evaporation, water quality and sediment) is operated by the Department of Water Affairs. A number of other countries (eg Lesotho, Swaziland), institutions (eg Departments of Agriculture and Environment Affairs, South African Sugar Association) and individuals maintain smaller hydrometereological networks in southern Africa. Climate and streamflow information from many thousands of stations in southern Africa implies mass data handling. Good publications on hydrological data exist and may serve for some studies on long-term trends. Additionally two computerized systems for disseminating hydrological information may be of use. These are described briefly below.

Computing Centre for Water Research (CCWR). The CCWR, established jointly by the Water Research Commission, ISM (Pty) Ltd (formerly IBM) and the University of Natal, is situated at the University of Natal's Pietermaritzburg campus. It acts as an information dissemination system for bona fide researchers in the broad field of water related subjects. Researchers can request inter alia hydrological and climatological data. This is done remotely, through one of several national computer networking facilities, the data being supplied in the format requested by the researcher. One of the major aims of the CCWR is to link researchers to available data banks and to obviate the researchers' themselves having to search for data from a number of collecting agencies, especially as the diverse sources of data are often unknown to the uninitiated researcher. In order to become a CCWR user, contact should be made with: The Manager, CCWR, P O Box 375, Pietermaritzburg 3200.

Hydrological Information System (HIS). The Department of Water Affairs, aided by funding from the Water Research Commission, is presently creating a national Hydrological Information System which will be directly accessible to all data users (not only researchers) throughout South Africa. It will contain information (first level of processing) and/or data on surface and ground water (streamflow, evaporation, submergence, "infilled" streamflow records, weir design and calibration data), reservoir levels, water quality (chemical, sediment and limnological), inventories and station/catchment descriptions. Components of the HIS, such as the streamflow data bank and the monthly evaporation data bank, are already complete and the data files will be constantly updated. For further information on the HIS, contact: The Manager Scientific Services, Department of Water Affairs, Private Bag X313, Pretoria 0001.

Published Data

A ready reference to hydrological data is the recently compiled "Register of South African Hydrological Data Sources" (James and Fuller 1987) of the Water Research Commission which is also available on computer as a data base through the South African Water Information Centre, P O Box 395, Pretoria, 0001. The Department of Water Affairs has published a number of data registers and summaries, including a register by Zietsman and Schutte (1980, to be revised in 1987), decadal summaries of monthly streamflow totals and other related streamflow and reservoir statistics as well as a summary of evaporation records, regular surveys of reservoirs for sediment deposition rates, and a water quality atlas for the Vaal catchment (van Vliet and Nel 1986). The widely used six volume series on "Surface Water Resources of South Africa" by Midgley et al (1981) contains not only summaries of monthly totals of observed streamflow for the catchments used in their synopsis of water resources, but also simulated streamflows for several hundred quarternary catchments, generally for a 55-year period up to 1975, based on the Pitman monthly hydrological simulation model. A very valuable source of past, present and anticipated future trends of water utilization by different major users (eg agriculture, irrigation, afforestation, mining, estuaries etc) is presented in the Department of Water Affairs' recently published seminal document, "Management of Water Resources of the Republic of South Africa" (Department of Water Affairs 1987).

With regard to water quality, a summary of some published data series is presented by Day et al (this volume). The Chemical Data Bank of the Department of Water Affairs is the major source of water quality information in South Africa, and is being incorporated into the HIS at present. Vast amounts of water chemistry data, not yet coordinated, are available inter alia from various water boards, municipalities, the CSIR's Division of Water Technology and the Department of Environment Affairs.

While much progress has been made in recent years in collating and computerizing hydrological data, much coordinating remains to be done especially in the field of water quality data.

TRENDS AND CYCLES IN STREAMFLOW DATA

Relationships exist between streamflow and rainfall for individual catchments and within regions. An example of the typical curvilinear relationship is that for 126 catchments in the humid northern and eastern parts of South Africa (van Biljon et al 1987; Figure 5.5). Streamflow, generally, will follow trends and cycles of rainfall, a topic addressed by Tyson (this volume).

"Cycles"

There is an apparent oscillatory pattern in the smoothed long-term streamflow records for southern African rivers, as is illustrated in Figures 5.8, 5.9, 5.10 and 5.11. The work of Abbott (1976) shows an apparent 20-year periodicity for streamflow from 10 gauging stations in the summer rainfall region (Figure 5.10), while the "cycle" in the southern Cape appears shorter and less distinct.

The issue of rainfall and streamflow cyclicity is still far from established as fact. Considerable research needs to be done on normalized and standardized data sets in southern Africa to confirm or reject the cyclicity of streamflows. The repercussions of using unadjusted data sets in planning for water resources and in studies of estuarine, ecological or other responses may be profound if real changes are not accommodated.

Trends

Pan Evaporation. Midgley et al (1983) suggest that there may be a change in pan evaporation measured at the 70 oldest pan recording stations in South Africa, as shown by the split data figures in Figure 5.2. The figures indicate a positive or negative change in annual evaporation (mm) in the second half of the record as compared with the first. The fact that there is some spatial organization in the changes tends to support the hypothesis that a trend is apparent, which may be related to a climatic trend or cycle, rather than the changes being of a random nature associated with factors at local sites.

Streamflow. Streamflow series may be affected considerably by changes in land use and development in a catchment. These effects may be be shown in long-term double mass plots as gradual or abrupt trends. Figure 5.3 illustrates effects which Braune and Wessels (1981) have identified from annual series of streamflow and rainfall for South Africa, which relate to apparent influences of urbanization, river abstraction, cultivation, soil conservation, farm dams, a larger dam, catchment conservation and afforestation. Because of problems of nonstationarity of many streamflow records, however, considerable caution should be exercised when deducing cause and effect for individual stations. Anthropogenic influences on streamflow series are not always as marked as in the examples shown.

A contentious issue in terms of the trade-off between economic return and water production from a region is the effect afforestation has on streamflow. Increases in biomass in a catchment are likely to reduce streamflow by increasing evapotranspiration losses. The effect of afforestation on streamflow has been widely studied. Bosch (1982) summarizes the findings of South African research to date (Figure 5.12). Decreases in streamflow are greater the higher the proportion of catchment that is afforested, and they vary with different species and in regions.

The increasing area of commercial timber plantations in South Africa is shown in Figure 5.13. The extent of plantations may have had a considerable effect on long-term records of streamflow in the humid, water producing regions of South Africa. Figure 5.14 shows the observed streamflow following afforestation of a small experimental catchment at Cathedral Peak, contrasted with the simulated streamflow assuming no afforestation to have taken place. Quantification of these streamflow reductions in southern Africa is now becoming possible through the development of dynamic process-based hydrological simulation models, such as the ACRU model (Schulze and George 1987).

General comment - a word of caution. Because the streamflow record reflects the influence of developments and land-use changes in catchments, and most catchments in South Africa are undergoing either hydrologically beneficial or detrimental dynamic change, great care will have to be exercised when using historical streamflow data to make prognoses for the future. Anthropogenic trends will have to be separated from natural variability within a complex hydrological system.

THE FUTURE: REQUIREMENTS AND RESEARCH NEEDS

Future research needs with regard to long-term hydrologically related data series may be grouped three-fold into those concerned with data requirements, data analyses and simulation modelling.

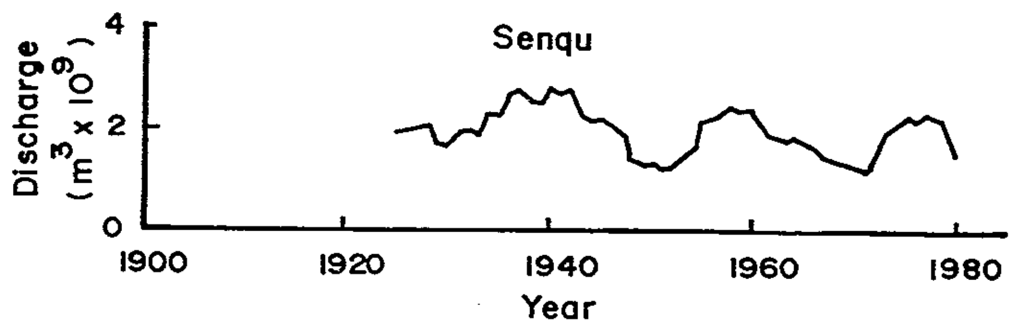

FIGURE 5.8 Seven-year moving average discharge of the Orange River in Lesotho (source: Sutcliffe and Knott 1987).

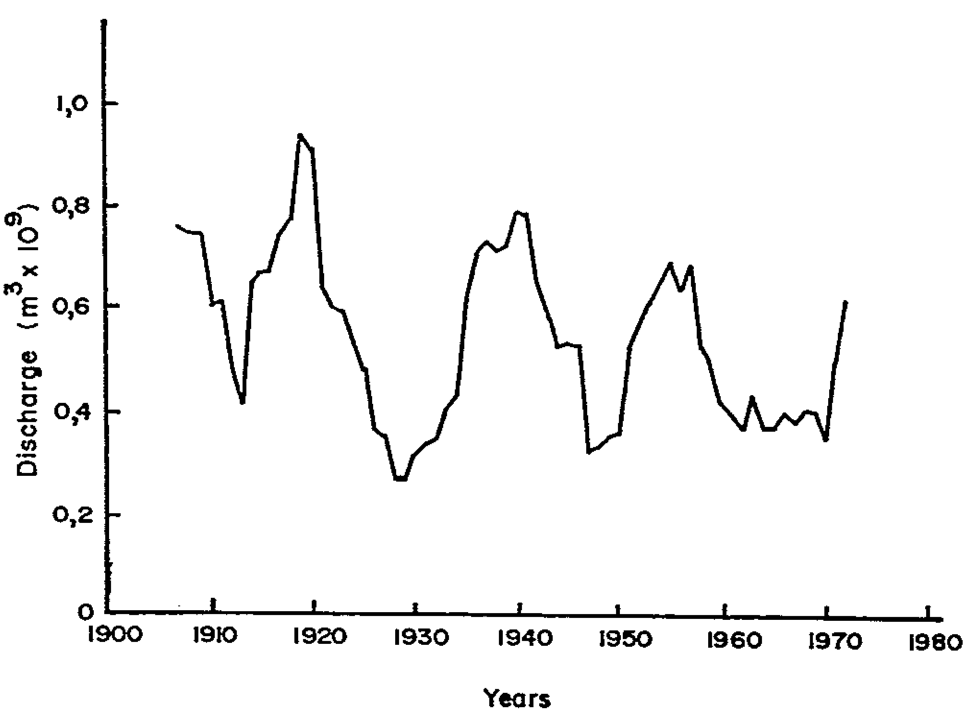

FIGURE 5.9 Seven-year moving average discharge of the Vaal River at Standerton.

Data requirements

In addition to requiring the collection of further data for shortcomings already outlined in this paper (eg the lack of long-term rainfall data from runoff-producing mountain catchments, underdeveloped and arid regions, or sparsity of long-term streamflow data from small catchments in areas whose land uses have not changed with time and which thus exhibit homogeneity of the streamflow record), perhaps the major hydrological data requirement is the collection and standardization of water quality data, both chemical and sediment (an issue already being addressed to some extent by HIS). A further data-need is that of long-term streamflow series in arid and semi-arid catchments which cover large tracts of South Africa.

Data analyses

Many analyses on long-term trends and cycles in data have, to date, been undertaken at the level of annual data, eg time series of annual rainfall, streamflow or evaporation. However, much information is "hidden" on the constituent digitized, daily or monthly data, suggesting future research on data with a finer resolution. Furthermore, research on long-term data sets on an event basis (eg flow patterns, hydrograph shape changes, annual peak discharge responses) is likely to reveal trends which at present have not been identified. More research is also required into variations between regions and between catchments of different magnitudes of periods, amplitudes of oscillation and trends. More attention should be given to the collection and computerization of appropriate statistics on changes in land use of catchments to enable cause and effect analyses to be made with greater certainty. The Geographical Information Systems (GIS) being mounted by the Department of Water Affairs and other institutions are a step in the right direction. Researchers should make use of the HIS and GIS database as well as contributing, through their research, to making data available to these information banks through the CCWR.

Hydrological simulation modelling

Deterministic, cause-and-effect models which simulate realistically the relevant hydrological processes, lags and feedbacks in a dynamic way (ie accommodating gradual or abrupt changes in land use or management over time) must be refined so that their output can be used to make prognoses of future responses to environmentally or anthropogenically induced change. Such models could be used to illustrate which elements of the hydrological system are most sensitive to change, and more detailed data could then be collected on these sensitive elements.

Modelling should preferably be undertaken on three scales:

- firstly, modelling hydrological consequences of global climatic change, eg increasing temperatures/rainfall;

- secondly, modelling large-scale (subcontinental) interactions and feedbacks, eg changing albedos or variations in overpassing air masses, paying particular attention to feedbacks (especially in evapotranspiration) affecting regional water balances; and

- thirdly, modelling, dynamically and for different rates of development, the main anthropogenic hydrological impacts (some of which are unique to southern Africa), such as effects of afforestation, construction of large or small dams, other agricultural land-use conversions, irrigation and related return flows. Also requiring modelling are socio-economic scenarios of the third world such as high-density low cost housing, informal sector peri-urban development, and first world urbanization and associated industrial growth, including phosphorous loadings and sediment deliveries.

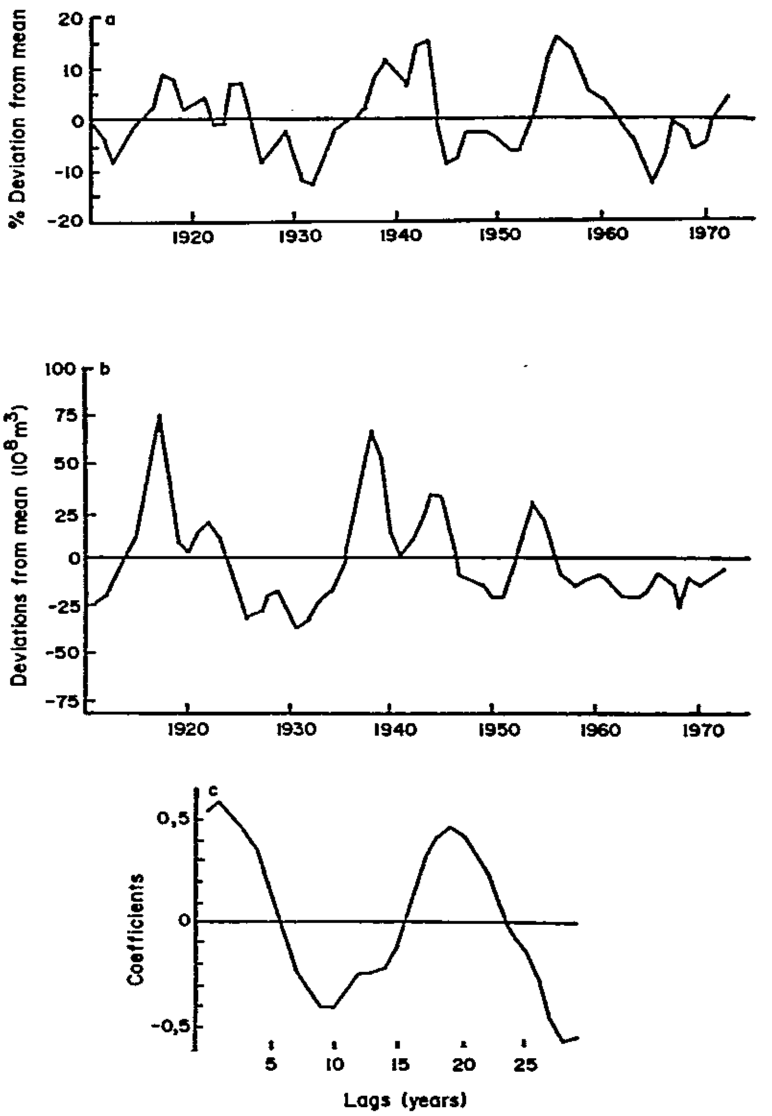

FIGURE 5.10 Correlation between smoothed rainfall deviations and smoothed runoff deviations for the Komati River showing a 20-year period (Abbott 1976).

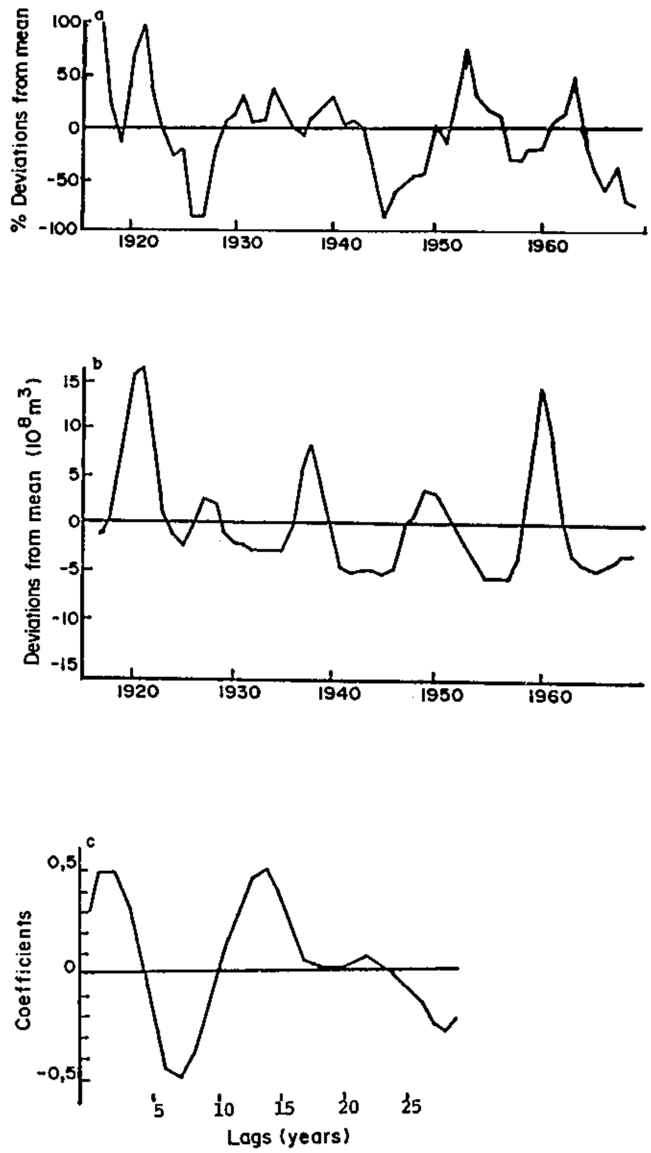

FIGURE 5.11 Correlation between smoothed rainfall deviations and smoothed runoff deviations for the Groot River showing a 10- to 15-year period (Abbott 1976).

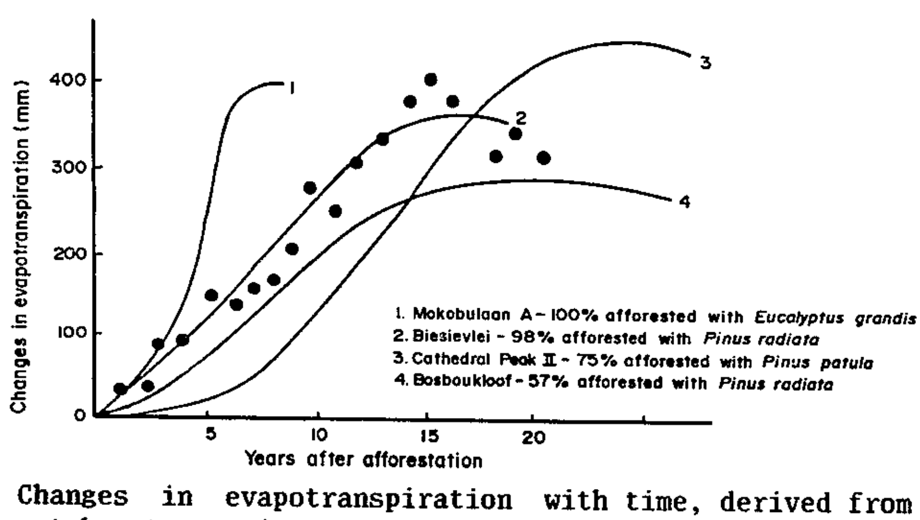

FIGURE 5.12 Changes in evapotranspiration with time, derived from four catchment experiments in South Africa (Bosch 1982).

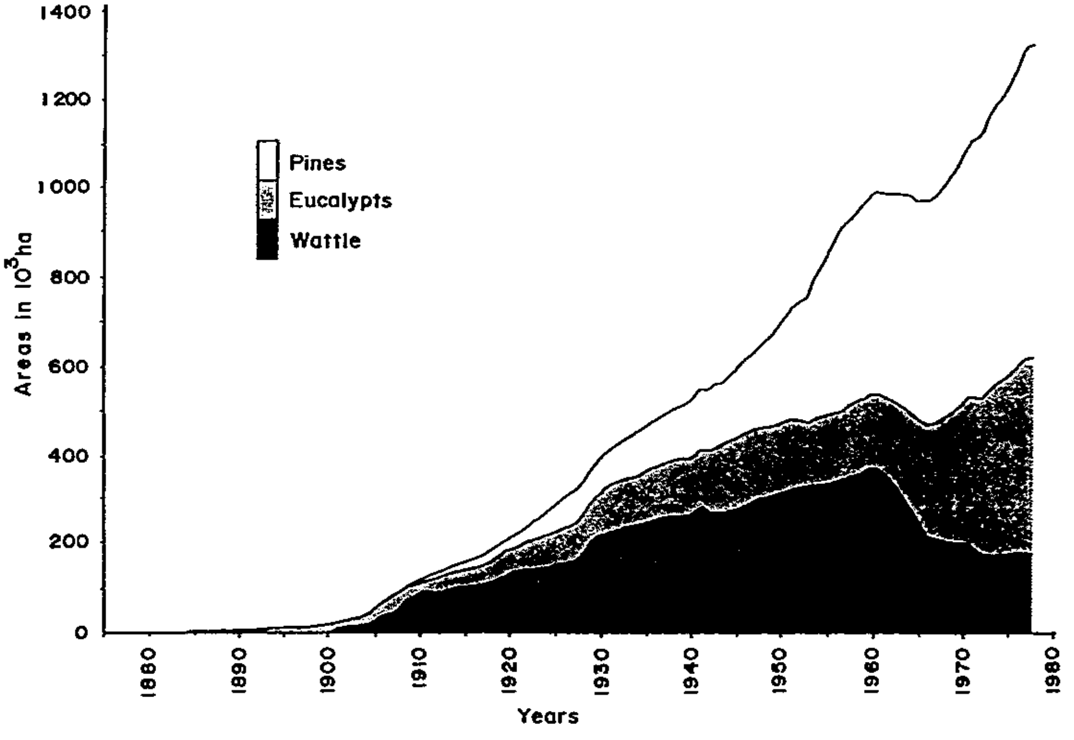

FIGURE 5.13 Trends in the extent of commercial timber plantations in southern Africa (van der Zel and Brink 1980).

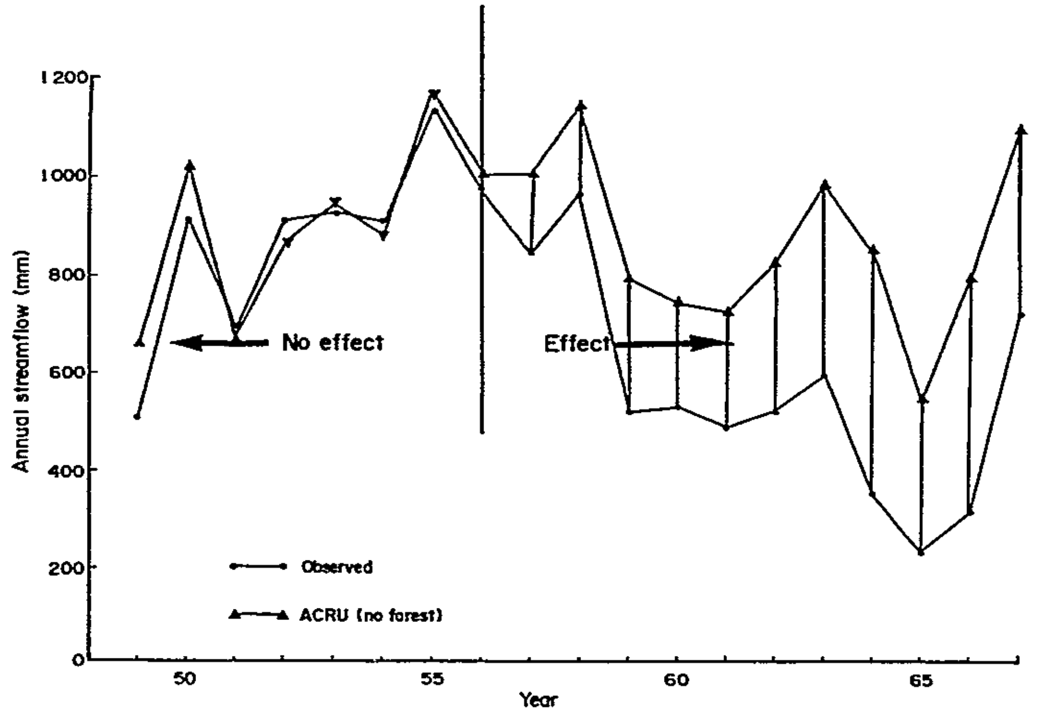

FIGURE 5.14 Observed annual water yield from Cathedral Peak experimental Catchment II afforested with *Pinus patula* in 1951 and 1952, and simulated water yield assuming no afforestation had taken place (Schulze and George 1987).

CONCLUSION

To a large degree the future economic development of South Africa is linked closely to the availability of water, a sparse and unevenly distributed natural resource, the quality of which has already deteriorated considerably in many areas of the country through urban, peri-urban, industrial and agricultural development. To this end the role of the hydrological system, as a natural "supplier" of water, as a sensitive respondent to anthropogenic influences and as a "carrier" and driving force of other systems (eg inland water ecosystems and estuaries), lies at the heart of the concern for southern Africa's renewable natural resources. Hydrological long-term data series will play a vital role in assessing important aspects of these renewable resources.

REFERENCES

Abbott M A 1976. The temporal and spatial variation of rainfall runoff for selected locations. The Wits Geographer 3, 85-102.

Adamson D T 1986. The South African Rainfall Database: a user guide. Department of Water Affairs, Durban.

Bosch J M 1982. Streamflow response to catchment management in South Africa. In: Hydrological research basins and their use in water resource planning. Proceedings of the international symposium held in Berne, Switzerland. September 1982, Vol 2, 279-289. Landeshyrologie, Berne.

Braune E and Wessels H P P 1981. Effects of land use on runoff from catchments and yield from present and future storage. In: Maaron H (editor) Workshop on the effect of rural land use and catchment management on water resources. Department of Water Affairs, Pretoria, TR113, 133-187.

Department of Water Affairs 1987. Management of the water resources of the Republic of South Africa. Department of Water Affairs, Pretoria.

Department of Water Affairs, Division of Hydrology 1981. List of hydrological gauging stations. Hydrological Information, Publication No 12. Department of Water Affairs, Pretoria.

James A G and Fuller H L M (compilers) 1987. Register of South African Hydrological Data Source. CSIR - South African Water Information Centre, Pretoria.

Lynch S D and Dent M C 1987. Appropriate record lengths for the estimation of mean annual and mean monthly precipitation in South Africa. In: Proceedings, Hydrological Sciences Symposium, Vol 1. Hydrological Research Unit, Rhodes University, Grahamstown. pp 50-61.

McMahon T A, Finlayson B L, Haines A and Srikanthan R 1987. Run-off variability: a global perspective. In: The influence of climate change and climatic variability on the hydrological regime and water resources. Proceedings of the Vancouver Symposium, IAHS Publication No 168, 3-11.

Midgley D C, Pitman W V and Middleton B J 1981. Surface Water Resources of South Africa. Hydrological Research Unit, University of the Witwatersrand, Johannesburg. HRU volumes 8/81-13/81.

Midgley D C, Pitman W V and Middleton B J 1983. Addendum to "Surface Water Resources of South Africa". Water Research Commission, Pretoria.

Schulze R E and George W J 1987. Simulation of the effects of forest growth on water yield with a dynamic process-based user model. In: Forest Hydrology and Watershed Management, Proceedings of the Vancouver Symposium, IAHS Publication No 167, 575-584.

Sutcliffe J V and Knott D G 1987. Historical variations in African water resources. In: The influence of climate change and climatic variability on the hydrologic regime and water resources. Proceedings of the Vancouver Symposium, IAHS Publication No 167, 463-475.

Van Biljon S, Cornelius F P and Moore K J 1987. Regionalization of statistical parameters in water resources analysis. In: Proceedings, Hydrological Sciences Symposium, Vol 1. Hydrological Research Unit, Rhodes University, Grahamstown. pp 479-499.

Van der Zel D W and Brink A J 1980. Die geskiedenis van bosbou in Suider-Afrika. Deel II: Plantasiebosbou. South African Forestry Journal 115, 17-27.

Van Vliet H R and Nel U 1986. Surface water quality of South Africa. The Vaal River catchment: 1979-1983. TR131, Department of Water Affairs, Pretoria.

Zietsman D and Schutte J 1980. The availibility of hydrological data. Department of Water Affairs, Pretoria.

ESTUARIES

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WORKING GROUP MEMBERS: F P Anderson, J S de Wet and K Esterhuysen

RATIONALE

The estuary is seen as the interface between the catchment and river on the one hand and the nearshore coastal region on the other. This estuarine region is dynamic and derives its character from the relative magnitude of forces acting upon it across the interface boundaries.

ORIGINS AND MODERN FEATURES

Estuaries should be looked at against a geological time setting, with major datum points being the sea level low about 18 000 BP and the last sea level high, about three metres above mean sea level (MSL), about 10 000 to 4 000 BP. The estuaries of South Africa were formed during this long period principally by the drowning of river valleys with the rise in sea level. Their evolution during this period depended upon topographical features including catchment area, height of source river, river gradient, presence or absence of a coastal plain, conditions of the mouth (spit/bar/barrier type etc) and sediment yield of the catchment, and on hydrology, in particular the quantity and nature of runoff.

Experience with these features allows classification of estuaries into at least three principal groups:

1) estuaries with a tidal prism (estuaries *sensu stricto*);

2) river mouths where there is no intrusion of sea water largely as a result of flow silting and sedimentation, eg the Tugela and Orange Rivers; and

3) lagoons with mouths that are seasonally open or closed, leading to those which are mainly closed as in the Bot River Lagoon, and the final developmental stages of coastal lakes, eg Lake Sibaya.

The development of this classification is largely the consequence of net sediment influx during the Holocene to the present day. This influx represents infilling from both land and sea, sediments derived from the sea being found on average within one kilometre of the mouth. The origin of sediments vary along the coast line: the Natal estuaries are dominated by fluviatile sediments, whereas many estuaries of the eastern, southern and south-western Cape have pronounced sand-infills from the sea. This variation underlines the importance of recognizing that sediments of terrestrial origin are not always a prime factor in estuarine sedimentation.

While the above groupings of estuaries describes the results of long-term changes, the episodic nature of river flow and flooding and variation in sand transport by longshore currents can cause an estuary *sensu stricto* to change into a river mouth during a single flood event, or close gradually as the sand bar increases in width and height above MSL. It is this essentially dynamic (or unstable) nature of our estuaries which makes any rigid system of classification unrealistic. Nevertheless, studies of the biological structure of estuaries and lagoons since 1948 have established a framework which is useful in describing the effect of varying sea and freshwater inputs on community diversity. Estuaries in which there is a measurable tidal prism exhibit a diverse marine euryhaline component. As salinity decreases with an increase in lagoon conditions, only those species which can withstand salinities less than $3^{\circ}/_{\circ\circ}$ for extended periods of time survive. This is a restricted group so that biological diversity falls.

FACTORS RESPONSIBLE FOR CHANGE AND BIOLOGICAL RESPONSES

Two factors responsible for change in estuarine systems have been identified as being of primary importance, namely:

- increased rate of infilling as a consequence of man-made changes in the catchment; and
- degradation within the estuarine environment due directly to the activities of man, eg floodplain development, bridges, discharge of industrial effluent and domestic sewage.

Current studies suggest that it is possible to derive an equilibrium slope for any given river system by using stream power concepts associated with river runoff. The downstream reaches of most of our rivers are steeper than the theoretical equilibrium slope, and as a consequence sediment deposition takes place as a natural process in the lower reaches of our rivers. This is not a continuous process but occurs in fits and starts. Depending on the magnitude of the floods, either accretion or mostly erosion would take place. So, for example, the lower reaches of the Mfolozi were scoured out to a depth greater than 15 m during the 1984 Domoina floods, only to be filled in again afterwards. On the other hand, in the September/October 1987 floods, the Mvoti, normally a 40 m wide stream, became between 400 and 700 m wide, but surveys within one week of the floods showed that the only bed level differences occurred in the mouth where depths were one metre deeper than before the flood.

The degree to which siltation takes place in the lower reaches of the rivers is also influenced by the sediment yield from the catchment. Figures on the influence of man on this yield vary but it is agreed that catchment malpractices can increase the sediment yield substantially. This will accelerate the siltation process. Obviously, as has happened in the Orange River, a stage can be reached where the top soil is denuded, and the yield will start dropping again. Sediment yield is also greater during a flood following a dry phase, than following a wet phase.

The net effect of this long-term siltation of our estuarine reaches is that eventually the tidal prism is affected, the bed levels are raised to above MSL and the estuary changes its classification as described above. The magnitude and mechanism of this process is the subject of a current study by Badenhorst of DEMAST/CSIR on the estuaries of Natal.

Input of fluvial sediments to estuaries is dependent on river flow. An analysis was made of available gauging data. In the case of 73 Natal rivers, only eight have gauging stations within 20 kms of the sea. This makes it extremely difficult to evaluate riverine inflow into the estuaries. In an effort to overcome this, the then National Research Institute for Oceanology, now part of the Division of Earth, Marine and Atmospheric Science and Technology (DEMAST), of the CSIR has compiled simulated runoff data on a monthly basis for the period 1921 to 1975, using data contained in Middleton et al (1981). Initially this was only done for Natal but it has now also been done for the Cape Province, excluding Transkei and Ciskei. Figure 5.15 shows a typical result of the simulated runoffs. Other outputs, including tabular representations, are also available.

The data in Figure 5.15 exhibit a highly erratic nature, with a high coefficient of variance. Monthly runoff exceeded 50% of the mean annual runoff for 11 individual months and once exceeded the mean annual runoff during the 55-year period. Although the degree of erraticism is greater in Natal that on the rest of the coastline, this figure is fairly representative of the riverine inflows into our estuaries.

As far as the wave driven sediment influx into estuary mouths is concerned, the best long-term data source is the dredging figures for Cave Rock Bight just south of Durban harbour, which cover the period 1903 to the present and show a large variability in the volume of material dredged from the sand trap (Figure 5.16). It has been shown (Campbell et al 1985) that the dredged volume is representative of the net north-bound longshore transport potential. Swart (1988) correlates the annual longshore transport potential with the annual runoff, on a three-yearly average basis, and concludes that there is a strong correlation between the patterns of magnitude of littoral drift and rainfall and runoff. This has significant implications for the stability of estuary mouths.

Perry (1982) performed a photo-interpretation/hydrological study of estuaries in Natal. Aerial photographs from the 1930's to the present were used together with simulated runoff data referred to earlier. Thirty systems have been studied in detail to date.

The biological structure of estuaries has been analysed numerically by Begg (1984a), who compiled a biotic index for Natal "estuaries" based on routine, regular biological sampling over a three-year period. The Division of Water Technology (DWT) of the CSIR, through Dr A E L Ramm's Estuarine and Coastal Processes Programme is continuing the biological sampling, firstly with an aim to extending Begg's data from a dry phase into a wet phase, and secondly to concentrating similar measurements on 15 selected key systems in Natal. Begg's data set, the original of which is on computer at the Oceanographic Research Institute (ORI) in Durban, with the extensions being undertaken by Ramm's group, constitute the best long-term data set on biota in estuaries.

Scientists at the Universities of Port Elizabeth, Rhodes and Cape Town have conducted quantitative biological research in selected estuarine systems. Taken together, these new sources of data will give clearer insight into the magnitude of change. Apart from these studies, estuaries hit by episodic events are also surveyed. For example, seven estuaries in the southern Cape were surveyed after the floods of August 1986 and, in a collaborative effort between the CSIR and the Universities of Natal and Port Elizabeth, a number of Natal estuaries are being surveyed at present, following the disastrous floods of September 1987.

PREDICTIVE CAPABILITY

The sedimentary deposits beneath present-day estuarine supratidal flats represent important historical records of estuarine, fluvial and shoreline trends during the past few tens of thousands of years. Systematic analysis of this record is possible by means of borehole data. The stratigraphic cores obtained from boreholes contain the chronologic record of events which took place in the estuary, and the reconstruction of these events is based on the interpretation of data derived from series of borehole cores. The nature of the sediment data is such that information from a single borehole may be ambiguous and insufficient for the reliable reconstruction of the local geochronology. Series of boreholes allow for improved reconstruction of historical events.

Such information can form the basis for a reliable long-term data series applicable to climatic changes, frequency of fluvial floods and cycles, sea level changes, and other related environmental changes in the coastal zone.

Data sets of this type have the advantage that a long time-span can be covered, thereby improving our sensitivity in recognizing systematic trends. However, the system suffers from incompleteness of the stratigraphic record in the sense that erosion can permanently destroy part of the record. Secondly, whereas it is rather simple to recognize the temporal sequence of events in a single record, and thereby reconstruct a sequence of events, the actual dating of the events may be problematic. Several methods of age-dating are available whereby certain compounds in estuarine sediments can be dated with reasonable accuracy (Esterhuysen and Rust this volume).

The 'Rosie' programmes of the University of Port Elizabeth have provided an important stratigraphic record of a number of estuaries on the south east coast, notably Swartkops.

The question "is modelling practical?" in the sense of providing a predictive tool with which to assess the effects of artificially reduced river discharge has been addressed by J S V Reddering of the University of Port Elizabeth (Reddering this volume). The solution suggested lies in the calibration of such mathematical models for priority catchment basins. This implies an adequate spread of rainfall runoff stations coupled with a gauging weir as near to the head of the estuary as possible. The effect of dams upon the flood hydrograph will be of equal importance.

Complementing such studies is the proposed monitoring by the Continuous Low-level Environmental Observation (CLEO) programme. This is being developed by the estuaries committee of SANCOR. Because there are about 300 estuaries along the seaboard it is not possible to routinely keep track of what is happening in all. It is intended that a number, about 50, of key estuaries should be selected on the basis of of their representativeness (or not) for investigation of CLEO observations. Routine forms have been compiled (see Tables 5.4 and 5,5) and are being tested for feasibility at present.

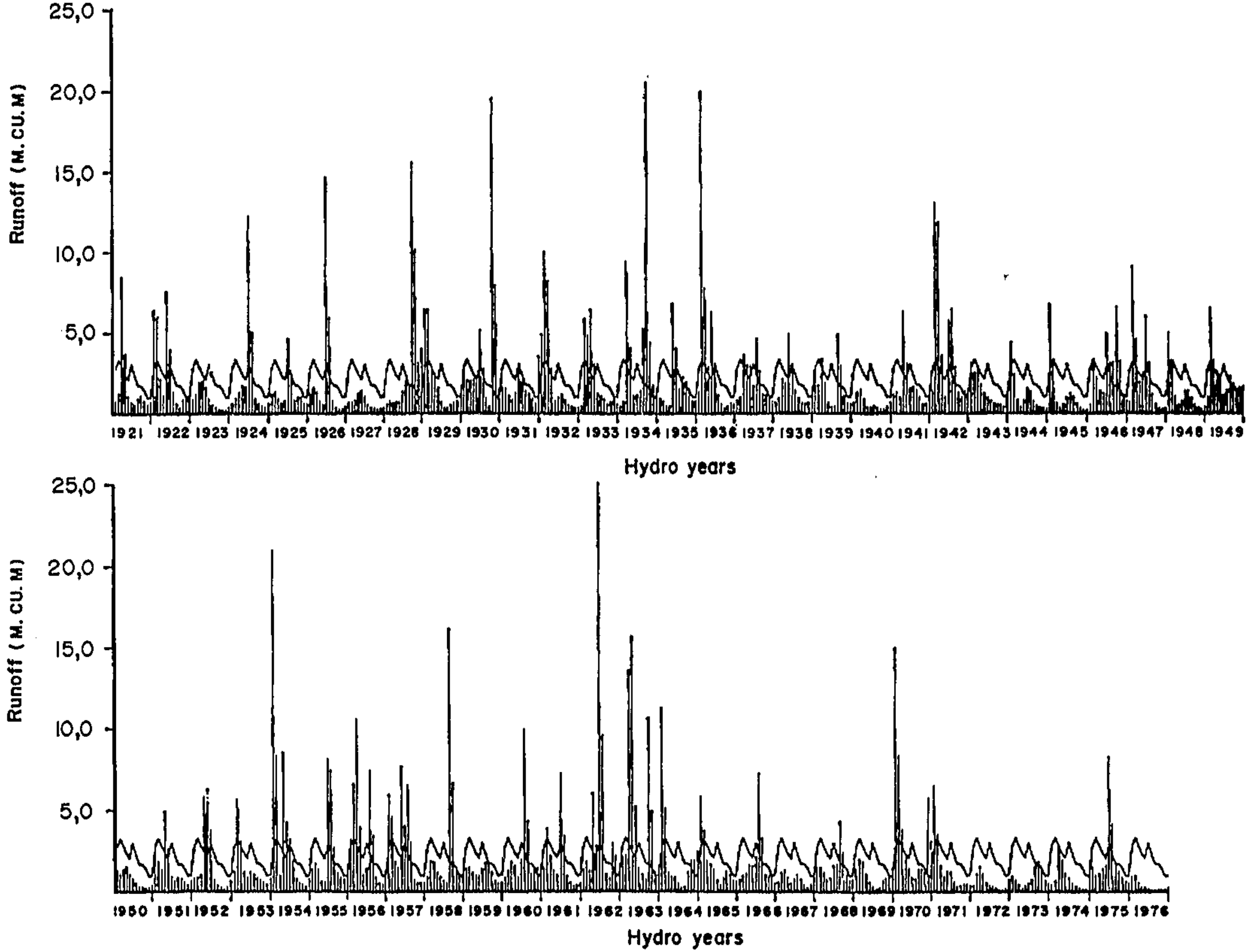

FIGURE 5.15 Simulated monthly runoff for the Mpenjati River, Natal from 1921 to 1976.

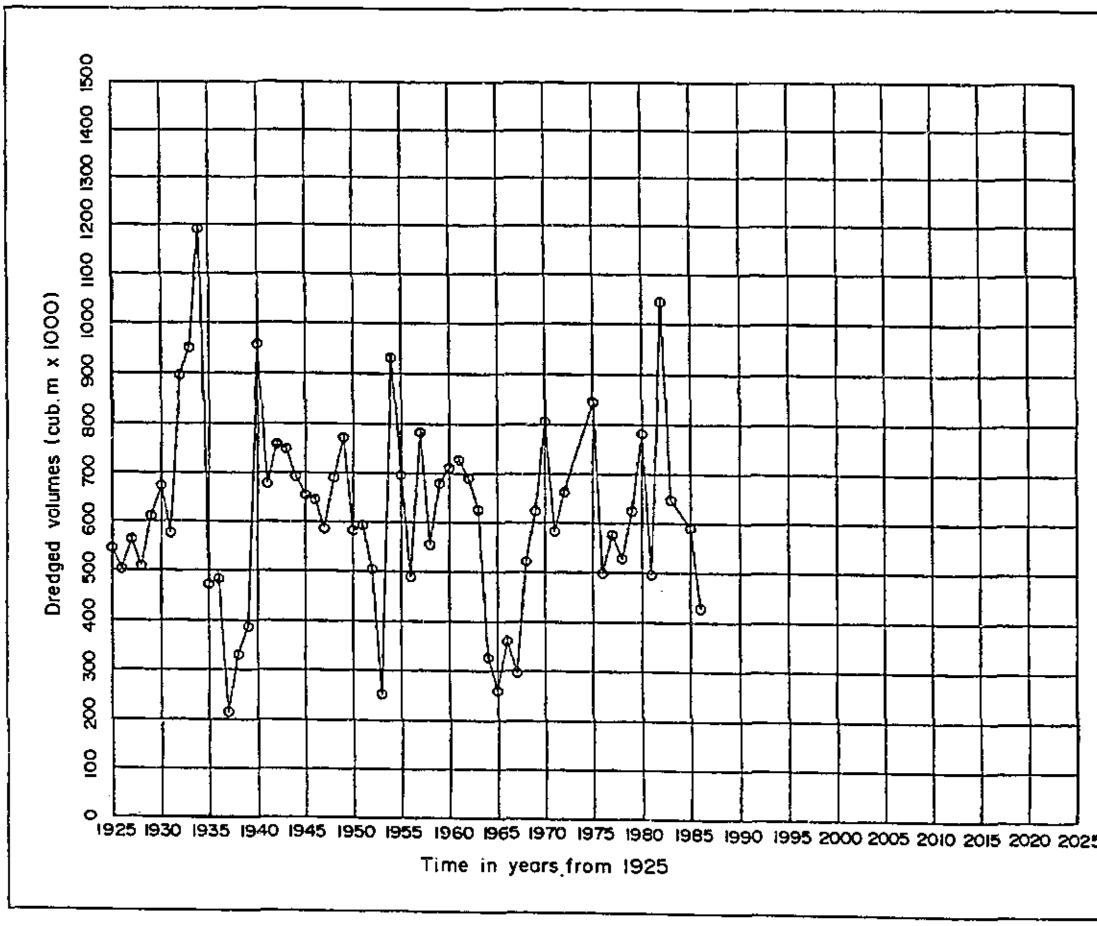

FIGURE 5.16 Annual volumes of sediment dredged from the Cave Rock Bite near Durban.

It is not the intention to claim that the CLEO Programme is research. It is a routine monitoring programme which is aimed at giving background information for research projects and which can serve to quantify the effect of episodic events if and when these occur. The working group looking into CLEO have identified the fact that estuaries form but an interface between the catchment/river and the coast/dunes and one of their preliminary recommendations is that CLEO should also be initiated for beaches, catchments and dunes. CLEO beach observations are being initiated on 30 Natal beaches late this year.

On the basis of the variability of runoff and littoral drift, (eg data in Figures 5.15 and 5.16), one must accept that estuaries are going to vary cyclically with a periodicity of five to 15 years, over and above any long-term trends due to the geophysical factors and human use of land.

Any data sets which are to be representative of the processes operative in an estuarine system, whether they be biological or physical, should really extend over the complete cycle, about 10 years. No data set exists at present which meets this criterion.

LINKED FACTORS WITH ESTUARINE RESPONSES

Factors linked with estuarine responses include hydrological data obtained from rivers near to the head of the estuary which reflect climatic change and changes in wave climate, longshore drift and sea level fluctuations.

AVAILABLE DATA

From the above it is apparent that not many long-term data are available. Data sources which could, however, prove useful are:

- the ORI data set on biological sampling of 61 Natal rivers, covering three years;
- the DWT/CSIR extension to this data set;
- simulated monthly runoff data from 1921 to 1975, as held at DEMAST/CSIR for all South African rivers;
- aerial photographs for all South African rivers, dating back to the 1930's, held at DEMAST/CSIR;
- Begg's "Estuaries of Natal" and the addendum thereto (Begg 1978, 1984a) as well as Begg's thesis (Begg 1984b);
- the data reports on follow-up monitoring in the DWT/CSIR series;
- Day's (1981) "Estuarine Ecology";
- the Rosie Reports, University of Port Elizabeth;
- the report of Allanson and Read (1987);
- the DEMAST/CSIR data reports on photo-interpretation of Natal's estuaries;
- the DEMAST/CSIR ECRU Reports on the synthesis of Cape estuaries, and related data reports on photo-interpretation and physical sedimentary processes;
- the bibliography of Allanson and Whitfield (1986) of estuarine research in South Africa, which should be expanded to include the "grey" literature;
- SANCOR documents on the agreed state of estuaries in the Cape and Natal.

CONCLUSIONS

The main driving forces which affect the fate of estuaries are hydrology, land-use practices in the catchment and in the estuarine flood plain and littoral, wave-driven motions of water and sediment.

Table 5.4

CLEO ESTUARIES
RECORDING SHEET
ABNEY LEVEL

CLEO-11

Space for Rough Notes

I. SITE NUMBER

1	2	3	4	5	6	7

II. DATE

DAY		MONTH		YEAR	
1	2	3	4	5	6

III. TIME in 24hr system

START					END				
1	2		3	4	5	6		7	8
		h					h		

IV. MOUTH CONDITION

Record state of mouth:
1 - Open
2 - Closed

1

Record whether mouth cross-section is:
1 - Widening
2 - Narrowing
3 - Stable

2

Refer to Fig.1 in plasic cover with kit and indicate type of mouth configuration:

3

Record whether mouth is slowly migrating:
1 - To left
2 - To right
3 - Stationary
(Facing sea)

4

If mouth is closed, record height at which horizon can just be seen accross narrowest point of sandbar:
(Too high: 9,9)

5		6
	,	

V. MOUTH DIMENSIONS

Record best estimate of width of mouth at its narrowest section:
(In metres)

1	2	3

Record best estimate of deepest water depth at narrowest section relative to mid tide level:
(To nearest 0,1 m)

4	5		6
		,	

Record best estimate of deepest point in narrowest section:
1 - First third
2 - Centre
3 - Far third

7

VI. FLOW VELOCITY

Note down direction in which ball moves:
1 - Seaward
2 - Inland

1

Record distance covered by ball during 30 seconds:
(In metres)

2	3	4

Record position in mouth where ball travelled:
1 - First third
2 - Center
3 - Far third

5

VII. HORIZON: REFERENCE POINT

Record vertical angle to the horizon from the reference beacon:
(To the nearest 5 min.)

	DEG.		MIN.	
	1	2	3	4
START:				
	5	6	7	8
END:				

VIII. VERTICAL REFERENCE DISTANCE

Record the vertical distance between bottom of the plate on the reference beacon and the mark (1 m above sand level) on the up-profile sighting rod, in cm to the nearest cm:

1	2	3

IX. MOUTH PROFILE OPPOSITE REFERENCE BEACON

POINT		VERTICAL ANGLE DEG.		VERTICAL ANGLE MIN.		DISTANCE		DESCRIPTION *	COMMENTS
1	2	3	4	5	6	7	8	9	10
0	1								
0	2								
0	3								
0	4								
0	5								
0	6								
0	7								
0	8								
0	9								
1	0								

* DESCRIPTION:
1 - Normal point
2 - Edge of water; upper sight
3 - Edge of water; lower sight
4 - Edge of water; opposite site

X. POSITION OF NARROWEST SECTION

Record number of paces from reference beacon in metres:

1	2	3

Record position relative to the reference beacon:
1 - Seaward
2 - Inland

4

XI. MOUTH PROFILE AT NARROWEST MOUTH SECTION

POINT		VERTICAL ANGLE DEG.		VERTICAL ANGLE MIN.		DISTANCE		DESCRIPTION *	COMMENTS
1	2	3	4	5	6	7	8	9	10
0	1								
0	2								
0	3								
0	4								

* DESCRIPTION:
1 - Normal point
2 - Edge of water; upper sight
3 - Edge of water; lower sight
4 - Edge of water; opposite site

Table 5.5

CLEO ESTUARIES
RECORDING SHEET

CLEO-12

Space for Rough Notes

I. SITE NUMBER

1	2	3	4	5	6	7

II. DATE

DAY		MONTH		YEAR	
1	2	3	4	5	6

III. TIME in 24hr system

START					END				
1	2		3	4	5	6		7	8
		h					h		

XII. TIDE

Note down relative state of tide:

1 - QUARTER ?
2 - MID ?
3 - THREE-QUARTER ?
4 - HIGH ?

1

Is the tide:

1 - RISING ?
2 - FALLING ?
3 - STATIONARY ?

2

XIII. WIND

Wind Speed:

RECORD WIND SPEED IN MPH (IF CALM, RECORD 0)

	1	2
BEST AVERAGE:		

	3	4
HIGHEST GUST:		

Wind Direction:

RECORD WIND DIRECTION TO NEAREST 5 DEGREES.

5	6	7

XIV. SAND SAMPLE

DURING FIRST OBSERVATION EVERY MONTH A SAND SAMPLE SHOULD BE COLLECTED AT THE WATER'S EDGE AND PLACED IN A PLASTIC BAG.

- MARK BAG WITH DATE.
- KEEP TILL THE CLEO OFFICER VISITS YOU.

WAS A SAMPLE TAKEN ?
1 - YES
0 - NO

1

XV. WATER LEVEL

RECORD WATER LEVEL AT BENCHMARK.

(TO NEAREST 5 cm)

m		cm	
1	2	3	4

XVI. WATER COLOUR

RECORD NUMBER OPPOSITE COLOUR ON CHART IN FIG. 3 IN PLASTIC COVER WITH LID WHICH COMPARES BEST WITH A WATER SAMPLE VIEWED LENGTHWISE THROUGH TEST TUBE.

1	2

XVII. WATER TURBITY

RECORD SECCI-DISC READING.

(IN cm)

1	2	3

XVIII. WATER SALINITY

DURING FIRST OBSERVATION EACH MONTH, TAKE A WATER SAMPLE IN SUPPLIED PLASTIC CONTAINER.

- MARK CONTAINER WITH DATE.
- KEEP TILL THE CLEO OFFICER VISIT YOU.

WAS A SAMPLE TAKEN ?
1 - YES
0 - NO

1

XIX. COMMENTS

Observation Site is located on:

1 - LEFT BANK
2 - RIGHT BANK

1

Was a Photograph taken ?

1 - YES
0 - NO

2

PLEASE PRINT

PLEASE CHECK FORM FOR COMPLETENESS

SITE NAME: ______________________

REMARKS: ______________________

OBSERVER : ______________________

Make any ADDITIONAL REMARKS, COMPUTATIONS or SKETCHES on the REVERSE SIDE of this form, or in the SPACE FOR ROUGH NOTES

Future research should have two main aims, namely:

1) To establish a continuous low-level monitoring programme in estuaries and the related catchment and coastal areas which will supply background data on the basic driving forces.

2) Directed, fundamental research aimed at quantifying the effect of each of the driving forces and interactions between them, as well as the actual processes involved. This includes biological, chemical, physical, geological, hydrological and sedimentological research. It will supply the reasons for monitored changes. Such research is being undertaken at various locations around the country, but due cognizance needs to be given to the time frame of variability in estuaries when designing new experiments.

ACKNOWLEDGEMENTS

The authors wish to thank Messrs D W H Cousens of the Water Research Commission and E Braune and H Maaron of the Department of Water Affairs for their helpful suggestions they made when reviewing this paper, and for providing information on hydrological data sources. They would also like to thank Mesdames C O'Mahoney, M Maharaj and P Emslie for preparing the diagrams.

REFERENCES

Allanson B R and Whitfield A K 1986. A bibliography of South African estuarine research (1950-1984). Institute for Freshwater Studies, Rhodes University, Grahamstown.

Allanson B R and Read G H L 1987. The response of estuaries along the south-eastern coast of southern Africa to marked variation in freshwater inflow. Institute for Freshwater Studies, Rhodes University, Grahamstown. Special Report No 2/87.

Begg G W 1978. The Estuaries of Natal. Natal Town and Regional Planning Commission Report. Vol 41.

Begg G W 1984a. The Estuaries of Natal, Part 2. Natal Town and Regional Planning Commission Report. Vol 55.

Begg G W 1984b. The comparative ecology of Natal's smaller estuaries. Natal Town and Regional Planning Commission Report. Vol 62.

Campbell N P, Macleod D C and Swart D H 1985. Bypassing and beach nourishment scheme at Durban. Proceedings of the 26th Permanent International Associations of Navigation Congresses, Brussels, Belgium.

Day J H 1981. Estuarine ecology with particular reference to southern Africa. A A Balkema, Cape Town.

Middleton B J, Lorentz S A, Pitman W V and Midgley D C 1981. Surface water resources of South Africa. Vol 5. Hydrological Research Unit Report No 12/81.

Perry J E 1982. The estuaries of Natal: A method of classification. Proceedings of the 18th International Conference on Coastal Engineering, Cape Town.

Swart D H 1988. Durban Beach Bypassing Scheme - long-term trends. Internal CSIR publication.

STRATIGRAPHIC BOREHOLE DATA FROM THE LOWER SWARTKOPS ESTUARY, PORT ELIZABETH

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INTRODUCTION

The sedimentary deposits beneath present day estuarine supratidal flats represent important historical records of estuarine, fluvial and shoreline trends during the past few tens of thousands of years. Systematic analysis of this record is possible by means of borehole data. The stratigraphic core obtained from boreholes contains the chronologic record of events which took place in the estuary, and the reconstruction of these events is based on the interpretation of data derived from series of borehole cores. The nature of the sediment data is such that information from a single borehole may be ambiguous and insufficient for the reliable reconstruction of the local geochronology. Series of boreholes allow for improved reconstruction of historical events.

Such information can form the basis for a reliable long-term data series applicable to climatic changes, frequency of fluvial floods and cycles, sea level changes, and other related environmental changes in the coastal zone.

Data sets of this type have the advantage that a long time-span can be covered, thereby improving our sensitivity in recognizing systematic trends. However, the system suffers from incompleteness of the stratigraphic record in the sense that erosion can permanently destroy part of the record. Secondly, whereas it is rather simple to recognize the temporal sequence of events in a single record, and thereby reconstruct a sequence of events, the actual dating of the events may be problematic. Several methods of age dating are available whereby certain compounds in estuarine sediments can be dated with reasonable accuracy.

TECHNIQUES

As a first experiment a single section line was selected across the lower Swartkops estuary in an area where interpretation of aerial photographs indicated that it might cross an abandoned channel of the Swartkops estuary. Vibracore holes were initially sunk at intervals of about 100 m (later at spacings as little as 25 m in places) and the positions surveyed accurately. Vibracore technique consists of driving a thin-walled aluminium tube (100 mm in diameter) vertically into the sediment as far as it will go and then extracting the sediment-filled tube. The driving force is a suitably modified concrete vibrator. The core pipe and the sediment inside are split in half lengthwise, thereby exposing all the various layers from top to bottom. Invariably the layers are somewhat compressed in the process of vibracoring but some corrections can be applied to reduce these effects of compaction. Also, depending on the consistency of the sediment, original structures, bedding features and other primary features may be somewhat distorted. Experienced operators normally make allowances for such distortions in logging and interpreting the sedimentary record.

Once split the core is logged in detail and sampled as required. Usually an epoxy-peel is made producing a permanent tangible record of the core which can be studied further in a variety of ways. Items which receive special attention in logging the cores include grain size, grain composition with emphasis on biogenic material, types of primary bedform structures, such as cross-bedding, ripple marks etc, type of bedding contact, and type of biogenic burrows.

The main significance of these items is as follows:

The grain size is an indicator of the energy level during sedimentation. Gravel and shell gravel indicate fairly high current velocities during deposition, whereas mud indicates sedimentation in sheltered areas or sedimentation during times of very low flow velocity. Due to the nature of the rocks and soils exposed in the catchment area some estuaries accumulate predominantly sandy sediment whereas others produce mostly muddy sediment.

Grain composition is a composite indicator reflecting the interplay between fluvial-produced and marine-produced material. A very important component is biogenically produced debris - mostly fragments of shells and calcareous algae, plant debris, tests of microorganisms etc. The biogenic material is a very sensitive indicator of the dominance of fluvial, marine or estuarine influence on the area as a whole. It is highly significant, for instance, to differentiate between articulated shells which are found in situ and articulated shells which have been transported. In addition, some biogenic components are exclusive indicators of subenvironments of the estuarine area, whereas other components are exclusively of marine derivation. It is possible by means of analysis of biogenic debris in shell gravels to determine the likelihood that they were produced by fluvial flood action or by barrier overwash following storm waves.

Primary bedform structures are significant parameters which yield information on current types and directions which operated in the estuaries in the past. Very careful sampling procedures are required if best use is to be made of this potential information. The association of primary structures, both in vertical relationship within one borehole core and laterally with respect to adjacent boreholes along a section line, is a powerful tool in reconstructing the hydrodynamic nature and historical development in a given estuary.

Generally speaking bedding contacts can be sharp, graded or erosive. Erosive contacts indicate a loss of historic data. Unfortunately such contacts are common in certain estuarine deposits. Sharp contacts, to which erosive contacts belong, indicate a distinct change in style of sedimentation and the contact plane itself represents a time interval of unknown duration. Graded contacts represent a progressive change in style of sedimentation. The exact nature of bedding contacts can be complex and problematic to interpret satisfactorily.

Biogenic burrows are very important and sensitive palaeoenvironmental indicators. Such burrows are surprisingly robust and easily identified in the sediment record by an experienced observer. They serve as diagnostic indicators of subenvironments such as supratidal flats, inlet channels, intertidal flats, flood-tidal deltas etc, and their vertical and lateral distribution traces the changing subenvironments of the palaeoestuary in space and time.

Seen in context, the various features recognizable in estuarine sediments serve to reconstruct the historical development of palaeoestuaries in substantial detail. The data can be recorded and represented in a variety of ways. The conventional method, almost always employed, is to log all the data in each borehole core and plot the data according to some standard graphic log. The various graphic logs are arranged in sequence according to their drill site localities, and the various key units are recognized and correlated along the section line. Each set of borehole data therefore consists of the three-dimensional coordinates of the borehole collar, and a strip of applicable data arranged in vertical sequence. These data can be stored in a computer database and plotted automatically. Several such systems are available.

Significant information can be obtained by means of isotopic and other analysis of shell and woody material deposited in estuarine sediments. The interpretation of such data is not free from complications and certain limitations, but indicators of age and palaeoenvironment can be obtained in this manner. Without reliable numerical age data the value of the primary stratigraphic data set is much reduced.

Depending on requirements several kinds of manipulations can be performed on the primary data. In the case of vibracore data, the effects of compaction, an artifact produced by the process of coring, can and should be removed by calculation. At present this is done by means of a fairly simple calculation based on measurements made in the field at the time of drilling. More sophisticated corrections are possible where different compaction corrections are applied to individual subunits within the borehole core rather than by means of a single overall correction factor applied to all units in the core. Lithofacies and biofacies manipulations of the primary data are viable where large data sets are available.

DATABASE

The present data set in the lower Swartkops estuary is a pilot study consisting of one main section line 2 000 m long containing 35 cored vibracored boreholes spaced at intervals between approximately 100 m and 25 m. The deepest core is about six metres and on average the cores go down about three metres. All the cores have been logged and the data stored in the conventional manner. Peels have been made of some of the boreholes. Epoxy peels are tedious to make and storage can be a problem. However, as a permanent, tangible and complete record of the borehole, peels represent a superb record easily amenable to future study and analysis. Several sets of data derived from other boreholes and inspection pits in the Swartkops estuary are also available.

Two samples of shell debris from Fishwater Flats were collected by J S V Reddering, (University of Port Elizabeth) near the main section line reported here, and dated according to the radiocarbon method by J C Vogel, (National Physical Research Laboratories, CSIR. Sample Pta-4463 (mollusc shells, 0,7 to 0,8 m below surface) gave a radiocarbon age of 3 980 ± 60 years BP and sample Pta-4464 (*Loripes clausus* shells, 0,8 to 1,4 m below surface) gave an age of 5 140 ± 60 years BP. No such analyses have been done on shell material from the main data set.

DISCUSSION AND CONCLUSION

A preliminary appraisal of the data set available in the Swartkops estuary indicates that stratigraphic borehole data are effective in characterizing and elucidating the development of palaeoenvironment and long-term trends in forcing mechanisms operating in estuaries. The single section line showed a clear distinction between a fluvially dominated facies south of Modderspruit, an abandoned palaeochannel of the Swartkops estuary, and a northern facies characterized by flood-tidal deposit with a strong marine influence. Although it is too early to present a detailed analysis of the data, it is clear that substantial information can be extracted. The long time base represented by such data makes stratigraphic boreholes an attractive method whereby long-term trends can be recognized. Reliable age determinations for such data sets are, however, essential if their full potential is to be realized.

THE EFFECTS OF ARTIFICIALLY REDUCED RIVER DISCHARGE ON THE ESTUARIES OF THE SOUTH-EASTERN CAPE: IS MODELLING PRACTICAL?

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INTRODUCTION

Estuaries are water bodies that occupy the lower reaches of river valleys where sea water mixes with freshwater and where tidal action occurs. Estuaries form the interface between marine and terrestrial environments, and are thus unique and important components of the coastal regime. Estuaries, being sensitive to overutilization of natural resources or abuse from industrial or recreational sources often require management. Freshwater inflow from the catchment area is an important factor which influences several aspects of normal estuarine functioning (physico-chemical dynamics, sediment movement, biological response etc).

PROBLEM

From observations on the historical development of estuaries it is possible to predict the long-term effects of reduced river discharge on mature estuaries. More sediment is likely to accumulate in an estuary during periods between river floods than would naturally be the case. During the same time the sediment, particularly if it contains clastic mud, will lose water and become erosion-resistant. Furthermore, sediment deposited in the intertidal zone reduces the tidal prism of the estuary, which in turn reduces the ability of such an estuary to scour open and maintain its tidal inlet, thus destabilizing the inlet. If the natural discharge and frequency of river floods is maintained these sediment deposits are readily eroded from an estuary, but if the discharge or frequency of floods is reduced sediment will steadily accumulate in the affected estuary. Detailed patterns of river discharge into estuaries, and during floods through the estuaries, are poorly documented. This problem needs to be addressed if the dependance of estuaries on freshwater is to be understood, and if their long-term freshwater requirements are to be included into a comprehensive strategy for management of estuaries.

SOLUTION

Physical - Install gauge stations at the tidal head of priority estuaries. These already exist on some systems (eg Swartkops and Krom estuaries).

Modelling - The discharge of priority catchment basins can be modelled mathematically, using records of rainfall runoff, or some other reliable criteria, as raw data and at the same time simulating the presence or absence of dams on the record. Projections of the effects of additional dams on simulated floods of different magnitude and behaviour should also be possible.

Information on the discharge behaviour of river floods is largely unavailable. Should such information become available it would enable reliable prediction of the response of an estuary to the prevailing conditions of river discharge and sensible management avenues could then be pursued. It will also be possible to assess the minimum water discharge from the catchment required to maintain the estuary in a viable state. In cases where damming of a river has priority, the effect on its estuary may be evaluated. If such a system is significantly affected by reduced discharge it may be possible to apply appropriate measures to minimize or even correct the harmful effects.

CHAPTER 6. FYNBOS TERRESTRIAL ECOSYSTEMS

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INTRODUCTION

The fynbos biome includes Acocks' (1953) veld types 46 (Coastal Renosterbosveld), 47 (Coastal Fynbos), and 69 (Fynbos) in their entirety, and parts of veld types 70 (False Fynbos), 4 (Knysna Forest), 34 (Strandveld) and 43 (Mountain Renosterbosveld) (Rutherford and Westfall 1986). Fynbos is a vernacular term (literally meaning fine-leaved bush) long used to describe the vegetation of the fynbos biome. This biome occurs in the south-western and southern Cape Province, and covers an area of about 70 000 km². It is characterized by the codominance of usually evergreen, sclerophyllous phanerophytes, chamaephytes and hemicryptophytes, although variations occur. The vegetation is an open to closed grassy, dwarf shrubby, shrub/woodland and generally does not exceed three metres in height (Rutherford and Westfall 1986). Acocks' veld type 4 (Knysna Forest) falls under the forest biome, and will not be considered here. This chapter identifies the known changes in the extent and condition of ecosystems within the fynbos biome, and catalogues the available data sets as well as the monitoring programmes that contribute to such sets. The conclusion evaluates our knowledge and identifies the needs for future research and monitoring.

Exogenous changes in fynbos communities

Exogenous causes of change in fynbos ecosystems - the forcing functions - include climate and human action. The Holocene, the past 10 000 years, was characterized by marked fluctuations in climate and sea levels. At the very least these fluctuations will have brought about changes in the position of vegetation boundaries. Annual variations in current rainfall patterns are not large, however, and variation in rainfall is therefore not considered an important factor driving change at present (Figure 6.1).

Human activities have resulted in land transformation, have caused changes in the biota through extinctions and through species introductions, have changed fire regimes and, more recently, biogeochemical cycles through pollution. These alterations have been overlaid on endogenous changes within fynbos ecosystems, such as post-fire succession.

During historical times there has been little change in climate, at least as reflected in rainfall statistics (Figure 6.1). It would be easy to conclude that most or all change in the fynbos biome since about 1600 AD has therefore been brought about by people, but too little is known of the processes of change in the constituent ecosystems to accept this universally. We attempt to assess change in the fynbos biome in terms of land transformation, and within untransformed landscapes, in terms of species introductions and invasions, extinctions, vegetation cover and layering, albedo, species composition and population sizes. In addition, recent trends in pollution are briefly examined.

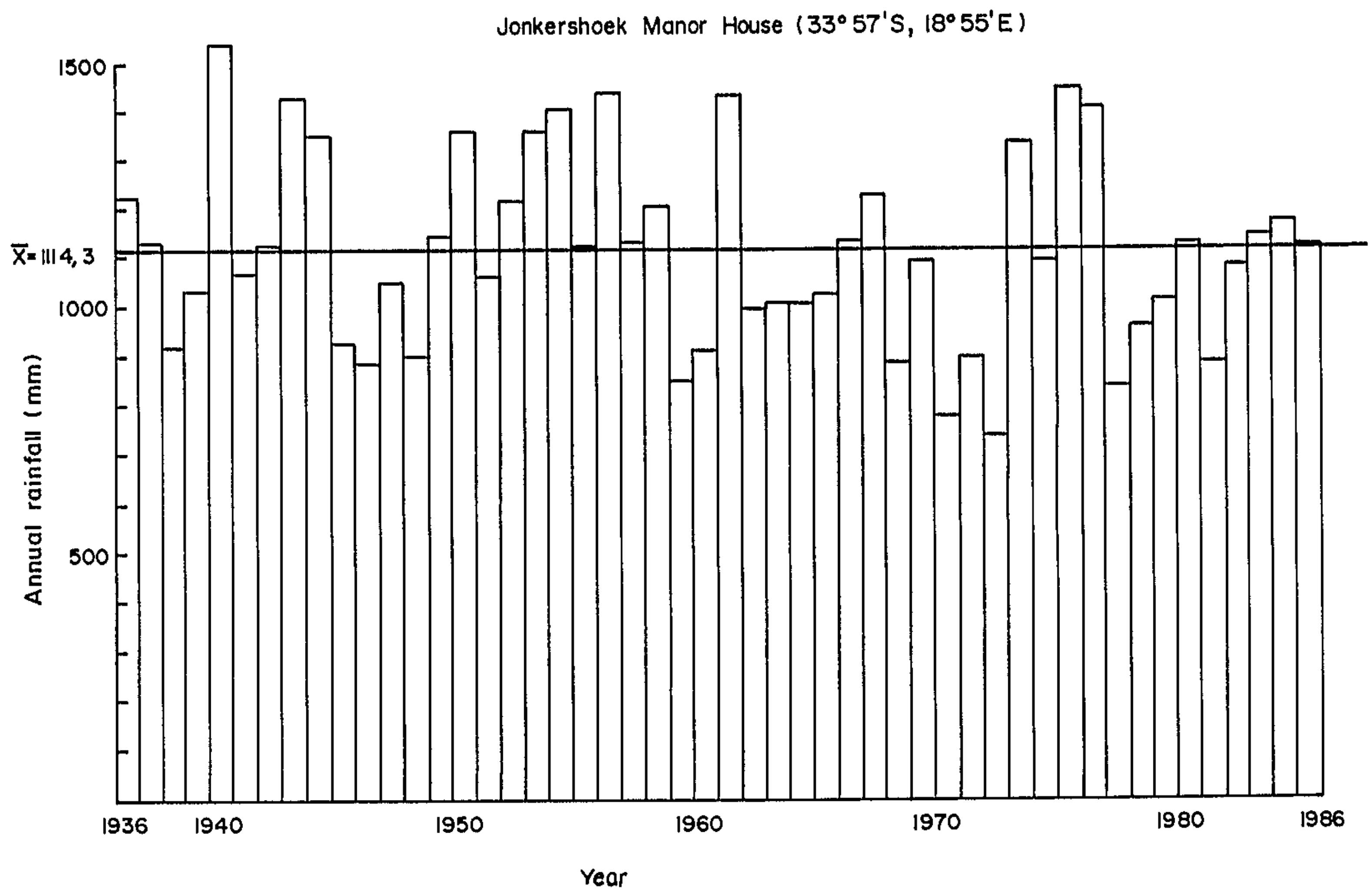


FIGURE 6.1 Fluctuations in total annual rainfall at a typical fynbos site (Jonkershoek Manor House, 33°57'S, 18°55'E) over the past 50 years. The series illustrates the relatively stable nature of annual rainfall. The horizontal line represents the mean annual rainfall (1 114,3 mm).

Endogenous changes in fynbos communities

The most prevalent change in fynbos which proceeds independently of exogenous change is succession following fire. Natural fire regimes for fynbos cannot be defined, and have undoubtedly changed in time with climate and changing human societies (Deacon 1983). Based on studies in areas minimally influenced by people in modern times, as well as from plant life histories, one may deduce that fires recurred once every six to 40 years, mainly in summer and autumn in environments with marked summer drought, but more evenly through the year in more humid, coastal environments (Kruger and Bigalke 1984; van Wilgen 1984). Under such regimes, the vegetation of at least Mountain (Acocks' types 69 and 70) and Lowland (Acocks' type 46) Fynbos is highly stable (Kruger 1987).

Plant succession in fynbos is one of changing life-form dominance while the species composition remains essentially the same (Kruger and Bigalke 1984). The canopy cover of sprouting species is re-established rapidly after fire whereas seeding species, which grow more slowly, become dominant as the interval since fire increases. The Restionaceae, Cyperaceae and Poaceae, primarily sprouters, grow vigorously after fires and are dominant in the understorey of young fynbos, up to the age of four to five years. Many of the herbaceous plants and geophytes are prominent only in the first few years after the fire and persist as seed or dormant storage organs until the next fire. The narrow-leaved sclerophyll shrubs, particularly seeding species, become dominant in the understorey from four to five years after a fire. The broad-leaved sclerophyll shrubs emerge from the understorey five to eight years after fire and dominate the community in mature fynbos (Kruger and Bigalke 1984). In old fynbos the overstorey, and to a lesser degree, the understorey shrub canopy, opens out and the cover of Restionaceae and Cyperaceae increases. Frequent fires reduce the cover of seeding species and can eliminate the slower maturing overstorey species in the community (van Wilgen 1981). Unusually long periods between fires, such as those brought about by active protection, result in senescence, declining seed reserves, and poor regeneration after fire (Bond 1980). Fire season can also have dramatic effects on the structure of fynbos communities. Bond (1984), for example, has shown that fires in spring can decimate populations of reseeding Proteaceae.

Trends in populations of small mammals after fire are also affected by the vegetation dynamics of fynbos communities. Unlike most other vegetation types in South Africa, fynbos shows little or no response to annual and even longer-term variation in climate. The vegetation is evergreen, is adapted to cope with drought and is usually of the same age. Regeneration is mainly a post-fire event and it is only the climatic conditions immediately after a fire that affect regeneration. By implication then, animals must perceive fynbos as being an extremely stable system. Food production and availability are far more constant than in most other ecosystems. Not only do plants flower and produce seeds throughout the year (most of the small mammals, including insectivores, are granivorous), but many plants, especially members of the Proteaceae, are serotinous. This means that both green plant material, and seeds are available to animals throughout the year. There is some variability in the availability of green material, as animals prefer to feed on the current year's leaf crop, but it seems unlikely that rainfall and the associated primary production could control small mammal density and diversity. Instead interspecific interactions may be an important factor in the structuring of small mammal communities of fynbos. Support for this supposition comes from the fact that the rodent species *Rhabdomys pumilio* and *Aethomys namaquensis* never co-occur at high densities in fynbos. *Aethomys*, an early successional species, is replaced by *Rhabdomys* after some five to 10 years (Fox et al 1985).

Long-term studies on small mammal communities in fynbos vegetation types may therefore have considerable value for understanding successional patterns. As they feed extensively on seeds and seedlings, it is only through long-term studies of the interactions between small mammals and the vegetation, that greater understanding of the observed patterns of fynbos regeneration will develop.

CHANGES WITHIN UNTRANSFORMED ECOSYSTEMS

Introduction

The several sources and types of data that are available, and which may indicate changes within extant untransformed ecosystems, have been summarized in Tables 6.1 to 6.3. These tables cover the three major veld types, namely fynbos, renosterbosveld and strandveld. For this scheme we have classified the variables used to measure or indicate change in relation to the level of the system. At the highest level are indicators of change in the entire biome or for each constituent veld type. These include, for example, the record of introductions of species from elsewhere, of extinctions in the region as a whole (as opposed to locally), and of changes in land use. The lowest level is at that of the population of a given species.

The intensity of sampling variables used to measure or indicate change is diverse and, to accentuate the diversity, we identified four classes of activity. On long-term ecological research sites (LTERS, Table 6.4), good data series are available over several decades for such variables as streamflow and, latterly, cover and composition of vegetation. The potential exists for continuation of such monitoring, closely coupled with explanatory research. Within conservation areas, research and routine monitoring, though less intensive than on the LTERS, has also provided records of several kinds. Few data series for the biome exist outside LTERS and conservation areas. Censuses and maps of the entire biome have yielded quantifications of changes in land use and historical analyses of archival material have documented species introductions and extinctions.

Changes operating at the level of the biome or veld type

Plant and mammal extinctions have been documented for the period from about 1650 (Skead 1980; Hall and Veldhuis 1985). For large mammals, the time series illustrated in Figure 6.2 shows rapid depletion soon after European settlement, although the last extinction was fairly recent, when the remnant herd of Knysna elephants *Loxodonta africana* retreated to the Forest Biome around 1950. For plants, the time course cannot be reconstructed; 29 species have been lost in historical times. Losses are expected to continue at about the present rate (Hall and Veldhuis 1985).

TABLE 6.1 Evaluation of the status of information on change in fynbos ecosystems in the fynbos biome. Variables monitored are classified hierarchically. Classes of sampling intensity range from intensive, on research sites, to extensive

Variables to be monitored at different levels	Intensity of sampling			
	On long-term ecological research sites	Samples within conservation areas	Systematic or random sample of whole biome	Censuses and maps
Biome or Veld Type				
Species introductions	-	Archival studies (Shaughnessey 1986; Wells et al 1986)	-	-
Extinctions	-	Some (Hall and Veldhuis 1985)	-	(Skead 1980; Hall and Veldhuis 1985)
Land use	Some (Brownlie 1982)	-	-	(Moll and Bossi 1984; Cook in Kruger 1982)
Ecosystem				
Fire regime	Good	Some Cederberg (Horne 1981)	Sparse	Sparse (Edwards 1984)
Deposition of pollutants	Sparse (van Wyk unpublished; Stock 1985)	-	-	-
Water yield and quality	Good (Bosch et al 1984; Bosch et al 1986)	Scarce	-	-
Community				
Vegetation cover	Moderate (van Wilgen and Kruger 1981; Kruger 1987)	Scarce	-	-
Vegetation layers	Moderate (same as above)	Scarce	-	-
Albedo	Scarce (Kruger 1987)	Scarce	-	-
Plant species composition	Good	Scarce	Scarce	-
Vertebrate species composition	Some (Kruger and Bigalke 1984; van Hensbergen unpublished)	Some (Bond et al 1980; Jarvis unpublished)	-	-
Population				
Densitites of selected plant and animal species	Some	Some	Many of variable quantity	-
Alien species	Scarce - Pella (Brownlie 1982; Macdonald unpublished)	Some (Taylor et al 1985)	Some	Moderate (McLachlan et al 1980)

TABLE 6.2 Evaluation of the status of information on change in renosterbosveld ecosystems in the fynbos biome. Variables monitored are classified hierarchically. Classes of sampling intensity range from intensive, on research sites, to extensive

Variables to be monitored at different levels	Intensity of sampling			
	On long-term ecological research sites	Samples within conservation areas	Systematic or random sample of whole biome	Censuses and maps
Biome or Veld Type				
Species introductions	-	-	-	-
Extinctions	-	-	-	-
Land use	-	-	(Tansley 1982)	(Moll and Bossie 1984; Cook in Kruger 1982)
Ecosystem				
Fire regime	-	Some - Bontebok Park	-	-
Deposition of pollutants	-	-	-	-
Water yield and quality	-	-	Scarce - Berg River (Water Affairs)	-
Community				
Vegetation cover	-	-	-	-
Vegetation layers	-	-	-	-
Albedo	-	-	Scarce (Fuggle unpublished)	-
Plant species composition	-	-	-	-
Vertebrate species composition	-	-	-	-
Population				
Densities of selected plant and animal species	-	Scarce (Bigalke unpublished)	-	-
Alien species	-	-	-	-

TABLE 6.3 Evaluation of the status of information on change in strandveld ecosystems in the fynbos biome. Variables monitored are classified hierarchically. Classes of sampling intensity range from intensive, on research sites, to extensive

Variables to be monitored at different levels	Intensity of sampling			
	On long-term ecological research sites	Samples within conservation areas	Systematic or random sample of whole biome	Censuses and maps
Biome or Veld Type				
Species introductions	Scarce - Nortier	Archival - Walker Bay	-	Scarce (Shaughnessey 1986)
Extinctions	-	-	-	Scarce (unpublished)
Land use	Scarce - Nortier	Achival - Walker Bay	-	(Moll and Bossi 1984; Boucher and Jarman 1977)
Ecosystem				
Fire regime	Scarce - Nortier	-	-	-
Deposition of pollutants	-	-	-	-
Water yield and quality	-	-	Some - Atlantis water supply	-
Community				
Vegetation cover	Some - Nortier	-	-	-
Vegetation layers	-	-	-	-
Albedo	-	Scarce (Fuggle unpublished)	Scarce (unpublished)	-
Plant species composition	Some - Nortier	-	-	-
Vertebrate species composition	-	-	-	-
Population				
Densities of selected plant and animal species	-	Scarce (Low unpublished)	-	-
Alien species	-	Scarce (Low unpublished)	-	-

TABLE 6.4 The most important long-term ecological research sites within the fynbos biome. The date of establishment is given after the site name

Site name	Location S lat	Location E long	Veld type	Geological formation	Mean annual rainfall, mm
Jakkals-rivier (1969)	34°01'	19°09'	Mountain Fynbos	TMS	1050-1185
Jonkershoek (1937)	33°57'	18°55'	Mountain Fynbos	Cape Granite and TMS	1200-3600
Moordkuil (1984)	33°54'	22°06'	Mountain Fynbos	TMS	700-1200
Nortier (1957)	32°02'	18°20'	Strandveld	Tertiary deposists	224
Pella (1978)	33°31'	18°32'	Coastal Fynbos	Tertiary sands	400
Zacharias-hoek (1968)	34°49'	19°02'	Mountain Fynbos	TMS	1000-1600

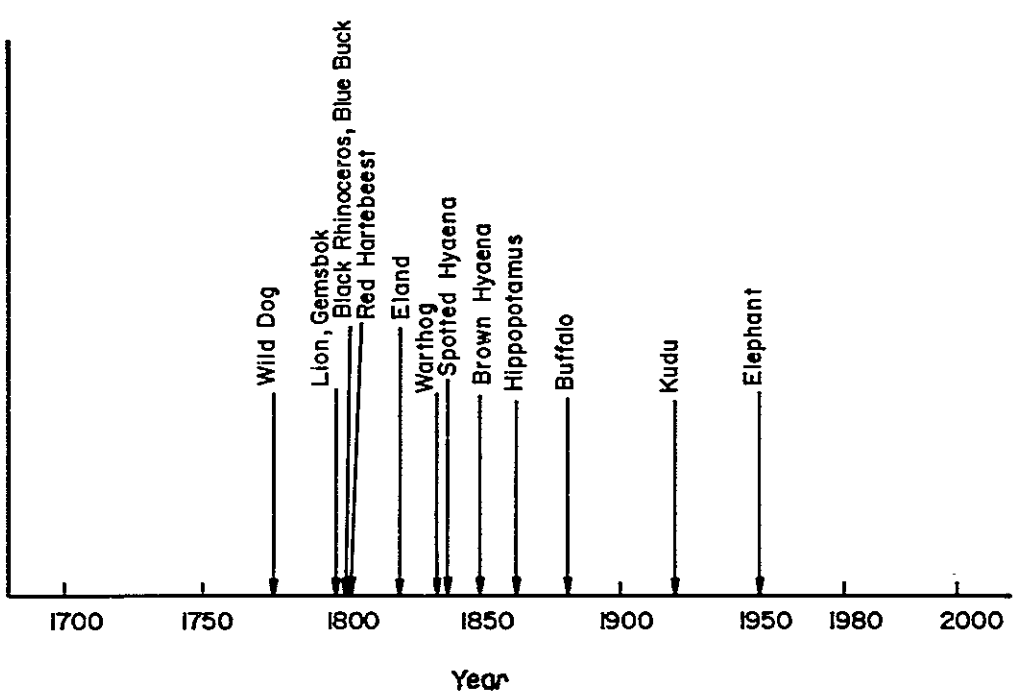


FIGURE 6.2 Local extinction dates of 14 large mammal species formerly occurring in the fynbos biome. Extinction dates are the last recorded sightings as given by Skead (1980).

About 360 alien plant species and less than 10 vertebrates are known to have been introduced (Macdonald and Richardson 1986). Dates of the introductions are not known, except in the case of trees and shrubs for the Cape Peninsula (Shaughnessy 1986), but could be reconstructed from archival records, such as for trees and shrubs (eg Kruger et al 1986). Given the spread and impact of invasive species in the fynbos biome, further documentation of introductions will be needed.

Changes in vegetation

Hall and Veldhuis (1985) give a list of 1 808 rare, threatened and recently extinct plants in the fynbos and karoo biomes. Following the IUCN categories these may be classed as 29 plants extinct, 118 endangered, 183 vulnerable, 495 critically rare, 281 indeterminate and 702 uncertain. The extent and causes of the threatened plant problem are discussed. Data are provided on the populations of and conservation priorities for about 250 species.

Some studies give detailed information on individual species. *Mimetes splendidus*, *M hottentoticus* and *M capitulatus* are all threatened species of Proteaceae with extremely small world populations confined to the fynbos biome. Since the early 1970's, monitoring sites have been established in most of the known localities of these species. Trends in all three species conform to the fynbos model of regeneration being dependent on fire. There has been an overall decline in numbers of all three species, despite the occurrence of fires (Figure 6.3). In some of the populations, this appears to be a result of poor regeneration following controlled fires of low intensity.

Several populations of the Clanwilliam cedar *Widdringtonia cederbergensis* have been monitored since 1971. Data from these sites were used by Manders (1985) to derive a transition probability model of the population dynamics of this species. The Clanwilliam cedar has undergone a noticeable decline in numbers during its recorded history. This decline is attributed to excessive harvesting in the past, farming and the inappropriate use of fire (Manders 1986). The Department of Forestry initiated a monitoring programme out of concern for the future survival of the species. Data show that most recruitment occurs after wild fires. These usually occur in summer, whereas prescribed burns have been carried out in winter and spring. Therefore the lack of regeneration after prescribed burns is attributed to seasonal responses of the population to fire.

Van Wilgen and Kruger (1981) compared mountain fynbos in 1971 and 1977 at permanent plots at Zachariashoek, Paarl. They concluded that no changes in the vegetation were apparent six years after a fire in six-year old vegetation. Some of the plots were resurveyed in 1983, but data have not been analysed. The methods were designed to detect major trends and were too coarse to detect subtle changes over the short time period involved. Data from lowland fynbos at Pella (Hoffman et al 1987) indicate that interannual, successional changes, particularly in number and cover of annuals, grasses and geophytes are significant. We have no data for renosterbosveld and strandveld.

Several vegetation surveys, using the descending point method, have been conducted at Jakkalsrivier in mountain fynbos near Grabouw between 1969 and 1985. Estimates of plant canopy cover assessed by means of several surveys between successive fires indicate that the vegetation is remarkably stable under, eg a five-year fire cycle (Figure 6.4).

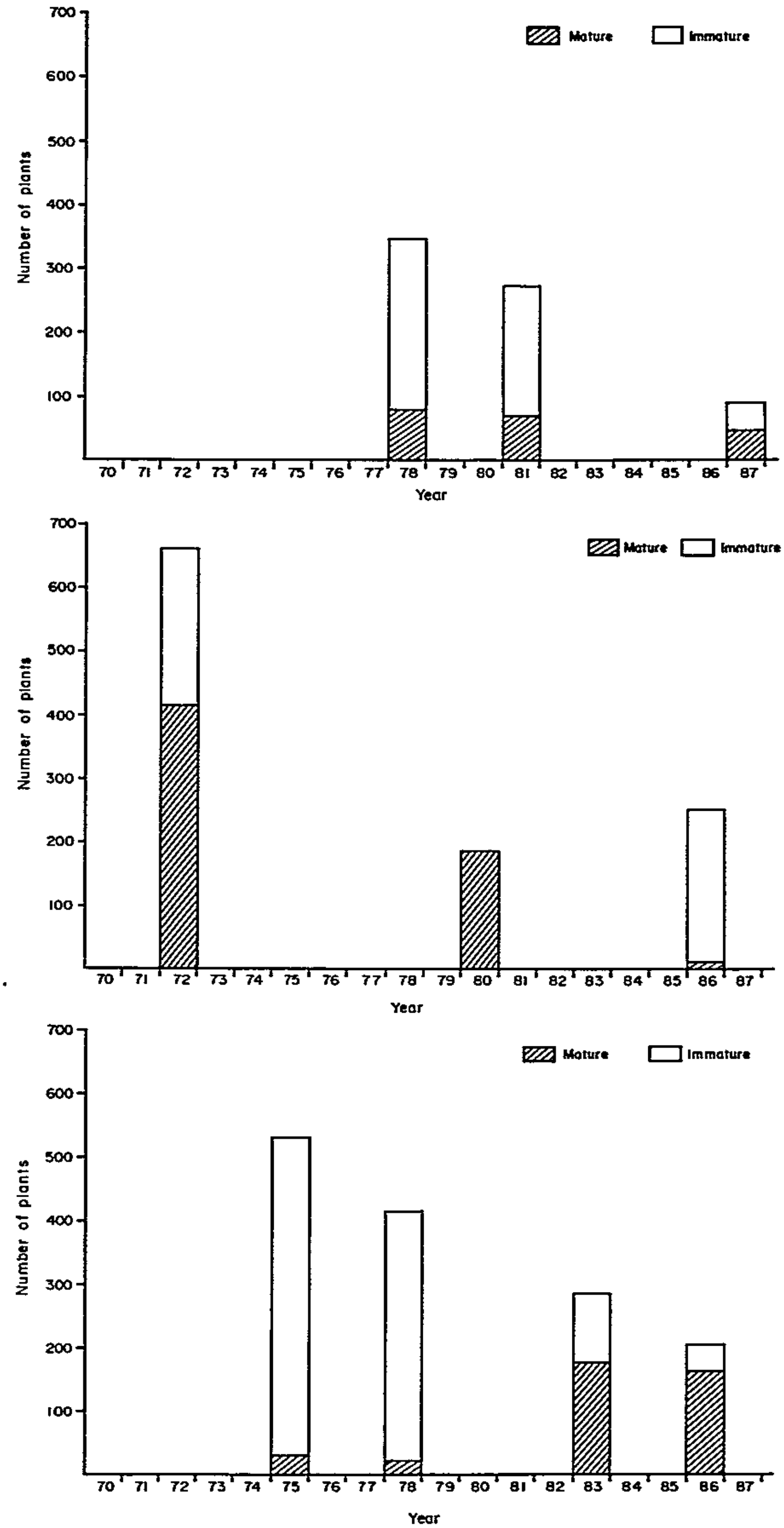


FIGURE 6.3 Total numbers of three *Mimites* species recorded in successive surveys on permanent monitoring sites. The figures are as follows: (a) *M splendidus*, eight sites in the Langeberg mountains; (b) *M capituiatus*, five sites in the Groenland mountains; and (c) *M hottentoticus*, three sites in the Kogelberg Forest Reserve.

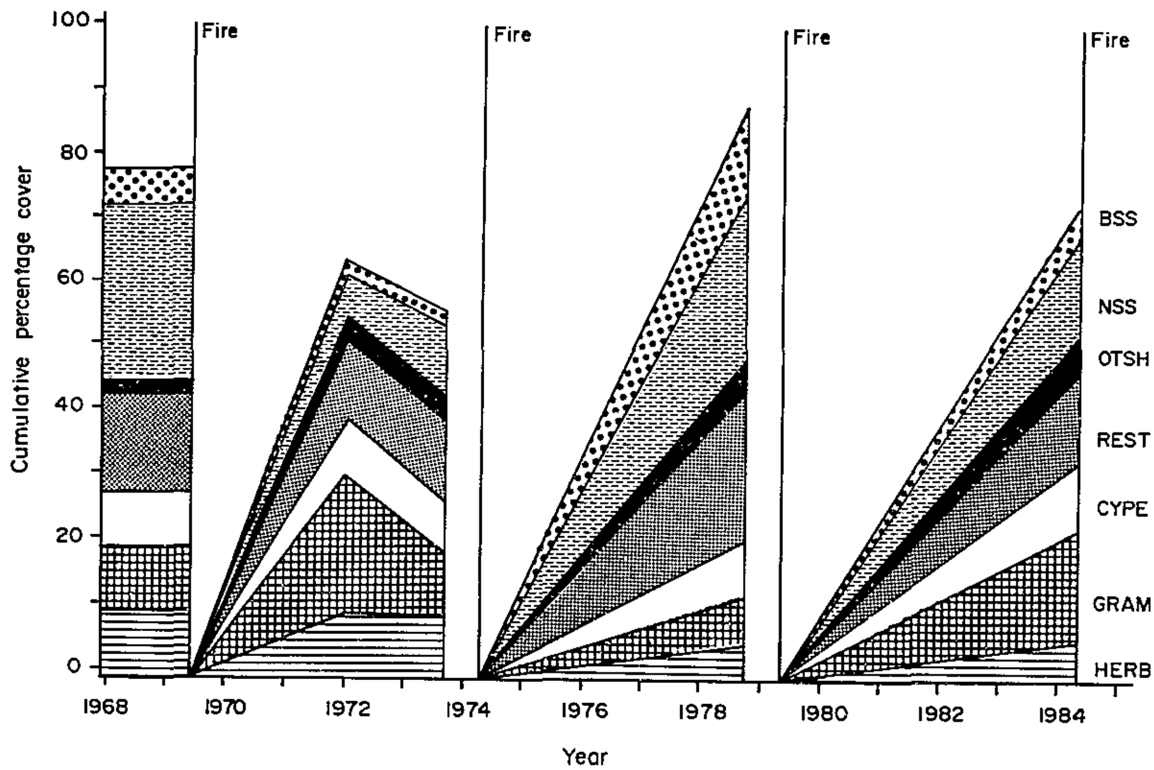


FIGURE 6.4 Changes in the cover of plants of different growth-forms at Jakkalsrivier plot 1F-1 (five-year burning cycle). HERB = geophytes and other nongraminoid herbs, GRAM = grasses, CYPE = sedges, REST = restioids, OTSH = other shrubs, NSS = narrow-sclerophyllous shrubs, and BSS = broad-sclerophyllous shrubs. Vertical lines show dates of fires.

All the above studies concentrate on fynbos ecosystems with little anthropogenic impact other than that of controlled or uncontrolled fire regimes. One mountain study has been carried out in a highly man-disturbed area, Table Mountain. The most impacted area is near the upper cableway station. Data from 1977 to 1985 (Moll unpublished) indicate that aerial plant cover was reduced by as much as 22% and that the contribution of weedy fynbos species to the overall composition increased by as much as 15%. In addition path, gulley and sheet erosion are all leading to changed water regimes, and these processes are accelerating with increased recreational usage.

Biological invasions

A few detailed accounts of invasion of fynbos areas by alien woody plants are available. Taylor and Macdonald (1985) and Taylor et al (1985) present data on invasion of the Cape of Good Hope Nature Reserve between 1966 and 1980. Richardson and Brown (1986), using aerial photographs, document invasion of mountain fynbos near Stellenbosch by *Pinus radiata* between 1938 and 1985 as do Smit and De Kock (1984) for *P pinaster*. Brownlie (1982) used aerial photographs from 1938 to 1979 to determine the extent of invasion at a coastal fynbos site. On the Cape Peninsula a resurvey of Hall's (1961) data indicated that, without active eradication, alien invasions are widespread and severe (McLachlan et al 1980).

Several studies have documented the spread of bird species through the fynbos biome from collections and sightings both published and unpublished, that span a period of more than 100 years (Macdonald 1986; Macdonald et al 1986; Macdonald and Richardson 1986). Species include the alien European Starling *Sturnus vulgaris*, the hadeda ibis *Bostrychia hagedash* and the pied barbet *Lybius leucomelas*, the last two being birds indigenous to southern Africa that were formerly absent from the fynbos biome and which have spread as a result of invasions by alien trees (Figure 6.5).

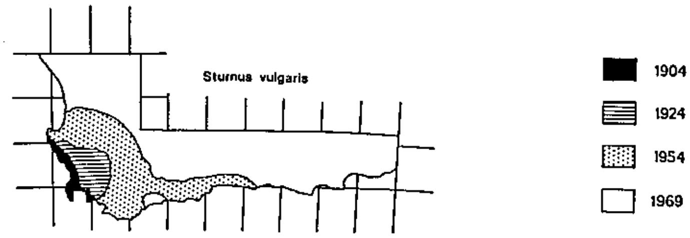
TRENDS IN LAND USE AND LAND TRANSFORMATION

Deacon (1983) and Deacon (1986) has described the peopling of the fynbos region. *Homo sapiens* have been present since at least 150 000 BP and have used fire throughout this period. Pastoral people introduced cattle and sheep and some alien plants about 1 500 to 2 000 years ago. European settlement occurred 330 years BP, but it was only around 1860 that the area under cultivation began to expand rapidly. Today, agricultural development accounts for most landscape transformation (Moll and Bossi 1984). Details are summarized in Table 6.5.

Some areas have been transformed to a far greater extent than others. For example, almost 96% of West Coast Renosterbosveld has been transformed to crop land and cultivated pastures since this is the most suitable land for cultivation. Mountain areas, on the other hand, have suffered little transformation simply because the soils are unsuitable for current agricultural practices. Overall, about 26% of the land has been transformed from the natural state. Continued transformation is predicted as more and more use is made of mountain land for afforestation, orchards and improved pastures.

AIR POLLUTION

Within the fynbos biome, industrial air pollutants are emitted at major urban centres, and are likely to have affected at least some areas. In the Cape Town region, these pollutants are trapped in strong marine inversions in the atmosphere, later to be transported by cyclonic and anticyclonic weather systems. At Jakkalsrivier (Table 6.4), rainfall is acidic and has unusually high ionic concentrations, indicating pollution, but this site has only been monitored for five years. Other sites do not show the same increase in rainfall acidity.



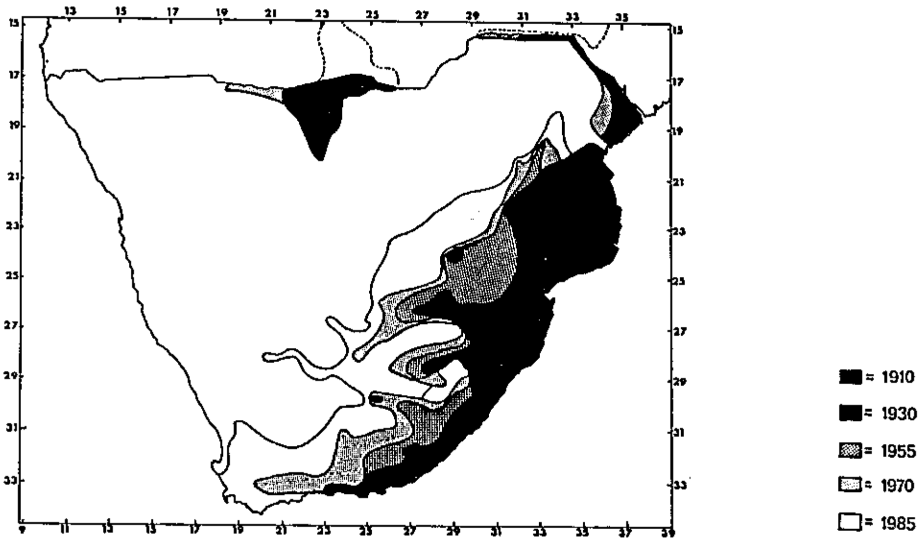


FIGURE 6.5 Range expansions of one indigenous and one introduced bird species in the fynbos biome. The maps show distributions of (a) the European starling (from Macdonald and Richardson 1986) and (b) the Hadeda ibis (from Macdonald et al 1986).

TABLE 6.5 Extent of transformation (per cent of the total land area) of fynbos biome vegetation. Note that forest and karoo types are not included here

Vegetation type	Original area (km^2)	Remaining area (km^2)	Percentage reduction
Mountain fynbos	38 051	33 411	12,2
Lowland fynbos	7 275	4 550	37,5
Renosterbosveld	27 648	16 687	39,6
Standveld	4 321	2 499	42,2
Total	77 295	57 147	26,1

CHANGES IN FAUNA

Extinctions and changes in rare species

Many species of animals, mainly large mammals, that were common in the biome 200 to 300 years ago, have been exterminated. The available evidence is presented by Skead (1980) and consists mainly of written accounts by early travellers and settlers. Species that could have had an important impact on the ecology of the area include elephant *Loxodonta africana*, black rhinoceros *Diceros bicornis*, hippopotamus *Hippopotamus amphibius*, lion *Panthera leo*, hyaenas (*Crocuta crocuta* and *Hyaena brunnea*), Cape mountain zebra *Equus zebra*, and various antelope species. Population densities are likely to have been highest in the lowland areas, which are now largely developed for agriculture. Data on recent changes in population sizes are available for the mountain zebra (Lloyd 1984).

At least one mammal endemic to the fynbos biome, the bluebuck *Hippotragus leucophaeus*, is extinct (Skead 1980; Smithers 1986). Mammal taxa currently occurring in the biome considered to be declining in numbers, and reasons for their decline, are listed by Smithers (1986). These include the white tailed mouse *Mystromys albicaudatus* (habitat destruction), honey badger *Mellivora capensis* (persecution), African wildcat *Felis lybica* (hybridization with the domestic cat), antbear *Orycteropus afer* (?), Cape mountain zebra (?), spectacled doormouse *Graphiurus ocularis* (no evidence), striped weasel *Poecilogale albinucha* (no evidence), aardwolf *Proteles cristatus* (hunted, roadkills), leopard *Panthera pardus* (persecution), bontebok *Damaliscus dorcas dorcas* (habitat destruction) and blue duiker *Cephalophus monticola* (no evidence). Question marks indicate uncertainty as to the reasons for declines.

McLachlan (1978) records one tortoise, four lizards, one snake and six frogs for the fynbos biome in an account of the threatened reptile and amphibian taxa of South Africa. Many are on the list as a result of their restricted distributions. The geometric tortoise *Psammobates geometricus* is endangered because of agricultural development, the Cape mountain lizard *Lacerta australis* "may have suffered as a result of mountain fires" (doubtful), while urban expansion is mentioned as a factor in possible declines of the Cape dainty *Cacosternum capense* and arum frog *Hyperolius horstockii*.

Data from population monitoring studies

Small mammals have been trapped on three of the mountain ranges in the southern Cape since 1978, representing the only known data series dealing with small mammals (Bond et al 1980). No obvious long-term trends were observed. The lambing percentage of bonteboks has been monitored in the Bontebok National Park since 1960 and showed a significant positive correlation with rainfall over the 12 months preceding the mating season (Novellie 1986).

FIRE HISTORIES

There are different opinions about historical fire regimes. One is that past landscapes had extensive, continuous areas of flammable vegetation, and that fires were predominantly infrequent, large, intense and forced by weather. Alternatively, humans using the natural landscape would have employed fire in their hunting activities and plant and animal husbandry, as well as to render their environment safer. Past anthropogenic fires may thus have been frequent, small, and of low intensity (Deacon 1983). European man may have affected fire regimes in different ways. For example, mountain areas have gone through periods of complete protection, followed by prescribed burning. Horne (1981) analysed fire records spanning the period 1951 to 1977 for the Groot Swartberg mountain range in the southern Cape. The analysis is useful in that a distinction is made between natural and man-caused fires, for which no change in the relative proportion is apparent over the period. As man accounted for 33% of the fires, there may have been a 33% increase in fire frequency if one assumes that presettlement man did not burn the vegetation deliberately.

Data on fires in the Cederberg have been accumulated from foresters' reports and diaries dating from 1905. Fires from 1905 to 1955 were seldom mapped, and areas indicated were often fairly coarse estimates. We consider, however, that the major fire events have been recorded and, though the accuracy of the data may be questionable, the loss of information will not conceal essential trends. Lighting of fires was not permitted in central parts of the Cederberg (those containing cedar populations) from 1905. It was permitted, however, in areas where buchu *Agathosma betulina* and bush tea *Aspalathus linearis* were being harvested until 1937, after which no fires at all were permitted in any areas. Prescribed burning on a four-year cycle to decrease fuel loads in cedar areas was proposed in 1957, and one burn was carried out in 1959. Complete protection was reinstituted after 1959. In 1972 a policy of prescribed burning was applied again. The Cederberg area was almost free of large wildfires from 1928 to 1958. Thereafter there have been frequent wildfires, several of which have covered large areas, been very intense, and caused high mortality in cedar populations.

The most plausible explanation of the increase of wildfires is the policy of protection which was in force until 1972. Under this policy efforts were made to prevent the occurrence and spread of wildfires, and the deliberate starting of fires was prohibited. One consequence of the decreased occurrence of fire was an increase in the general post-fire vegetation age in the area. The increase in fuel present, and heat intensity of any wildfire which may eventually occur, in turn limits the extent to which the fire may be controlled or contained within an area. To what extent this has influenced the areas and intensities of fires since the lifting of the protection policy can only be surmized, but it is apparent that the introduction of prescribed burns in 1972 had no appreciable effect on the occurrence of wildfires (Figure 6.6).

In 1966 the Department of Forestry started a database to record fires in the areas it administers throughout the country. Figure 6.7 shows an increase in the number of fires started by lightning reported from State Forests in the western and southern Cape for the period since 1976, compared to the record for previous years. This may be due to management staff not having reported all lightning fires prior to 1976 through a lack of understanding of the importance of such statistics. We regard the record since 1976 as reliable, and no trend can be discerned in this later period.

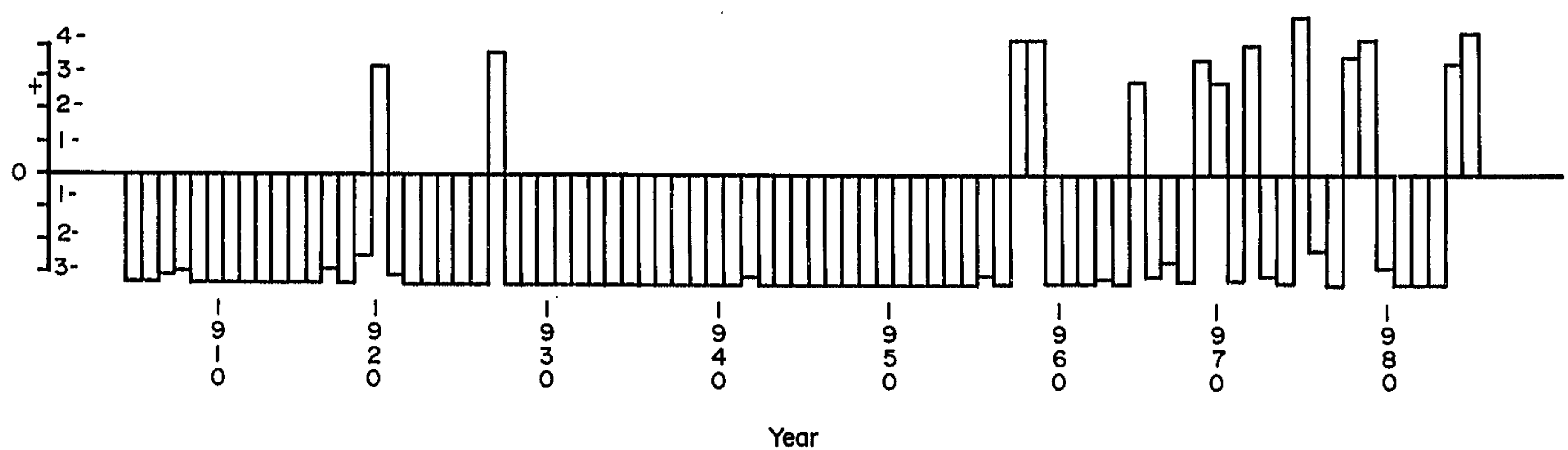


FIGURE 6.6 Areas burnt annually in wildfires in the Cederberg from 1905 to 1985. Areas are expressed as the deviation in log10 hectares from the 81-year mean of 1 828 ha yr^{-1}.

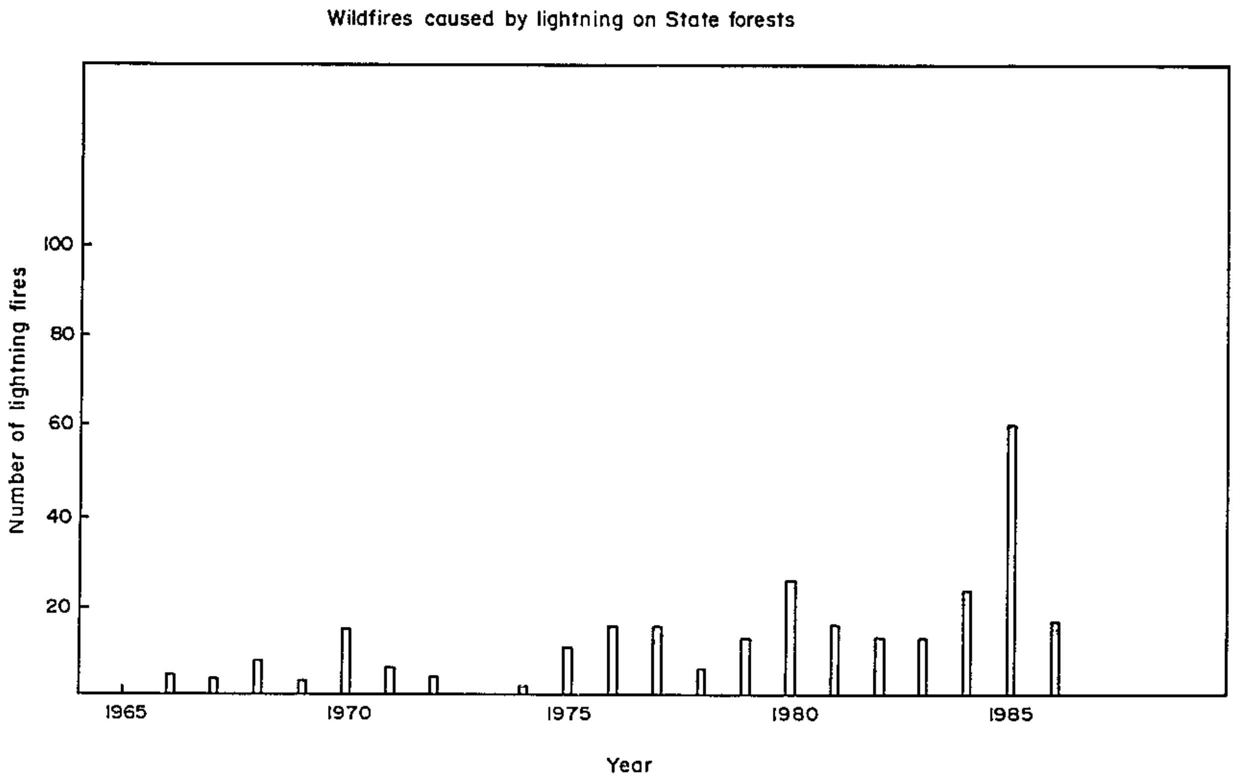


FIGURE 6.7 Trends in the numbers of lightning fires reported from State Forestry areas in the southern and western Cape during the period 1965 to 1986.

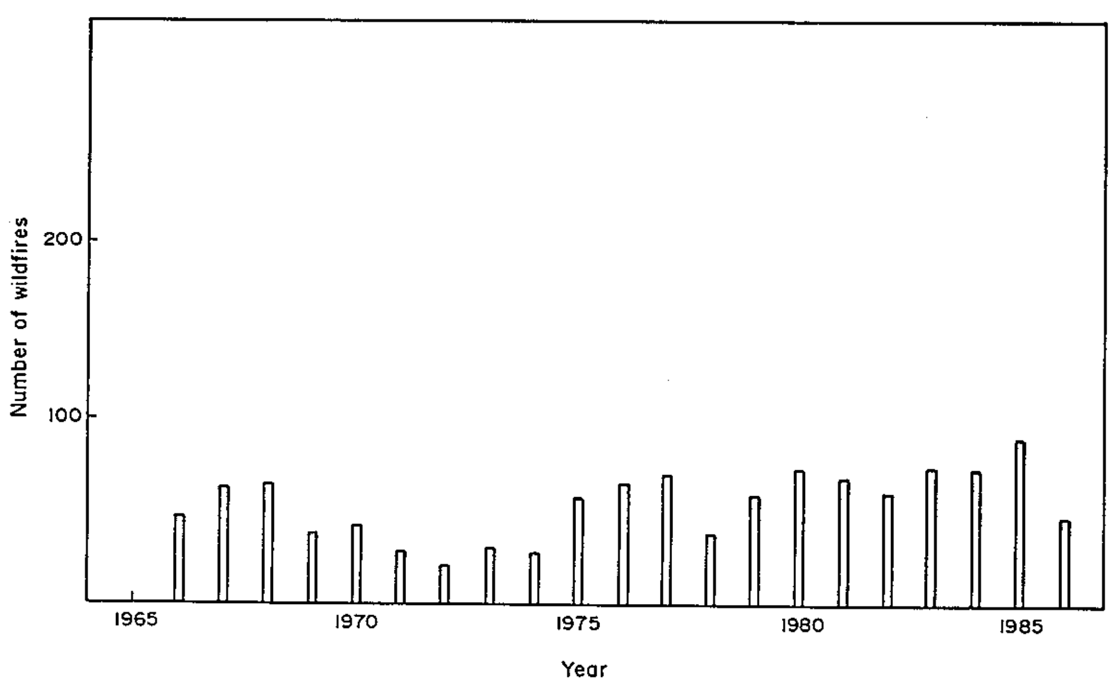


FIGURE 6.8 Trends in the numbers of wildfires reported from State Forestry areas in South Africa during the period 1965 to 1986.

Data for wildfires (as opposed to those started deliberately, such as prescribed burns) from forestry areas around the country show a marked increase in the number of fires from 1965 to 1987. We attribute this to increased sources of ignition related to increases in human populations (Figure 6.8).

CONCLUSIONS

Major forced changes in the biome

There have been major changes in the biome. The transformation of large areas of natural vegetation to agricultural lands (Table 6.5) may have implications for the climate, at least locally, through changes in the albedo (Fuggle unpublished). In addition, the driving force of fire would have been affected as fuel beds have been broken up and fires can no longer spread naturally. Afforestation would also have had an impact on hydrological cycles (Versfeld and van Wilgen 1986). The ecological effects of the extinction of most of the large mammal fauna are unknown but it has been suggested that one of them is an increased susceptibility to invasion by alien plants (Macdonald 1984). The large mammals would mainly have occurred in those ecosystems which are now transformed.

The invasions by alien woody weeds have impacts on nutrient and hydrological cycles in the biome, and on the fire regime by changing fuel properties. These impacts are reviewed by Versfeld and van Wilgen (1986).

There have been changes in the fire regime in the biome and these changes have had major effects in places. The changes include a period of exclusion of fire between 1940 and 1970, followed by prescribed burning, often in "unnatural" seasons. In addition, fires are simply more frequent due to human ignitions. The impacts of a changed fire regime will manifest themselves in changes in the dominant vegetation, such as reduced biomass or loss of overstorey shrubs.

Pollution, emanating from industrial sources, agricultural fertilizers, weedicides and the like has not been adequately documented, but no doubt holds potentially severe implications for the functioning of the ecosystem.

The growth in the human population in the biome remains a dominant driving force. In addition, changing social values and demands on resources could lead to radical changes in land use in the future.

There are major gaps or weaknesses in the long-term data series available. The monitoring of vegetation and faunal changes has been poor in terms of information content, the length of time series, and the scope of sampling.

Natural changes in the biome

The possibility that the number of rare and/or endangered plant species, and recent plant (eg *Mimetes stokei*) and animal (eg bluebuck) extinctions may be due to natural factors needs investigation. The biome is unique in many aspects, eg relatively few genera with very large numbers of species and the occurrence of isolated species as well as some that are almost ubiquitous. Additionally the "vacant tree niche" (Moll et al 1980) and other such properties lead to speculation that we are witnessing an "end" to a fynbos epoch. This could be caused by genetic constipation of a large number of the constituent plant species, especially since these species have had an extremely long and, apparently, stable history. This stability is deduced from the existence of familial and generic links with other Gondwanaland masses, the fact that Africa has been relatively static latitudinally and longitudinally, and has had a reasonably constant climate. As a vegetation type, fynbos is relatively independent of climatic change (unless massive) and hence the species have evolved in such a way as to show little response to changes. As these species are now (suddenly, in terms of an evolutionary time scale) faced with major changes, they are not coping and many extinctions may be expected.

For the future, it is imperative to develop the means to predict the influence of changing climate, CO_2 concentration, pollutant deposition, and invasive organisms on the functioning of fynbos ecosystems, communities and populations, as well as on their sustainable use. We will need to know the impacts of these factors in terms of water balance, primary production, extinction and immigration, and the interactive, dynamic links between species and communities.

Clearly, research will be required to address these needs, but it should proceed in the knowledge of endogenous change. It is crucial to maintain long-term ecological research sites and to improve their concomitant monitoring programmes. It will then be necessary to link methods of monitoring with prediction of change at larger scales. Monitoring will necessarily depend on remote sensing and georeferenced data systems, and prediction on feedbacks between forcing functions and ecosystem processes that emerge with increasing scale. Our challenge is to unravel "natural" trends from forced changes.

REFERENCES

Acocks J P H 1953. Veld types of South Africa. Memoir of the botanical survey of South Africa 28, Government Printer, Pretoria.

Bond W J 1980. Fire and senescent fynbos in the Swartberg. South African Forestry Journal 114, 68-71.

Bond W J 1984. Fire survival of Cape Proteaceae - influence of fire, season and seed predators. Vegetatio 56, 65-74.

Bond W J, Furgeson M and Forsyth G 1980. Small mammals and habitat structure along altitudinal gradients in the southern Cape Mountains. South African Journal of Zoology 15, 34-43.

Bosch J M, Schulze R E and Kruger F J 1984. The effect of fire on water yield. In: Booysen P de V and Tainton N M (editors) The ecological effects of fire in South African ecosystems. Springer-Verlag, Berlin. pp 327-348.

Bosch J M, Van Wilgen B W and Bands D P 1986. A model for comparing water yield from fynbos catchments burnt at different intervals. Water SA 12, 191-196.

Boucher C and Jarman M L 1977. The vegetation of the Langebaan area (South Africa). Transactions of the Royal Society of South Africa 42, 241-272.

Brownlie S F 1982. The effects of recent landuse on a fynbos site. Final report to the Fynbos Biome Project by the School of Environmental Studies, University of Cape Town, Cape Town.

Deacon H J 1983. The peopling of the fynbos region. In: Deacon H J, Hendey Q B and Lambrechts J J N (editors) Fynbos paleoecology: A preliminary synthesis. South African National Scientific Programmes Report No 75. CSIR, Pretoria. pp 183-204.

Deacon H J 1986. Human settlement in South Africa and archeological evidence for alien plants and animals. In: Macdonald I A W, Kruger F J and Ferrar A A (editors) The ecology and managment of biological invasions in southern Africa. Oxford University Press, Cape Town. pp 3-19.

Edwards D 1984. Fire regimes in the biomes of South Africa. In: Booysen P de V and Tainton N M (editors) The ecological effects of fire in South African ecosystems. Springer-Verlag, Berlin. pp 18-37.

Fox B J, Quinn R D and Breytenbach G J 1985. A comparison of small mammal succession following fire in shrublands of Australia, California and South Africa. Proceedings of the Ecological Society Australia 14, 179-197.

Hall A V 1961. Distribution studies of introduced trees and shrubs in the Cape Peninsula. Journal of South African Botany 27, 101-110.

Hall A V and Veldhuis H A 1985. South African Red Data Book: Plants - Fynbos and Karoo biomes. South African National Scientific Programmes Report No 117. CSIR, Pretoria. 144 pp.

Hoffman M T, Moll E J and Boucher C 1987. Post-fire succession at Pella, a South Afrcain lowland fynbos site. South African Journal of Botany 53, 370-374.

Horne I P 1981. The frequency of veld fires in the Groot Swartberg Mountain Catchment Area, Cape Province. South African Forestry Journal 118, 56-60.

Kruger F J 1982. Use and management of mediterranean ecosystems in South Africa - current problems. In: Conrad C E and Oechel W C (editors) Dynamics and management of mediterranean-type ecosystems. USDA Forest Service, General Technical Report PSW-58. pp 42-48.

Kruger F J 1987. Succession after fire in selected fynbos communities of the south-western Cape. PhD Thesis, University of the Witwatersrand, Johannesburg.

Kruger F J and Bigalke R C 1984. Fire in Fynbos. In: Booysen P de V and Tainton N M. Ecological effects of fire in South African Ecosystems. Springer-Verlag, Berlin. pp 67-114.

Kruger F J, Richardson D M and van Wilgen B W 1986. Processes of invasion by alien plants. In: Macdonald I A W, Kruger F J and Ferrar A A (editors) The ecology and managmeent of biological invasions in southern Africa. Oxford University Press, Cape Town. pp 145-155.

Lloyd P H 1984. The Cape mountain zebra 1984. African Wildlife 38, 144-149.

Macdonald I A W 1984. Is the fynbos biome especially susceptible to invasion by alien plants - a reanalysis of available data. South African Journal of Science 80, 369-377.

Macdonald I A W 1986. Range expansion in the pied barbet and the spread of alien tree species in southern Africa. Ostrich 57, 75-94.

Macdonald I A W and Richardson D M 1986. Alien species in terrestrial ecosystems of the fynbos biome. In: Macdonald I A W, Kruger F J and Ferrar A A (editors) The ecology and management of biological invasions in southern Africa. Oxford University Press, Cape Town. pp 77-91.

Macdonald I A W, Richardson D M and Powrie F J 1986. Range expansion of the hadeda ibis Bostrychia hagedash in southern Africa. South African Journal of Zoology 21, 331-342.

Manders P T 1985. The autecology of Widdringtonia cederbergensis in relation to its conservation management. MSc Thesis, University of Cape Town, Cape Town.

Manders P T 1986. An assessment of the current status of the Clanwilliam cedar (Widdringtonia cedarbergensis) and the reasons for its decline. South African Forestry Journal 139, 48-53.

McLachlan G R 1978. South African Red Data Book: Reptiles and amphibians. South African National Scientific Programmes Report No 23. CSIR, Pretoria. 53 pp.

McLachlan D, Moll E J and Hall A V 1980. Resurveys of the alien vegetation in the Cape Peninsula. Journal of South African Botany 46, 127-146.

Moll E J and Bossi L 1984. Assessment of the extent of the natural vegetation of the fynbos biome of South Africa. South African Journal of Science 80, 355-358.

Moll E J, McKenzie B and McLachlan D 1980. A possible explanation for the lack of trees in the fynbos, Cape Province, South Africa. Biological Conservation 17, 221-228.

Novellie P 1986. Relationships between rainfall, population density and the size of the bontebok lamb crop in the Bontebok National Park. South African Journal of Wildlife Research 16, 39-46.

Richardson D M and Brown P J 1986. Invasion of mesic mountain fynbos by Pinus radiata. South African Journal of Botany 52, 529-536.

Rutherford M C and Westfall R H 1986. Biomes of southern Africa - an objective classification. Memoirs of the Botanical Survey of South Africa 4, Botanical Research Institute, Pretoria.

Shaughnessy G L 1986. A case study of some woody plant introductions to the Cape Town area. In: Macdonald I A W, Kruger F J and Ferrar A A (editors) The ecology and management of biological invasions in southern Africa. Oxford University Press, Cape Town. pp 37-43.

Skead C J 1980. Historic mammal incidence in the Cape Province Vol 1. Cape Department of Nature and Environmental Conservation, Cape Town.

Smit H A P and de Kock G L 1984. Ruintelike diffusie van die indringerplant Pinus pinaster teen die hange van Stellenboschberg. South African Forestry Journal 129, 10-16.

Smithers R H N 1986. South African Red Data Book: Terrestrial mammals. South African National Scientific Programmes Report No 125. CSIR, Pretoria. 216 pp.

Stock W D 1985. An investigation of nitrogen cycling processes in a coastal fynbos ecosystem in the south-western Cape Province, South Africa. PhD Thesis, University of Cape Town, Cape Town.

Tansley S 1982. Koppie conservation project. Report, Wildlife Society of South Africa, Cape Town. 100 pp + 6 maps.

Taylor H C and Macdonald S A 1985. Invasive alien woody plants in the Cape of Good Hope Nature Reserve. I. Results of a first survey in 1966. South African Journal of Botany 51, 14-20.

Taylor H C, Macdonald S A and Macdonald I A W 1985. Invasive alien woody plants in the Cape of Good Hope Nature Reserve. II. Results of a second survey from 1976 to 1980. South African Journal of Botany 51, 14-20.

Van Wilgen B W 1981. Some effects of fire frequency on fynbos plant community composition and structure at Jonkershoek, Stellenbosch. South African Forestry Journal 118, 42-55.

Van Wilgen B W 1984. Fire climates in the southern and western Cape and their potential use in fire control and management. South African Journal of Science 80, 358-362.

Van Wilgen B W and Kruger F J 1981. Observations on the effects of fire in mountain fynbos at Zachariashoek, Paarl. Journal of South African Botany 47, 195-212.

Versfeld D B and van Wilgen B W 1986. Impact of woody aliens on ecosystem properties. In: Macdonald I A W, Kruger F J and Ferrar A A (editors) The ecology and mangement of biological invasions in southern Africa. Oxford University Press, Cape Town. pp 239-246.

Wells M J, Pyonton R J, Balsinhas A A, Musil C F, Joffe H, van Hoepen E and Abbott S K 1986. The history of introduction of invasive alien plants to southern Africa. In: Macdonald I A W, Kruger F J and Ferrar A A (editors) The ecology and management of biological invasions in southern Africa. Oxford University Press, Cape Town. pp 21-35.

CHAPTER 7. SOUTHERN AFRICAN FORESTS

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INTRODUCTION

Indigenous forests cover only 3 000 km² of southern Africa south of the Limpopo River (Anonymous 1982; Huntley 1984). They grow on all geological formations within areas receiving mean annual rainfalls of between 600 mm and 2 000 mm (Geldenhuys 1987). The forests occur as scattered patches of varying size in the eastern zones of southern Africa from the Soutpansberg inland at 22°40'S and the Maputaland coast at 27°S to the Cape Peninsula at 34°S (Cooper 1985; Anonymous 1987a; Figures 7.1 and 7.2), resulting in a large ratio of margin to forest area. Consequently, they are affected by adjacent land-use practices.

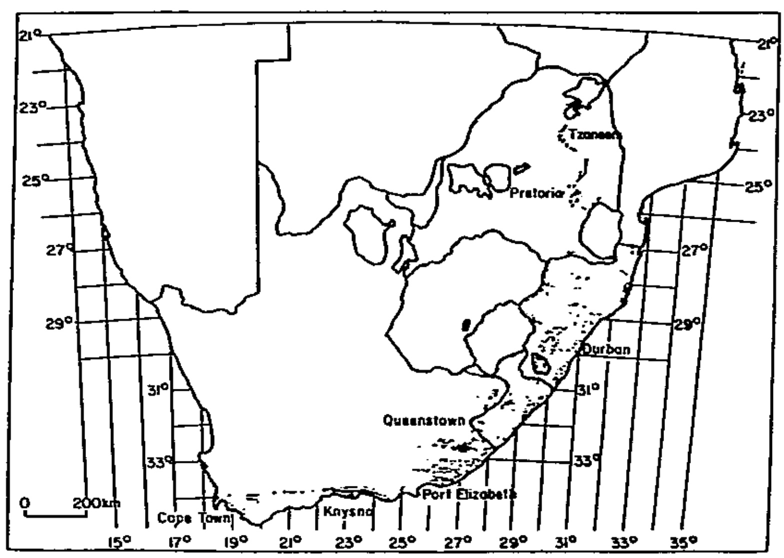

FIGURE 7.1 Distribution of indigenous forests in southern Africa.

The forests play a role in the welfare of South African society which is disproportionately greater than their small extent and low potential for commercial exploitation (Geldenhuys et al 1986). The value of forest-based recreation and of minor forest products such as ferns for flower arrangements, poles and laths for building material, firewood, medicinal components, and craftwork materials is often overlooked. Many forests were cleared for agriculture, commercial plantation forestry, settlements and infrastructure development (King 1938, 1941; Darrow 1973). The introduction of alien tree species and the establishment of plantations of these species since 1780 (Phillips 1963; Darrow 1973; Geldenhuys et al 1986) caused a gradual decrease in the demand for timber from the indigenous forests.

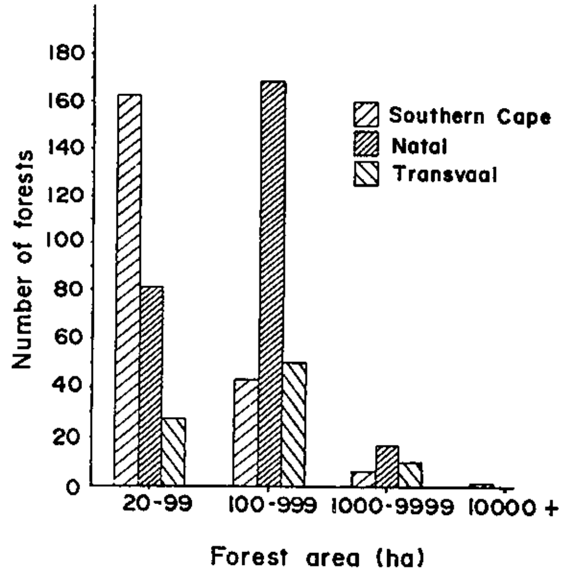

FIGURE 7.2 Sizes of forests in the southern Cape, Natal and Transvaal.

No long-term data exist which relate changes in forest distribution, composition or growth to changes in the abiotic environment. There are, however, scattered data which relate to human influences. Recently collection of appropriate short-term data has been initiated in order to separate human influences from natural causes. In this chapter we draw on both published and unpublished information to indicate possible trends.

FACTORS CONTROLLING THE DISTRIBUTION OF INDIGENOUS FOREST

It appears that natural fire patterns in relation to topography had a major influence on forest distribution in the southern Cape (Geldenhuys in preparation). Evidence suggests that forest patches mainly occur in "bergwind shadow" areas. Rainfall, geology and soils both inside and outside forest on the coastal platform are similar and cannot account for the patchy distribution of forest. Neither can past exploitation and clearing of forest account for this pattern. The understorey near the edges of forests differs from that near the centre of forests on the same soils, and these areas have long-lived seeds of the pioneer leguminous tree *Virgilia divaricata* and charcoal below the litter. This suggests that these forest edges have recovered from high intensity bergwind fires which penetrated the normal bergwind shadow area. The large areas outside the forest patches which are currently under fynbos, plantations or farmland had been kept clear of forest by recurrent bergwind fires, possibly since the mid-Holocene.

Shallow water tables as a result of impermeable subsurface hardpan horizons control the distribution of forest on the plainsland catchments of Lake St Lucia in Zululand (Tinley 1971). Forests are confined to "islands" of higher ground and the coastal dunes. These sites are well watered and well aerated, whereas the plains below are waterlogged for long periods.

Variations in moisture regime as affected by aspect could also influence forest distribution. In many areas forests occur only on south-eastern to south-western slopes. However, no quantitative data are available.

DEFORESTATION AND FOREST EXPANSION

Various reports deal with the destruction of indigenous forest over the last 300 years (eg Sim 1907; King 1938, 1941; Phillips 1963; Darrow 1973; Wells 1973; Cooper 1985). However, very few quantitative data are available. Of the total area of 60 500 ha of forest in the southern Cape, of which 70% occurs on state land, 238 ha have been cleared since 1970 (Von dem Bussche unpublished; Geldenhuys 1983; Geldenhuys et al in press; Table 7.1). These are absolute minimum figures as no accurate records are available for privately owned forests, and none for forest patches destroyed or damaged by fire.

TABLE 7.1 Area of forest cleared since 1970 in the southern Cape

Purpose of clearing	State forest	Private forest
Roads	63 ha	3 ha
Powerlines	19 ha	?
Conversion to agricultural fields, plantations and dams	16 ha	137 ha

State owned forests in the southern Cape are actively re-established to consolidate the forest edges to manageable boundaries (Von dem Bussche 1975; van Daalen in press). This together with the natural expansion of forests as a result of current management practices, protection of plantations against fire and controlled burning of fynbos in catchments will reduce the net forest area lost in this region considerably. Again, no figures are available.

In Natal large areas of riverine, swamp and coastal forest have been destroyed. Cooper (1985) noted extensive destruction of riverine forest (having a total extent of only 1 887 ha) in KwaZulu along the north bank of the Mkuze River and along the Pongola River. He also mentioned that large areas of rare swamp forest (total of only 4 843 ha) along the coast of Natal and Zululand have been cleared for sugarcane growing. According to M C Ward (personal communication), about 1 000 ha out of a total of 2 500 ha swamp forest at Kosi Bay have been completely or partially converted to agricultural lands. When the Manguzi Forest Reserve was proclaimed in 1950 to protect the coastal forest, the area reserved was 5 600 ha. Today there is about 270 ha left.

Fourcade (1889 ex Taylor 1961) estimated the extent of the Natal mistbelt forest at Karkloof in 1880 as 32 375 ha. Rycroft (1944) estimated its size in the early 1940's as between 6 070 ha and 9 000 ha. He suggested that even if the 1880 estimate was high, it did mean that there might have been as much as 80% reduction of forest area in only 60 years. Taylor (1963) stated that the extent of the Nxamalala Forest, near Pietermaritzburg, was reduced from 3 240 ha in 1880 to only 600 ha 70 years later.

The extent of the afromontane *Podocarpus* forests of Natal Drakensberg are believed to have been reduced considerably as a result of frequent fires during the dry winter months. Everard (1986) indicated that regular burning has played a major role in detrimentally changing the structure and dynamics of the marginal communities of these forests.

FOREST SUCCESSION

Only two known quantitative studies record forest succession, viz in Hluhluwe Game Reserve and Mlalazi Nature Reserve near Mtunzini.

The forest succession in Hluhluwe Game Reserve, Zululand, has been studied for the last 50 years (Downing 1980; Watson and Macdonald 1983; Whateley in press). Despite intensive woody plant eradication campaigns and improved burning policies the bush and forest encroachment continued (Brooks and Macdonald 1983). Estimates for the increase of forest since 1937 vary from five per cent for the period 1937 to 1974 (Downing 1980) to between 14% and 20% for the period 1937 to 1975 (Watson and Macdonald 1983) to 33% for the period 1937 to 1982. Generally there is a progression from grassland to thickets or woodlands of small-leaved, shade-intolerant, fire-tolerant woody species to woodlands and forests of broad-leaved, shade-tolerant, fire-intolerant woody species.

Mlalazi Nature Reserve is a unique site for studying forest advancement along a primary successional gradient (Moll 1972; Weisser and Backer 1983; van Daalen et al 1986). Most of the coastal dune areas of the world are eroding as a result of rising sea levels. In contrast, the beach at Mlalazi is prograding rapidly and has advanced about 120 m in the last 40 years, mainly as a result of the enormous sand loads deposited into the sea by the nearby Tugela River, 40 km south of the study site. This sand is transported northwards by longshore drift associated with an inshore counter current and deposited along the beaches north of the Tugela River mouth. Plants such as *Scaevola plumieri* often colonize the landward part of the beach. Dunes form through the accumulation of sand grains around the plants, which, in turn, respond by growing up through the developing dune. In time, the dunes become stabilized and colonized by other plant species. Eventually dune forest develops. Good aerial photograph coverage since 1937 is available. Dunes formed since then can therefore be aged, providing an excellent study site for forest succession. The following approximate rates of succession were determined by Weisser et al (1982):

i) It will take about 13 years for the pioneers to colonize the dunes and for the appearance of the open dune scrub community.

ii) After about 71 years the dunes will be covered by a closed dune scrub community.

iii) If protection against seawinds and salt spray is provided by the seaward ridges and their vegetation, a dune forest would develop after about 119 years, beginning in the dune slacks and spreading from there.

On the inland margin of the coastal forests, and particularly along lake shores, *Acacia karroo* plays a prominent role in forest succession

(Breen 1979). It forms dense groves for at least 20 years before conditions for the invasion of climax forest species are suitable. Because *A karroo* belongs to the Leguminosae and has root nodules it possibly fixes atmospheric nitrogen on these nutritionally poor sites. On the Zululand coastal dunes between Richards Bay and the Mfolozi River *A karroo* woodland and secondary dune scrub increased from five per cent of the total area in 1937 to 19% in 1974. It is estimated that under the present climatic conditions it will take 30 to 150 years for mature *A karroo* woodland to develop into secondary dune forest.

Several cases have been recorded where indigenous tree communities expanded their local distributions by colonizing the understorey of stands of alien woody plants (Geldenhuys et al 1986; Knight et al 1987).

CHANGES IN FOREST COMPOSITION

The unsystematic, uncontrolled felling by private woodcutters of trees in the southern Cape forests until 1939 has eliminated trees of good quality of certain valuable timber species (Phillips 1963). Trees of valuable species that remained were too large, had defects, or were not easily accessible. Favoured species were *Ocotea bullata*, *Podocarpus latifolius*, *P falcatus* (to a lesser degree), *Apodytes dimidiata*, *Curtisia dentata*, and a few others. Later nurse stands of *Halleria lucida*, *Rhamnus prinoides* and *Burchellia bubalina* developed in the damaged forests, under which canopy species regenerated. But even under the "single tree selection system" practised by state-employed, scientifically-trained forest officers from 1965 to 1980 some species were regularly favoured for removal or retention (Geldenhuys 1980). Based on a removal preference index, *Canthium obovatum*, *Olea capensis* subspecies *macrocarpa*, *Burchellia bubalina*, *Maytenus peduncularis* and *Ocotea bullata* were regularly overexploited. *Pterocelastrus tricuspidatus* and *Curtisia dentata* were consistently marked below the level of equal selection. Since 1980 improvements have been implemented to ensure that the removal of species is proportional to their contribution to stand composition (Seydack et al unpublished).

In the eastern Cape, towards the end of the previous century, thousands of *Ptaeroxylon obliquum* trees were cut for sleepers, telephone poles and fuelwood (Palmer and Pitman 1972). Wells (1973) suggested that selective timber removal for building, mine props, sleepers and wagon building has made the recognition of primary forest communities in the Amatole forests extremely difficult.

Mistbelt *Podocarpus* forests in Natal were intensively worked for timber until 1940. The main trees cut were *Podocarpus* species, *Ocotea bullata*, *Ptaeroxylon obliquum* and *Olea capensis*. In addition, thousands of poles, laths and saplings were collected for hut building. The forests were also used as winter grazing for cattle which detrimentally affected regeneration (Moll 1972). Moll (1972) also found that the tree species regenerating in the Karkloof forest were species other than those currently dominant in the canopy. He concluded that there was a tendency towards dominance by species capable of tolerating a drier climate.

The only minor forest product for which relatively long-term data are available is the seven weeks fern *Rumohra adiantiformis*. Local research into the sustained utilization of this fern started in 1982 (Geldenhuys and van der Merwe 1986). The amplitude of annual oscillations in fern frond (ie leaf) density (Figure 7.3) and frond size (not shown in Figure 7.3) steadily declined over three years of frond harvesting. The decline in frond production and size was attributed to potassium depletion and reduction in photosynthetic surface area (see also Milton and Moll 1987). Data from the control plots suggest that decreased rainfall in the third year during the period of frond development increased the magnitude of harvesting effects on the mature fronds. Bud density was not affected by rainfall. A five-year period seems adequate to study the effect of utilization of the fern and to develop management procedures for its long-term sustainable yield.

Minor forest products are increasingly being exploited on a commercial scale in Natal/KwaZulu and northern Transkei to supply the urban demand for traditional medicines and sticks. Changes in the size classes selected due to commercial demand for sticks (which may preferentially be made from split trunks) is of significance as the trees selected have low rates of annual increment (eg *Ochna arborea*) and demand is widespread (eg sticks from Nkandla Forest are sold in Johannesburg; Cunningham unpublished). Thus "minor product" use can have a major effect on forest structure and species diversity. Nowhere is this more apparent than in the herbal medicine trade, which is currently under investigation (Cunningham 1986).

The use of bark and roots for medicines is similar to the species specific overexploitation resulting from commercial craftwork production (Cunningham 1987). The differences lie in the easier provision of an alternative supply source (artificial dyes) and the limited number of forest species involved (mainly *Euclea natalensis* and *E divinorum*) in the craftwork section.

Gathering of wild fruits and spinaches, on the other hand, has a low impact on forest but is an important subsistence activity in areas of marginal agricultural potential where a high percentage of households sampled gathered fruits of *Manilkara discolor*, *M concolor* and *Landolphia kirkii* (Cunningham 1985).

Preferential use of hardwoods also characterizes selection of hut building materials (Cunningham and Gwala 1986). Although Cunningham (1985) has recorded high (1 400 to 2 000) quantities of laths used per hut, and lath cutting was of concern to Colonial Authorities (Storr-Lister 1902; Sim 1907), the effects of fuelwood collection and the cutting of poles and laths are only now under investigation (D Muir personal communication).

The only known long-term data on forest animals are those on the Knysna elephant. A drastic decline of the elephant population has occurred during the last century. Koen (1984) summarized the population estimates since 1876 (Figure 7.4). They declined from 400 to 500 in 1876 to 11 to 13 in 1920. This decline is attributed mainly to hunting throughout an area much larger than the forests. Since then they have been confined to the forests due to the growth of agriculture and human population pressure. Phosphate and copper supplies in the forests are deficient, which is believed to have given rise to low vigour and low reproduction rates which have resulted in the present low elephant population.

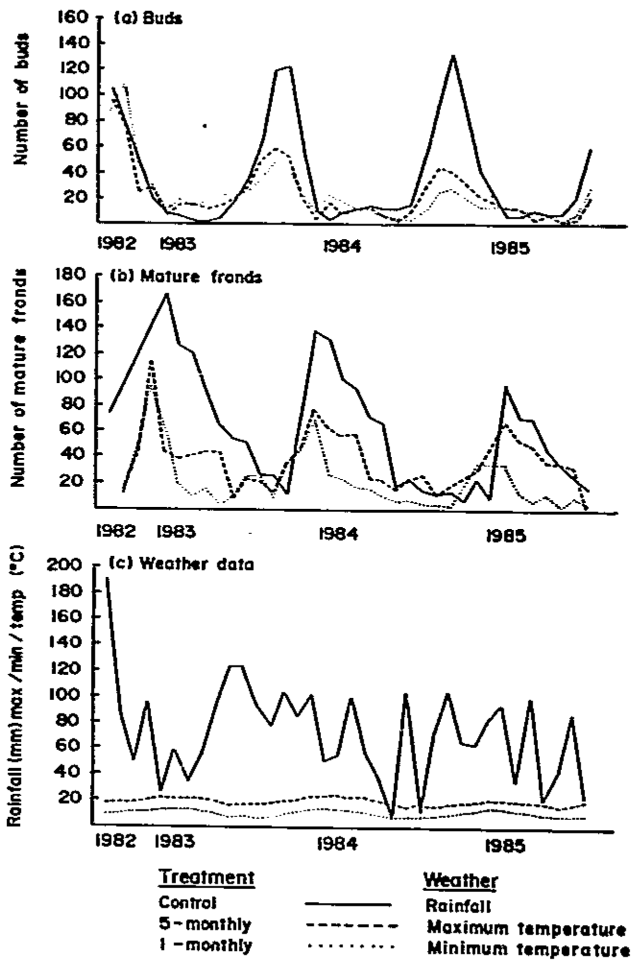

FIGURE 7.3 Seasonal variation in total number of (a) buds and (b) mature fronds of *Rumohra adiantiformis* in the Groenkop Forest, near George, and (c) weather data collected at the nearby Saasveld Weather Station.

FOREST GROWTH

Data for three increment studies are available, viz at Knysna in the southern Cape (ongoing), for *Ptaeroxylon obliquum* at Alexandria in the eastern Cape and at Xumeni in the Natal Midlands.

In the Knysna area individual tree growth rates have been measured for the last 40 years. Between 1937 and 1955 the forest on the growth study site on the Diepwalle State Forest was subjected to various thinning treatments. Since then no more trees have been removed. The fastest growing species was *Rapanea melanophloeos* with a mean annual diameter at breast height (DBH) increment of 2,26 mm. *Ochna arborea* grew the slowest with only 0,34 mm mean annual DBH growth for the period 1972 to 1978. The two most abundant species were *Olea capensis* subspecies *macrocarpa* and *Podocarpus latifolius* comprising 36,11% and 21,88% respectively of the total basal area per hectare. Therefore, their mean

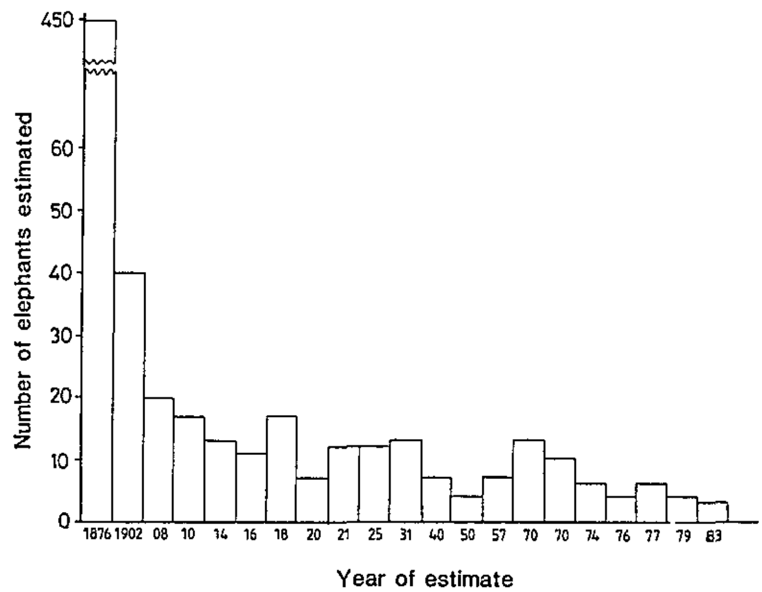

FIGURE 7.4 Estimates of the number of elephants in the southern Cape forests between 1876 and 1983.

basal area and volume increment were highest. Total annual basal area increment for all species together was 0,344 m^2 ha^{-1} or in terms of utilizable timber volume 2,135 m^3 ha^{-1}. Compared to an annual timber volume increment of 28 m^3 ha^{-1} for the alien *Pinus radiata* at Jonkershoek (F J Kruger personal communication) and up to 56 m^3 ha^{-1} on fertile soils at Isidenge State Forest near Stutterheim in the eastern Cape (T Netterville personal communication) this increment rate is extremely slow. The Xumeni growth rates were similar to those measured at Knysna. Mean basal area increment per tree for planted *Ptaeroxylon obliquum* at Alexandria decreased from 0,00029 m^2 yr^{-1} for the period 1904 to 1914 to only 0,00017 m^2 yr^{-1} during 1956 to 1962. This decrease was attributed to competition (Geldenhuys 1977).

Compared to the annual basal area increment rate of 1,13% at Knysna the annual mortality rate of 0,8% is relatively high. When ingrowth (ie all trees that entered the lower size classes since the first measurement) is taken into account, the mean net growth rate for the Knysna study site between 1972 and 1978 was only 0,56%.

For about half the study site net growth data are available since 1942. Annual growth rates decreased over this period from 1,63% in 1942 to 1954, 1,46% in 1954 to 1972, and 0,59% in 1972 to 1978.

From Figure 7.5 it can be seen that most of the growth between 1972 and 1978 occurred in the size classes below 400 mm DBH. This, together with the decrease in growth rates since 1942 suggests that the forest is reaching a climax or equilibrium state. From this study it can be deduced that the carrying capacity of the site lies in the region of 33 m^2 ha^{-1} and that forests in the southern Cape can recover within 30 years from the levels of disturbance associated with timber utilization.

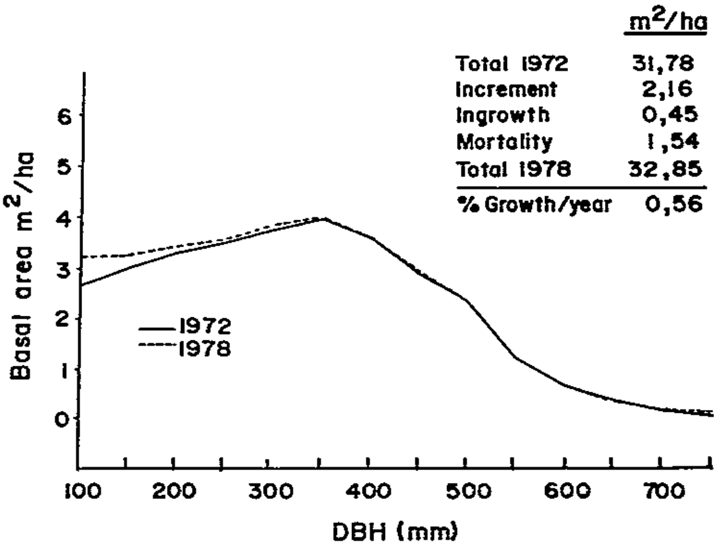

FIGURE 7.5 Mean basal area distributions for 1972 and 1978 on the growth study site at Diepwalle State Forest, near Knysna.

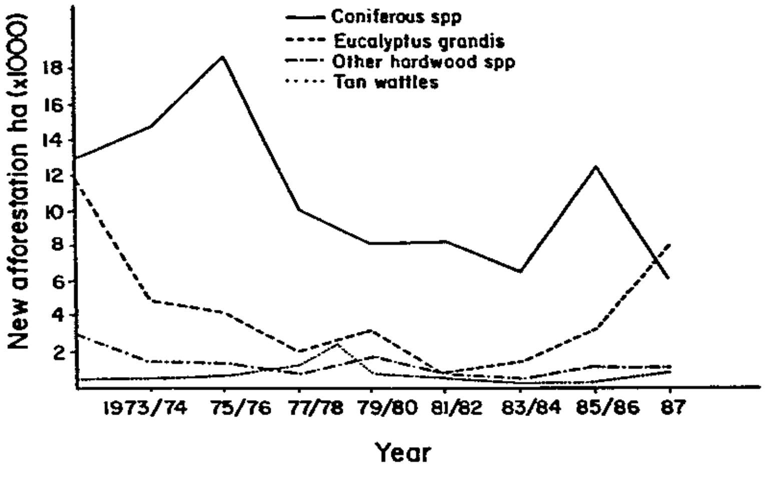

FIGURE 7.6 New afforestation rates in the Republic of South Africa.

PLANTATION FORESTRY

In 1960 the area of commercial timber plantations in South Africa was 900 000 ha (Geldenhuys et al 1986). This increased to 1 133 224 ha in 1986 of which 52% was in Transvaal (and the Orange Free State), 37% in Natal, and 11% in the Cape Province. Transkei has a further 61 753 ha of commercial plantations, Ciskei 6 438 ha and Venda 6 173 ha. In South Africa 70,5% of the plantation area is privately owned. In Transkei, Ciskei and Venda all plantations are state property (Anonymous 1987b).

In 1986 *Pinus* species and other coniferous species covered 55,5% of all plantation areas in South Africa, *Eucalyptus* species 33,3%, wattles 10,5% and other hardwood species 0,7%. New afforestation in South Africa decreased from an annual rate of 28 170 ha in 1971 to 8 978 ha in 1982, and increased again to 16 604 ha in 1986 (Figure 7.6; Anonymous 1985, 1986, 1987b; Geldenhuys et al 1986).

CONCLUSIONS

The lack of relevant long-term data series precludes discrimination between human and natural causes of forest change. Only tentative conclusions and speculation are possible on driving forces for change in the forests. Successional processes following human disturbances seem to be the main driving force and overshadow other possible trends emerging from the data.

On the whole, the forests in the Republic of South Africa are presently much better protected and managed than a few decades ago. In the southern and eastern Cape, Natal and Transvaal there are definite indications of forest expansion (Cooper 1985; van Daalen in preparation) through reduced fire frequency resulting from fire protection of timber plantations. However, certain areas, in particular rural areas of the Ciskei, Transkei and KwaZulu, are experiencing overexploitation and clearing of forest on a large scale.

After the marked decline in the establishment of new plantations of alien species between 1971 and 1983, there has been a noticeable increase since then. In order to satisfy the increasing demand for timber, this increase in afforestation rate will have to be maintained. The plantations are important as they reduce pressure on indigenous forest resources and as they allow the dispersal of indigenous forest propagules.

There are clear indications that forests on state forest land in the southern and eastern Cape are recovering from past overexploitation. In the southern Cape forests there is evidence that some forests are reaching the "shifting mosaic steady-state" where tree-fall gaps are the major structuring factor (Bormann and Likens 1979). The spatial distribution of Amatole forest trees in the eastern Cape indicate that these forests are still in an earlier stage (van Daalen in preparation).

The slow-growing forests of the southern Cape could reach maturity and full stocking (where the steady-state is reached) within 30 years. This indicates that the disturbance levels of most of these forests were within their tolerance limits. Controlled harvesting of timber and other products is possible and compatible with the conservation of the forests, provided that they are not pushed beyond the threshold levels for recovery. The forests do have a remarkable ability to overcome drastic disturbances if the period allowed for their recovery is long enough. Sim (1907) published photographs and written accounts of the overexploitation of the Amatole forests. In some cases the high forest had been reduced to scrub forest. Although some of this depauperated forest has been destroyed completely, many forests recovered to high forest again (Van Daalen in preparation).

The long-term data that are available on the sustained use of forest products are far from adequate. There is an urgent need for the collection of these data. As in the case of *Rumohra* in the southern Cape, 'long-term' must be seen relative to the life cycle of the specific forest component. A few years' data might be sufficient to determine trends.

LONG-TERM STUDIES STARTED OR ENVISAGED

The Forest Map (Cooper 1985; Anonymous 1987a) provides a database for the present distribution of forests. Collection of cryptic data could provide a better understanding of past forest distribution, eg on the sugarcane areas of Natal. Future changes can be monitored by keeping a detailed register of all forest clearing.

Two studies on the biogeography of forests in southern Africa have been initiated during the last two years; one at Saasveld Forestry Research Centre and one at the CSIR in Pretoria. These studies follow on the biogeographic description of southern Africa's forests by White (1978) and Moll and White (1978).

In Transvaal, Orange Free State and Natal all forests larger than 50 ha have been mapped and lists of bird and plant species compiled (Cooper 1985). This information will provide a useful database for any long-term study of these forests. Similar databases are available for the southern Cape.

In the Groenkop forest, near George, studies on ecosystem processes in relation to climatic information are ongoing.

In the Drakensberg a forest succession study has been started recently, and, on the Zululand coast, forest species composition, bird occurrence and faunal composition and abundances are monitored.

In KwaZulu long-term successional data from dune, coastal, sand and swamp forests and structural data on sand and coastal forest are being collected; utilization of medicinal plants, poles, laths and firewood from selected forests and changes in mammal populations in sand forests are monitored, and growth rates of specific forests and forest tree species are measured.

Apart from the permanent sample plots in the Knysna forest, four 0,5 to 0,8 ha plots have been demarcated and surveyed in the Amatole forests for growth studies by the indigenous forest research team at Saasveld Forestry Research Centre. Further plots will be demarcated at Orangekloof on the Cape Peninsula, Alexandria Forest, Manubi in southern Transkei, Weza and Dukuduku in Natal and Zululand, and Woodbush in the eastern Transvaal. These will be remeasured at intervals of five years. About 20% of the southern Cape state forests are managed for timber production. The Indigenous Forest Planning Section of the Directorate of Forestry in Knysna estimates the timber stock of production compartments on 400 m^2 circular temporary plots on a 80 m x 100 m grid, ie a five per cent sampling intensity. Since 1985 half these plots are marked permanently for monitoring, and increment and mortality determination. These will be remeasured every 10 years.

REFERENCES

Anonymous 1982. Forestry guide plan for South Africa. Department of Environment Affairs, Pretoria.

Anonymous 1985. Commercial timber resources and roundwood processing in South Africa 1983-84. Directorate National Forestry Planning, Department of Environment Affairs, Pretoria.

Anonymous 1986. Commercial timber resources and roundwood processing in South Africa 1984/85. Directorate National Forestry Planning, Department of Environment Affairs, Pretoria.

Anonymous 1987a. Map of indigenous evergreen forests of South Africa, Sheets I and II. Forest Biome Project, National Programme for Ecosystem Research, FRD, CSIR, Pretoria.

Anonymous 1987b. Commercial timber resources and roundwood processing in South Africa 1985/86. Directorate National Forestry Planning, Department of Environment Affairs, Pretoria.

Bormann F H and Likens G E 1979. Catastrophic disturbance and the steady state northern hardwood forests. American Science 67, 660-669.

Breen C M 1979. The dune forest: its structure and maintenance. In: Allanson B R (editor) Lake Sibaya. Monographiae Biological Vol 36. pp 21-33.

Brooks P M and Macdonald I A W 1983. The Hluhluwe-Umfolozi Reserve: An ecological case history. In: Owen-Smith N (editor) Management of large mammals in African conservation areas. Haum Educational Publishers. pp 51-77.

Cooper K H 1985. The conservation status of indigenous forests in Transvaal, Orange Free State, South Africa. Wildlife Society of South Africa.

Cunningham A B 1985. The resource value of indigenous plants to rural people in a low agricultural potential area. Unpublished PhD Thesis, University of Cape Town, Cape Town.

Cunningham A B 1986. An investigation of the herbal medicine trade in Natal/KwaZulu. Phase 1 report. Institute of Natural Resources Working Paper No 8.

Cunningham A B 1987. Commercial craftwork: Balancing out human needs and resources. South African Journal of Botany 53(4), 259-266.

Cunningham A B and Gwala B R 1986. Building material and plant species used in Tembe-Thonga hut construction. Annals of the Natal Museum 27(2), 491-511.

Darrow W K 1973. Forestry in the eastern Cape Border Region. Bulletin 51, Department of Forestry, Pretoria.

Downing B H 1980. Changes in the vegetation of Hluhluwe Game Reserve, Zululand, as regulated by edaphic and biotic factors over 36 years. Journal of South African Botany 46(3), 225-231.

Everard D 1986. The effects of fire on the Podocarpus latifolius forests of the Royal Natal National Park, Natal Drakensberg. South African Journal of Botany 52, 60-66.

Geldenhuys C J 1977. Die aanwas van Ptaeroxylon obliquum in die Alexandriabos, Oos-Kaap. South African Forestry Journal 102, 83-87.

Geldenhuys C J 1980. The effect of management for timber production on floristics and growing stock in the southern Cape indigenous forests. South African Forestry Journal 113, 6-15.

Geldenhuys C J 1983. A critical evaluation of indigenous forest management. In: Proceedings of the Jubilee Symposia, University of Stellenbosch, Stellenbosch. Foris 98, 497-524.

Geldenhuys C J 1987. Distribution and classification of indigenous evergreen forest and deciduous woodland in South Africa. In: Von Gadow K, van der Zel D W, van Laar A, Schönau A P G, Kassier H W, Warkotsch P W, Vermaas H F, Owen D L and Jordaan J V (editors) South African forestry handbook. V&R Printers, Pretoria.

Geldenhuys C J and van der Merwe C J 1986. Effects of frond harvesting on growth of the fern Rumohra adiantiformis in the southern Cape forests. South African Forestry Research Institute Report S.85/30.

Geldenhuys C J, Le Roux P J and Cooper K H 1986. Alien invasions in indigenous evergreen forest. In: Macdonald I A W, Kruger F J and Ferrar A A (editors) The ecology and management of biological invasions in southern Africa. Oxford University Press, Cape Town. pp 119-131.

Geldenhuys D J, Kotze D and van der Merwe C J (In press). Road-building and the survival of indigenous forest in the southern Cape. South African Forestry Journal.

Huntley B J 1984. Characteristics of South African biomes. In: Booysen P de V and Tainton N M (editors) Ecological effects of fire in South African ecosystems. Springer-Verlag, Berlin. pp 2-17.

King N L 1938. Historical sketch of the development of forestry in South Africa. Journal of the South African Forest Association 1, 4-16.

King N L 1941. The exploitation of the indigenous forests of South Africa. Journal of the South African Forest Association 6, 26-48.

Knight R S, Geldenhuys C J, Masson P H, Jarman M L and Cameron M J (editors) 1987. The role of aliens in forest edge dynamics: a workshop report. Occasional Report No 22. FRD, CSIR, Pretoria. 41 pp.

Koen J H 1984. A study of the distribution, population composition, movements and feeding of the Knysna elephants Loxodonta africana africana (Blumenbach 1797). South African Forestry Research Institute Report S.84/6.

Milton S J and Moll E J 1987. Utilization potential of Rumohra adiantiformis in the southern Cape forests. Project Report Series, Ecosystem Programmes, FRD, CSIR.

Moll E J 1972. A preliminary account of the dune communities at Pennington Park, Mtunzini, Natal. Bothalia 10, 615-626.

Moll E J and White F 1978. The Indian Ocean coastal belt. In: Werger M J A (editor) Biogeography and ecology of southern Africa. W Junk, The Hague. pp 561-596.

Palmer E and Pitman E 1972. Trees of Southern Africa. Vol 2. Balkema, Cape Town.

Phillips J F V 1963. The forests of George, Knysna and the Zitzikama - a brief history of their management 1778-1939. Government Printer, Pretoria.

Rycroft H B 1944. The Karkloof Forest, Natal. Journal of the South African Forestry Assocition No 11, 14-25.

Sim T R 1907. The forests and forest flora of the Colony of the Cape of Good Hope. Taylor and Henderson, Aberdeen.

Storr-Lister J 1902. Report on Forestry in Natal and Zululand. Government Report, Colony of Natal. Times Printing and Publishing Company, Pietermaritzburg.

Taylor H C 1961. The Karkloof Forest, a plea for its protection. Forestry in South Africa 1, 123-134.

Taylor H C 1963. A report on the Nzamalala Forest. Forestry in South Africa 2, 29-51.

Tinley K L 1971. Lake St Lucia and its peripheral sand catchment. The ecology and implications of proposals to reprieve a condemned system. MSc Thesis, University of the Witwatersrand, Johannesburg.

Van Daalen J C (In press). Riglyne vir die herrestiging van woud in die Suid-Kaap. Pamphlet, Department of Environment Affairs.

Van Daalen J C, Geldenhuys C J, Frost P G H and Moll E J 1986. A rapid survey of forest succession at Mlalazi Nature Reserve. Occasional Report No 11. FRD, CSIR, Pretoria. 33 pp.

Von den Bussche G H 1975. Indigenous forest conservation management. South African Forestry Journal 93, 25-31.

Watson H K and Macdonald I A W 1983. Vegetation changes in the Hluhluwe-Umfolozi Game Reserve complex from 1937 to 1975. Bothalia 14, 265-269.

Weisser P J, Garland I F and Drews B K 1982. Dune advancement 1937-1977 at the Mlalazi Nature Reserve, Mtunzini, Natal, South Africa, and a preliminary vegetation - succession chronology. Bothalia 14, 127-130.

Weisser P J and Backer A P 1983. Monitoring beach and dune advancement and vegetation changes 1937-1977 at the farm Twinstreams, Mtunzini, Natal, South Africa. In: McLachlan A and Erasmus T (editors) Sandy beaches as ecosystems - developments in hydrobiology. W Junk, The Hague. pp 727-732.

Wells M J 1973. The effect of the wagon building industry on the Amatole forests. Bothalia 11, 153-157.

Whateley A M (In press). Forest succession in a subtropical woodland. Journal of Ecology.

White F 1978. The Afromontane region. In: Werger M J A (editor) Biogeography and ecology of Southern Africa. W Junk, The Hague.

MONITORING IN NATURAL AREAS IN ZULULAND STATE FORESTS

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Environmental monitoring is one of the primary management objectives for the natural areas in the Zululand state forests. These natural areas cover an area of approximately 78 000 ha and include Sodwana, Cape Vidal, Eastern Shores, Dukuduku and Nyalazi State Forests as well as Ntendeka Wilderness Area and Maphelane Nature Reserve.

Long-term monitoring has been planned for:

1) groundwater levels on Eastern Shores State Forest
2) streamflow levels
3) coastal form and coastal erosion
4) beach profiles
5) extent of major vegetation formations
6) composition of vegetation
7) phenology of vegetation
8) faunal composition and abundance
9) daily rainfall data.

The monitoring programmes implemented to date are given in Table 7.2.

TABLE 7.2 Monitoring programmes in the Zululand State Forests

Component	When started	Time interval	Areas
Groundwater	1973	Weekly	3
Streamflow	1973	Weekly	3, 6
Forest composition	1983-1986	Variable	1, 4, 5, 7
Grassland and other vegetation composition	1980-1985	Variable	1, 2, 3, 4, 6
Extent of vegetation formations	1942	Variable	
Bird occurrence	1980	Monthly, but variable	1, 2, 3, 4, 5, 6, 7

Key to areas:
1. Sodwana State Forest; 2. Cape Vidal State Forest; 3. Eastern Shores State Forest; 4. Maphelane Nature Reserve; 5. Dukuduku State Forest; 6. Nyalazi State Forest; 7. Ntendeka Wilderness Area.

The indigenous forest monitoring programme consists of the following:

1. Initial survey of the forest on a grid pattern with transects spaced one kilometre apart and sample points at 80 m intervals along the transects.

2. Measurement of the following parameters in 20 x 20 m permanently marked plots located at each sample point.

2.1 Species, DBH and height of all woody species above five metres in height.

2.2 Density per meter height class for each species of woody plant above 0,4 m in height.

2.3 Density for each species between 0,2 and 0,4 m in height.

3. Evaluation of initial assessment using ordination and classification techniques in order to determine the programme for the reassessment of the plots.

Initial surveys have been completed for Maphelane Nature Reserve and for sections of Sodwana and Dukuduku State Forests and the classification and ordination analysis is being undertaken at present.

No reassessments have been undertaken to date.

AERIAL PHOTOGRAPHS AS A LONG-TERM DATA SOURCE FOR VEGETATION STUDIES

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Many vegetation types encountered today can only be understood in terms of their history. In most cases the habitat history and the changes that occurred in the vegetation are not known. Therefore the existence of historical aerial photographs can be a very valuable data source to supply missing information that can contribute to an improved understanding and interpretation of vegetation.

Aerial photographs as a long-term data source were used in dune vegetation studies in Zululand (Weisser 1979; Weisser and Marques 1979; Weisser and Backer 1983; Weisser and Müller 1983). The advantages and disadvantages found when using aerial photographs as a data source and on information gathered from literature (Edwards 1972) are outlined below.

ADVANTAGES OF AERIAL PHOTOGRAPHS AS A LONG-TERM DATA SOURCE

- Objectivity: the material obtained is independent of the gatherer.
- Interpretation and data gathering can be checked retrospectively.
- Aerial photography may give qualitative as well as quantitative information, eg area covered by a vegetation type.
- It provides a synoptic view of habitat as well as vegetation.
- It is a multidisciplinary data source, eg for geologists, botanists, geomorphologists, geographers, zoologists etc.
- It permits "cause variable monitoring" (eg erosion [cause] in relation to river and lake siltation [effect]), as well as "effect variable monitoring" (eg erosion as a probable effect of vegetation degradation).
- The sampling is nondestructive.
- Extensive areas can be efficiently studied with relatively little effort.
- This data source is versatile, being easily adapted to the problem to be solved. The combination of different scales with different film types facilitates sufficient technical flexibility to ensure the highest possibility of success towards solving a particular problem.

- The photographs are easily stored and can be reused as a data source.
- Additional sensitivity and resolution power can be expected in the future from improvements in photographic equipment and films, and from refinements of interpretation techniques such as image enhancement.
- Automatic interpretation will probably become more common in the future, and will help to increase the objectivity as well as the efficiency of interpretation.

DISADVANTAGES

- The use of aerial photographs as a long-term data source is limited to a few decades, since aerial photographic techniques are relatively recent.
- The initial capital outlay for equipment and operations for obtaining the photographs can be considerable.
- Some exploratory work is usually necessary to ensure the adequacy of the method in relation to the problem to be solved.
- Seasonal changes as well as extreme situations, such as droughts and floods, can increase the difficulty of interpretation.
- Sometimes ground truth for vegetation must be obtained relatively soon after the photos were taken, eg the vegetation image may change with the season as well as with the advancement of succession.

SUMMARY

In many cases aerial photos can be the key to solving problems requiring long-term data. The suitability of aerial photographs as a data source for botanical studies varies considerably depending on scale, quality of imagery, type of film, time of the year, inherent characteristics of the vegetation or species considered and the type of research problem to be solved. Aerial photographs have proven to be a good long-term source for basic vegetation data, and are sufficient to allow identification and mapping of major plant communities.

REFERENCES

Edwards D 1972. Remote sensing in the evaluation of the natural vegetation resources of South Africa. Proceedings of the 5th Symposium on Remote Sensing, Pretoria, CSIR. pp 99-102.

Weisser P J 1979. Suitability of air-photo interpretation for monitoring coastal dune vegetation of the Zululand Dunes, South Africa. In: The use of ecological variables in environmental monitoring. The National Swedish Environment Protection Board, Report PM 1151, 62-72.

Weisser P J and Marques F 1979. Gross vegetation changes in the dune area between Richards Bay and the Mfolozi River, 1937-1974. Bothalia 12, 711-721.

Weisser P J and Backer A P 1983. Monitoring beach and dune advancement and vegetation changes 1937-1977 at the farm Twinstreams, Mtunzini, Natal, South Africa. In: A MacLachlan and T Erasmus (editors) Sandy Beaches as Ecosystems. Developments in Hydrobiology No 19. W Junk, The Hague. pp 727-732.

Weisser P J and Müller R 1983. Dune vegetation dynamics from 1937-1976 in the Mlalazi-Richards Bay area of Natal, South Africa. Bothalia 14, 661-667.

CHAPTER 8. LONG-TERM DATA SERIES FROM SOUTH AFRICAN GRASSLANDS

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INTRODUCTION

The aim of this chapter is to outline what is known about change over time, in grassland, in the longer term. In essence the goal is to synthesize existing knowledge and provide a common repository for long-term grassland data. Long-term studies in grassland are rare and often difficult to locate, particularly those that have been discontinued. One intention is the exposure of such data so that they may be meaningfully applied.

Specific objectives include 1) an examination of the goals of long-term data collection in grassland, 2) the determination of directional trends or oscillatory fluctuations, 3) the identification of the possible forcing variables and 4) an assessment of our current predictive ability.

For the purposes of this document, the geographical boundaries of the grassland biome have been based on Acocks (1975). Grassland vegetation covers approximately 27% of South Africa, mainly occurs in the eastern portion of the country (Figure 8.1) and can be subdivided (Table 8.1) as follows (after Mentis and Huntley 1982):

1) the climatic climax or "pure" grasslands in the west, essentially the Dry *Cymbopogon-Themeda* veld (Acocks Veld Type 50);

2) the fire climax or "false" grasslands seral to forest which occur mainly in the humid eastern portions of the country; and

3) also fire climax grassland but in this instance grassland seral to bushveld or savanna which occurs mainly in the north but also in the south.

In this chapter the classification of grass species according to their response to grazing intensity into four classes after Tainton (1981) will be followed. "Decreaser" species are those which dominate in veld of good condition and decline in abundance in deteriorating veld. The class "Increaser I" comprises species which are not abundant in veld of good condition but increase when veld is underutilized. "Increaser II" species are not abundant in veld in good condition but increase when veld is overutilized. The "Increaser III" class consists of species which are not abundant in veld which is in good condition but which increase when veld is selectively grazed.

LONG-TERM DATA SERIES IN GRASSLAND

Most ecologists are of the opinion that long-term studies are inherently useful, yet these studies are rare. This paradoxical situation is due to a matrix of constraints imposed on scientists, which includes funding, design, continuity and interpretative problems (Strayer et al 1986).

TABLE 8.1 A grouping and listing of the grassland Veld Types, as recognized by Acocks (1975), and the extent of each type as supplied by the Botanical Research Institute (Scheepers unpublished)

Number	Veld type name	Extent (km^2)	% of biome
PURE GRASSLANDS			
22	Invasion of Grassland by Thornveld	4 622,3	1,31
41	Pan Turf Veld invaded by Karoo	1 217,5	0,35
42	Karriod *Merxmuellera* Mountain Veld	2 258,7	0,64
48	*Cymbopogon-Themeda* Veld	37 531,6	10,67
49	Transitional *Cymbopogon-Themeda* Veld	17 147,3	4,87
50	Dry *Cymbopogon-Themeda* Veld	47 071,5	13,38
51	Pan Turf Veld	2 257,8	0,78
52	*Themeda* Veld or Turf Highveld	10 797,9	3,07
53	Patchy Highveld to *Cymbopogon-Themeda* Veld Transition	12 115,1	3,44
54	Turf Highveld to Highland Sourveld Transition	2 902,4	0,82
55	Bankenveld to Turf Highveld Transition	629,1	0,18
56	Highland Sourveld to *Cymbopogon-Themeda* Veld Transition	9 899,8	2,81
57	North-Eastern Sandy Highveld	14 752,0	4,19
58	*Themeda-Festuca* Alpine Veld	9 800,8	2,79
59	Stormberg Plateau Sweetveld	2 567,2	0,73
60	Karriod *Merxmuellera* Mountain Veld	15 223,2	4,33
Subtotal		190 794,2	54,37
GRASSLAND SERAL TO FOREST			
1	Coastal Forest and Thornveld	26 399,5	7,50
3	Pondoland Coastal Plateau Sourveld	833,1	0,24
5	'Ngongoni Veld	11 965,8	3,40
8	North-Eastern Mountain Sourveld	9 528,4	2,71
44	Highland Sourveld and Dohne Sourveld	31 737,8	9,02
45	Natal Mist Belt 'Ngongoni Veld	3 944,8	1,12
Subtotal		84 409,4	24,00
GRASSLAND SERAL TO SAVANNA			
21	False Thornveld of Eastern Cape	3 891,3	1,11
61	Bakenveld	30 033,6	8,54
62	Bakenveld to Sour Sandveld Transition	1 519,4	0,43
63	Piet Retief Sourveld	7 888,3	2,24
64	Northern Tall Grassveld	5 405,8	1,54
65	Southern Tall Grassveld	18 437,4	5,24
66	Natal Sour Sandveld	5 771,6	1,64
67	Pietersburg Plateau False Grassveld	2 489,9	0,71
68	Eastern Province Grassveld	673,3	0,19
Subtotal		76 110,6	21,63
Grand total		351 314,2	100,00

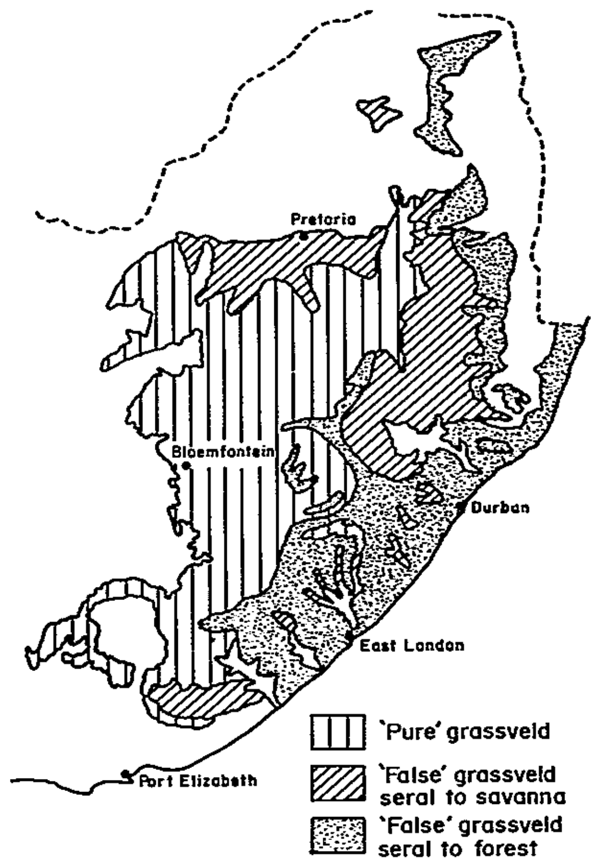

FIGURE 8.1 Distribution of grassland vegetation in South Africa (after Mentis and Huntley 1982).

It is only recently that ecologists have called for more attention to be paid to long-term studies. Generally, in the past, long-term data has been collected for a specific project. While scientific results are important in their own right, the major insights and findings should be applied to the problems of management and utilization.

This synthesis of long-term data series provides an account of how forcing variables influence species composition, production, nutrient cycling and the autecology of individual species. The forcing variables considered are abiotic, fire and biotic influences. There is necessarily some overlap where long-term studies have addressed more than one of the above issues simultaneously.

The following are abstracts of currently known long-term data pertaining essentially to the grassland biome. Many of the précis refer to individual projects and include references to published articles and or the data rather than attempting to reproduce raw data.

Influence of abiotic factors on grassland

Tainton (1984) reports that the work undertaken so far on the influence of abiotic forcing variables on grassland has been almost totally confined to investigations on individual species and only recently has work been undertaken on mixed communities.

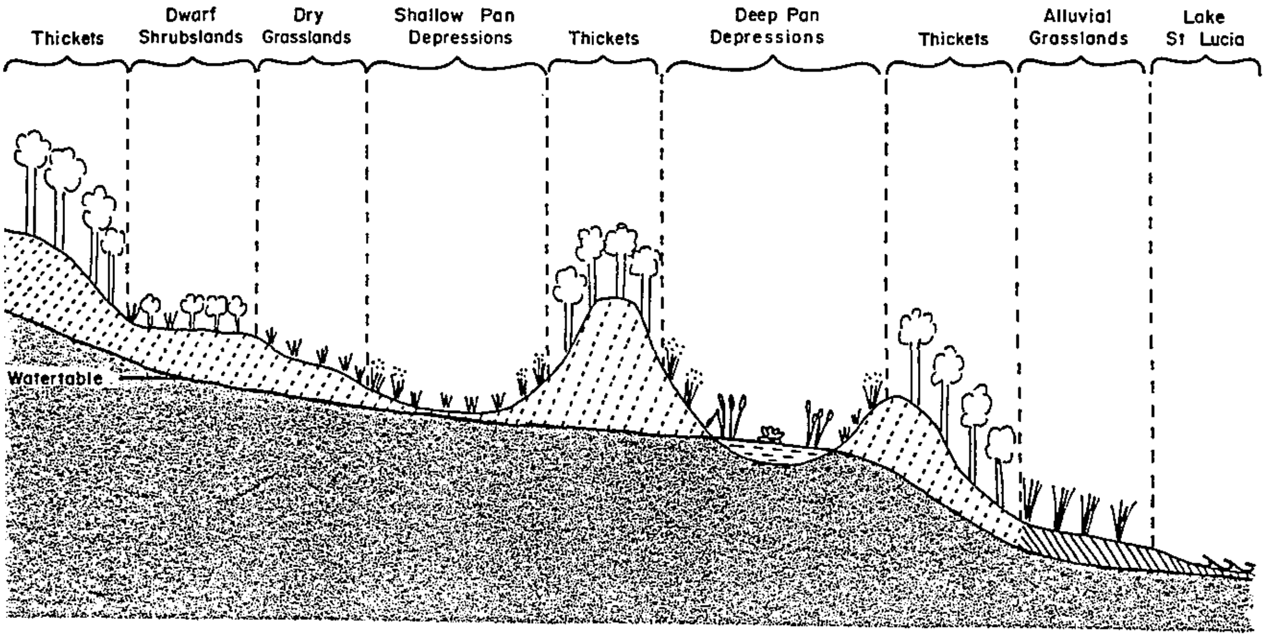

FIGURE 8.2 Diagrammatic section of the Zululand coastal grasslands study area showing vegetation communities.

The following work reported by van Wyk and Tomlinson (unpublished) is an apt example. Five distinct vegetation types related to water table and coastal position were recognized in the Zululand coastal grasslands (thickets excluded) on the western shores of Lake St Lucia (Figure 8.2). These were monitored annually by the same workers for the period 1982 to 1986 using a dry weight ranking method (t'Mannetjie and Heydock 1963).

The results (Figure 8.3) indicate that during periods of low rainfall deep pan depressions are dominated by palatable grass species *Acroceras macrum*, *Bracharia humidicola* and *Hermarthria altissima* (66% contribution to total dry mass). Within the shallow pan depressions the unpalatable species *Digitaria diversinervis* and *Sporobolus subtilis* predominate (52%). During wet periods these grasslands are rapidly invaded by sedges *Fuirena pachyrrhiza*, *Rhyncospora holoschoenoides* and *Eleocharis limosa* (from between 12 and 55% contribution to total dry mass).

Alluvial grassland occurs adjacent to the lake shore (Figure 8.2). This vegetation type is characterized by *Digitaria natalensis* and *Themeda triandra* (both palatable species) and *Cymbopogon validus* (unpalatable) during dry periods. Sedges, *Fimbristylis complanata* and *Mariscus solidus*, invade during periods of high rainfall (Figure 8.3).

The dry grassland and dwarf shrubland vegetation types were not directly affected by fluctuations in the water table due to their elevated catenal position.

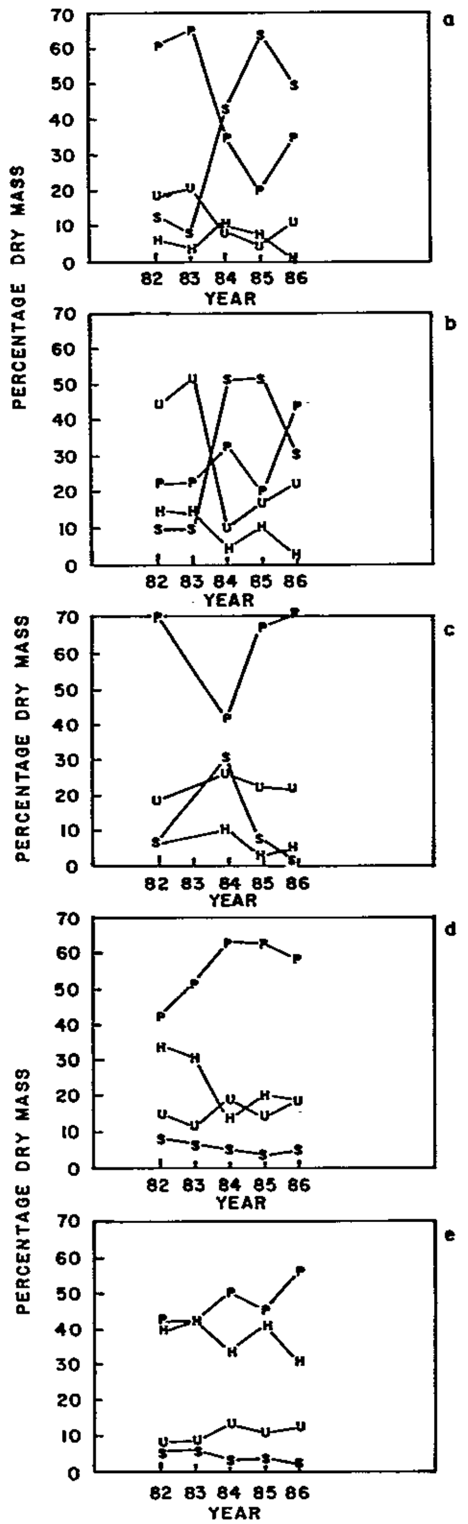

FIGURE 8.3 Percentage contribution of four components of the herbaceous layer in five catenal positions in the Zululand coastal grassland, 1982 to 1986. (P = palatable grass species; U = unpalatable grass species; H = herbs; S = sedges); a - deep pan depressions; b - shallow pan depressions; c - alluvial grasslands; d - dry grasslands; e - dwarf shrublands).

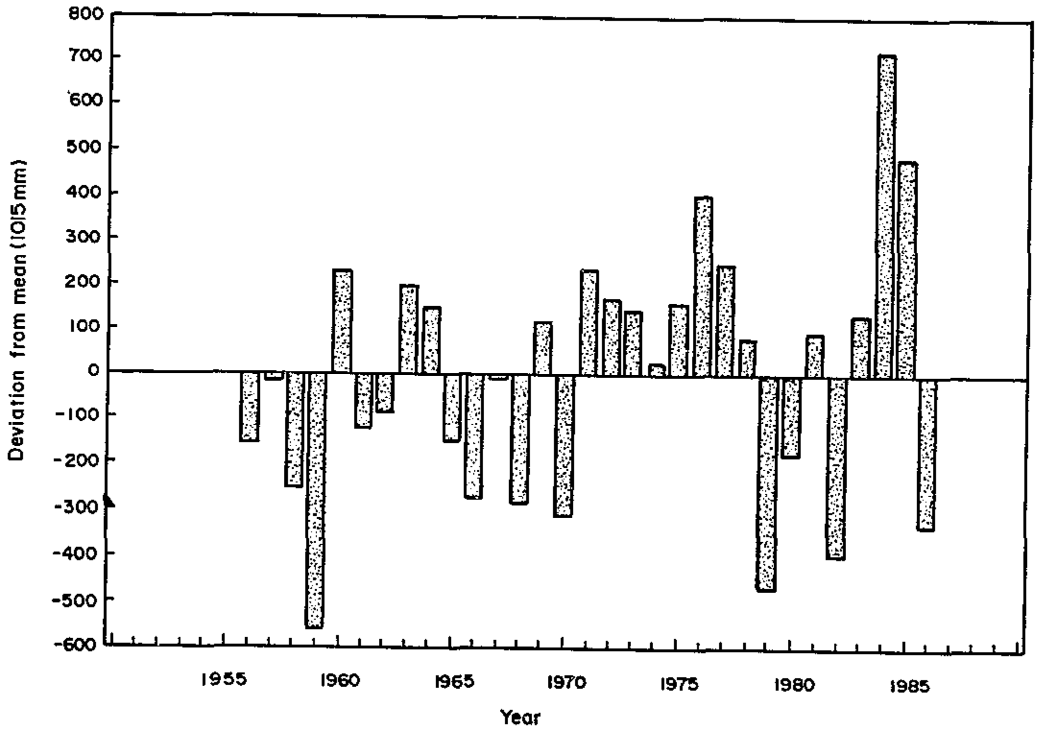

FIGURE 8.4 Deviations from mean annual rainfall at Nyolozi State Forest, 1955 to 1986.

In conclusion, the species composition of Zululand coastal grassland is related to rainfall patterns and responds rapidly to changes in water table levels. Palatable grasses predominate in dry periods and are replaced by sedges during periods of high rainfall. Alternating wet and dry periods are a feature of the climate of these coastal grasslands (Figure 8.4) and changes in species composition are thus expected to occur every five to 10 years.

The University of Natal long-term veld fertilizer trial provides meaningful data on the response of dry matter yield to an abiotic forcing variable. Treatments, initiated in 1952, on a replicated balanced layout were designed to test the effect of N, P, K and lime on grassland production. Periodic assessments were made of species-composition, soil chemistry and animal performance on an ad hoc basis. Initial trends indicate an increase in production as a result of the N application followed by a species-composition shift to an Increaser II dominated sward, mainly *Eragrostis* and *Sporobolus* species (P J K Zacharias personal communication).

Influence of fire on grassland

Burning trials have been undertaken widely and over a long period in South Africa.

The University of Natal long-term mowing and burning trial at Ukulinga in the Tall Grassveld (Acocks 1975) of Natal is perhaps one of the most important of these experiments. Work was initiated in 1952 when a replicated balanced orthogonal design was laid out. The aim was to test the response of vegetation (species-composition and production) to different combinations of burning and mowing treatments. A standard harvesting procedure (a spring mow followed by two hay cuts) was applied to all treatments except the control, at seven-year intervals from the 18th season onwards. These data provide information on the long-term effects of fire free from any short-term confounding effects of different treatments (Tainton and Mentis 1984). The results, after 26 years of treatment, show that, in the absence of any other form of defoliation, annual burning produces a denser cover (15,3%) and a higher veld condition score (80%) than biennial (cover 8,9% and score 60%) or triennial burning (cover 6,1% and score 45%). However, where the grassland is mown for hay in summer the frequency of burning has no influence on basal cover, but affected veld condition score. Where burning is frequent, *Themeda triandra* makes up a greater proportion of the cover than when mowing is used as a defoliation agent instead of fire. Here *Tristachya leucothrix* replaces *Themeda triandra* even though defoliation is frequent (three times a season). Burning annually and mowing twice for hay in summer produces a denser cover and a greater dominance of *Themeda triandra* than does annual burning without summer mowing (Tainton and Mentis 1984).

The effects on yield of previously burnt and mown plots was that the former treatments, whether applied in late winter or with the rains in spring, produced more herbage than the mown treatments (Tainton and Mentis 1984). Reduced yields which are recorded in the season immediately following a burn are temporary and not a permanent effect of fire on grassland (Figure 8.5). Tainton and Mentis (1984) report that the mown veld out-yields the burnt veld only in those seasons in which a burn was also applied.

The South African Forestry Research Institute's Brotherton burning trial conducted at Cathedral Peak in Natal is another major experiment designed to test the long-term effects of frequencies and seasons of burning on species composition.

Detailed investigations were initiated in 1980. These are reported here by Everson (unpublished).

The Brotherton burning trial is situated on the "Little 'Berg" at an altitude of 1 800 m. The vegetation is a uniform stand of Highland Sourveld (Acocks 1975). The experiment is a randomized block design with three replicates per treatment. The treatments include 14 different combinations of frequency and season of burning, protection from fire, mowing and application of Gramoxone. Two hundred point positions are sampled using the levy bridge in each plot (25 m x 25 m) to derive estimates of species composition. Vegetation assessments are carried out biennially to monitor changes in species composition.

The experimental area was burnt in October 1980 prior to the first vegetation assessments (April 1981). The first four assessments (1981, 1983, 1985 and 1987) were completed using the same technique and operators.

Four treatments representing a range of defoliation frequencies are discussed here. These are the annual winter and biennial spring burn

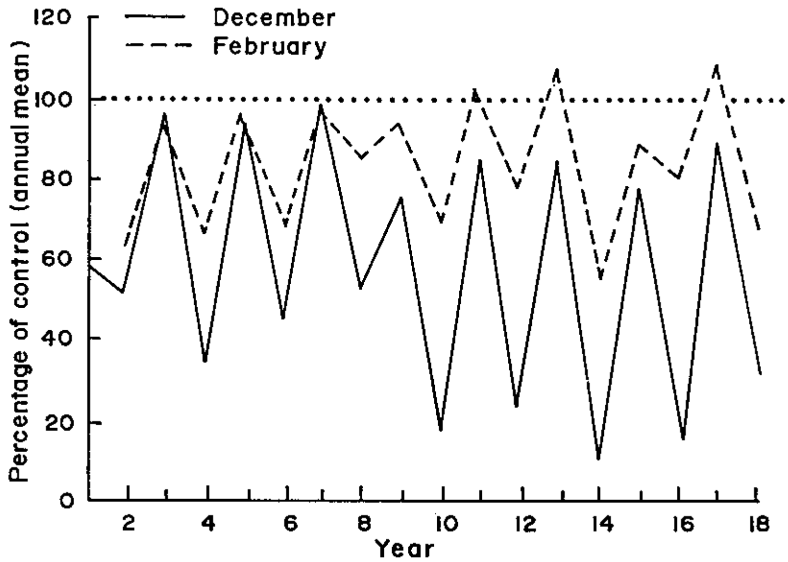

FIGURE 8.5 Yields recorded in early (December) and late (February) summer, from veld burnt and mown in alternate years after the first spring rains and expressed as a percentage of the control (mown plots). Veld burnt in even years (after Tainton and Mentis 1984).

treatments (representing normal management operations), a biennial summer burn treatment (representing an extreme treatment) and protection from fire (seven years). The six most important species examined are *Themeda triandra*, *Heteropogon contortus* and *Trachypogon spicatus* (Decreaser species) and *Tristachya leucothrix*, *Stiburus alopecuriodes* and *Harpechloa falx* (Increaser I species) (Everson and Tainton 1984).

The common species eg *Themeda triandra* and *Tristachya leucothrix*, with composition scores greater than 10%, generally had lower coefficients of variation (<10%) than the less abundant species, where coefficients of variation of up to 70% were measured (Table 8.2).

The results show that species changes within the different burning treatments are evident after seven years of experimentation. Summer burning resulted in the most dramatic changes with *Themeda triandra* decreasing from 31,5% in 1981 to 10,2% in 1987. This decrease of 21,3% corresponded to an increase in *Harpecloa falx* from 5,2% to 18,8% (ie an increase of 13,6%) over this six-year period.

Similar trends were apparent in the no burn treatment where *Themeda triandra* decreased from 34,7% in 1981 to 22,0% in 1987 (ie 12,7%). Although the percentage composition of *Harpecloa falx* remained unchanged, that of *Tristachya leucothrix* increased by 17,8% from 14,5% in 1981 to 32,3% in 1987.

Species changes, although not as dramatic as the extreme treatments, were also evident in the annual winter burn treatment. Here *Tristachya leucothrix* decreased from 27,7% in 1981 to 15,2% in 1987 (12,5%), while *Themeda triandra* increased by only 2,6% (from 27,2% to 30,3%) during the same period.

No significant changes in species composition were shown in the biennial spring burn treatment. This treatment is therefore the most suitable for maintaining species at their present levels of abundance.

The results show that the ecological groups, Decreaser and Increaser I, respond along a gradient of defoliation frequency (from annual burning to protection). These trends in species composition are apparent after seven years of experimentation.

Everson and Tainton (1984) in another exercise compared the effects of 30 years of past burning treatments on the species composition of Highland Sourveld at Cathedral Peak. Veld burning had resulted in no significant change in the veld condition scores of areas burnt annually in winter, biennially in spring or with light summer grazing. However, even after short periods of protection (only five years) there was a change in species composition. Particularly noticeable is the decrease in *Themeda triandra* and increase in *Alloteropsis semialata* and the corresponding drop in veld condition.

Long-term effects of total protection from fire have been recorded for Thabamhlope and Cathedral Peak in Natal. The plots at Thabamhlope represent vegetation which has been protected from grazing and fire for periods up to 40 years. The original Highland Sourveld grassland of the Thabamhlope Plateau has progressed towards a scrub forest, while the Kloof has proceeded towards forest containing *Podocarpus latifolius*. Westfall et al (1982) report that the Kloof has now become resistant to fire. The results indicate that the grassland is a fire-maintained biotic climax. Protection has resulted in a more stable water supply and in *Podocarpus latifolius* becoming established.

Catchment IX at Cathedral Peak has been protected since 1951. Three complete enumerations were made in 1951, 1976 and again in 1986. Granger (unpublished), Granger and Schulze (1977) and Everson and Breen (1983) have reported the results. A secondary forcing variable was elucidated by Granger and Schulze (1977) who found the effects of radiation to be important in the absence of fire treatments.

Frequent fires in the humid grasslands would seem, therefore, to have no long-term detrimental effects on grassland although shifts in species composition do occur (Tainton and Mentis 1984). This, however, is not the case in more arid regions. Theron (1937 ex Tainton and Mentis 1984) showed that grass plants were stunted and perennial species died when veld in these regions was burnt annually. However, no substantial long-term data on these arid grasslands exists.

<u>The effects of biotic factors on grasslands</u>

Ukulinga in the Tall Grassveld of Natal is a major source of long-term data on the effects of the biotic component and especially grazing on grassland species composition and herbage quantity and quality.

A trial to determine the long-term effects of variations in the periods of occupation and absence on veld composition and yield was initiated in 1968 by the University of Natal. Different rotational grazing and rotational resting regimes were used to test their effect on grassland species-composition and on animal performance. The experimental layout was a randomized block design with two replications. Results are reported by Booysen et al (1974) who recommend the number of camps for various rotational grazing systems.

A further University of Natal experiment at Ukulinga was begun in 1970 to assess the long-term effects of different systems of grazing management and stocking rates on veld composition and yield. The trial was terminated in 1983 but results are not yet available.

TABLE 8.2 Mean species composition changes following different burning treatments

		Species composition (%)											
		1981			1983			1985			1987		
Treatment	Species	x	se	cv	x	se	cv	x	se	cv	x	se	cv
Biennial Summer Burn													
	T triandra	27,7	1,7	6,0	30,8	5,8	18,7	33,3	3,6	10,8	30,3	1,0	3,3
	T leucothrix	15,2	3,8	24,8	18,3	5,2	28,6	16,7	2,4	14,4	16,5	2,9	17,5
	S alopecuroides	8,7	4,9	56,8	7,8	6,2	78,7	4,3	3,3	76,9	1,0	0,8	76,4
	H contortus	1,3	0,9	66,1	7,8	1,3	16,6	3,2	0,4	13,9	3,3	1,4	40,9
	H falx	5,2	0,9	17,1	8,0	1,5	19,1	13,3	2,5	18,7	18,8	1,3	6,9
	T spicatus	7,3	0,3	4,5	2,0	0,0	0,0	3,7	1,1	29,8	0,5	1,8	39,0
No Burn													
	T triandra	34,7	2,4	7,0	35,7	3,8	9,2	30,0	4,6	15,3	22,0	4,0	18,0
	T leucothrix	14,5	2,6	17,7	22,7	1,2	5,1	30,3	3,4	11,1	32,3	2,9	8,9
	S alopecuroides	9,8	4,7	47,8	9,2	4,9	52,9	12,3	5,3	42,7	9,2	5,7	61,7
	H falx	8,0	1,3	15,7	7,2	2,2	30,2	7,5	0,6	7,7	10,5	0,6	5,5
	H contortus	3,7	0,2	4,5	1,8	1,0	55,3	1,3	1,3	99,9	1,8	0,9	48,1
	T spicatus	3,3	2,1	63,8	5,2	1,6	30,8	1,8	0,7	36,4	1,8	0,9	48,1
Annual Winter Burn													
	T triandra	27,7	1,7	6,0	30,8	5,8	18,7	33,3	3,6	10,8	30,3	1,0	3,3
	T leucothrix	19,3	2,4	12,2	21,5	3,2	15,0	17,2	0,7	3,9	15,2	2,3	15,4
	S alopecuroides	9,7	4,4	45,7	7,7	4,2	54,9	6,2	3,1	50,1	4,8	2,5	52,2
	H falx	6,8	1,2	17,6	5,3	0,9	16,5	5,0	1,0	20,8	5,7	0,7	12,8
	H contortus	3,8	1,6	42,8	4,8	2,0	40,7	8,2	0,6	7,4	8,3	0,9	10,6
	T spicatus	4,2	0,9	22,3	3,8	1,2	30,4	5,8	1,2	20,0	6,2	1,3	21,1
Biennial Spring Burn													
	T triandra	30,0	4,6	15,3	28,2	3,4	12,2	26,3	2,8	10,5	26,7	2,1	7,8
	T leucothrix	17,5	0,8	4,4	17,8	2,3	13,0	17,0	0,6	3,4	15,5	0,5	3,2
	S alopecuroides	12,5	3,2	25,7	10,3	2,7	26,4	8,5	2,8	32,8	7,8	0,9	11,3
	H falx	10,0	2,3	22,9	8,0	2,0	25,3	8,0	2,4	29,5	7,3	1,4	19,4
	H contortus	2,5	0,5	20,0	6,7	1,5	21,8	4,2	1,0	24,3	6,2	1,5	24,0
	T spicatus	4,0	1,8	43,9	6,7	1,6	23,8	6,2	1,0	16,4	6,5	2,3	35,3

x = mean; se = standard error; cv = coefficient of variation

A trial reported by Beukes and Trollop (unpublished), was laid out in 1979 in the False Thornveld, Veld Type 21 (Acocks 1975), of the eastern Cape, to monitor the rates of karroo invasion into sweet grassveld receiving different grazing treatments. Two plots (approximately one hectare each) were demarcated in the Alice district of Ciskei. One plot was infrequently, but heavily, utilized by both small and large stock while the other plot was continuously overgrazed by these types of stock. Grass surveys (200 points per survey) were conducted annually using the nearest plant technique.

In the infrequently but heavily utilized plot there was only a small increase in the percentage composition of karroid species from 2,1% (mean for 1979 to 1980) to 2,8% (mean for 1984 to 1987). There was a much larger increase in the continuously overgrazed plot namely from 0,5% to 5,4% respectively (Figure 8.6 and Table 8.3).

Differential changes in the percentage composition of karroid species in the infrequently but heavily utilized and the continuously overgrazed plots can possibly be explained by comparing the effects of the different treatments on the grass sward. Infrequent heavy defoliations maintained the grass sward relatively dense and vigorous. The more competitive state of the grass sward has kept the rate of karroo invasion down. Continuous overgrazing reduced the density, vigour and therefore competitiveness of the grass sward and karroid seedlings were able to establish themselves.

Continuous overgrazing in the sweetveld areas of the Ciskei results in deterioration of the grass layer by causing less palatable and less productive karroid species (eg bitter karroo *Chrysocoma tenuifolia*) to invade. It appears that the encroachment by karroid species in overgrazed veld on shale soils is generally much more severe than in veld on doleritic soils. Karroo invasion results in a reduction in the grazing capacity of the veld with obvious economic implications. It is not heavy defoliation per se that causes deterioration of the grass layer but it is continuous heavy defoliation that results in karroo invasion. This is supported by observations made in the Ciskei where paddocks that have been burnt annually for the last 10 to 15 years are dominated (percentage composition is approximately 70%) by *Themeda triandra.*

The effects of stocking rate on the long-term species composition of Highland Sourveld at Thabamhlope were tested by the Department of Agriculture (M B Hardy personal communication). Initiated in 1978, the study monitored the effect of grazing by cattle on species composition. Eight hundred points were located biennially. The wheel point apparatus was used to obtain observations of the nearest plant on an approximately 300 m long transect through each treatment. Comparisons were made between 1978 and 1986. A grazing gradient was apparent and with time all treatments showed a species composition shift. The highest stocking rate caused the greatest differences in species composition. M B Hardy (personal communication) reports that no major climatic fluctuations occurred though rainfall was below the long-term mean from 1982 to 1984. Further results are reported in van Niekerk et al (1984) and Hardy (unpublished).

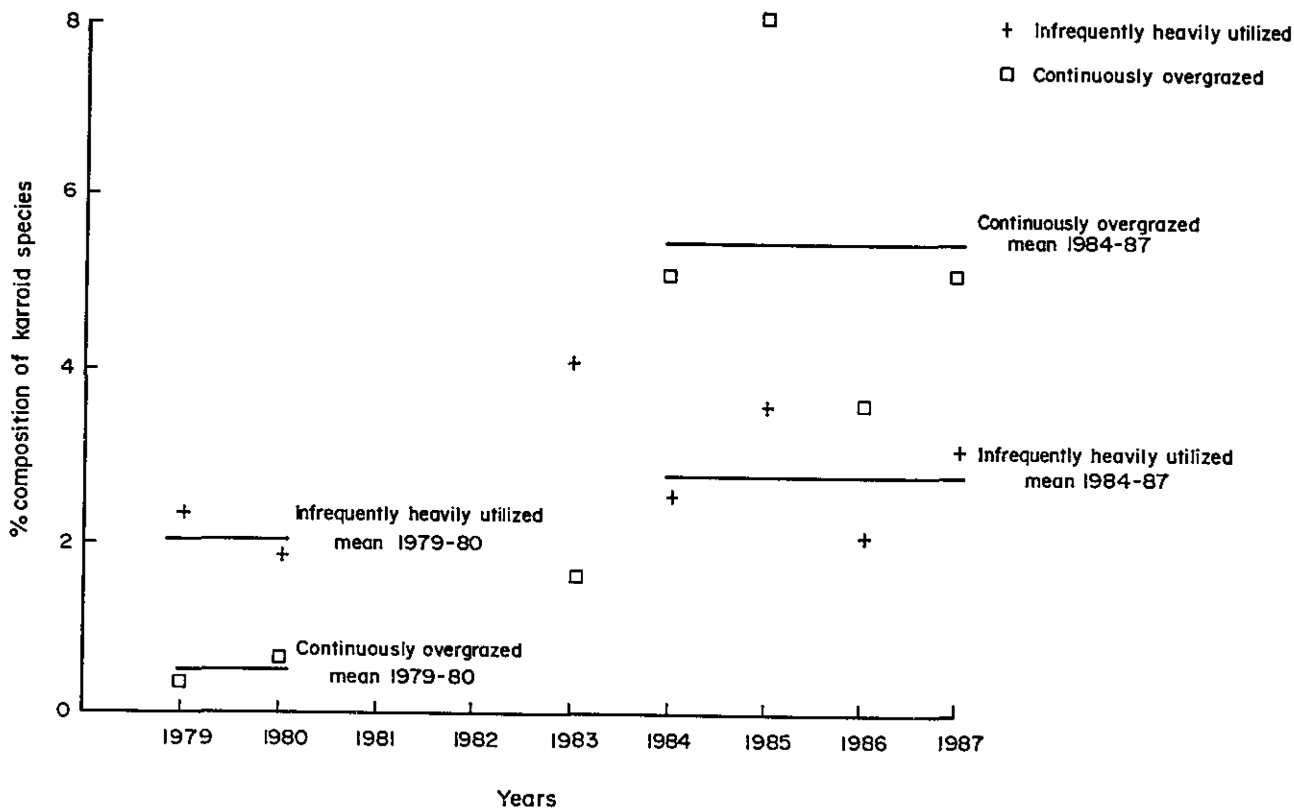

FIGURE 8.6 Per cent composition of karroid species of two plots receiving different grazing treatments.

FUTURE LONG-TERM DATA SERIES FROM GRASSLANDS

Various monitoring exercises have been initiated by, particularly, nature conservation organizations. These programmes generate long-term data and are ongoing projects. The data in most cases have not been analysed but could have an important contribution to make in the future. These programmes generally adopt a null hypothesis of no change over time (after Mentis 1984). The test for change is a difference between baseline and any subsequent follow-up survey. It is important to point out that the factors responsible for change are not necessarily known nor is their timing (Mentis 1984). A suitable classification of these data is difficult but they are included here for the sake of completeness.

D Krynauw (personal communication) reports a data series of this sort for the western Transvaal nature reserves. Baseline surveys, initiated in 1985, recorded species composition and basal cover.

J E Granger and C Shackleton (personal communication) describe a monitoring study for the Pondoland Coastal Plateau Sourveld initiated in

TABLE 8.3 Results of grass surveys done in two plots receiving different grazing treatments (1979 to 1987)

Treatment	Plant species	Year							
		1979	1980	1982	1983	1984	1985	1986	1987
Plot 1 Infrequently heavily utilized plot	Themeda triandra	3,0	3,0	5,5	5,0	6,0	4,5	3,0	5,5
	Panicum stapfianum	5,0	3,5	4,0	4,5	4,0	2,5	4,0	2,5
	Cymbopogon plurinodis	7,7	5,5	8,0	5,5	11,0	9,5	11,5	18,0
	Digitaria eriantha	44,4	48,1	42,5	40,5	49,0	51,0	55,0	49,0
	Cynodon dactylon	10,0	10,3	9,0	4,0	4,0	4,5	1,5	2,5
	Tragus berteronianus	7,0	3,9	4,5	4,5	2,5	1,5	0,5	0,0
	Karroid species	2,3	1,8	0,0	4,0	2,5	3,5	2,0	3,0
Plot 2 Continuously over-grazed plot	Themeda triandra	3,3	3,0	5,0	3,5	4,0	4,5	4,0	3,0
	Panicum stapfianum	7,3	6,5	0,0	3,5	7,0	7,0	6,5	8,5
	Digitaria eriantha	44,9	48,9	41,0	48,5	47,0	40,0	50,5	48,5
	Aristida congesta	10,3	7,7	6,5	11,5	6,5	11,5	11,5	9,5
	Karroid species	0,3	0,6	0,0	1,5	5,0	8,0	3,5	5,0

1985. Comparisons of protected and open plots are done for root biomass (measured at three-monthly intervals), decomposition rates and standing crop estimates (measured monthly).

P Thompson (personal communication) reports a number of monitoring plots established in the grasslands of Natal Parks Board reserves. Some 24 and 37 plots are enumerated in Mount Currie and Coleford Nature Reserves respectively; 17 at Weenen and eight at Moorpark Nature Reserves. The 30 m x 30 m plots are measured using a wheelpoint apparatus and the nearest plant method. Enumerations were begun in 1979.

The Karroo/Grassland interface is monitored at Dikkopvlakte about 30 km north-west of Grahamstown. The method described by Dyer (1937) to collect total floristic data along two approximately 50 m-transects was used to collect the baseline data. Fixed point photographs were also taken. The same sites as surveyed in 1929 were reassessed by A R Palmer (personal communication) in 1987 using identical methods. The transects were subjected to continuous grazing by domestic livestock throughout the intervening years and there has been an apparent increase in the grass component. However, the data have not been statistically analysed (A R Palmer personal communication).

A burning/mowing experiment was started by the Department of Agriculture at Thambamhlope in Natal in 1946. The aim was to compare the effects of burning and mowing on species composition and, also, on annual dry matter production. A 10-point Levy bridge was used to assess composition scores but the data have not been analysed. Herbage mass (kg DM/ha) was estimated for each treatment each season. The data have, in this instance, been analysed but not yet published (M B Hardy personal communication).

The response of *Protea roupelliae*, a fynbos element occurring in montane grassland, to fire has been monitored by F R Smith (personal communication). Data on vegetation dynamics (demography and structure) have been collected since 1979. The aim was to determine fire regimes under which *Protea roupelliae* is stable in order to prescribe a regime appropriate for the continued maintenance of the population. Survival and growth of tagged adults is measured on a 0,25 ha plot. Recruitment, survival and growth of seedling and juvenile cohorts are measured in 25 m x 25 m sample plots. In addition, fire behaviour characteristics are recorded for each treatment burn.

Leaving aside the philosophical arguments for or against long-term studies, in the grassland biome these studies appear to be in need of improvement if the objective of improving predictive ability is to be realized.

Few long-term data exist on the autecological response of individual species to abiotic and biotic forcing variables. The influence of these variables on the functional processes of the hydrological, energy and biogeochemical cycles in the longer term also need to be better researched (Booysen 1984).

CONCLUSION

Grasslands are relatively stable, at least in the more humid areas, if they are not subjected to extreme mismanagement.

Two major forcing variables, fire and grazing, dominate in grasslands. The long-term effects of naturally occurring fluctuations in rainfall on humid grasslands are negligible relative to those of fire and grazing. The arid grassland areas are thought to be influenced to a greater extent by rainfall variability but no relevant long-term data seem to exist.

Given then that grasslands seem to be both relatively stable and resilient one can query the usefulness of further long-term studies. M T Mentis (personal communication) suggests that ideas are important and conceptual models more instructive. The accumulation of adequate long-term data seems an unrealistic research objective in the face of a rapidly modifying biome faced with short-term planning horizons. Adaptive management that is properly documented and modified provides a vehicle for gathering more flexible data. These data need not be strictly quantitative but with the advent of management decision aids, such as expert systems, can possibly be of more use in the future.

REFERENCES

Acocks J P H 1975. Veld types of South Africa. Memoirs of the Botanical Survey of South Africa 40, 1-128.

Booysen P de V 1984. Concluding remarks. Fire research - A perpective for the future. In: Booysen P de V and Tainton N M (editors) Ecological effects of fire in South African ecosystems. Springer-Verlag, Heidelberg. pp 363-366.

Booysen P de V, Klug J R and Yeork B S 1974. Number of camps for rotational grazing of veld. Proceedings of the Grassland Society of Southern Africa 9, 145-148.

Dyer R A 1937. The vegetation of the divisions of Albany and Bathurst. Memoirs of the Botanical Survey of South Africa 17, 1-138.

Everson C S and Breen C M 1983. Water stress as a factor influencing the distribution of the ericoid shrub Philippia evansii in the Natal Drakensberg mountains, South Africa. South African Journal of Botany 2, 290-296.

Everson C S and Tainton N M 1984. The effect of thirty years of burning on the Highland Sourveld of Natal. Journal of the Grassland Society of Southern Africa 1, 15-20.

Granger J E and Schulze R E 1977. Incoming solar radiation patterns and vegetation response: examples from the Natal Drakensberg. Vegetatio 35, 47-54.

Mentis M T 1984. Monitoring in South African grasslands. South African National Scientific Programmes Report No 91. CSIR, Pretoria. 55 pp.

Mentis M T and Huntley B J 1982. A description of the grassland biome. South African National Scientific Programmes Report No 62. CSIR, Pretoria. 29 pp.

Strayer D, Glitzenstein J S, Jones C G, Kolasa J, Likens G E, McDonnell M J, Parker G G and Pickett T A 1986. Long-term ecological studies: an illustrated account of their design, operation, and importance to ecology. Occasional publication of the Institute of Ecosystem Studies, Number 2.

t'Mannetjie L and Haydock K P 1963. The dry-weight-rank method for the botanical analysis of pasture. Journal British Grassland Society 18, 286-275.

Tainton N M 1981. The ecology of the main grazing lands of South Africa. In: Tainton N M (editor) Veld and pasture management in South Africa. Shuter and Shooter in association with University of Natal Press, Pietermaritzburg.

Tainton N M 1984. A guide to the literature on research in the grassland biome of South Africa. South African National Scientific Programmes Report No 96. CSIR, Pretoria. 77 pp.

Tainton N M and Mentis M T 1984. Fire in Grassland. In: Booysen P de V and Tainton N M (editors) Ecological effects of fire in South African ecosystems. Springer-Verlag, Heidelberg. pp 115-147.

Theron D C 1937. Veld management investigations at the School of Agriculture, Potchestroom. Preliminary report. Department of Agriculture, Union of South Africa, Bulletin 166, 1-23.

Van Niekerk A, Hardy M B, Mappeldoran B and Lesch S F 1984. The effect of stocking rate and lick supplementation on the performance of lactating beef cows and its impact on Highland Sourveld. Journal of the Grassland Society of Southern Africa 1, 18-21.

Westfall R H, Everson C S and Everson T M 1982. The vegetation of the protected plots at Thabamhlope Research Station. South African Journal of Botany 2, 15-25.

CHAPTER 9. THE NAMIB DESERT

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INTRODUCTION

"Long-term" data series relating to renewable natural resources - spanning 50 to 100 years - do not exist for the Namib Desert. Because of the close relationship in a desert between renewable natural resources and rainfall, however, an approximation of a natural resource data series can be derived from existing rainfall data. This potential for extrapolation provides the added advantage of being able to extend the resource record back in time, a record which, in the Namib, is further supplemented by a well exposed stratigraphic record that spans much of the Cainozoic.

Geographical limits

The Namib is a long narrow desert extending some 2 000 km from the Olifants River in the Cape Province northwards to approximately the Carunjamba River in south-western Angola (Figure 9.1). It is bounded by the South Atlantic Ocean on the west and the Great Escarpment to the east at about 140 km inland. Numerous descriptions have been given of its geographical boundaries (eg Logan 1960; Rogers 1977; Ward et al 1983). From south to north there are repetitive changes in the substrate which alters between sand dunes, ephemeral, usually dry, watercourses and gravel plains. Moreover, there is a transition in dune type and surficial crust composition from the coast inland which roughly parallels a steep climatic gradient.

Climate

The current extremely arid climate of the Namib is controlled by the interacting effects of the South Atlantic Anticyclone, the divergent SE trade winds, the cold water Benguela system and the desert's location on the rainshadow side of southern Africa (van Zinderen Bakker 1975). Consequently there is a steep climatic gradient from a cool, foggy coastal belt dominated by the SSW wind to a warm, rain-influenced interior below the Escarpment. Mean annual rainfall on the coast averages less than 15 mm, increasing inland to approximately 25 mm at Gobabeb (56 km inland) and approaching 100 mm at the base of the Escarpment (Logan 1960; Schulze 1969; Besler 1972; Seely and Stuart 1976; Lancaster et al 1984). This represents a variation in rainfall of at least sixfold along a stable gradient across the width of the Namib (Figure 9.2). Over the length of the Namib, the rainfall changes from predominantly winter in the south to predominantly summer in the north (Meteorological Services 1943, Wellington 1955).

Rationale

Extreme deserts such as the Namib are environments where the abiotic factors are of paramount importance and biotic interactions are less important, if they occur at all (Noy-Meir 1973). In most deserts,

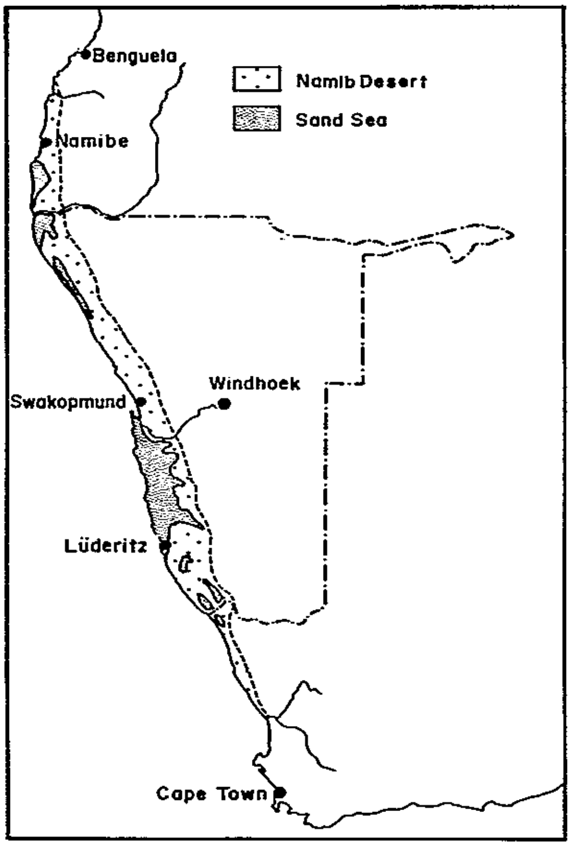

FIGURE 9.1 Locality sketch of the Namib Desert in south-western Africa.

rainfall is usually the single most important limiting factor and the pulse-reserve model can be applied (Noy-Meir 1979/1980). In the Namib, however, the picture is complicated by the occurrence of two major sources of moisture:

- rain; less predictable, episodic, large amount in one event;
- fog; more predictable and regular, small amount in one event (Pietruszka and Seely 1985).

These sources of moisture are used in different ways by long-lived and short-lived organisms (Seely 1978; Seely et al 1983).

The large, ephemeral watercourses, eg the Kuiseb and Swakop Rivers, traversing the Namib act as linear oases extending the distribution of nondesertic flora and fauna into the desert (Seely et al 1980/1981). The irregular flooding of these usually dry watercourses therefore has an additional influence on the biota of these systems, as well as on the animals which move between river and adjacent desert. These riparian systems are thus driven mainly by the higher rainfall in their catchments outside the desert (Figure 9.3) and are maintained largely by their subterranean water reserves within the Namib tract.

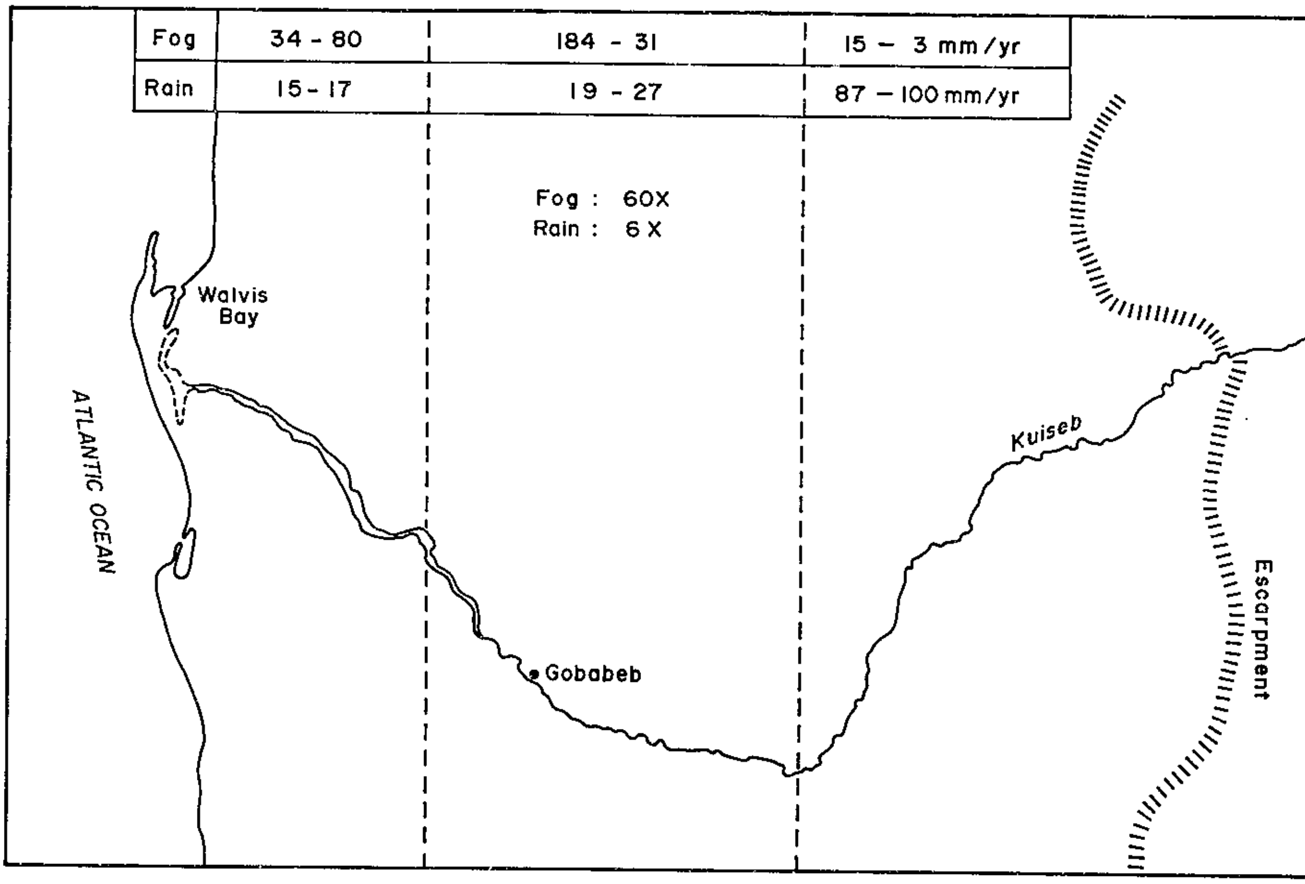

FIGURE 9.2 Variation in annual precipitation (fog and rainfall) across the central Namib Desert.

An appreciation of any "long-term" data series from the Namib can be obtained from examining the effects of rainfall or river flow on the biota (eg Seely 1978). This can be recognized in the immediate past (eg Seely and Louw 1980; Louw and Seely 1982; Wharton and Seely 1984) as well as in the geological record (Brain and Brain 1977; Ward 1984).

CURRENT KNOWLEDGE OF LONG-TERM VARIABILITY

Despite the great length and climatic variability of the Namib, most research has been carried out in the more accessible central areas. Here dunes, plains and ephemeral watercourses occur and summer rainfall predominates.

Geological record

The current hyperarid conditions in the Namib Desert are attendant on the full development of the cold water Benguela upwelling system that dates from the Late Miocene, some seven to 10 million years ago (Siesser 1978, 1980). Remnants of aeolianites, notably the Fiskus Beds in the southern Namib (Stockton 1978) and palaeo-dunes interbedded in the Oswater Conglomerate of the central Namib (Ward 1982, 1984), testify to a dominant southerly wind regime and desert conditions during the Pliocene to Early Pleistocene. Palaeo-dunes associated with Middle and Late Pleistocene pan deposits in the central Namib indicate the persistence of the southerly wind regime (Ward 1984). However, these pan deposits, together with relict tufa and calcified reed deposits, also indicate that the predominantly arid conditions were interrupted intermittently by short-lived wetter periods during the last one to 1,5 million years. Nevertheless, the hierarchy of fluvial deposits preserved in the Uis River (Korn and Martin 1957) and in the Kuiseb River (Ward 1984) suggests that, in the Namib, there has been a general trend towards progressive aridification from the Late Tertiary.

These observations support the conclusions of other workers (including Soares Carvalho 1961; Siesser 1978, 1980; Tankard and Rogers 1978; Tankard et al 1982; Dingle et al 1983) that the present Namib Desert has developed progressively during the Late Cainozoic.

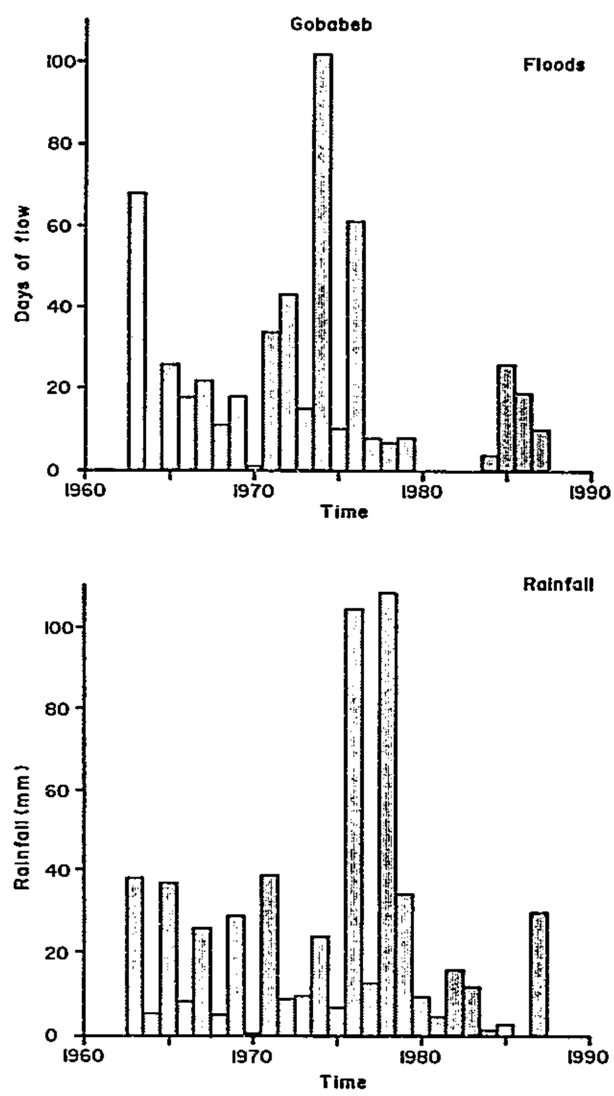

FIGURE 9.3 Annual rainfall and Kuiseb River flow at Gobabeb, central Namib Desert, 1963 to 1983.

Furthermore, the Late Cainozoic Namib Desert was preceded by a more extensive arid phase that, although not well dated and therefore controversial, appears to fall within the time span from the Late Eocene, approximately 40 Myr ago, to the Early Miocene, approximately 20 Myr ago (Martin 1950; Ward 1984). These proto-Namib Desert conditions, which were also under the influence of a dominant southerly wind regime, led to the accumulation of aeolian, ephemeral stream and pan deposits that constitute the bulk of the Tsondab Sandstone Formation (Ollier 1977; Besler and Marker 1979; South African Committee for Stratigraphy 1980; Ward 1984). The pre-Miocene age has been questioned by Partridge (1986) who considers it highly unlikely that the Tsondab Sandstone is older than about 15 Myr, ie Middle Miocene.

Regardless of the controversy concerning its age, the Tsondab Sandstone indicates that the aridity has been controlled primarily by the regional wind circulation system and the location of the Namib Desert west of the Escarpment (an ancient feature that has been in existence from the end of the Cretaceous (Dingle and Scrutton 1974). Subsequently the cold water Benguela upwelling system has contributed to the present character of the Namib Desert, eg the foggy nature of the coast belt (Meteorological Services 1943) and the distribution of gypsum crusts roughly parallel to the coastline (Martin 1963).

Recent geomorphological studies

The dunes of the Namib harbour, a comparatively rich invertebrate fauna, include at least four endemic genera and some 17 endemic species (Koch 1962). It has been suggested that the rate and direction of movement of sand dunes may influence the distribution of biota in the sand seas of the Namib (Endrödy-Younga 1982).

In the Sperrgebiet of the southern Namib, barchan dunes move northwards at an average of about 25 m yr^{-1} (Endrödy-Younga 1982), although rates of up to about 75 m yr^{-1} have also been measured (I Corbett personal communication).

In contrast, rate of dune movement in the central Namib is considerably slower and the direction of movement, although generally northwards, more variable. A small linear dune near Gobabeb is extending northwards at some three to four metres per year (Besler 1975). The large linear dunes entering the Kuiseb River valley are encroaching northwards (range: NW to ESE) at rates from 0 to 1,85 m yr^{-1} whereas the coastal crescentic dunes are also moving northwards (range: N to ENE) but at somewhat faster rates of 0,8 to 6,4 m yr^{-1} in the Kuiseb Delta and up to 10 m yr^{-1} near Walvis Bay (Barnard 1975; Ward 1984; Ward and Von Brunn 1985). Dune and sand movement is retarded by vegetation growth.

Recent climatological studies

Measurements of precipitation in the central Namib by the Weather Bureau and the Desert Ecological Research Unit, which date back to the end of the 1800's, indicate exceptional rainfall in the area in 1934, 1976 and 1978 (Weather Bureau records; DERU autographic records; Lancaster et al 1984). Rainfall five times greater than the mean annual rainfall occurred in these years. Excluding these unusual years, variation between years may exceed 30-fold at a site. Nevertheless, these recent variations in rainfall do not appear to have been as great as those preserved in the Cainozoic record, eg pan and tufa deposits, that indicate short-lived, wetter periods.

The occurrence of fog has been studied in Swakopmund on at least three different occasions (Gulland 1907; Nagel 1962; Nieman et al 1978). The methods were not identical and the comparability of the records are thus in question. Fog-water precipitation has been recorded in the central Namib at a number of sites since 1966 (Lancaster et al 1984). The amount of fog-water precipitation at a site may vary up to threefold between years as opposed to a 100-fold variation in ranfall at the same site, eg Gobabeb (Figure 9.4).

Number of days of flow of the Kuiseb and other central Namib rivers has been noted since the last century (Stengel 1964, 1966; Seely et al 1980/1981). Between 1837 and 1963 the Kuiseb flowed into the Atlantic fifteen times; the interval between floods ranged from one to 21 years (Stengel 1964). Between 1965 and the present, the Kuiseb flowed past Gobabeb every year except for the period 1980 to 1983 (four years); the duration of flow varied between one and 102 days (Figure 9.3).

Recent biological studies

Unusually high rainfall in the Namib causes temporary changes in standing biomass of plants and animals approaching two orders of magnitude (Walter 1936, 1971; Seely 1978; Seely and Louw 1980; Wharton and Seely 1984). In some instances the effects have persisted for at least 11 years and may last much longer. Although these variations in the biota reflect an opportunistic response to episodic rainfall - the magnitude of which appears to correlate roughly with the amount of rain - the threshold amounts required, the mechanisms of response, and the lag periods of response vary between organisms. Figure 9.5 illustrates the variation to be expected between components of the dune habitat for two major rainfall events separated by a time span not atypical of the Namib (Louw and Seely 1982).

Despite the large fluctuations in rainfall (over a 100-fold between years) and production of vegetation and animals (over 50-fold between years) the Namib is currently a relatively stable system. Nevertheless, because of the large fluctuations in rainfall, and hence in the production of plants and animals, local extinctions of elements of the biota undoubtedly occur. Major rainfall events then provide an important mechanism for dispersal of organisms leading to recolonization of local areas. This process of local extinction and recolonization thus contributes to the overall stability of the Namib.

Although rainfall is the primary factor influencing distribution of the biota, its effects are greatly modified by substrate (Coetzee 1969; Seely and Griffin 1986). Hence, the use of rainfall as the single parameter describing productivity is somewhat complicated, particularly with respect to sand dunes and gypsum crusts.

UNPUBLISHED INFORMATION

A number of "long-term" studies have been directed towards measurement of the dynamic components of the Namib ecosystem, particularly in the central area. These projects include:-

Abiotic components

Climate records. Records from a number of autographic stations, some dating from 1962, include:

- fog-water and rain precipitation;
- temperature and relative humidity;
- wind speed and direction;
- potential evaporation (Gobabeb only);
- radiation (Gobabeb only); and
- soil temperatures (Gobabeb only).

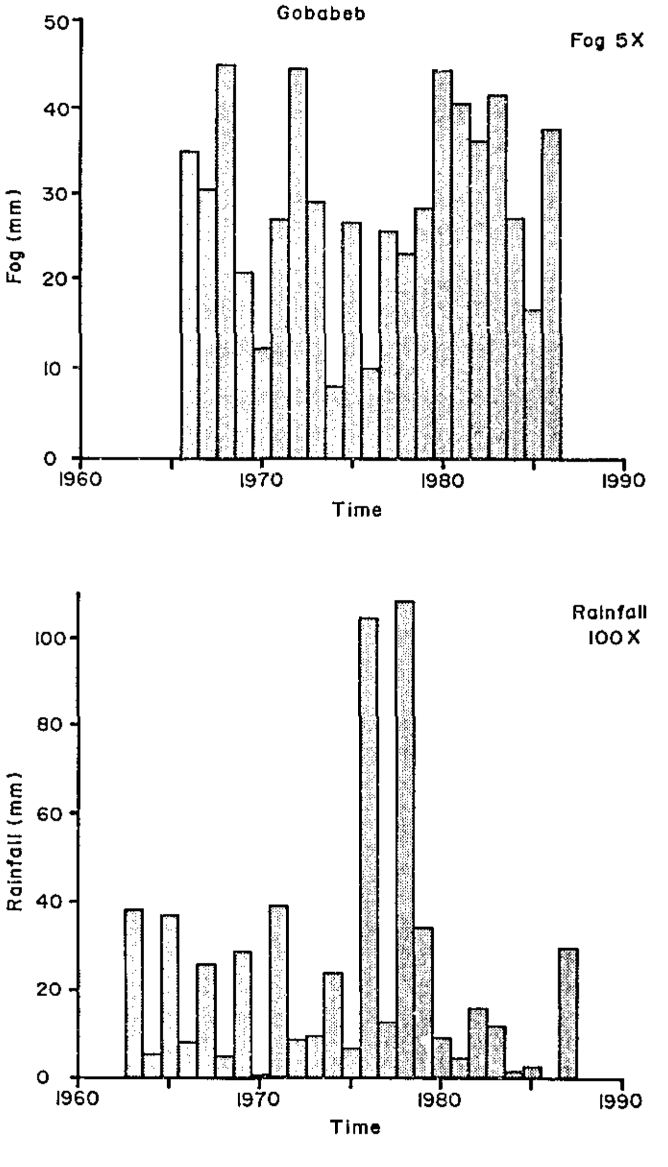

FIGURE 9.4 Variation in annual precipitation (fog five times; rainall 100 times) at Gobabeb in the central Namib Desert.

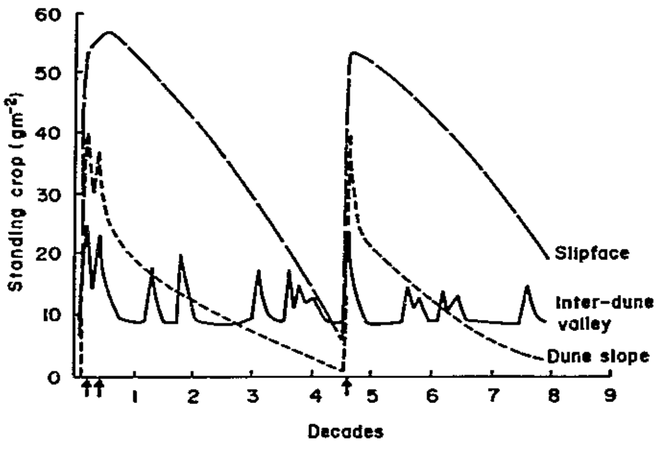

FIGURE 9.5 Variation in standing crop of detritus and vegetation in three Namib dune habitats after two major rainfall events (arrowed). Hypothetical curves are based on long-term precipitation records and measurements of standing crop before and after rain (from Louw and Seely 1982).

<u>Sand dune movement</u>. Rates of sand dune movement have been measured at specific localities along the northern boundary of the main Namib Sand Sea from 1969 to the present.

<u>Kuiseb flood record</u>. Kuiseb River floods past Gobabeb into the Namib Desert have been monitored for the last 24 years.

<u>Biotic components</u>

<u>Kuiseb riverine vegetation</u>. Growth of riverine vegetation along the lower course of the Kuiseb River has been monitored at intervals over the last 10 years (partly covered in Huntley 1985). Invasive alien plants are not considered at this stage to be an important component of the Namib flora and are mostly restricted to the larger ephemeral watercourses (Brown et al 1985).

<u>Perennial dune vegetation</u>. Change in the status of the perennial vegetation on the linear dunes of the Namib Sand Sea near Gobabeb has been monitored over the last 12 years.

<u>Annual interdune vegetation</u>. A record of the growth of annual vegetation in the interdune valleys of the Namib Sand Sea near Gobabeb is available for the last 12 years.

<u>Surface activity of epigaeic fauna</u>. Pit-fall trapping has been used to monitor the occurrence of invertebrates in the dunes, interdunes, Kuiseb River and gravel plains near Gobabeb in the central Namib for the last five to 10 years.

<u>Coastal wetland bird populations</u>. A J Williams, Directorate of Nature Conservation, SWA/Namibia, has been monitoring bird populations on the Sandwich Harbour and Walvis Bay wetlands for approximately the last five years.

Large mammal populations of the northern Namib. The Directorate of Nature Conservation has been monitoring large mammal populations for approximately the last decade. Information from earlier (particularly last century) travellers is also available.

Human populations and resource useage in the central Namib during the Holocene. Archaeologists of the State Museum, Windhoek, are investigating this aspect (Kinahan 1976; Jacobsen 1984).

TRENDS AND CYCLES

Geological record

A progressive but fluctuating trend toward increasing aridity from the Late Miocene to the present is apparent in the Cainozoic record.

Recent climatological variations

Although great variations in the rainfall record have been noted during this century, there is no evidence for a trend or cycle. Other climatic parameters, measured for shorter periods, also do not suggest any obvious trend or cycle.

Recent biological variations

Populations of surface active invertebrate fauna, standing biomass of annual vegetation and most other components of the biota show great variation between years. However, as there is no evidence for a trend or cycle in the rainfall, a similar conclusion must be drawn for the biological data.

FUTURE RESEARCH

Geology

The lack of suitable material for absolute dating of surficial deposits is the major weakness in the current understanding of the Cainozoic record in the Namib. Therefore future research should be directed towards resolving the ages of the Cainozoic deposits, in particular the Tsondab Sandstone which harbours considerable palaeoclimatic and palaeoecological information.

Climatology and biology

The major deficiency in the climatological and biological data currently at hand is the length of the record available. The great variability of rainfall in a desert necessitates a longer continuous record than may be required in other habitats. Future research should include a continuation of field observations and monitoring of:

- climate;
- desert adapted fauna;
- fauna making opportunistic use of the desert;
- riverine vegetation; and
- annual and perennial dunes and plains vegetation;

with emphasis on aspects of the biology of key species, including:

- population fluctuations;
- changes in distribution patterns;
- changes in biological response;
- correlation of above with rainfall and fog-water precipitation; and
- correlation of above with other climatic parameters.

DRIVING FORCES

Major climatic driving forces

The major forces driving the climate are thought to be the prevailing atmospheric and oceanic circulation patterns which have been established since the Late Miocene.

Forces driving evolutionary processes

The long established aridity, augmented by the influence of the cold water Benguela system, has led to the evolution of a well adapted fauna and flora, many components of which persist using only fog-water as a source of moisture. Nevertheless, most species are keyed into the widely spaced, episodic rainfall events particularly with respect to aspects of recruitment and establishment.

Anthropogenic driving forces

With increased pressure to develop the Namib coast, particularly for recreation activities and to a lesser extent, mining and industry, changes to the environment are inevitable. In most cases, these changes are likely to be detrimental to the ecologically sensitive Namib Desert and include:-

- abstraction of water from subterranean reservoirs in ephemeral watercourses, eg Koigab, Kuiseb and Omaruru Rivers;
- damming of influent watercourses east of the Namib;
- expansion of coastal towns, eg Henties Bay;
- offroad vehicle damage to gypsum crust communities and lichen fields, as well as their impact on the aesthetics of the desert;
- damage caused by road-building activities;
- farming in marginal country, particularly along the eastern fringe of the Namib;
- introduction and spread of alien vegetation;
- destruction of indigenous vegetation and herbivore/carnivore populations;
- removal of dead wood for fuel.

At this stage, large parts of the Namib Desert are offered a degree of protection and therefore the anthropogenic effects are limited as a driving force influencing evolutionary change in this specialized and sensitive environment.

REFERENCES

Barnard W S 1975. Geomorfologiese prosesse en die mens: die geval van die Kuiseb delta, SWA. Acta geographica 2, 20-43.

Besler H 1972. Klimaverhaltnisse und klimageomorphologische Zonierung der zentralen Namib (Sudwestafrika). Stuttgarter Geographische Studien 83. 209 pp.

Besler H 1975. Dynamische Geomorphologie. Wurzburger Geographische Arbeiten 43, 135-147.

Besler H and Marker M E 1979. Namib Sandstone: A distinct lithological unit. Transactions of the Geological Society of Southern Africa 82, 155-160.

Brain C K and Brain V 1977. Microfaunal remains from Mirabib: some evidence of palaeoecological changes in the Namib. Madoqua 10, 285-293.

Brown C J, Macdonald I A W and Brown S E 1985. Invasive alien organisms in South West Africa/Namibia. South African National Scientific Programmes Report No 116. CSIR, Pretoria. 74 pp.

Coetzee C G 1969. The distribution of mammals in the Namib Desert and adjoining inland escarpment. Scientific Papers of the Namib Desert Research Station 40, 23-36.

Dingle R V and Scrutton R A 1974. Continental breakup and the development of post-Palaeozoic sedimentary basins around southern Africa. Bulletin of the Geological Society of America 85, 1467-1474.

Dingle R V, Siesser W G and Newton A R 1983. Mesozoic and Tertiary Geology of Southern Africa. A A Balkema, Rotterdam. 375 pp.

Endrödy-Younga S 1982. Dispersion and translocation of dune specialist tenebrionids in the Namib area. Cimbebasia 5, 257-271.

Gulland V A 1907. Aus dem deutsch-sudwestafrikanischen Schutzgebiete. Das Klima von Swakopmund. Literatur aus dem Duetschen Schutzgebiet.

Huntley B J 1985. The Kuiseb environment: the development of a monitoring baseline. South African National Scientific Programmes Report No 106. CSIR, Pretoria. 138 pp.

Jacobson L 1984. Recent Namibian coastal archaeology. Nyame Akuma 24/25, 13.

Kinahan J 1987. The archaeological structure of pastoral producton in the central Namib Desert. South African Archaeological Society Goodwin Series 5, 69-82.

Koch C 1962. The Tenebrionidae of southern Africa XXXI. Comprehensive notes on the tenebrionid fauna of the Namib Desert. Annals of the Transvaal Museum 24, 61-106.

Korn H and Martin H 1957. The Pleistocene in SWA. In: Clarke J D and Cole S (editors) Proceedings III Pan African Congress on Prehisotry, Livingstone. Chatto and Windus London. pp 14-22.

Lancaster J, Lancaster N and Seely M K 1984. Climate of the central Namib Desert. Madoqua 14, 5-61.

Logan R F 1960. The Central Namib Desert, South West Africa. National Academy of Science National Research Council Publishers 758, Washington DC.

Louw G N and Seely M K 1982. Ecology of Desert Organisms. Longman, London.

Martin H 1950. Sudwestafrika. Geologische Rundschau 38, 6-14.

Martin H 1963. A suggested theory for the origin and a brief description of some gypsum deposits of South West Africa. Transactions of the Geological Society of South Africa 66, 345-351.

Meteorological Services of the Royal Navy and the South African Air Force 1943. Weather on the coasts of southern Africa Vol II(1) The West Coast of Africa from River Congo to Olifants River 3-61. Cape Times, Cape Town.

Nagel J F 1962. Fog precipitation measurements on Africa's south-west coast. Notos 11, 51-60.

Nieman W A, Heyns C and Seely M K 1978. A note on precipitation at Swakopmund. Madoqua 11(1), 69-73.

Noy-Meir I 1973. Desert ecosystems: environment and producers. Annual Review of Ecology and Systematics 4, 25-51.

Noy-Meir I 1979/1980. Structure and function of desert ecosystems. Israel Journal of Botany 28, 1-18.

Ollier C D 1977. Outline geological and geomorphic history of the Central Namib Desert. Madoqua 10(3), 207-212.

Partridge T 1986. The palaeoclimatic significance of Cainozoic terrestrial stratigraphic and tectonic evidence from South Africa: a review. South African Journal of Science 81, 245-247.

Pietruszka R D and Seely M K 1985. Predictability of two moisture sources in the Namib Desert. South African Journal of Science 81, 682-685.

Rogers J 1977. Sedimentation on the continental margin off the Orange River and the Namib Desert. Joint Geological Survey/UCT Marine Geoscience Group Bulletin Cape Town.

Schulze B R 1969. The climate of Gobabeb. Scientific Papers Namib Desert Research Station 38, 5-12.

Seely M K 1978. Grassland productivity: the desert end of the curve. South African Journal of Science 74, 295-297.

Seely M K and Louw G N 1980. First approximation of the effects of rainfall on the ecology and energetics of a Namib Desert dune ecosystem. Journal of Arid Environments 3, 25-54.

Seely M K and Stuart P 1976. Namib climate: 2. The climate of Gobabeb, ten-year summary 1962-1972. Namib Bulletin Supplement No 1 Transvaal Museum Bulletin 7-9.

Seely M K and Griffin M 1986. Animals of the Namib Desert: Interactions with their physical environment. Revue de Zoologie Africaine 100, 47-61.

Seely M K, Buskirk W H, Hamilton W J III and Dixon J E W 1980/1981. Lower Kuiseb River Perennial Vegetation Survey. Journal XXXIV/XXXV of the South West African Scientific Society, 57-86.

Seely M K, Lewis C K, O'Brien K A and Suttle A E 1983. Fog response of tenebrionid beetles in the Namib Desert. Journal of Arid Environments 6, 135-143.

Siesser W G 1978. Aridification of the Namib Desert: Evidence from oceanic cores. In: van Zinderren Bakker E M (editor) Antarctic Glacial History and World Palaeoenvironments. Balkema, 105-112.

Siesser W G 1980. Lae Moiocene origin of the Benguela upwelling system off northern Namibia. Science 208, 283-285.

Soares Carvalho G 1961. Geologia do deserto de Mocamedes (Angola). Memorias da Junta de Investigacoes do Ultramar, Lisbonne 26. 227 pp.

South African Committee for Stratigraphy 1980. Stratigraphy of South Africa Part 1. In: Kent L E (editor) Handbook of the Geological Survey of South Africa 8, 578-609.

Stengel H 1964. The rivers of the Namib and their discharge into the Atlantic Part I: Kuiseb and Swakop. Scientific Papers of the Namib Desert Research Station 22, 1-50.

Stengel H 1966. The rivers of the Namib and their discharge into the Atlantic Ocean Part II: Omaruru and Ugab. Scientific Papers of the Namib Desert Research Station 30, 1-35.

Stocken C G 1978. A review of the late Mesozoic and Cenozoic deposits of the Sperrgebiet. Published Report SACS 1980, Handbook of the Geological Department of the Consolidated Diamond Mines of South West Africa (Pty) Limited. 37 pp.

Tankard A J and Rogers J 1978. Late Cenozoic palaeoenvironments on the west coast of southern Africa. Journal of Biogeography 5, 319-337.

Tankard A J, Jackson M P A, Eriksson K A, Hobday D K, Hunter D R and Minter W E L 1982. Crustal Evolution of Southern Africa. 3,8 Billion Years of Earth History. Springer-Verlag, Berlin.

Van Zinderen Bakker E M 1975. The origin and palaeoenvironment of the Namib Desert biome. Journal of Biogeography 2, 65-73.

Walter H 1936. Die vegetationsverhaeltnisse in der Namib-Nebelwueste. Forschungen und Fortschritte, Berlin 12(24), 293-294.

Walter H 1971. Ecology of Tropical and Subtropical Vegetation. Oliver and Boyd, Edinburgh.

Ward J D 1982. Aspects of a suite of Quarternary conglomeratic sediments in the Kuiseb Valley, Namibia. In: Coetzee J A and van Zinderen Bakker E M (editors) Palaeoecology of Africa 15, Balkema 211-216.

Ward J D 1984. Aspects of the Cenozoic Geology in the Kuiseb Valley, Central Namib Desert. Unpublished PhD Thesis, Department of Geology, University of Natal, Pietermaritzburg.

Ward J D and Von Brunn V 1985. Sand Dynamics along the lower Kuiseb River. In: Huntley B J (editor) The Kuiseb environment: the development of a monitoring baseline. South African National Scientific Programmes Report No 106. CSIR, Pretoria. 138 pp.

Ward J D, Seely M K and Lancaster N 1983. On the antiquity of the Namib. South African Journal of Science 79, 175-183.

Wellington J H 1955. Southern Africa - a geographical study. Vol 1. Physical Geography University Press Cambridge.

Wharton R A and Seely M 1984. Species composition of and biological notes on Tenebrionidae of the lower Kuiseb River and adjacent gravel plain. Madoqua 13(1), 5-25.

CHAPTER 10. THE KAROO REGION

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INTRODUCTION

The most important renewable resource in the karoo (see Cowling 1986 for a description of the biome) is the natural vegetation, which provides the basis for extensive small stock production (Roux et al 1981; Roux and Vorster 1983a; Vorster et al 1983). The threat of degradation of this resource through overgrazing has highlighted the need to determine the factors influencing vegetation trends. This need has provided the impetus for most of the long-term studies conducted in the karoo. These studies have concentrated on: interrelationships between rainfall and the abundance of different components of the vegetation (Roux 1966), relationships between soil erosion and vegetation composition (Roux 1981; Roux and Opperman 1986) and the influence of different grazing systems, stocking rates and stock breeds on veld composition (Skinner 1976; Vorster et al 1983; Roux and Vorster 1983b; Donaldson 1986).

Of equal importance are water resources, and several long-term data series relate to these, including trends in precipitation (Tyson 1986; Venter et al 1986), monitoring of river flows and reservoir levels, mineralization of natural waters (Görgens and Hughes 1986), sediment deposition in reservoirs (Görgens and Hughes 1986; Hodgson 1986; Roux and Opperman 1986) and ground water levels (Hodgson 1986).

Smaller bodies of long-term data sets are available from the organizations responsible for the numerous conservation areas in the karoo (Department of Nature and Environmental Conservation of the Cape Provincial Administration, National Parks Board, Defence Force).

Palaeoecological data sets are given by Deacon et al (1984); Bousman et al (in press) and Meadows et al (1987).

LONG-TERM VARIABILITY OF THE ECOSYSTEM: A REVIEW

Climate

The karoo is an arid to semi-arid region and, as is typical of such regions, rainfall can be extremely variable in both space and time.

An early hypothesis ascribed the degradation of the vegetation in the karoo, as well as the tendency for the karoo to invade adjacent grassveld regions, to a progressive reduction in rainfall. Analysis of precipitation data has not substantiated this and there appear to have been no progressive changes in macroclimate during the historical period (Roux and Vorster 1983a; Tyson 1986).

The evidence does, however, indicate oscillatory variations in rainfall

(Tyson 1986; Venter et al 1986). The patterns described by Tyson (1986) suggest that different oscillations are associated with different parts of the karoo. The 18-year oscillation (roughly nine years wetter than average followed by nine years drier than average) characteristic of the summer rainfall areas of South Africa may be apparent in the north-eastern karoo. A 10 to 12-year oscillation, which is confined mainly to the all-season rainfall region of the southern Cape, may apply to the southern parts of the karoo. A quasi-biennial (two to three-year oscillation) has its core area over the western and central karoo.

Venter et al (1986) analysed rainfall trends from data pooled from different parts of the karoo. They report signs of a 15 to 20-year oscillation in the karoo since the 1920's, which is in rough accord with the findings of Tyson (1986).

There is some tendency for the south-western Cape to evidence an opposite trend to that found in the summer-rainfall regions, the winter-rainfall region experiencing higher rainfall when droughts are occurring in the interior (Tyson 1986). Tyson (1986) also noted that during the winter between two dry summers, when the south-western Cape is receiving good rains, an increasing frequency of cloudiness and light rain is experienced over the summer rainfall regions. This tendency, if real, will result in the karoo receiving increased precipitation in winter during those years when summer rainfall is poor.

Although the oscillations in rainfall are discernible, they are subject to considerable spatial and temporal variation. Neither the 18-year nor the 10 to 12-year oscillations account for more than 20 to 30% of the inter-year variation (Tyson 1986). It is not yet possible to predict local variations in annual rainfall with any certainty in any part of the karoo.

The effect of rainfall variations on karoo vegetation

The results of a 16-year trial (1949 to 1965) examining relationships between vegetation composition and variations in rainfall are reported by Roux (1966). During the late 1940's and early 1950's summer rainfall was low whereas winter rainfall was comparatively high. Summer rainfall increased during the 1950's and winter rainfall declined. The 1960's saw a decline in summer rainfall and a relative increase in winter rainfall.

These changes in rainfall were associated with marked changes in the basal cover of perennial grasses and karoo bushes. The trends in grass basal cover were closely correlated with the change in summer rainfall. Grass cover increased by up to seven-fold from the late 1940's to the mid-1950's and then declined during the early 1960's. The cover of karoo bushes, on the other hand, was correlated with fluctuations in winter rainfall. Roux (1966) concluded that, owing to differences in phenology, spring and summer rain (September to February) tended to favour grasses, whereas autumn and winter rain (March to August) favoured the karoo bushes.

The trends in cover of the different vegetation components were evident irrespective of the treatments applied during the trial (protection from grazing, continuous grazing and rotational grazing). The magnitude of fluctuations in basal cover of both grass and karoo bushes tended to be greater in the protected camps than in those subjected to grazing (Roux 1966).

Relationships between vegetation cover and soil erosion

Measurements of sheet erosion over a period of 16 years showed that soil losses were much lower (4,9 mm) in veld dominated by grass than in veld dominated by karoo bushes (20,7 mm) (Roux 1981; Roux and Opperman 1986).

Relationships between vegetation composition and grazing

Long-term grazing trials in the karoo are reviewed by Roux and Vorster (1983b), Vorster et al (1983) and O'Connor (1985). These include one of the longest-running trials in the country, the "Camp No 6 Grazing Experiment" which was initiated in 1934 (Donaldson 1986).

These trials have shown that grazing can be a major determinant of vegetation composition, depending on its intensity and the time of the year when it is applied. Summer grazing by sheep *Ovis aries*, followed by winter rest, tends to suppress the grass and promote karoo bushes. Grazing in winter (when grasses are dormant) and resting the veld in summer has the opposite effect - grasses are promoted and karoo bushes suppressed (Vorster et al 1983).

In general the results show that rotational grazing is superior to continuous grazing in terms of both veld condition and animal performance (Roux and Vorster 1983b). However, at moderate stocking rates continuous grazing can result in better animal performance over the long term than some rotational systems if the latter are rigidly and injudiciously applied (Donaldson 1986).

It has also been shown that different types of stock have different effects on the vegetation. In an 11-year trial in the central lower karoo Skinner (1976) showed that continuous grazing by angora goats *Capra hircus* had no significant effect on the basal cover of palatable perennial plants. On the other hand merino sheep *Ovis aries*, at a stocking rate comparable to that of the goats, caused a significant decline in the basal cover of palatable perennials. Indications of differences in plant species composition between areas grazed by sheep and areas grazed by springbok *Antidorcas marsupialis* are reported by Davies (1986).

Major vegetation trends in the karoo

It has long been recognized that the vegetation of the karoo is degrading in the sense that palatable plants (especially perennial grasses) are disappearing, to be replaced by unpalatable species (Acocks 1975; Roux and Vorster 1983a). It is also evident that the karoo vegetation is advancing northwards and eastwards into adjacent biomes (Acocks 1975; Jarman and Bosch 1973). As there is no evidence to indicate progressive climatic changes, these vegetation trends in the karoo and adjacent grassveld have been attributed to overgrazing by domestic stock.

Patterns of long-term vegetation change in the karoo have been postulated by workers with long experience in the region (Acocks 1975; Roux and Vorster 1983a) but, unfortunately, these are poorly supported by long-term quantitative data. Roux and Vorster (1983a) proposed that vegetation change in the karoo proceeded in five overlapping phases:-

Phase 1, in which the vegetation characteristic of the karoo 300 years ago underwent primary degradation. Palatable plants, especially perennial grasses, were thinned out as a result of overgrazing during the last century.

Phase 2 entailed further decreases in palatable species. Unpalatable species could not spread fast enough to replace them, and phase 2 was characterized by high rates of soil erosion and the development of extensive bare patches. It is postulated that this phase reached its peak during the droughts of the early 1930's.

Phase 3 was a phase of revegetation by less palatable, woody species. This resulted in an increase in cover and the obliteration of bare patches, a process which occurred particularly during the late 1960's and 1970's.

Phase 4 follows if phase 3 vegetation is subject to further overgrazing. It is characterized by the almost complete dominance of certain unpalatable woody species and a ground cover of ephemerals which is present only when it rains. Since the ephemerals represent the only available forage the grazing capacity of this vegetation is very low.

Phase 5 is characterized by desertification. It is postulated that this phase might in future be the result of further misuse of phase 4 vegetation.

Roux and Vorster (1983a) emphasize that these phases represent an overall picture which need not hold for all regions of the karoo. For example in the eastern areas, which have a higher rainfall, phase 2 may be absent; and heavily grazed phase 1 vegetation may progress directly to phase 3.

Water resources

A considerable body of information on the rate of sediment deposition in dams in the karoo has been accumulated, and this provides an indication of long-term trends in soil losses (Department of Water Affairs 1986). This record shows that the greatest sedimentation took place before 1940. Sediment accumulation and runoff have in fact declined significantly over the last 30 to 40 years (Roux and Vorster 1983a; Department of Water Affairs 1986). The apparent decline in erosion in recent decades has been attributed to various factors: (i) soil conservation measures (Whitmore 1959); (ii) a decrease in the amount of erodable topsoil after the initial heavy losses earlier this century (Rooseboom and Harmse 1979 as cited in Görgens and Hughes 1986; Roux and Opperman 1986); and (iii) the thickening up of the vegetation associated with the development of phase 3 vegetation in the karoo (Roux and Opperman 1986).

Mineralization, or gross inorganic salt contamination of natural waters, is a particular concern in arid and semi-arid regions. Evaporation tends to exceed precipitation and this leads to high concentrations of salt in runoff, groundwater and dams. Long-term records of chloride concentrations in the waters of Lake Mentz (Sundays River catchment) showed a marked increase during the late 1970's, in association with a period of high rainfall (Görgens and Hughes 1986). This apparently had harmful effects on irrigated citrus trees.

Data from conservation organizations and conservation areas

A number of posters presented at this meeting give data sets from conservation areas. Norton (unpublished) modelled population processes of mountain reedbuck *Redunca fulvorufula* in order to test trends in the data. The most important trend found was a rapid increase in population after the high rainfall in the mid-1970's. Data on mountain reedbuck in the Mountain Zebra National Park (Novellie unpublished) indicates that numbers are related to fluctuations in rainfall. The 1960's experienced below-average rainfall and at the end of that decade the mountain reedbuck numbered 480. During the 1970's rainfall increased and the mountain reedbuck showed a corresponding increase, reaching a peak of about 1 270 in 1975. At that time culling of mountain reedbuck commenced and the population steadily declined to 455 in 1980. After 1982 culling was substantially reduced but the mountain reedbuck failed to increase to their former numbers. The reason for this may be the below-average rainfall of the early 1980's.

Fairall (unpublished) recorded fluctuations in dassie *Procavia capensis* populations in the Nuweveld Mountains between 1981 and 1987. He ascribed fluctuations in their numbers to changes in predator densities and rainfall. Long-term data, dealing with foaling rates and foaling intervals of Cape mountain zebra *Equus zebra* mares are discussed by Penzhorn (1985). This study showed that between-year variation in foaling percentages was not correlated with rainfall fluctuations.

Trends in "problem animal" populations for the whole Cape Province are apparent from returns from bounties paid in the 1930's to 1950's, although the data are subject to major biases (Norton unpublished). In the karoo a general decrease in jackal *Canis mesomelas* populations has evidently been accompanied by an increase in caracal *Felis caracal* populations, although this did not occur in all regions. Data on leopard *Panthera pardus* distribution from bounty returns have been examined together with historical records and recent control permit returns. These show a gradual decrease from a once widespread range throughout the Cape Province to the present distribution which is restricted to the mountains of the south and south-west and the broken veld of the lower Orange River (Norton 1986a). Changes in the distributions of other large mammal species over the historical period are examined by du Plessis (1969) and Skead (1980, 1987).

Le Roux (in preparation) collected data on vegetation cover in the winter rainfall karoo (Hester Malan Nature Reserve) over a period of 15 years (1973 to 1987). Fluctuations in plant cover were correlated with fluctuations in annual rainfall. However, over the 15-year period total cover showed a slight increase. This increase was largely due to an increase in the unpalatable plant species. Some palatable species showed moderate increases, but most either remained stable or declined in cover. The moderate extent of the increase in total vegetation cover (only about eight per cent over 15 years) is unexpected in view of the fact that herbivore biomass in the area was well below the carrying capacity recommended by the Department of Agriculture.

Palaeoecology

Excavation of the Boomplaas cave deposits (Deacon et al 1984) showed that in the layers dated 32 000 BP to 18 000 BP, mean cave temperatures fell from 13,5 to 9,5 degrees Celsius (speliotherm data). Woody species, common in the deposit prior to this cold period, were reduced relative to grass species and the proportion of browsing relative to grazing antelope bones in the deposit was low.

As temperatures ameliorated after the last glacial, woody vegetation became better represented in the charcoal of the deposit. Browsing animals (*Raphicerus* and *Pelea*) increased while grazers (Alcelaphines and Equids) decreased. At 10 000 BP, a thicket vegetation dominated by species with tropical affiliations was present in the Boomplaas area. After 6 000 BP, and up to historic times, *Acacia karroo* became increasingly common, possibly indicating a cooler climate and an increase in the summer component of rainfall (Deacon et al 1984).

In the headwater catchments of the Kikvorsberg, 12 km east of Noupoort, Cape Province, repeated cut and fill cycles with durations of 600 to 3 500 years occurred after 7 800 BP. Donga incision was followed by pool formation with organic deposition. Sediments contain diatoms and ostracods which provide evidence of salinity cycles. Palynological evidence suggests that these cycles were initiated by increased precipitation following periods of desiccation (Bousman et al in press).

In the Blydefontein basin the most recent cycle of incision began after 290 BP (Bousman et al in press). Although aggravated by local overgrazing in the present century, there is abundant evidence to suggest that the initiation of this phase of donga cutting was in response to natural environmental circumstances.

Pollen analysis of vlei sediments in the eastern Cape has indicated that karroid vegetation has drifted eastward at various times during the past in association with periods of greater aridity (see Meadows et al 1987).

FURTHER INFORMATION LIKELY TO BECOME AVAILABLE

Studies likely to be in print soon

A long-term study of the phenology of certain karoo plants is being prepared for publication (M Vorster personal communication). A R Palmer (personal communication) is conducting repeat surveys of an area of karoo vegetation near Grahamstown, which was surveyed originally by R A Dyer in 1929 (Dyer 1937). Preliminary indications are that this area has not undergone any marked changes. The conservation organizations in the karoo have recently been planning vegetation monitoring programmes (Norton 1986b) but few conservation areas have long-term data sets at present (an exception being the Hester Malan Nature Reserve in the winter rainfall karoo; see Le Roux above). Long-term data on brown locust *Locustana pardalina* outbreaks will shortly be published in the Proceedings of the Locust Conference, South African Institute of Ecology.

"Cryptic data"

Aerial photographs, available from the Surveyor General, date back to 1936. These have not been subjected to systematic analysis.

Records on the silt volumes in dams in the karoo are available from the Department of Water Affairs. Records for some dams date back to the early 1920's. Also available from the Department of Water Affairs are data on mineralization of natural waters and on ground water supplies.

The Department of Agriculture (Karoo Region) has raw data from grazing trials conducted between 1949 and 1973. Raw data from trials measuring sheet erosion are also available.

Archival data, dealing with farming or hunting activities, the types of animals kept on farms, and the stocking rates at which the animals were maintained in historical times are possibly of great value.

Old photographs which might have appeared in newspapers or in private collections would also provide an indication of long-term changes.

TRENDS AND CYCLES: TENTATIVE CONCLUSIONS AS TO DRIVING FORCES

In common with arid and semi-arid ecosystems in general, rainfall can be expected to be a major driving variable in the karoo. Rainfall is evidently subject to oscillatory changes, but the oscillations at best account for only a moderate proportion of the variance. The timing and spatial patterns of rainfall are therefore poorly predictable.

Nevertheless there is reason to expect that the north-eastern parts of the karoo are under the influence of the 18-year oscillation, and are thus likely to experience nine years of wet summers followed by nine years of dry summers. A further important point is that, in the summer rainfall regions of the karoo, the proportion of rain falling in winter may tend to be higher during the dry phases of the oscillation than during the wet. If this is so, then the findings of Roux (1966) suggest that the composition of the veld in the north-eastern karoo may undergo changes in accordance with the 18-year oscillation, with grass predominating during wet phases, and karoo bushes predominating during dry phases when winter rainfall is proportionately higher.

The pattern of rainfall during the 16-year trial described by Roux (1966) did indeed follow the general pattern of the 18-year oscillation (see above). However, in view of the considerable variation associated with the rainfall oscillation, it seems unlikely that cover of grass and bushes follows clearly defined and predictable oscillatory changes.

Although the oscillatory nature of rainfall may in some respects be open to question (Markham 1980) it is certainly true that portions of the karoo have experienced runs of years in which "grass rains" predominate, and runs in which "bush rains" predominate. The changes in veld composition associated with such rainfall phases have many important implications. Because of the different characteristics of grasses and karoo bushes the rate of sheet erosion and runoff are likely to differ depending on which vegetation component is dominant (Roux 1981; Roux and Opperman 1986). The climate-induced changes in the forage supply available to both wild and domestic herbivores may well bring about changes in the performance of different breeds/species depending on whether they favour grass (eg cattle, black wildebeest *Connochaetes gnou*, mountain reedbuck) or browse (goats, eland *Taurotragus oryx*, grey rhebuck *Pelea* *capreolus).* In presettlement days the distribution of wild ungulates probably differed depending on rainfall patterns, eg grazers like blesbok *Damaliscus dorcas* or black wildebeest may have penetrated much deeper into the karoo proper during phases when 'grass rains' predominated.

The influence of rainfall on veld composition is undoubtedly one of the key processes in the karoo. But its effects are randomly fluctuating with a tendency towards oscillations, rather than directional or progressive. The main agent of progressive change in karoo vegetation is evidently overgrazing by domestic stock. Economic circumstances provide an incentive to overgraze the karoo, and it is estimated that the carrying capacity of the region is currently exceeded by 40% - which represents three million too many small stock (Roux 1986).

FUTURE RESEARCH: WEAKNESSES IN THE DATA SERIES

Attention has been drawn to the fact that our current understanding of relationships between land use and hydrology is inadequate (Department of Water Affairs 1986; Görgens and Hughes 1986). The processes of sedimentation and mineralization will increasingly determine how effectively surface water can be utilized, and controlled experiments are required to determine the way in which these processes are influenced by patterns of land use.

Perhaps the most important shortcoming is the lack of quantitative data whereby the nature and direction of grazing-induced changes in the karoo can be evaluated. The trends described by Acocks (1975) and by Roux and Vorster (1983a) represent hypotheses that need to be tested. The collection of data to test these hypotheses is beset with difficulties. Firstly there is the necessity for representativeness. The spatial variation in both rainfall and grazing management in the karoo is such that data collection would need to cover extensive areas before it could be considered to be representative. Second, there is the need to distinguish the relative contributions of various factors, in particular rainfall, grazing and sampling error, to the observed vegetation trends. Unless the effects of the different factors can be partitioned a predictive understanding will not be obtained. Reference areas or witness stands are essential aids to distinguishing these effects (Wilson 1984). Determining long-term trends in the vegetation of the karoo will therefore require a carefully planned and coordinated research and monitoring programme.

The various sources of "cryptic" data noted above deserve analysis to determine their worth, and research needs to be intiated and directed towards this. Data relating grass cover to seasonal distribution of rainfall and to broad weather patterns (eg those induced by El Niño events) would provide a better perspective on long- and short-term changes in productivity of karoo vegetation for grazing animals.

Shifts in the local abundance of seed-eating birds could be indicative of seed availability and even recruitment events of certain plants. Lag phases between rainfall and the response of plant guilds, migrating birds and insects of economic importance also require monitoring.

REFERENCES

Acocks J P H 1975. Veld types of South Africa. Memoirs of the Botanical Survey of South Africa 40, 1-128.

Bousman C B, Partridge T C, Scott L, Metcalfe S E, Vogel J C, Seaman M and Brink J S (In press). Palaeoenvironmental implications of Late Pleistocene and Holocene valley fills in Blydefontein basin, Noupoort, C P, South Africa. Palaeoecology of Africa.

Cowling R M 1986. A description of the Karoo Biome Project. South African National Scientific Programmes Report No 122. CSIR, Pretoria. 42 pp.

Davies R A G 1986. A comparison of Springbok Antidorcas marsupialis and Merino sheep Ovis aries on Karoo veld. Unpublished MSc Thesis, University of Pretoria, Pretoria.

Deacon H J, Deacon J, Scholtz A, Thackeray J F, Brink J S and Vogel J C 1984. Correlation of palaeoenvironmental data from the late Pleistocene and Holocene deposits at Boomplaas cave, southern Cape. In: Vogel J C (editor) Late cainozoic palaeoclimates of the southern hemisphere. Balkema, Rotterdam. pp 339-351.

Department of Water Affairs 1986. Management of the Water Resources of the Republic of South Africa. Government Printer, Pretoria.

Donaldson C H 1986. The camp no. 6 veld grazing trial: An important milestone in the development of pasture research at the Grootfontein College of Agriculture. Karoo Agriculture 3, 1-6.

Du Plessis S F 1969. The past and present geographical distribution of the Perissodactyla and Artiodactyla in southern Africa. Unpublished MSc Thesis, University of Pretoria, Pretoria.

Dyer R A 1937. The vegetation of the divisions of Albany and Bathurst. Memoirs of the Botanical Survey of South Africa 17, 1-138.

Görgens A H M and Hughes D A 1986. Hydrology. In: Cowling R M, Roux P W and Pieterse A J H (editors) The karoo biome: a preliminary synthesis. Part I - physical environment. South African National Scientific Programmes Report No 124. CSIR, Pretoria. pp 53-83.

Hodgson F D I 1986. Geohydrology. In: Cowling R M, Roux P W and Pieterse A J H (editors) The karoo biome: a preliminary synthesis. Part I - physical environment. South African National Scientific Programmes Report No 124. CSIR, Pretoria. pp 84-91.

Jarman N and Bosch O J H 1973. The identification and mapping of extensive secondary invasive and degraded ecological types (test site D). In: D G Malan (editor) To assess the value of satellite imagery in resource evaluation on a national scale. CSIR Special Report. pp 77-80.

Meadows M E, Meadows K F and Sugden J M 1987. The development of vegetation on the Winterberg escarpment. The Naturalist 31, 26-32.

Markham R 1980. Prediction of annual rainfall in South Africa. Technical Report TWISK 152. National Research Institute for Mathematical Sciences, CSIR, Pretoria.

Norton P M 1986a. Historical changes in the distribution of leopards in the Cape Province, South Africa. Bontebok 5, 1-9.

Norton P M (editor) 1986b. Handbook of standardized monitoring techniques for Cape nature reserves. Cape Department of Nature and Environmental Conservation.

O'Connor T G 1985. A synthesis of field experiments concerning the grass layer in the savanna regions of southern Africa. South African National Scientific Programmes Report No 114. CSIR, Pretoria. 126 pp.

Penzhorn B L 1985. Reproductive characteristics of a free-ranging population of Cape mountain zebra (Equus zebra zebra). Journal of Reproduction and Fertility 73, 51-57.

Roux P W 1966. Die uitwerking van seisoensreenval en beweiding op gemengde karooveld. Proceedings of the Grassland Society of Southern Africa 1, 103-110.

Roux P W 1981. Interaction between climate, vegetation and runoff in the karoo. Technical Report No TR 113. Department of Water Affairs, Pretoria.

Roux P W 1986. Weidingstrategie: Karoostreek. Unpublished Report, Conservation Advisory Committee, Department of Agriculture.

Roux P W and Vorster M 1983a. Vegetation change in the karoo. Proceedings of the Grassland Society of Southern Africa 18, 25-29.

Roux P W and Vorster M 1983b. Development of veld management research in the karoo region. Proceedings of the Grassland Society of Southern Africa 18, 30-34.

Roux P W and Opperman D P J 1986. Soil erosion. In: Cowling R M, Roux P W and Pieterse A J H (editors) The karoo biome: a preliminary synthesis. Part I - physical environment. South African National Scientific Programmes Report No 124. CSIR, Pretoria. pp 92-111.

Roux P W, Vorster M, Zeeman P J L and Wentzel D 1981. Stock production in the karoo region. Proceedings of the Grassland Society of Southern Africa 16, 29-35.

Skead C J 1980. Historical mammal incidence in the Cape Province. Vol 1. The western and northern Cape. Cape Department of Nature and Environmental Conservation, Cape Town.

Skead C J 1987. Historical mammal incidence in the Cape Province. Vol 2. The eastern half of the Cape Province, including the Ciskei, Transkei and east Griqualand. Cape Department of Nature and Environmental Conservation, Cape Town.

Skinner T E 1976. A comparison between the effects of continous grazing by angora goats and merino sheep on veld in the central lower karoo. Proceedings of the Grassland Society of Southern Africa 11, 131-134.

Tyson P D 1986. Climatic change and variability in southern Africa. Oxford University Press, Cape Town.

Venter J M, Mocke C and de Jager J M 1986. Climate. In: Cowling R M, Roux P W and Pieterse A J H (editors) The karoo biome: a preliminary synthesis. Part I - physical environment. South African National Scientific Programmes Report No 124. CSIR, Pretoria. pp 39-52.

Vorster M, Botha P and Hobson F O 1983. The utilization of karoo veld by livestock. Proceedings of the Grassland Society of Southern Africa 18, 35-39.

Whitmore J S 1959. The effect of conservation farming practices on runoff from a semi-arid catchment. Technical Report 5, Department of Water Affairs, Pretoria.

Wilson A D 1984. Points of reference in the assessment of change in vegetation and land condition. Australian Rangeland Journal 6, 69-74.

CHAPTER 11. SOUTHERN AFRICAN SAVANNA ECOSYSTEMS

GENERAL OVERVIEW

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INTRODUCTION

This chapter is limited to the southern African savanna biome as described by Huntley (1982). It deals mainly with the biotic data series emanating from conservation areas in the savanna biome and concentrates primarily on woody plant and faunal dynamics. The dynamics of the herbaceous stratum are covered by Walker (this volume) as are the agricultural developments and trends by Scotney (this volume). Human population trends in the savanna will not be discussed.

Meteorological recording stations are widely dispersed throughout the savanna biome. The time period covered by these records varies considerably both within and between the variables being measured. There appear to be a large number of stations with rainfall records of between 50 and 74 years duration but none which exceed this. Temperature records are generally shorter with the exception of Skukuza which has an 80-year record. Analyses of variation in annual rainfall have been undertaken by Gertenbach (1980), Tyson (1986) and Goodman (unpublished) and generally a 19- to 22-year periodicity, with alternating dry or wet phases lasting eight to 11 years, has been found, as has an increase in the proportion of annual rainfall falling in the winter dry season during the dry phase of the cycle (Gertenbach 1980). With regard to the currently available temperature record, no trends are evident in the short term. However, major changes on a geological time scale are evident (Tyson 1986; Partridge this volume).

Since most of the savanna biome is located in the lower reaches of river catchments, changes in water flows in the major rivers can be of great consequence. With regard to water flow in the rivers in the eastern lowveld and northern Natal coastal savanna, concern has been expressed regarding a net decline in stream flow (Pienaar 1985) which is currently under investigation and will be covered in more detail by Schulze et al (this volume).

PUBLISHED DATA

Climate

Rainfall patterns in Kruger National Park and Mkuzi Game Reserve have been analysed but only at a very coarse level (Gertenbach 1980; Goodman unpublished). What is lacking is an analysis of rainfall patterns at a finer scale of resolution, eg local variations in both intensity and spatial pattern. These data are needed to explain landscape level processes.

Fire

Published accounts on the occurrence, characteristics and effects of fire include van Wyk (1971), Berry and Macdonald (1979), Gertenbach and Potgieter (1979), Edwards (1984) and Trollope (1984).

Soil/Erosion

Published accounts of long-term trends in soil erosion are documented by Partridge (this volume).

Vegetation

Few quantitative long-term studies of changes in vegetation have been undertaken and published. However, gross changes such as marked bush encroachment could easily be quantified by using sequential aerial photographs.

Single species studies. No long-term data series on single species have been published.

Community studies. Long-term trends in plant communities have been determined from palaeontological investigations, notably by Scott (1984) and Prior and Tuohy (1987). King (1987) studied changes in the woody plant cover of Hluhluwe Game Reserve and van Rooyen et al (1984) report changes in the vegetation of the Kalahari Gemsbok National Park.

O'Connor (1985) has summarized the results of numerous shorter-term herbaceous layer monitoring programmes, as have Coetzee et al (1977) for those carried out in the central district of the Kruger National Park.

These proceedings summarize the preliminary conclusions of two new studies, those of Blakeway and Page (this volume) and Viljoen (this volume).

Fauna

Single species studies. Owen-Smith (1984, unpublished) reports changes in kudu *Tragelaphus strepsiceros* densities in the central region of the Kruger National Park. Smuts (1978, 1982, unpublished) and Starfield et al (1976) report trends in wildebeest *Connochaetes taurinus* and zebra *Equus burchelli* populations for the central region of the Kruger National Park. Berry (1981) has documented wildebeest population trends in Etosha National Park. Trends in the buffalo *Syncerus caffer* and elephant *Loxodonta africana* populations in the Kruger National Park have been reported in de Vos et al (1983). Mason (unpublished) reports changes in the sex and age structure of many large herbivore species between 1981 and 1986. Taylor (unpublished) has summarized the long-term trends of the hippo *Hippopotamus amphibius* population in Maputaland (1951 to 1986).

Community studies. Brooks and Macdonald (1983) report changes in the population sizes of the large herbivore community in the Hluhluwe/Umfolozi Complex. Joubert et al (this volume) report on changes since 1977 in the large herbivore community of the Kruger National Park. Nel et al (1984) have monitored changes in small mammal populations in Kalahari Gemsbok

National Park. Goodman (1985) presented figures on the harvested production from Ndumu (1968 to 1983) and Mkuzi (1960 to 1983) Game Reserves.

UNPUBLISHED DATA

Climate

Unanalysed climatic data from throughout the savanna biome is available from the South African and South West Africa/Namibian Weather Bureaux.

Hydrology

Stream flow data are available for all major rivers throughout the biome from the Department of Water Affairs.

Fire

The National Parks Board, SWA Directorate of Nature Conservation and all provincial nature conservation departments record, as a minimum, the timing and extent of prescribed, accidental and arson fires in all protected areas under their jurisdiction.

Soil/erosion

There appear to be no currently unpublished long-term data series on soil erosion per se but the potential for deriving these exists, particularly estimation of donga expansion through the analysis of successive aerial photographs. Short-term erosion and runoff data (1982 to 1987) are available for the Hluhluwe/Umfolozi Complex (Venter unpublished).

Vegetation

Baseline phytosociological surveys have been undertaken in most savanna conservation areas. These surveys could be repeated and changes analysed. Major studies include de Moor et al (1977), Bredenkamp (unpublished), Gertenbach (1978), le Roux (unpublished), Coetzee (1983), Jankowitz (unpublished), Whateley and Porter (1983).

Single species studies. Goodman (unpublished) has annual density data from 1978 for *Solanum panduraeforme* in and outside a large-herbivore exclusion plot in Mkuze Game Reserve.

Community studies. Page (unpublished) has data from 1976 on density, mortality and recruitment of woody plants in the Tuli Block, Botswana.

There are a large number of current vegetation monitoring programmes, the results of which are as yet incompletely analysed and unpublished (Table 11.1).

TABLE 11.1 Current monitoring programmes

Subject/Nature of Project	Place	Date of inception	Frequency	Technique used
A: VEGETATION				
Changes in woody vegetation component	Hluhluwe Game Reserve	1969	4 yearly	Fixed point photography (FPP)
Changes in woody vegetation component	Umfolozi Game Reserve	1974	4 yearly	FPP
Changes in distribution of broad physiognomic types	Hluhluwe Umfolozi	1937 1937	±10 yearly ±10 yearly	Aerial survey
Changes in herbaceous layer, composition, structure and utilization	Hluhluwe Umfolozi	1974-1983 1979	Annually Annually	Walker transects
Changes in woody layer, composition, structure and utilization	Hluhluwe Umfolozi	1974-1983 1978-1983	Biennially Biennially	Walker transects
Species composition and frequency in herbaceous layer	Hluhluwe Umfolozi	1979-1983 1979-1983	Annually Annually	Wheelpoint surveys, line intercepts, nested quadrants
Woody plant density, structure, composition and utilization	Hluhluwe	1979-1982	Biennially	Mapped transects
Erosion levels	Hluhluwe Umfolozi	1978-1984 1978-1984	Annually	Subjective veld assessment
Range condition evaluation	Hluhluwe Umfolozi	1985 1985	Annually	Soil movement biomass utilization levels
Alien plant distribution/intensity of infestation	Hluhluwe Umfolozi	1978 1978	5 yearly	
Herbaceous fuel loads for planning burning prescriptions	Hluhluwe Umfolozi	1984	Annually	
Woody plant densities, composition and structure for the evaluation of the effects of prescribed burns	Hluhluwe Umfolozi	1983	Annually	
Vegetation changes	Itala Game Reserve	1972		Fixed point and aerial photography
Vegetation changes	Kenneth Stainbank Nature Reserve	1982		FPP and species composition on permanent plots
Vegetation changes	Krantzkloof Nature Reserve	1982		FPP and species composition on permanent plots
Vegetation changes	Enseleni	1986		FPP
Vegetation changes	Harold Johnson Nature Reserve	1986		FPP
Alien plant monitoring and effects of fire on woody plants	Vernon Crookes Nature Reserve	1985		FPP and permanent plots
Effects of fire on forest and <u>Protea roupelliae</u>	Umtamvuna Nature Reserve	1986		FPP and permanent plots

TABLE 11.1 (Continued)

Subject/Nature of Project	Place	Date of inception	Frequency	Technique used
Grassland changes	Itala Game Reserve	1986		Old Croplands manipulation project
Change in vegetation physiognomy	Natal (largely unconserved areas)	±1836		Historical oblique and aerial photography analysis
Vegetation change	False Bay	1978	4 yearly	FPP
Vegetation change	False Bay	1984	Annually	Subjective assessment points
Grassland species composition	Weenen Nature Reserve	1979	5 yearly	Foran and related methods
Species presence and abundance	Ndumu and Mkuze Game Reserves	1977	Annually	Subjective assessment
Vegetation change	Kruger National Park	1939	Irregularly	Small-scale aerial photography
Vegetation change	Kruger National Park	1981	Annually	Aerial photography and monitoring in fixed transects
Vegetation change	Kruger National Park	1977	Biennially	± 600 FPP
Variables in field layer	Kruger National Park	1978	Annually	Aerial surveys
Vegetation change	Etosha National Park	1986	5 yearly	FPP
Vegetation changes	Percy Fyfe Nature Reserve	1985	5 yearly	FPP and species composition on permanent plots
Vegetation changes	Percy Fyfe Nature Reserve	1985	Bi-monthly	Disc pasture metre surveys
Vegetation changes	Nylsvley Nature Reserve	1982	5 yearly	FPP and species composition on permanent plots
Vegetation changes	Langjan Nature Reserve	1981	5 yearly	FPP
Vegetation changes	Langjan Nature Reserve	1986	Bi-monthly	Disc pasture metre surveys
Grass species composition	Langjan Nature Reserve	1984	Biennially	Line intercepts
Grass species composition	Hans Merensky Nature Reserve	1984	Biennially	Line intercepts
Grass species composition	Messina Nature Reserve	1984	Biennially	Line intercepts
Variables in field layer	Manyaleti Private Nature Reserve	1982		Aerial survey

TABLE 11.1 (Continued)

Subject/Nature of Project	Place	Date of inception	Frequency	Technique used
Vegetation composition	Klaseri Private Nature Reserve Timbavati Private Nature Reserve	1986	Annually	Subjective field assessment and aerial surveys
Vegetation changes	Suikerbosrand Nature Reserve	1984	Six monthly	FPP
Grassland stand phytomass	Suikerbosrand Nature Reserve	1987	Annually	Disc pasture metre
Grass species composition	Suikerbosrand Nature Reserve	1987	Annually	Wheel point
Vegetation changes	Loskop Dam Nature Reserve	1987	Annually	FPP, disc pasture metre and wheel point
B: FAUNAL POPULATIONS				
Game removals	Hluhluwe Umfolozi	1954 1959	Daily	N/A
Game counts	Hluhluwe Umfolozi	1929 1960		Foot counts
Game counts	Hluhluwe Umfolozi	1967		Helicopter
Game counts	Hluhluwe Umfolozi	1981	Tri-annually	Fixed-wing aircraft
Population structure (giraffe, lion, black and white rhinoceros)	Hluhluwe Umfolozi	1974 1975	Annual	N/A
Register of small mammals	Hluhluwe Umfolozi		For 1 year every 6 years	
Large herbivore census	Sodwana	1986	Annual	Aerial transects
Cape vulture breeding colonies	Umtamvuna Nature Reserve	1983	Monthly Apr - Oct	Nest records
Small forest antelopes	Kenneth Stainbank Nature Reserve	1982	Annually	Foot counts
Large herbivore numbers	Vernon Crookes Nature Reserve	1984		Horseback counts
Age/sex classes of large herbivores	Itala Game Reserve	1986		Known group method
Monitoring individual animals - black and white rhinoceros	Itala Game Reserve	1986		
Large herbivore numbers	False Bay	1982	Annually	Line transects
Large herbivore numbers	Eastern Shores Nature Reserve	1982	Annually	Line transects and mean groups
Large herbivore densities	Mkuze Game Reserve	1963	Annually	Various complete counting and sampling techniques

TABLE 11.1 (Continued)

Subject/Nature of Project	Place	Date of inception	Frequency	Technique used
Sex and age structure of large herbivores	Mkuze Game Reserve	1977	Annually	Road sample count
Large herbivore densities	Ndumu Game Reserve	1982	Annually	Aerial and ground transects
Mortalities	All Natal Parks Board Reserves	c 1965	Monthly	Location of carcasses during field patrols
Herbivore counts	Kruger National Park	1954-1975	Annually	Road-strip census
Lion populations	Kruger National Park	1958 to present	Continuous	Rangers reports
Elephant and buffalo numbers	Kruger National Park	1960-1962		Fixed-wing aircraft
Elephant and buffalo numbers	Kruger National Park	1964 to present	Annually (Dry season)	Helicopter
Hippopotamus numbers	Kruger National Park	1955-1964 1974 to present	Annually Annually (Dry season)	Foot census Helicopter
Lion numbers	Kruger National Park (Central District)	1974-1977	Annually	Identification of all prides through marking of individuals
All major herbivore counts	Kruger National Park	1977 to present	Annually (Dry season)	Total count, fixed-wing aircraft
Crocodile counts	Kruger National Park	1984 to present	Annually	Helicopter (part of annual hippo count)
Ostrich *Struthio camellus* and ground hornbill *Bucorvus leadbeateri*	Kruger National Park	1977 to present	Annually	Fixed-wing aircraft (part of annual herbivore count)
Major herbivore species counts	Etosha National Park	1969-1984	Annually	Aerial
Elephant totals	Etosha National Park	1860	±10 yearly	Estimates
Lion totals	Etosha National Park	1978	Annually	
Lion totals	Savuti (Chobe National Park)	1982-1985	Annually	Nonsampling ground surveys (known group)
Several bird species (herons, storks, etc) associated with rivers and other waters	Kruger National Park	1984 to present	Annually	Helicopter (part of annual hippo count)
Brown hyaena *Hyaena brunnea* totals	Kalahari Gemsbok National Park	1982	Annually	
Large herbivore totals	Kalahari Gemsbok National Park	1976	Biennial	Fixed-wing aircraft
Elephant totals	Chobe National Park	1973-1975	Annually	Aerial (fixed-wing)

TABLE 11.1 (Continued)

Subject/Nature of Project	Place	Date of inception	Frequency	Technique used
* Wildebeest	Botswana (Williamson)	1981-1984		Aerial (fixed-wing)
**Large herbivore totals	Northern Botswana	1984-1986	Annually	Fixed-wing aircraft (sample counts)
Game counts	Nylsvley Nature Reserve	1982	Annually	Known group method
Game counts	Langjan, Hans Merensky, and Messina Nature Reserves	1981	Annually	Aerial
Game counts	Percy Fyfe Nature Reserve	1982	Annually	Known group method
Game counts	Timbavati and Klaseri Private Nature Reserves	1982	Yearly	Aerial (helicopter)
Game distribution and counts, age and sex classes	Suikerbosrand Nature Reserve and Loskop Dam Nature Reserve	1987	Tri-monthly	Ground survey
Game condition	Loskop Dam Nature Reserve	1987		Blood analyses
Crocodile counts	Rivers of the Transvaal	1981	5 yearly	Aerial survey

* Several surveys (all aerial) in different parts of Botswana since 1973. Most of these counts were in the Central Kalahari and northern Botswana and stretched over a two- to three-year period (approximately 12 unpublished reports).

** These surveys were extended in 1987 to the rest of the country.

Fauna

The large mammal component of almost all national and provincial game reserves is monitored on an annual basis (Table 11.1), but small mammals appear to have been largely neglected. Distribution records throughout the savanna biome are currently available for other faunal groups such as fish, reptiles, amphibians and birds. These could be analysed for temporal shifts, cf Macdonald (1982) and Boshoff et al (1983).

TENTATIVE CONCLUSIONS ON TRENDS AND CYCLES

Fire

Fire frequency appears to be related strongly to rainfall fluctuations (Gertenbach unpublished). Short-term data (1970 to 1979) from Etosha National Park support this conclusion (Siegfried 1981). However, it is strongly suspected that the influence of intensive grazing on the herbaceous sward can, by reducing the available fuel load, substantially modify the apparently overriding influence of rainfall (Brooks and Macdonald 1983).

It is suspected that the regularity of fire experienced at a site was formerly controlled by fuel load and hence by rainfall and grazing pressure, and was thus essentially irregular. This has changed to the more recent pattern which is now highly regularized wherever fire is applied for specific management purposes.

With the advent of fire-breaks the boundaries of single fire events have been artificially restricted. Similarly it is thought that the pattern and mosaic of unburnt vegetation of different ages has changed from highly irregular and small scale to one which is currently highly regularized and is often of larger scale and in geometric shapes (block burning). This could have detrimental consequences for species diversity (Nel 1978; Kern 1981).

Methods of controlled burning could also have ecological impacts - eg regular upwind burning or ring-burning of management blocks are all "unnatural" burning methods characterized by higher fire intensities than are typical of wild fires.

Seasonal timing of fire has changed. Just how it has changed is subject to debate and is likely to vary with rainfall and vegetation differences within the biome. It seems to be controlled by the date of onset of the spring rains (Trollope 1984).

Soils

The rate of soil loss decreases with an increase in ground cover (Venter unpublished). Recent trends (1972 to 1986) in the Timbavati/Klaserie Nature Reserves (de Villiers unpublished) indicate an overall increase in bare ground.

Vegetation

The encroachment of open savanna by woody plants since the mid-1850's is widespread in Natal (Blakeway and Page unpublished; Figure 11.1). More recent records from the Hluhluwe Game Reserve indicate that since 1937 the area of closed canopy woodland and forest has increased from 22% to 48,5% (King 1987; Table 11.2). Watson and Macdonald (1983) estimated that in Hluhluwe Game Reserve between 1937 and 1975 woody plant cover increased from 53% to 82% and the area covered by tall grasslands decreased from 35% to 14%.

Similarly, 25% of the bushveld region of 30 million ha in southern Africa has been adversely affected by bush encroachment (du Toit in Owen-Smith and Cooper 1985).

In the Kruger National Park there is evidence of a decline in mature trees since 1944 within certain land units (Viljoen this volume; Gertenbach unpublished).

In the Tuli Block, Botswana during the last 10 years (dry phase) the density of all woody species has declined (Page unpublished; Figure 11.2).

Intensive livestock use of the herbaceous layer initiates species composition changes from grass to dwarf shrub which in turn encourages changes in livestock species, ie from cattle to sheep, each species being more destructive to vegetation than the preceeding one in this man-made grazing succession (van Niekerk 1977).

In South West Africa/Namibia the entire arid savanna has experienced large-scale increases in woody shrub species such as *Acacia mellifera* and *Dichrostachys cinerea* between the early 1950's and the present. Since 1985 widespread die-offs of *A mellifera* have been noted, mainly in the central area of its distribution. This die-off may be associated with one or more fungal pathogens (Versfeld 1986).

Fauna

The early historic data series available for large herbivores indicate large increases from the low population levels at the turn of the century which resulted from early hunting activities and the rinderpest epizootic. More recently, many of these populations have stabilized and some have fluctuated within fairly small ranges (Brooks and Macdonald 1983; de Vos et al 1983; Joubert and Viljoen this volume).

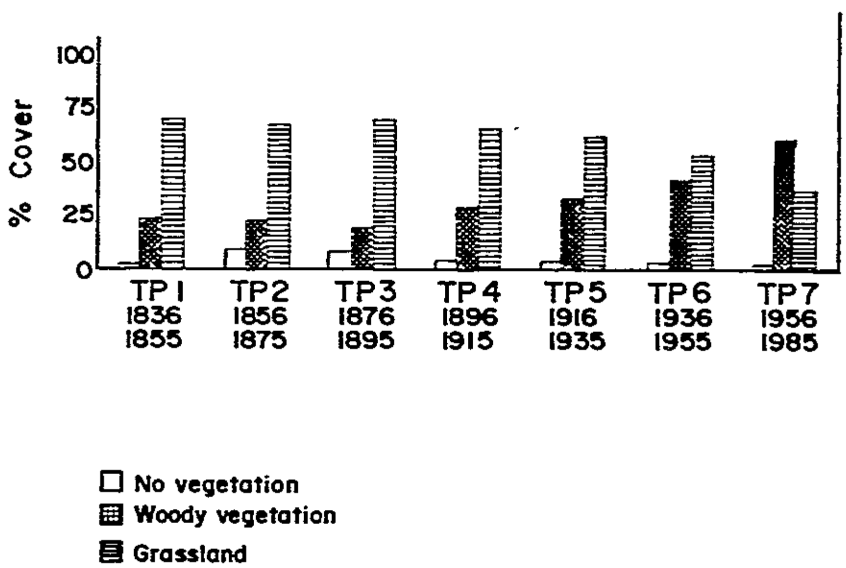

FIGURE 11.1 Changes in vegetation cover in areas excluding river valleys in Natal between 1836 and 1985 (derived from oblique ground photographs, paintings and sketches - source Blakeway and Page unpublished).

At least certain of the large mammal species in savanna ecosystems show cyclic changes in distribution and abundance that appear to be related to fluctuations in annual rainfall (Macdonald 1982). Possibly the best documented example of this comes from the multispecies counts carried out in the Central District of the Kruger National Park since 1968. Although direct comparisons between the different census methods are not possible at this stage, the wildebeest population in the Central District, for example, appears to have declined from 1970 to 1977, after which the population increased at a steady rate (Figure 11.3). These population fluctuations appear to be linked to rainfall (Figure 11.4). With the exception of wildebeest, most large herbivores declined in numbers following the low rainfall of the 1982/83 rainy season (Figures 11.3 and 11.4).

TABLE 11.2 Increase in the component of forest (F) and scrub (S) vegetation in Hluhluwe Game Reserve, 1937 to 1982 from analysis of aerial photographs (King 1987).

Total area 14 714 ha	1937		1954		1960		1975		1982		
	F	S	F	S	F	S	F	S	F	S	TOTAL
Area (ha)	1799	1466	2037	1737	2062	3020	2154	4086	2393	4734	7127
% of total area of reserve	12,2	9,8	13,8	11,8	14,0	20,5	14,6	27,8	16,3	32,2	48,5
Increase in area (ha)	-	-	239	291	25	1283	92	1066	239	648	
Increase as % of total area	-	-	1,6	2,0	0,2	8,7	0,6	7,3	1,7	4,4	
Increase pa (ha)	-	-	14,0	17,1	4,2	213,8	6,1	71,1	34,1	92,6	
Increase pa (% of total area)	-	-	0,1	0,12	0,03	1,45	0,04	0,49	0,24	0,63	
Increase as % of previous area of type	-	-	13,2	20,1	1,2	73,9	4,5	35,3	11,1	15,9	
Increase pa (% of previous area of type)	-	-	0,7	1,2	0,2	12,3	0,3	2,35	1,6	2,3	
Total % increase of type in 45 years	-	-	-	-	-	-	-	-	33	227	
Mean % increase pa 1937 to 1982	-	-	-	-	-	-	-	-	0,7	5,0	

Since the mid-1960's large herbivore populations in many of the larger conservation areas have been reduced or controlled by management. Published examples may be found in Brooks and Macdonald (1983) for the Hluhluwe/Umfolozi Complex, de Vos et al (1983) for the Kruger National Park and Goodman (1985) for Mkuzi and Ndumu Game Reserves. Recently, wildebeest have declined almost to extinction in the central Kalahari while elephant numbers continue to increase in north-eastern Botswana (Kalahari Conservation Society unpublished; Williamson unpublished). Brooks and Macdonald (1983) summarized data on the "natural" declines of common reedbuck *Redunca arundinum*, waterbuck *Kobus ellipsiprymnus*, bushbuck *Tragelaphus scriptus*, steenbok *Raphicerus campestris* and klipspringer *Oreotragus oreotragus* in the Hluhluwe/Umfolozi Complex.

The major large predators showed a similar early increase to that of the large herbivores described above (see Smuts 1976, 1982 for the trend in lion numbers since the early 1900's). More recently black-backed jackals *Canis mesomelas* have shown a marked decline in abundance within the conservation areas of Natal, eg in Hluhluwe Game Reserve (Whateley and Brooks 1985). The major large raptors of the biome, the bataleur *Terathopius ecaudatus*, martial *Polemaetus bellicosus* and tawny *Aquila rapax* eagles, have all shown recent declines (Boshoff et al 1983; Tarboton and Allan 1984).

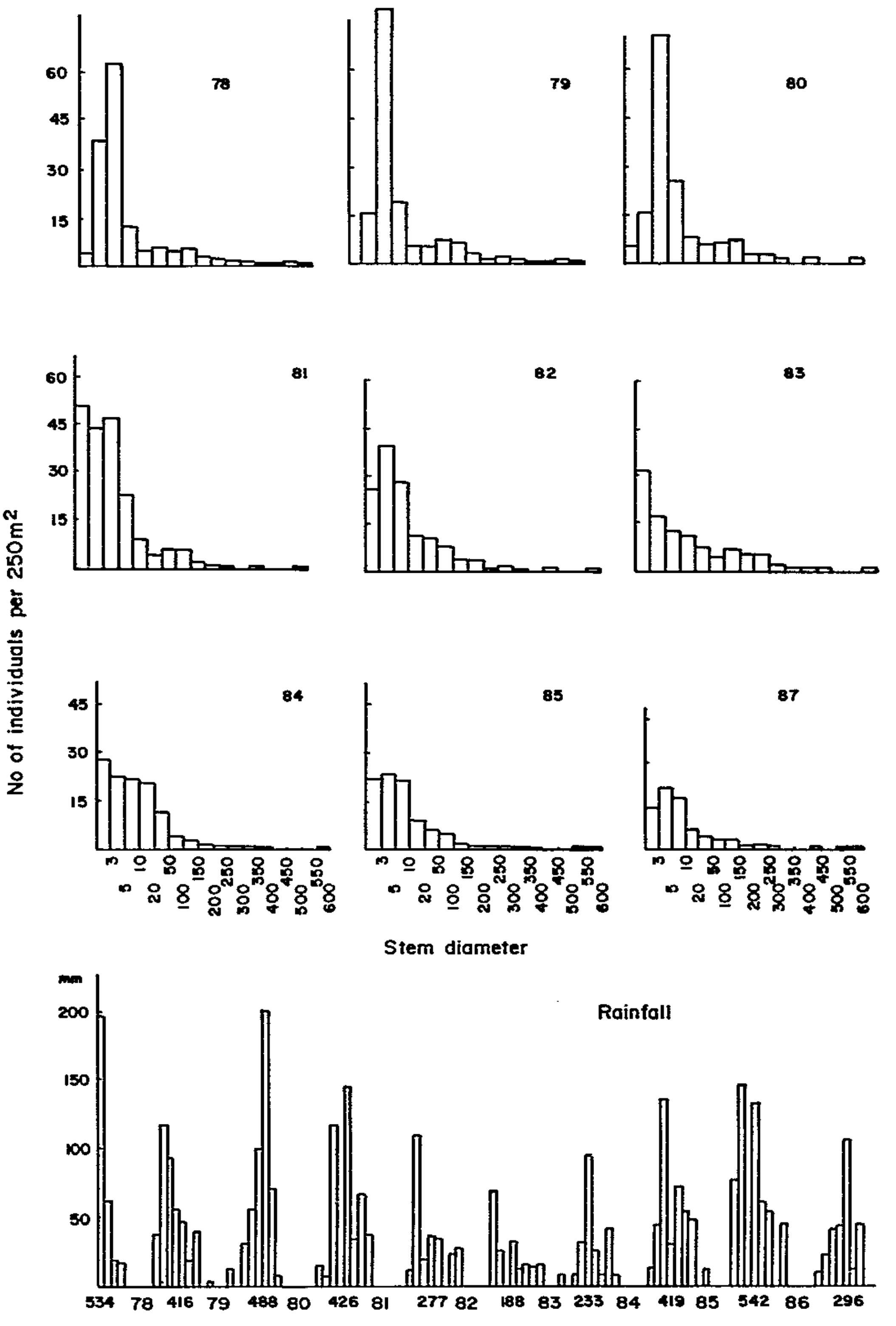

FIGURE 11.2 Number of *Acacia tortilis* plants per stem diameter class, in millimetres, from 1978 to 1987 in selected plots in Tuli Blok, Botswana, and records of monthly rainfall for the same period - seasonal amounts in millimetres are indicated between the years (from Page unpublished).

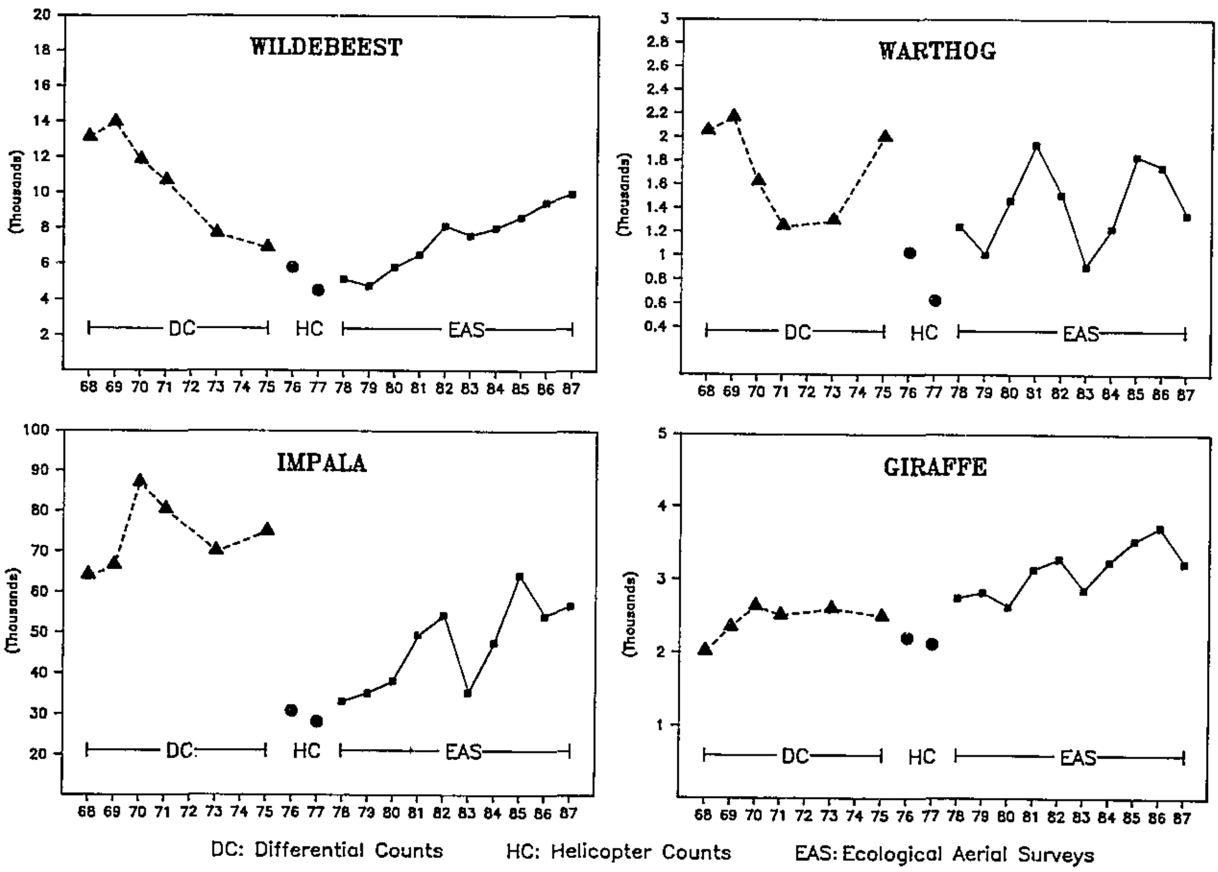

FIGURE 11.3 Population trends of four large herbivores from 1968 to 1987 in the Central District of the Kruger National Park as determined by differential ground counts, helicopter counts and ecological aerial surveys (fixed-wing counts, see Joubert and Viljoen this volume).

RESEARCH PRIORITIES

Climate

Research needs to be carried out on the intensity and spatial distribution of rain and the extent to which variations in these parameters affect management decisions.

Soil

Comparative studies of soil characteristics, across boundaries of different forms of land use, are required. Protected areas may be used as benchmark sites, to measure the extent of the changes in soil characteristics and the rates of soil loss under various forms of land use.

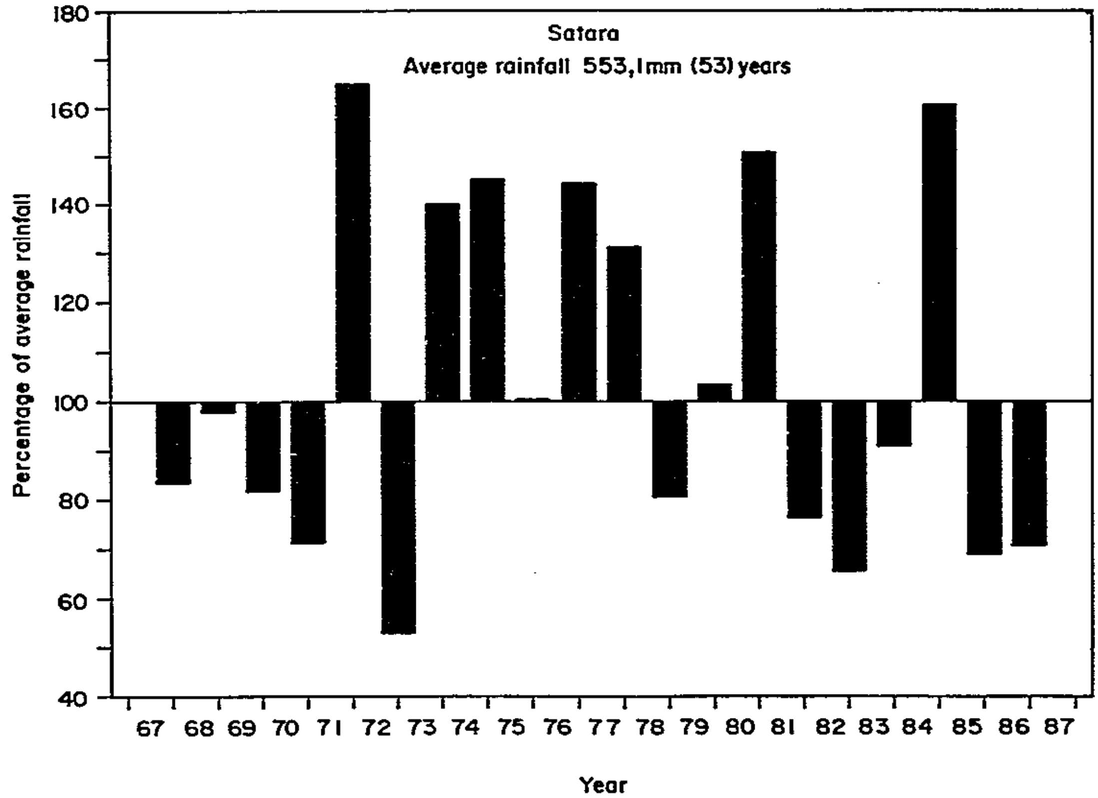

FIGURE 11.4 Percentage of average annual rainfall at Satara in the Central District of the Kruger National Park, July 1967 to June 1986.

Fire

For a variety of reasons many of the long-term veld-burning trials in the savanna have been discontinued. The reasons for continuing those that are currently being maintained, ie those in the Kruger National Park and Trollope's Eastern Cape plots, must be carefully evaluated. A dearth of long-term burning experiments in the western arid savanna areas is noticeable. Research on fire should generally be cast in the framework of adaptive management and detailed monitoring.

The establishment of prehistoric patterns of fire use from recent (<1 000 years) palaeo records is a high priority.

Vegetation

Major priorities are the analysis and synthesis of data being collected in existing monitoring schemes and long-term experiments by land-use agencies. This illustrates a general failing of those responsible for monitoring schemes in the biome in that they have failed to analyse and interpret information adequately and make it available to managers and decision-makers.

Another priority area is that of research into the community and population dynamics of the most important woody and herbaceous species and their interaction. Emphasis is required on the effects of plant utilization by herbivores, of fire and of other environmental variables on recruitment and survival of such plant species, eg regeneration of woody species, seed bank studies.

Interpretation and comparison of long-term data series from different savannas would be facilitated by a more appropriate and functional classification of savannas, eg a classification based on functional responses to fire, herbivory, desiccation etc.

Fauna

A high priority is the measurement of the effect changes in patterns of surface water distribution have on the density and distribution of herbivores and the consequent landscape scale changes that result.

A major problem in protected areas within the biome is that the dynamics of large mammal populations are still poorly understood despite a large body of long-term data. Major areas which need research are predator-prey relationships, mortality analysis, prey vulnerability, competition, parasite and pathogen effects and recruitment rates.

Long-term monitoring of the effectiveness of large protected areas in the conservation of species not confined by such areas but totally dependent on them, eg large raptors and oxpeckers, deserves more research input.

The roles of invertebrate herbivores which either affect or respond to vegetation changes, eg termites and mopani caterpillars, requires elucidation which can only be obtained through long-term studies.

TENTATIVE CONCLUSIONS AS TO THE DRIVING FORCES INVOLVED

Fire

The incidence of lightning-caused fires is related to the fuel load, its state and the rainfall pattern. There has been an historical change to more regular fire regimes in terms of the frequency, spatial extent and shape of fires, and the time of year in which they occur. Currently fire regimes are mainly under active control within the biome.

Reduction in fire incidence in many savanna areas is undoubtedly the result of an increased abundance of grazing ungulates consuming grass over extensive areas and thereby removing the most important fuel source. In this case ungulate numbers are therefore the ultimate factor driving the fire regime.

Soil

Increases in bare ground and gully erosion in eastern Transvaal private nature reserves is an outcome of increased densities of grazing ungulates coupled with restrictions on their movements by fencing during a drought period. Once again ungulate numbers appear to be the ultimate driving force.

Vegetation

Widespread encroachment of open savanna by woody plants during the historical period is believed to have been caused by less frequent application of hot fires as a result of the increased proportion of the annual grass production being consumed by grazers. The historical reduction in the numbers, and therefore the impact, of large destructive browsers such as elephant and black rhinoceros *Diceros bicornis* throughout most of their southern African ranges as well as in those of the smaller selective browsers, is thought to have exacerbated this situation.

In the Kruger National Park woody plant increases in some areas may likewise be related to changed fire management coupled with heavy grazing and drought. The observed decreases in woody plants in other areas may be attributed to the application of frequent hot fires and the effects of elephant browsing. Reductions in the density of mature trees in the Tuli Block in Botswana appear to be related to increased elephant abundance while the mechanisms restricting recruitment of juvenile trees remain unknown.

Reduction in the area of tall grassland in Umfolozi Game Reserve is directly related to increased abundance of grazing ungulates, in particular of the white rhinoceros *Ceratotherium simuum*. Similar mechanisms are responsible for observed changes in eastern Transvaal private nature reserves, but in this area increased provision of water is thought to have been an important contributing factor.

Fauna

Early 20th century population increases of large wild herbivore species are undoubtedly related to the protection measures afforded these species at the end of the rinderpest epidemic and the super-abundance of food while populations were low.

Fluctuations of some species in Kruger National Park are related to the effects of wet and dry rainfall periods on the vegetation. Some species increase during wet phases, while grazers of short grass tend to decline during these periods but increase during dry phases. For kudu, rainfall variations accounted for >90% of the year-to-year variability in calf survival, but had relatively little influence on the survival of prime-aged adults (Owen-Smith 1984, in preparation).

Extreme cold climatic events may have an additional impact on mortality either directly or by frosting evergreen trees, shrubs and grasses. Population crashes involving adults are believed to result either from prolonged drought conditions reducing availability of food plants, or from a combination of drought stress with a second factor such as cold or disease outbreak (eg kudu, Owen-Smith in preparation). Provision of artificial water points, and the concomittant increase in the densities of water- dependent herbivore species, may reduce or eliminate areas of reserve grazing away from natural surface water, resulting in population crashes of these species having a greater magnitude than normal (Walker et al 1987).

In addition, the provision of artificial water points in the Kruger

National Park has changed the density and distribution of lions (Smuts 1976). This in turn has changed the predation rates on previously unaffected prey species and, in certain cases, has led to their decline (Smuts 1978).

Declines in numbers of reedbuck, bushbuck and waterbuck in the Hluhluwe/ Umfolozi Complex appear to be related to changed vegetation cover - tall grass declining in the case of reedbuck, and perhaps also waterbuck, and the reduction of the riparian forest understorey in the case of bushbuck and resource competition with nyala *Tragelaphus angasi* (Brooks and Macdonald 1983).

Declines in the numbers of wildebeest and zebra in Etosha National Park appear to be due to a combination of their movements having been restricted by fences as well as the effects of water in gravel pits promoting increased predator numbers as well as serving as reservoirs for disease (anthrax) transmission (Berry 1981).

The virtual elimination of wildebeest from the central Kalahari in the last few decades has resulted from veterinary cordon fences preventing movements to water during drought conditions combined with reduced food availability due to overgrazing by large numbers of cattle.

The generally observed increase in mammalian carnivore numbers inside protected areas appear to be directly related to increased prey populations as well as to their reintroduction to certain of these conservation areas. The jackal declines throughout Natal appear to be disease related.

On the other hand, the decline of large raptors outside conservation areas is due to the illegal shooting, trapping and poisoning of these birds. In addition, another major cause of mortality is accidental poisoning as a result of these birds consuming poison baits set for classified "problem animals" such as jackals, lynx *Felis caracal* and stray dogs (unpublished results of the Birds of Prey Survey, Cape Department of Nature and Environmental Conservation).

REFERENCES

Berry H H 1981. Population structure, mortality patterns and a preditive model for estimating future trends in wildebeest numbers in Etosha National Park. Madoqua 12, 255-266.

Berry A and Macdonald I A W 1979. Fire regime characteristics in the Hluhluwe-Corridor-Umfolozi Game Reserve Complex in Zululand: 1. Area description and an analysis of causal factors in the Central Complex with particular reference to the period 1955-1978. Paper presented at the workshop on vegetation dynamics of the Central Complex, Hluhluwe Game Reserve, 10-12 August 1979. Natal Parks Board, Pietermaritzburg.

Boshoff A F, Vernon C J and Brooke R K 1983. Historical atlas of the diurnal raptors of the Cape Province. Annals of the Cape Provincial Museum 14(7), 173-297.

Brooks P M and Macdonald I A W 1983. The Hluhluwe-Umfolozi reserve: An ecological case history. In: Owen-Smith R N (editor) Mangement of large mammals in African conservation areas. Haum, Pretoria. pp 51-77.

Coetzee B J 1983. Phytosociology, vegetation structure and landscapes of the Central District, Kruger National Park, South Africa. Dissertationes Botanicae 69, 1-456.

Coetzee B J, Gertenbach W P D and Nel P J 1977. Korttermyn plantegroei- struktuurveranderings op basalt in die Sentrale Distrik, Nationale Kruger Wildtuin. Koedoe 20, 53-65.

De Moor P P, Pooley E, Neville G and Barichievy J 1977. The vegetation of Ndumu Game Reserve, Natal: A quantitative physiognomic survey. Annals of the Natal Museum 23, 239-272.

De Vos V, Bengis R G and Coetzee H J 1983. Population control of large mammals in the Kruger National Park. In: Owen-Smith R N (editor) Management of large mammals in African conservation areas. Haum, Pretoria.

Edwards D 1984. Fire regimes in the biomes of South Africa. In: Booysen P de V and Tainton N M (editors) Ecological effects of fire in South African ecosystems. Ecological Studies 48. Springer-Verlag, New York. pp 19-37.

Gertenbach W P D 1978. Plantgemeenskappe van die gabbrokompleks in die Noordweste van die Sentrale Distrik van die Nasionale Krugerwildtuin. MSc Thesis, Potchefstroom University for CHE, Potchefstroom.

Gertenbach W P D 1980. Rainfall patterns in the Kruger National Park. Koedoe 23, 35-43.

Gertenbach W P P and Potgieter A L F 1979. Veldbrandnavorsing in die Struikmopaniveld van die Kruger Nasionale Wildtuin. Koedoe 22, 1-28.

Goodman P S 1985. Multi-species wild herbivore systems vs domestic single species systems: A comparison of net animal productivity. Journal of the Grassland Society of Southern Africa 2, 13-16.

Huntley B J 1982. Southern African Savannas. In: Huntley B J and Walker B H (editors) Ecology of tropical savanna. Ecological Studies 42. Springer-Verlag, Berlin. pp 101-119.

Kern N G 1981. The influence of fire on populations of small mammals of the Kruger National Park. Koedoe 24, 125-157.

King N D 1987. Vegetation dynamics in Hluhluwe Game Reserve, Natal, with the emphasis on bush encroachment. MSc Thesis, University of Natal.

Macdonald I A W 1982. The influence of short-term climatic fluctuatons on the distribution of savanna organisms in southern Africa. MSc Thesis, University of Natal, Durban.

Nel J A J 1978. Habitat heterogeneity and changes in small mammal community structure and resource utilization in the southern Kalahari. Bulletin of the Carnegie Museum of Natural History 6, 118-131.

Nel J A J, Rautenbach I L, Els D A and De Graaf G 1984. The rodents and other small mammals of the Kalahari Gemsbok Park. Koedoe 27, 195-220.

O'Connor T G 1985. A synthesis of field experiments concerning the grass layer in the savanna regions of southern Africa. South African National Scientific Programmes Report No 114. CSIR, Pretoria. 126 pp.

Owen-Smith N 1984. Demography of greater kudu in relation to rainfall. Acta Zoologica Fennika 172, 197-199.

Owen-Smith N and Cooper S M 1985. Comparative consumption of vegetation components by kudus, impalas and goats in relation to their commercial potential as browsers in savanna regions. South African Journal of Science 81, 72-76.

Pienaar U de V 1985. Indications of progressive desiccation of the Transvaal Lowveld over the past 100 years and implications for the water stabilization programme in the Kruger National Park. Koedoe 28, 93-167.

Prior J and Tuohy J 1987. Fuel for Africa's fires. New Scientist 115, 48-51.

Scott L 1984. Paleoecological evidence for quaternary paleoenvironments in southern Africa. In: Klein R G (editor) Southern African Prehistory and Paleoenvironments. Balkema, Rotterdam. pp 65-80.

Siegfried W R 1981. The incidence of veld-fire in the Etosha National Park, 1970-1970. Madoqua 12, 225-230.

Smuts G L 1976. Population characteristics and recent history of lions in two parts of the Kruger National Park. Koedoe 19, 153-164.

Smuts G L 1978. Interrelations between predator, prey and their environment. Bioscience 28, 316-320.

Smuts G L 1982. Lion. Macmillan, South Africa.

Starfield A M, Smuts G L and Shiell J D 1976. A simple wildebeest population model and its application. South African Journal of Wildlife Research 6, 95-98.

Tarboton W R and Allan D G 1984. The status and conservation of birds of prey in the Transvaal. Transvaal Museum Monograph No 3, Transvaal Museum, Pretoria.

Trollope W S W 1984. Fire in savanna. In: Booysen P de V and Tainton N M Ecological effects of fire in South African Ecosystems. Ecological studies 48. Springer-Verlag, New York. pp 149-175.

Tyson P D 1986. Climatic change and variability in southern Africa. Oxford University Press, Cape Town.

Van Niekerk J P 1977. Bosbeheer met die onkruiddoder Torden 225. Jaarverslag Departement Landboutegniese Dienste, SWA-streek.

Van Rooyen N, van Rensburg D G, Theron G K and Botha J P 1984. A preliminary report on the dynamics of the vegetation of the Kalahari Gemsbok Park. Koedoe 27. Supplement. pp 83-102.

Van Wyk P 1971. Veld burning in the Kruger National Park, an interim report of some aspects of research. Proceedings of the Tall Timbers Fire Ecology Conferences 11, 9-31.

Versfeld W V R 1986. Bennuting van ariede Kalahariveld met ses produksiestelsels. Agricola 3, 50-59.

Walker B H, Emslie R H, Owen-Smith R N, Scholes R J 1987. To cull or not to cull: lessons from a southern African drought. Journal of Applied Ecology 24, 381-402.

Watson H K and Macdonald I A W 1983. Vegetation changes in the Hluhluwe/Umfolozi Game Reserve complex from 1937 to 1975. Bothalia 14, 265-269.

Whateley A and Brooks P M 1985. The carnivores of the Hluhluwe and Umfolozi Game Reserves: 1973-1982. Lammergeyer 35, 1-27.

Whateley A and Porter R N 1983. The woody vegetation communities of the Hluhluwe-Corridor-Umfolozi Game Reserve Complex. Bothalia 14, 745-758.

ECOLOGICAL AERIAL MONITORING IN THE KRUGER NATIONAL PARK

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Kruger National Park

INTRODUCTION

Long-term and comprehensive ecological monitoring is essential to create a database for the study and analysis of ecosystems, to provide a basis for management programmes and for the possible development of predictive models.

Aerial ecological surveys in the Kruger National Park covering not only large herbivore species, but also a variety of environmental variables, commenced in 1977. The study is aimed, firstly at monitoring trends of individual animal populations and secondly, at relating those trends to possible interactions between animal populations and other components of the ecosystem.

METHODS

Data collection involves systematic low-level aerial coverage of the whole Kruger National Park during the winter months (May to August) when maximum visibility in most vegetation types is possible. The park of 19 485 km^2 is divided into 66 census blocks. Every census block is covered by flight paths 800 m apart at a height of 70 m above ground level with a flight crew of four observers, a navigator and a pilot. The data are recorded on maps which are later computerized with the aid of a digitizer tablet. Animal distributions, densities and environmental variables can then be plotted on specially prepared computer paper which has a map outline of the whole park.

Although a total count is attempted, it is realized that only a portion of the total population of each species is counted. All possible steps are taken to ensure that the same census techniques are used so as to ensure that the proportions of the different species counted remain the same. The larger herds are estimated, whilst smaller herbivore species and carnivores are only noted. In addition the distribution of vulture nests and large, easily observed birds such as ostrich and ground hornbill are recorded as well. Subjective data on the following environmental variables are collected - field layer: height, cover, greenness of plant

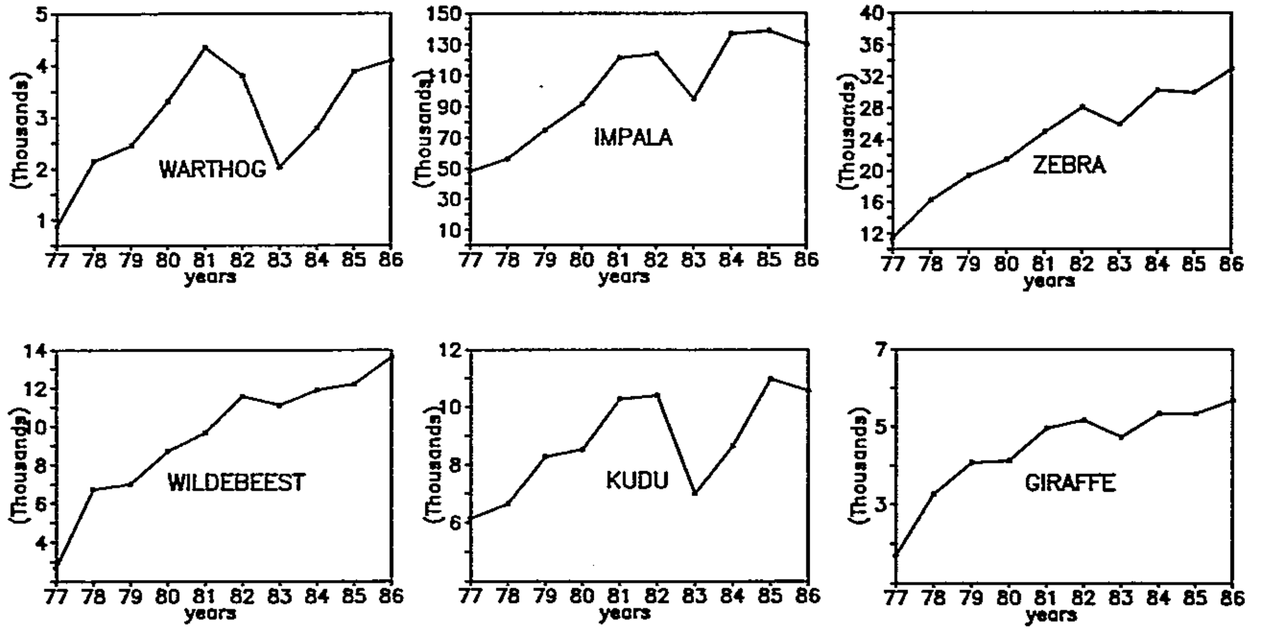

FIGURE 11.5 Annual fluctuations in the total numbers of six herbivore species counted during aerial surveys in the Kruger National Park from 1977 to 1986.

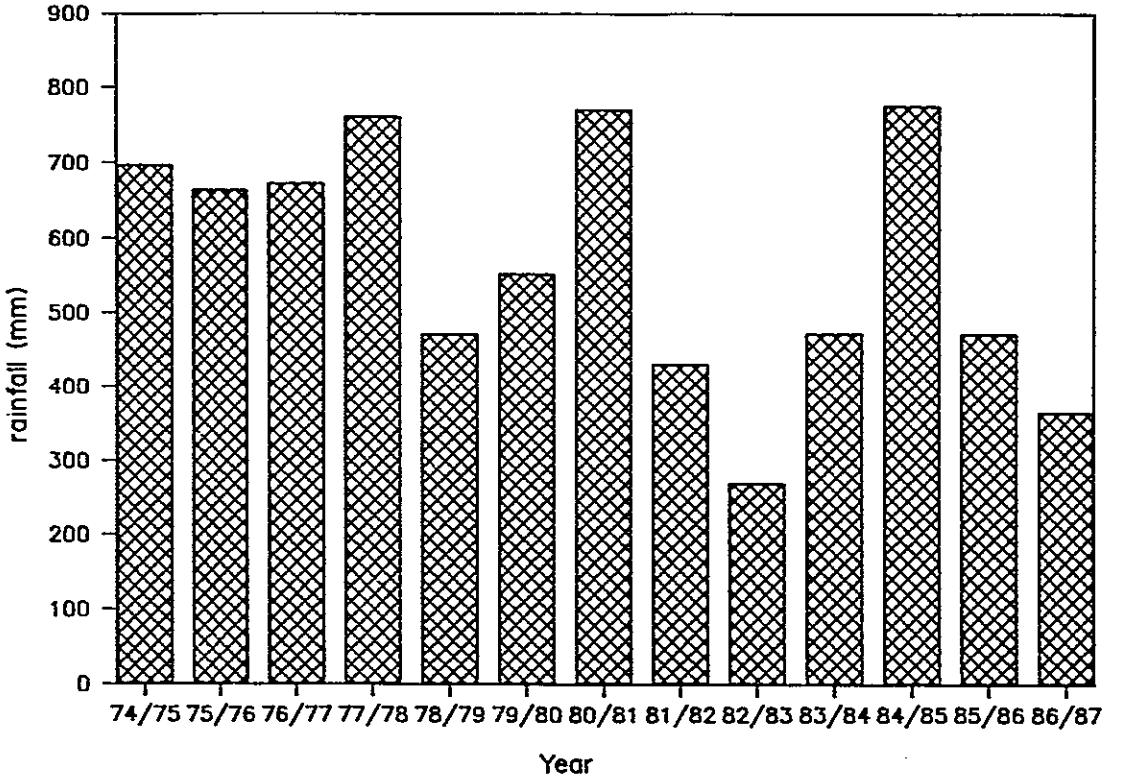

FIGURE 11.6 Average total rainfall recorded at 23 weather stations in the Kruger National Park from 1974 to 1987.

material, plant growth stage, litter, utilization, fire; woody vegetation: phenology, fire; water resources: natural water resources, artificial water resources.

The population trends over a 10-year period of six large herbivore species, representing browsers, grazers and mixed feeders, are illustrated (Figure 11.5) together with variations in rainfall (Figure 11.6) to depict the scope of the data collected.

Since 1977 most herbivore numbers have shown an overall increase. Several species, in particular warthog, impala and kudu showed a temporary decrease in numbers during the period following a season of low rainfall in 1982/83.

LONG-TERM CHANGES IN THE TREE COMPONENT OF THE VEGETATION IN THE KRUGER NATIONAL PARK

A J VILJOEN
Kruger National Park

INTRODUCTION

Various vertical aerial photography surveys which can be used for long-term vegetation monitoring in the Kruger National Park are available. These photographs were taken at different times of the year, over different areas and have different scales (Figure 11.7). Some sequences are presently being used in order to analyse long-term changes in the tree component of the vegetation, eg two areas (Figure 11.7) in the *Sclerocarya birrea/Acacia nigrescens* Savanna (Gertenbach 1983). The first area is situated on the plains south-east of Satara, and the other on the plains south of Lower Sabie. The vegetation is similar in both areas and comprises open tree savanna with the dominant tree species being *Acacia nigrescens*, *Sclerocarya birrea* and *Combretum imberbe*. The available aerial photographs for the areas are as follows:

Job 56/44	(1944)	1:30 000	Satara area
Job 740	(1974)	1:30 000	Satara area
Job 539	(1965)	1:60 000	Lower Sabie area
Job 788	(1977)	1:30 000	Lower Sabie area
Job 155/40	(1940)	1:20 000	Lower Sabie area

METHODS

For each area 10 random points were chosen on the oldest set of the photographs. In the approximate vicinity of each of these points on all the available sets, a plot measuring 500 m x 500 m was randomly placed using a transparent overlay. The photographs were optically enlarged to the same scale by using a WILD AVIOPRET APT 1 zoom stereoscope and all trees with canopy diameters greater than six metres were counted.

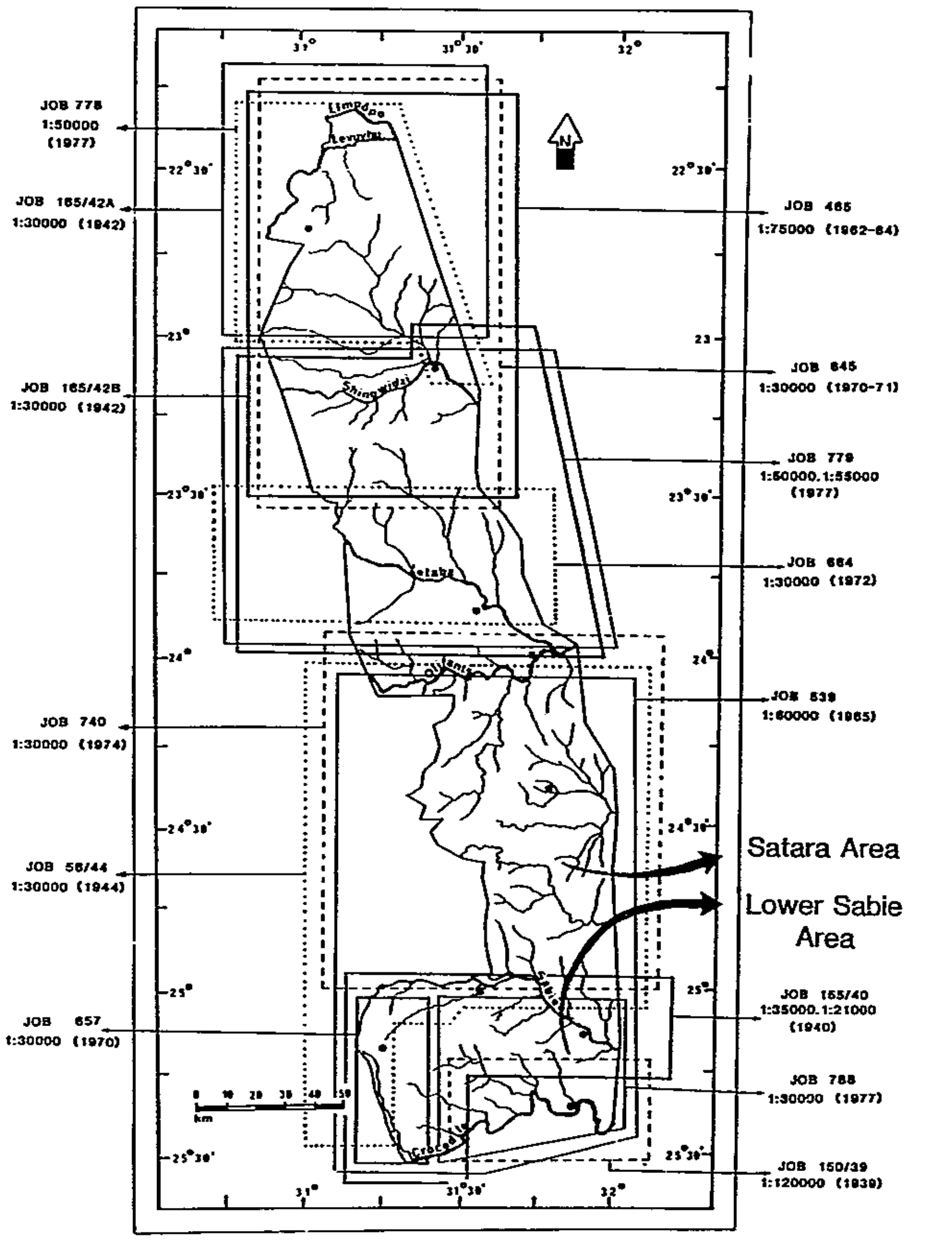

FIGURE 11.7 Aerial photography for the Kruger National Park showing the location of the two tree-monitoring areas.

Due to the scale of the 1965 photographs the choice of large trees was to a large extent subjective and the minimum number of trees was most probably counted. This was also the case with the 1944 set due to poor resolution. Only trees which could be distinguished as large trees with a reasonable degree of certainty were counted.

Two strips of aerial photographs on a scale of 1:4 500 were taken in both areas in 1981. Ten random plots of 150 m x 150 m were selected in each area and once again all trees with crowns greater than six metres in diameter were counted. It was not possible to use 500 m plots due to the cover and scale of the photographs.

RESULTS

The number of trees per hectare in the Satara area is shown in Figure 11.8. For the period 1944 to 1965 (21 years) the number of trees decreased by 24,7% and for the period 1944 to 1974 (30 years) they decreased by 82,2%. The total decrease from 1944 to 1981 was 93,4%.

The number of trees per hectare in the Lower Sabie area is shown in Figure 11.9. A decrease of 9,4% was recorded for the period 1940 to 1965 (25 years) and a decrease of 47,3% for the period 1940 to 1977 (37 years). The total decrease until 1981 was 49,6%.

DISCUSSION

In both the Satara and Lower Sabie areas the decrease in the number of trees for the period up to 1965 was insignificant especially as not all trees were counted due to the scale and resolution of the 1965 photographs. For the shorter period, from 1965 to the mid-1970's, the decrease was dramatic, especially in the Satara area.

Reasons for the decrease of large trees are speculative, and the following may have contributed:

1. During the first part of the century, elephants were eliminated by hunters. Natural recolonization took place during the mid-1960's. Available census data (Joubert unpublished) show a possible correlation between an increase in elephant numbers and a decrease in trees (Figure 11.10). The higher elephant density in the Satara area (roughly 0,3 km^{-2} in recent years when elephants were counted over a 5 560 km^2 area including Satara) compared with the Lower Sabie area (roughly 0,2 km^{-2} in recent years when the elephants were counted over 3 680 km^2) may account for the sharper decrease in tree numbers in the Satara area. It is also possible that due to the absence of elephants, trees increased abnormally, and a natural process of elimination started when the elephants returned.

2. Drought may be another contributory factor. A long and intense drought occurred during the 1960's (Figure 11.11; Gertenbach 1980). A large number of dead leadwood trees *Combretum imberbe* is conspicuous, especially in the Satara area. As these trees are not normally utilized by elephant, they could possibly have died due to a change in the water table after an extended drought.

3. Planned rotational burning was started in 1954 (Brynard 1972). Frequency, season and method of burning, combined with the above-mentioned factors, may also have contributed to a limited recruitment of young trees, and therefore aggravated the decrease.

Although it is difficult to determine the causes of vegetation change, historical aerial photographs present a valuable source of information to be exploited, notwithstanding the fact that they have limitations in resolution and scale. Since 1982, aerial photographs on a scale of 1:4 500 of 120 fixed transects have been taken annually, presently with false-colour infrared film. This forms part of a long-term vegetation monitoring programme which is being developed for the Kruger National Park

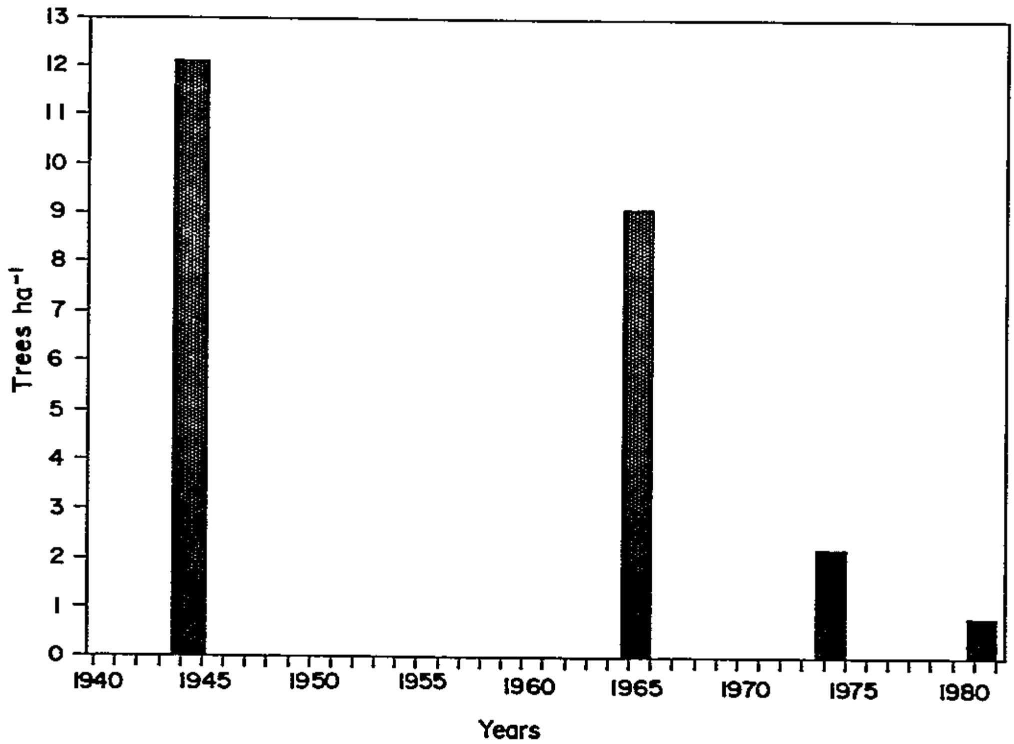

FIGURE 11.8 Number of trees per hectare in the Satara study area.

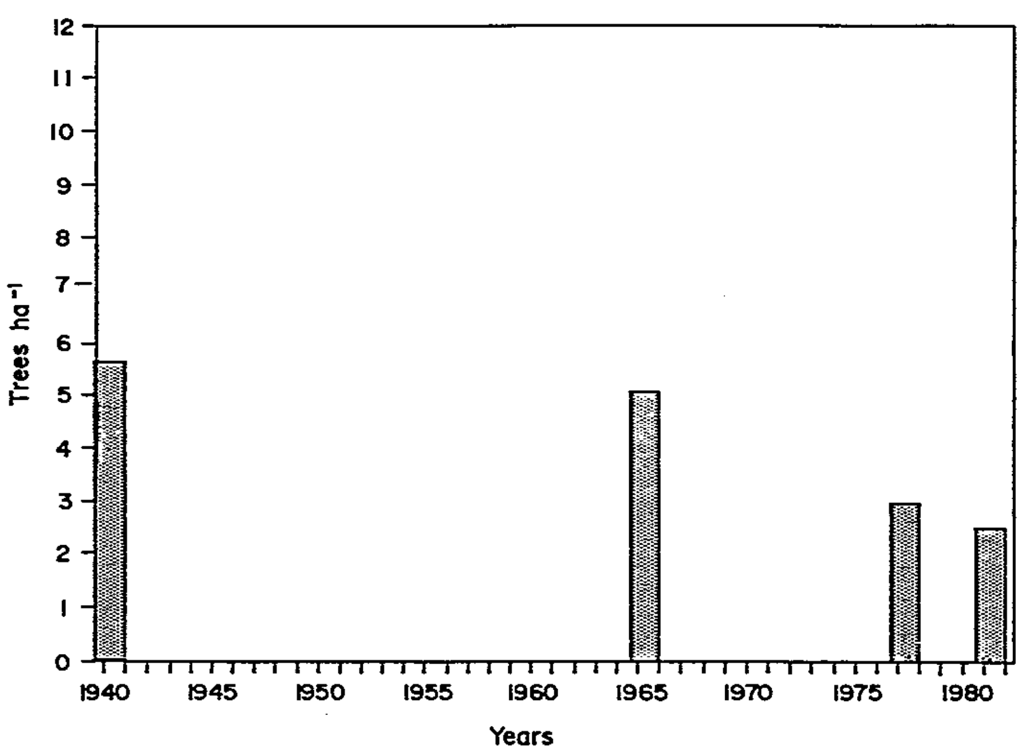

FIGURE 11.9 Number of trees per hectare in the Lower Sabie study area.

(Viljoen unpublished). Analysis of historical aerial photographs presents valuable background information which can be effectively utilized during analysis of recent aerial photography.

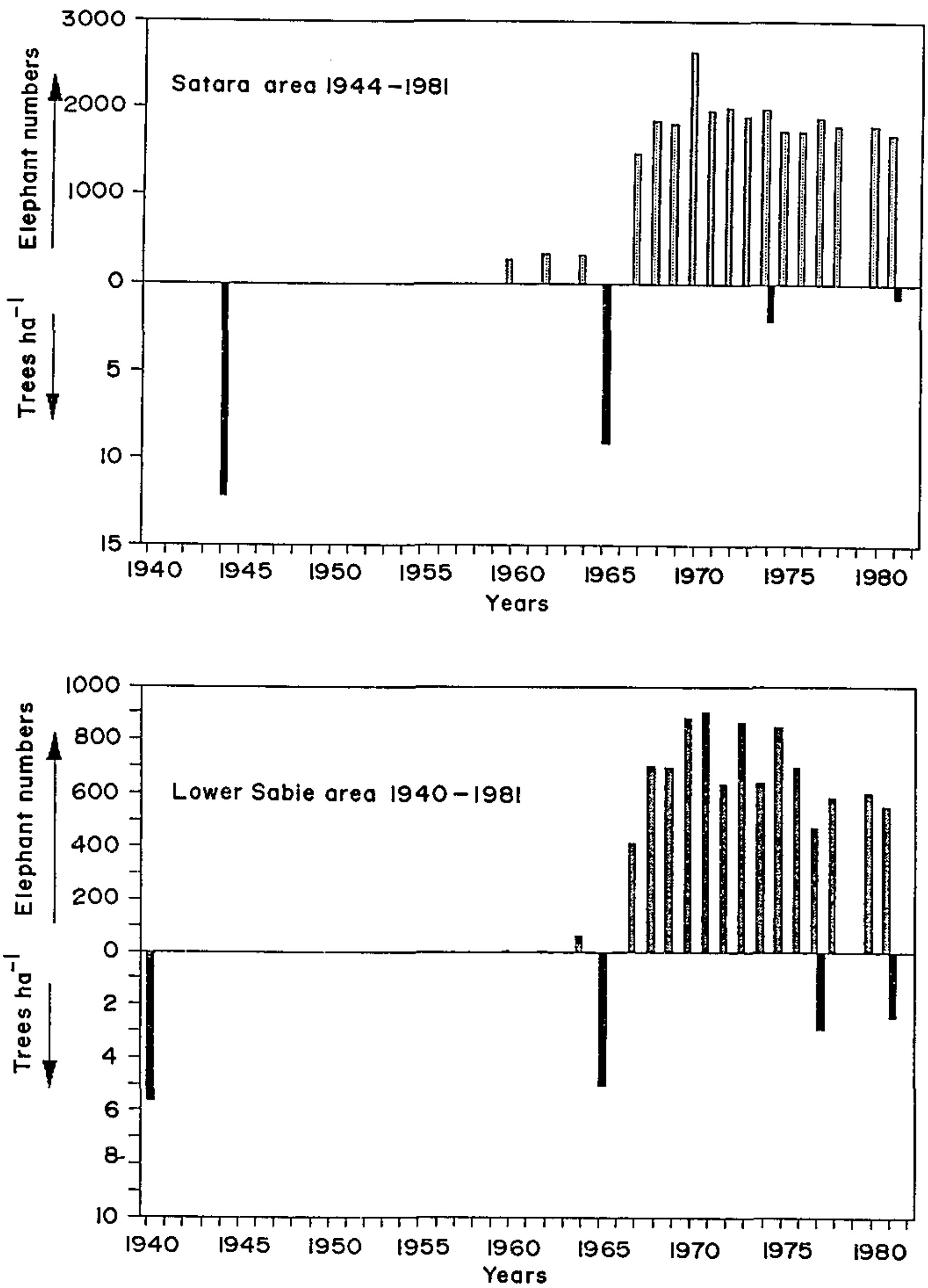

FIGURE 11.10 Elephant numbers and tree densities in the two study areas (Satara area = 5 560 km², Lower Sabie = 3 680 km²).

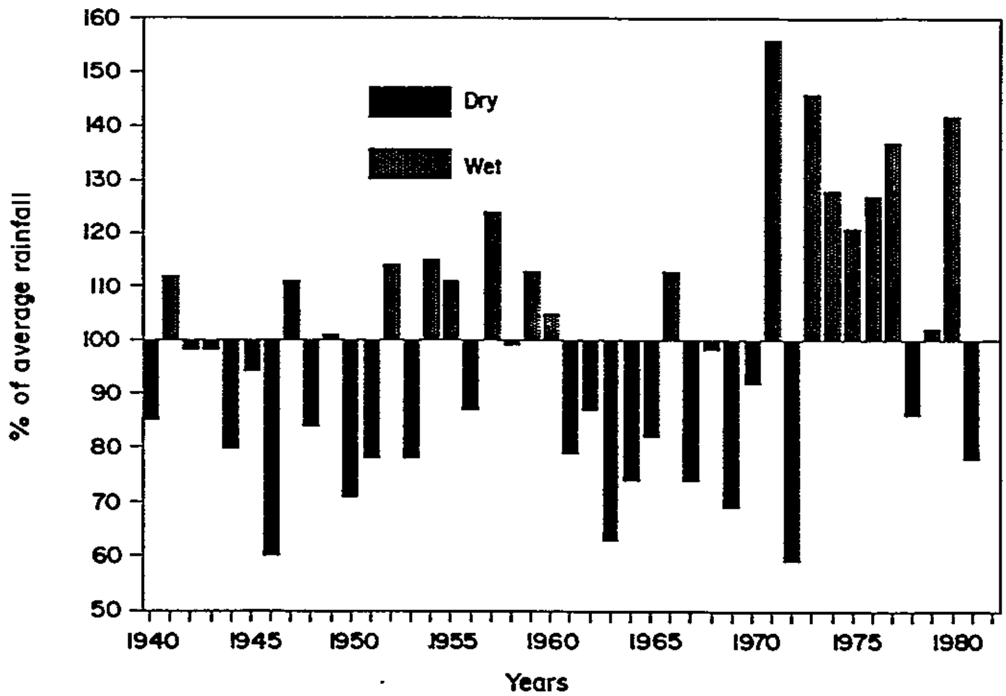

FIGURE 11.11 Percentage of average annual rainfall in the Kruger National Park, 1940 to 1980.

REFERENCES

Brynard A M 1972. Controlled burning in the Kruger National Park - History and Development. Proceedings of the Tall Timbers Fire Ecology Conference 11, 219-231.

Gertenbach W P D 1980. Rainfall patterns in the Kruger National Park. Koedoe 23, 35-43.

Gertenbach W P D 1983. Landscapes of the Kruger National Park. Koedoe 26, 9-121.

CHAPTER 12. THE AGRICULTURAL AREAS OF SOUTHERN AFRICA

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INTRODUCTION

The objectives and aims of the agricultural industry are clearly stated in the White Paper on Agricultural Policy for the Republic of South Africa announced in 1984. In general the prime concern is to ensure that agriculture contributes to the optimum economic, political and social development and stability of the country. This implies the development of an economically sound farming community.

Within this framework several production and marketing goals are important. These include the promotion of:

- optimal resource utilization;
- the preservation of high potential agricultural land;
- a maximum number of well-trained farmers;
- optimal use of labour;
- an appropriate free market system; and
- quality products and hygienic standards.

These aims imply attaining self-sufficiency in the production of food and fibre, supplying the materials at acceptable prices, contributing to regional development in South Africa and at the same time fostering development elsewhere in Africa.

Agriculture, with many activities involved in producing food and fibre, is a prime user of South Africa's natural resource base. Although it provides a generous supply of food for the nation, foreign exchange and opportunities for much needed employment, a high price has been paid in terms of the degradation of natural ecosystems. Results of an imbalance created by biotic simplification on the one hand and the lack of managerial expertise on the other, described by Booysen (1980) as the "scourge of agriculture", are witnessed in many parts of the country.

Because of the wide range of agricultural activities only a few specific examples have been selected to illustrate changes that have taken place over time. These are restricted to activities that have had major impacts on the abiotic and biotic components of the ecosystem, viz crop and livestock production. In South Africa, as in most southern African countries, maize is the most extensively grown crop and justifies special attention. Similarly, with 87% of the land used for agriculture comprising natural grazing, the impact of the livestock industry on this valuable resource is of particular concern. Other related issues, such as fertilization and erosion are also noted.

No attempt has been made to consider other issues such as production levels, financial returns and managerial expertise. However, brief reference is made to the natural resource base since it facilitates better understanding of environmental changes that have taken place.

Long-term data relevant to agriculture are many and varied. Nevertheless, there are severe limitations concerning their availability to users, accuracy, reliability, and suitability for various interpretations. Sources of such data are not well known to many potential users. Agricultural data exist at both the macro (eg national) and micro (eg farm) levels. The former are given emphasis in this chapter and primarily concern the farming activities of the white population group. This does not imply that agricultural data relevant to the Black States and self-governing territories are of lesser importance. On the contrary, long-term data for these areas are of vital concern to future agricultural development of southern Africa but are, unfortunately, hard to come by.

Review of major environmental changes suggests several important driving forces, especially those of an economic nature. Regrettably such influences have in some cases led to developments contrary to the ideals of optimal resource utilization and which disregard the potential of the natural resource base. For example, the recent launching of the National Grazing Strategy bears witness to the continued deterioration of veld resources over a long period of time (Bruwer unpublished).

Many of the requirements for overcoming the limitations of current acquisition and analysis of agricultural data can be identified. Those related to the agricultural census and to establishing "bench marks" for future monitoring of change are among the most important. In many cases there is urgent need to effect these improvements.

CONSIDERATIONS OF LONG-TERM VARIABILITY

Natural agricultural resources

Consideration of long-term variability in agriculture requires an appreciation of the natural resource base. During the mid-1930's the first attempts were made to demarcate homogeneous agroecological areas using physical and biological criteria (Departement van Landbou en Bosbou 1943). Pentz (1949) completed his well known agroecological survey of Natal in 1946, a study which was to be followed by Phillips' bioclimatic classification of the same region in 1973 (Phillips 1973). Agricultural development in South Africa has suffered greatly from not having a scientifically sound national inventory of its natural resource potential. Apart from single-resource studies such as that of veld types by Acocks (1953), most resource surveys have been of local areas and for specific purposes. In 1972 the Department of Agriculture and Water Supply commenced a survey of land types defined in terms of soil pattern, terrain form and macroclimate for the entire country. Although not yet completed it is already proving to be of considerable value as a resource base against which agricultural development, trends in production and land-use practice may be viewed (MacVicar 1986). A preliminary assessment of South Africa's agricultural potential made by Schoeman and Scotney (1987) is shown in Table 12.1. This assessment confirms that only 13,5% of the land is suitable for cultivation.

At a regional level, land types are generally grouped into relatively

TABLE 12.1 Crop production potential and present cultivation of white-owned farmland in South Africa (after Schoeman and Scotney 1987)

Agricultural region	Area (ha)	Rain-fed crop production potential						Suitable for rain-fed crop production		
		High		Medium		Low		Area (ha)	% of white area of RSA	* Present cultivation (ha)
		ha	%	ha	%	ha	%			
Transvaal	15 249 041	1 198 600	7,9	890 000	5,8	1 042 800	6,8	3 131 400	20,5	2 202 000
Natal	5 832 100	1 539 400	26,4	400 000	7,5	70 000	1,2	2 049 400	35,1	933 500
Highveld	11 585 900	190 000	1,6	4 440 500	38,3	1 316 400	11,4	5 946 900	51,3	5 678 200
Free State	20 482 310			68 000	0,4	946 000	4,6	1 014 000	5,0	1 683 600
Winter rainfall	13 800 000			912 000	6,6	582 800	4,2	1 494 800	10,8	1 800 000
Eastern Cape	5 400 000	194 400	3,6	241 200	4,5	176 600	3,3	612 200	11,4	426 300
Karoo	29 060 000			10 000	0,03	10 000	0,03	20 000	0,06	192 000
Other land mainly national parks	3 122 400									
Total white area of RSA	105 373 400	3 122 400	3,0	7 001 700	6,6	4 144 600	3,9	14 268 700	13,5	12 915 600

* Includes irrigated land

homogeneous farming areas to provide a sound basis for planning. For example, in the Highveld Region 219 land types have been grouped into 57 farming areas. Realistic assessments of the potential for producing crops and livestock on defined resource units have also been made (Scheepers et al 1984). Resource inventories of such a nature are of vital importance to those concerned with monitoring change or studying agricultural impact over the long term.

Crop production

Areas cultivated. Recent estimates of the area of cultivated land (including irrigated land) and crops grown suggest an area of 12,9 million ha with maize and wheat dominating the cropping enterprizes (Schoeman and Scotney 1987; Scotney 1987). Available provincial data for the past eight decades are presented in Table 12.2 and show that the total area cultivated peaked in the early 1970's then declined to 10,1 million ha in 1981. The more recent expansion of cultivation is reflected by Table 12.1. Similar variations in the area under individual crops are reflected by available data sources. For example, the total area under maize during 1975/76 and 1985/86 was 4,5 million ha and 4,0 million ha respectively (Department of Agricultural Economics and Marketing 1987). Despite this,

TABLE 12.2 Total area cultivated in South Africa: 1911 to 1981

Total area under cultivation *(ha)									
	Province								
Year	Cape	% of total farming area	Natal	% of total farming area	Transvaal	% of total farming area	Orange Free State	% of total farming area	South Africa
1911	1 434 505	2,415	522 797	10,708	1 115 440	7,208	958 456	6,678	4 031 198
1921	1 206 513	2,190	328 866	8,051	1 166 480	6,203	1 100 562	8,998	3 802 423
1931	1 260 003	2,491	432 031	9,661	1 451 855	9,289	1 519 688	12,477	4 663 578
1941	**	**	**	**	**	**	**	**	**
1951	1 989 275	3,665	357 118	8,014	2 150 703	13,342	2 455 009	20,546	6 952 107
1961	2 538 806	4,350	716 011	15,597	3 095 172	18,403	2 854 428	23,668	9 204 420
1971	3 492 181	6,077	935 615	20,670	3 870 735	24,673	3 309 266	28,384	11 607 799
1981	3 512 576	6,327	891 536	20,790	2 678 286	18,318	3 106 964	26,237	10 189 365

* Cultivated area includes annual and perennial field crops and permanent pastures (source: Agricultural census)

** No data available for this decade as a result of the Depression and the Second World War

Burger (1983) has reported a 0,5% annual increase in area planted to maize in the main production areas over the same period. Such discrepancies usually arise when different sources of data are used. Many reasons, mainly economic, account for changes in the area cultivated and the type of crops grown. It is also clear that scant attention has been paid to agricultural resource potential. The area planted to maize for the period 1911 to 1981 is shown in Table 12.3.

Soil fertility and soil improvement. Reliable data on fertilizer usage are available and many relevant reports have been published (Botha 1973; Ranwell 1975; Botha and Russel 1977). According to Kassier (1987) fertilizer usage (NPK) in South Africa reached a peak (± 900 tons) in 1981 only to be followed by a sharp decline to low levels in 1983 and 1984 as a result of drought and the financial implications thereof. Similar trends are reflected for lime. Almost 60% of fertilizer used is applied to maize (Burger 1983).

With the decomposition of soil humus, plant nutrients are released and utilized by the cultivated crop. Some are lost through runoff and erosion of the top soil. The more soluble nutrients leach down the soil profile and even into the subterranean waters. Portions of the nitrogen fractions may also be volatilized. During the oxidation of NH_4^+ to NO_3^-, hydrogen ions are released. This process acidifies the soil. In addition,

TABLE 12.3 Total area planted to maize in South Africa: 1911 to 1981

Total area under maize (ha)									
	Province								
Year	Cape	% of total cultivated area	Natal	% of total cultivated area	Transvaal	% of total cultivated area	Orange Free State	% of total cultivated area	South Africa
1911	98 880	6,892	94 531	18,081	364 023	32,634	369 486	38,550	926 922
1921	111 951	9,279	143 936	43,767	691 717	59,300	704 006	63,968	1 651 612
1931	107 497	8,532	156 341	36,187	640 951	44,147	772 883	50,858	1 677 671
1941	*	*	*	*	*	*	*	*	*
1951	184 103	9,255	148 768	41,658	976 309	45,395	1 390 565	56,642	2 699 746
1961	203 831	8,029	176 713	24,681	1 481 012	47,850	1 440 664	50,471	3 302 219
1971	304 341	8,715	137 170	14,661	2 008 864	51,899	1 780 654	53,808	4 231 033
1981	629 334	17,917	180 549	20,251	1 996 260	74,535	1 596 246	51,376	4 031 719

* No data available for this decade as a result of the Depression and the Second World War (source: Agricultural census).

the destruction of humus causes a breakdown of soil structure. This may lead to crust formation, soil compaction, increased runoff and erosion, and poorer aeration, root development and plant growth.

Accurate long-term data on soil fertility are scarce in South Africa and statistics showing an overall depletion of soil fertility are consequently lacking. The best alternative is to study nutrient removal from soils and fertilizer consumption (Biesenbach 1984). Assumptions become complex when higher N fertilization leads to higher P and K uptake by plants. Fertilizer imbalances then become particularly important. Calculated trends presented in Figure 12.1 reflect increasing use of nitrogenous fertilizers relative to phosphatic and potassium fertilizers. Phosphatic fertilizers generally supply sufficient sulphur for crop production which is not the case with nitrogenous fertilizers. The acidification of soils caused by increased N usage is also likely to lead to a lowering of the cation status and a depletion of both macro- and micronutrients. This is a matter of considerable concern for the future.

Although changes in soil productivity are complex, no attempt has yet been made to monitor the rise and fall of soil fertility or organic matter status throughout the country. Eisenberg et al (1985) made one of the first attempts to characterize soil fertility status (potassium) at a regional level. The study showed that the K status as determined by soil analysis over time is very much a function of texture, bioclimatic area and season.

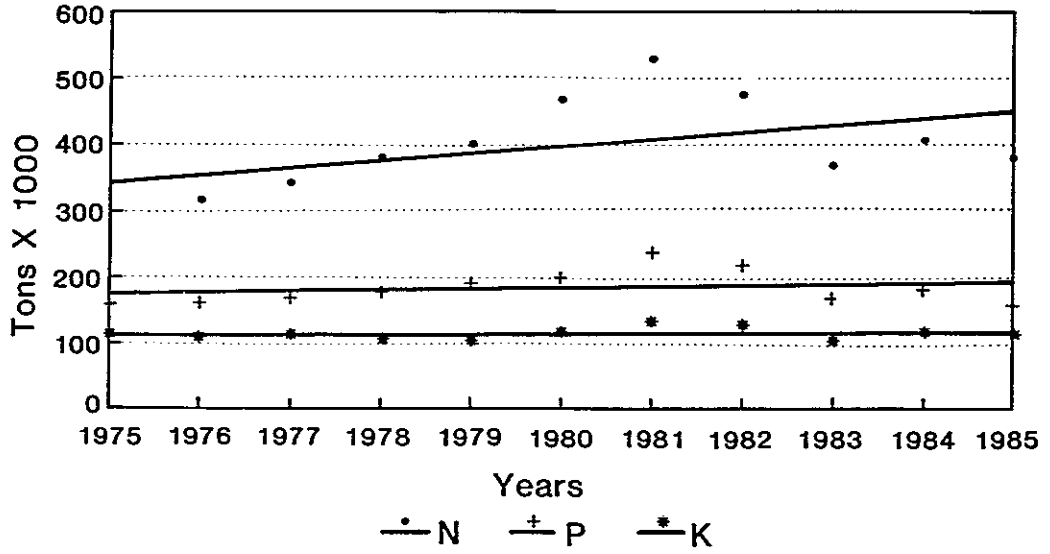

FIGURE 12.1 Trends in consumption of N, P and K fertilizers, 1975 to 1985.

Weedicides and pesticides. Weedicides and pesticides have long been used in South Africa, but the lack of data or the short duration of available records does not permit realistic assessments to be made of their impacts. There is an urgent need to make good this limitation since the impacts of such chemicals on water supplies and ecological processes could be far reaching.

Irrigation. With 65% of South Africa receiving less than 500 mm mean annual rainfall, it is not surprising that irrigation has played a valuable role in stabilizing agricultural production. According to Schoeman (unpublished) an area of approximately 1,2 million ha is currently irrigated and a further 256 000 ha is of suitable potential. Growth and predicted trends of both area irrigated and methods employed between 1950 and 2000 have been summarized by Bruwer (1977) and are shown in Figure 12.2. Rapid growth in sprinkler irrigation at the expense of flood irrigation is clearly evident. This change to more sophisticated irrigation practice allows more efficient use of irrigation water but has not always been to the economic advantage of the farmer.

Livestock production

Long-term data concerning livestock populations show much variation over time and sometimes rapid change when the economy, drought and disease have taken their toll. In early times diseases such as lung sickness, rinderpest and east coast fever caused severe losses in regions, eg Natal.

Current estimates suggest a total livestock population of almost 29 million small stock and eight million large stock (Bruwer unpublished). Much higher numbers and large variations have been recorded. For instance, Roux and Opperman (1986) noted that the numbers of woolled sheep in South Africa peaked at 40,3 million in 1933 then dropped to 24,3 million in 1946.

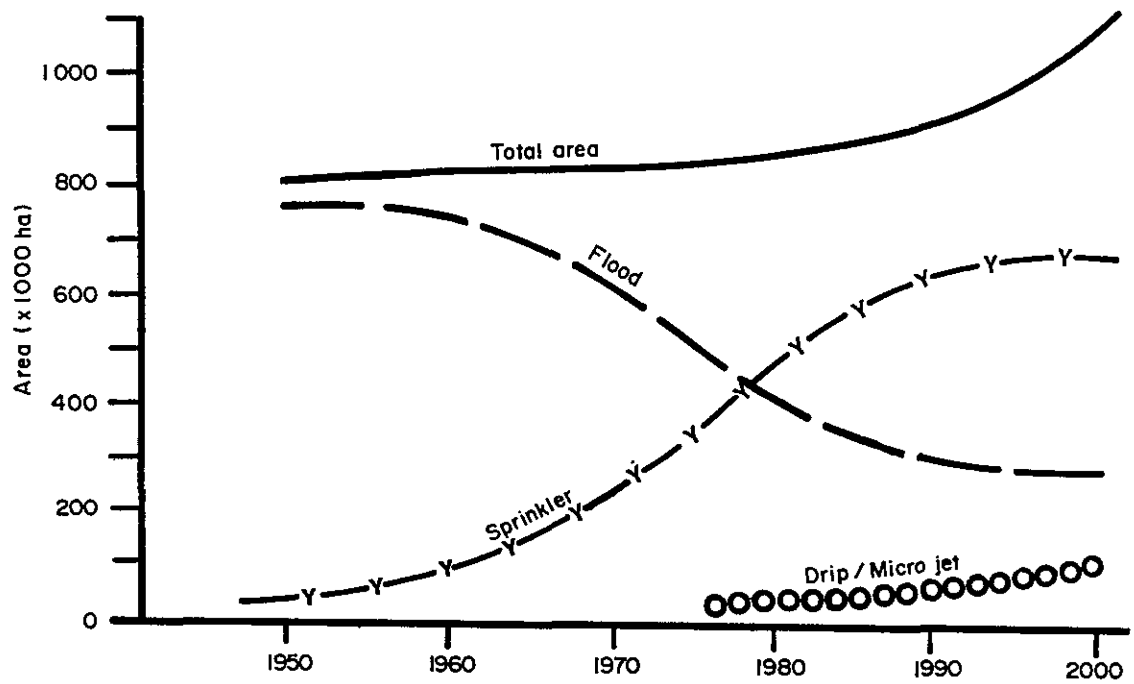

FIGURE 12.2 Area irrigated and methods used (after Bruwer 1977).

Cloete (unpublished) has reviewed long-term tendencies in total livestock numbers (cattle, woolled sheep, nonwoolled sheep, pelt sheep, Angora goats and meat goats) over a period of 30 years (1956 to 1985) in the white farming areas of the RSA over six consecutive five-year cycles. These data are presented in Table 12.4.

The most significant change in any ruminant production enterprise over the past 30 years has been the marked decrease in the number of woolled sheep. This was mainly the result of droughts during the sixties and seventies and a drop in wool prices. Favourable mutton prices over the same period resulted in the number of nonwoolled sheep showing a steady increase. Similar trends have occurred between meat and Angora goats. The changes in the number of pelt sheep should be interpreted with caution and, although an increase of 35% is reflected for the 30-year period, numbers have been reduced dramatically since 1982 as a result of the collapse of the global pelt market. Today the number stands at only 24% of that during the 1970's when prices were highest.

It is fair to conclude from these data that local and world market prices for specific fibres have, in addition to drought, had a profound influence on animal numbers, and in bringing about change to other ruminant production enterprises.

Long-term data concerning meat consumption reflect market-related trends and are perhaps more meaningful than livestock numbers per se. The consumption of white and red meat and eggs is presented in Table 12.5. The marked increase in poultry consumption over the past two decades is clearly evident.

TABLE 12.4 Changes in ruminant livestock numbers over five-year cycles during the past 30 years (1956 to 1985) (millions) (source: Department of Agricultural Economics and Marketing)

5 Yr Cycle*1*	Cattle	Change*2* (%)	Woolled sheep	Change (%)	Nonwoolled sheep	Change (%)	Pelt sheep	Change (%)	Angora goats	Change (%)	Meat goats	Change (%)
1956-60	8,3	-	29,4	-	3,5	-	1,4	-	0,8	-	1,6	-
1961-65	8,6	3,6	30,2	2,7	4,2	20,0	1,2	-14,3	1,3	62,5	1,4	-12,5
1966-70	7,2	16,2	31,0	2,6	4,3	2,3	1,3	8,3	N/A	-	N/A	-
1971-75	8,1	12,5	24,0	-22,6	4,4	2,3	1,9	46,2	1,0	-	1,2	-
1976-80	9,0	11,1	24,3	1,2	5,1	15,9	2,0	5,3	1,2	20,0	1,2	0
1981-85	8,3	-7,8	22,6	-7,0	5,6	9,8	1,5	-25,0	1,7	41,7	1,1	-8,3
Total period (1956-85)	8,2	6,2	26,9	-21,8	4,5	19,6	1,6	38,5	1,3	30,0	1,2	-20,0

1 Numbers indicated in the various columns represent the mean of a five-year cycle.

2 Percentage change columns represent changes over two consecutive combined five-year cycles (thus a smoothed and overlapping 10 year cycle) whereas mean changes over the 30-year period (1956 to 1985) were obtained by combining the first three and last three five-year cycles.

TABLE 12.5 Consumption of white and red meat and eggs in South Africa: 1955 to 1985 (source: Department Agricultural Economics and Marketing)

Year	Consumption of white meat		Consumption of red meat		Consumption of eggs tons x1000
	Total tons x1000	Per capita kg	Total tons x1000	Per capita kg	
1955/56	29	1,95	612	40,6	59
1960/61	42	2,50	682	40,7	66
1965/66	61	3,20	740	38,8	75
1970/71	120	5,34	863	38,4	93
1975/76	290	11,44	801	31,6	130
1980/81	339	11,49	898	30,4	135
1985/86	520	15,40	1100	31,5	160

Grazing capacities and veld management. The interest in livestock numbers largely concerns the effect of stocking rate on the condition of natural veld. Calculations of stocking rate have been central to many studies on grassland management and conservation. Helberg (unpublished) presented estimated stocking pressures for all magisterial districts. These estimates have been updated recently by Pieterse et al (1986).

Many studies have aimed at assessing grazing capacities, especially since the launching of the National Grazing Strategy in 1985. Nearly all studies reflect excessive stocking rates which, together with injudicious veld management, is the major cause of widespread degradation. Scientists have estimated that as much as 60% of the veld is currently in a poor condition (Bruwer unpublished).

The problem of stocking rates exceeding grazing capacity is illustrated by an example from the karoo region where it has been estimated that a "safe" stocking rate lies between 7,0 and 7,5 million small stock units (SSU). Present stocking rates are estimated at 10 million units suggesting that the region is overstocked by almost 30% (Roux and Opperman 1986). Comparison of maps depicting estimates of grazing capacities of the karoo region made in 1923, 1972 and 1987 also reflects the progressive deterioration of the veld resource over a period of more than 50 years. The percentage of the region in each grazing capacity category is shown in Table 12.6.

The Department of Agriculture and Water Supply has recently completed assessments of grazing capacity in all its agricultural regions to provide a basis for implementing the provisions of the Conservation of Agricultural Resources Act (Act 43 of 1983).

TABLE 12.6 Changes in grazing capacity of the karoo region (source: Department of Agriculture and Water Supply)

Grazing capacity	% of total area in grazing capacity category		
(ha/SSU)	1923	1972	1987
< 1	0,6	-	0,3
1 - 2	17,6	18,0	7,2
2 - 3	81,8	29,8	18,9
3 - 4		22,2	19,5
5 - 6		30,0	24,6
> 6			29,5

(SSU: small stock unit)

Effective veld management is facilitated by the provision of adequate paddocks and stockwatering facilities. The Drought Investigation Commission of 1923 strongly advocated subdivision of grazing land, claiming carrying capacities could be increased by this means (Drought Investigation Commission 1923). However, there are those who suggest that the Fencing Act (Act 17 of 1912) has led to drastic and unfavourable changes in veld exploitation. Unfortunately, long-term data relating to fencing, stockwatering schemes and farm impoundments are not readily available.

Much controversy has centered on veld burning as a management tool, yet accurate long-term data on burning practices by farmers and the extent of burning throughout the country are not available. Edwards et al (1983) have demonstrated the potential of satellite imagery for providing a reliable monitoring system. Existing legislation provides for control over veld burning practices.

The lack of carefully sited reference sites for monitoring change in veld condition throughout the country is a most serious limitation. However, this is a prerequisite of the National Grazing Strategy and already attempts are being made to establish and monitor such sites.

Influence of climate

In most parts of the country it is generally the overall moisture supply that largely influences production levels. It has been estimated that about 23% of agricultural production is lost as a result of adverse weather conditions including drought, excessively high temperatures, hail and frost (Theron et al 1973; Carter 1977; Gillooly 1978).

Numerous studies have analysed long-term rainfall records in attempts to assess drought frequency and severity (Tyson and Dyer 1975). Records concerning the percentage of time during which individual magisterial districts have been declared drought-stricken over a 30-year period (1956 to 1986) show that as much as 27% of the country is drought stricken for more than 50% of the time (Department of Agriculture and Water Supply unpublished). Roux and Opperman (1986) also claim that the Karoo experiences drought conditions for between 30 and 50% of the time. There is much scope for developing reliable drought indices and procedures to assess and monitor the impact of moisture deficiencies. Satellite systems could aid such monitoring.

Most crops are particularly sensitive to moisture stress during specific phenological stages and these short-term effects on production levels are becoming increasingly important in agro-climatic modelling. Since the severity of crop losses varies with type of weather hazard as well as with crop type, identification of high risk areas is important. An example is given in Figure 12.3 which reflects hail risk expressed in monetary terms for the Transvaal.

In this example, short-term hail damage data are expressed in terms of the value of district hail insurance claims per area insured. These values are converted to district hail risks by adjusting with a factor which represents the ratio of the expected district hail frequencies to the number of hailstorms which caused the damage. A long-term data set is essential for calculation of the former value.

The hail risk, as given in Figure 12.3, reflects current market prices and should not be used to estimate the magnitude of the expected financial loss suffered by maize farmers in the area. It does, however, highlight those regions in which a greater hail risk exists. Such information can be used to delimit climatically hazardous zones for the cultivation of a particular crop.

Resource conservation

Concern for the conservation of natural resources in South Africa was first expressed by the Governor of the Cape, W A van der Stel, almost three centuries ago. Over the years many conservationists have echoed similar concern and expressed disappointment at the lack of adequate research and the poor progress with conservation. Theron (1983) has summarized most of the milestones in conservation history including the following:

1914 Select Committee appointed to study droughts and erosion
1920 Drought Investigation Commission appointed
1929 National Soil Erosion Conference held in Pretoria
1930 Soil Erosion Advisory Council established
1939 Division of Soil and Veld Conservation created
1943 Reconstruction of Agriculture Committee report published
1944 National Veld Trust established
1946 Soil Conservation Act (Act 45/1946) promulgated
1967 Soil Conservation Act (Act 76/1969) promulgated
1983 Conservation of Agricultural Resources Act (Act 43/1983) promulgated
1985 National Grazing Strategy announced
1986 Economic Advisory Council investigation into restructuring agriculture

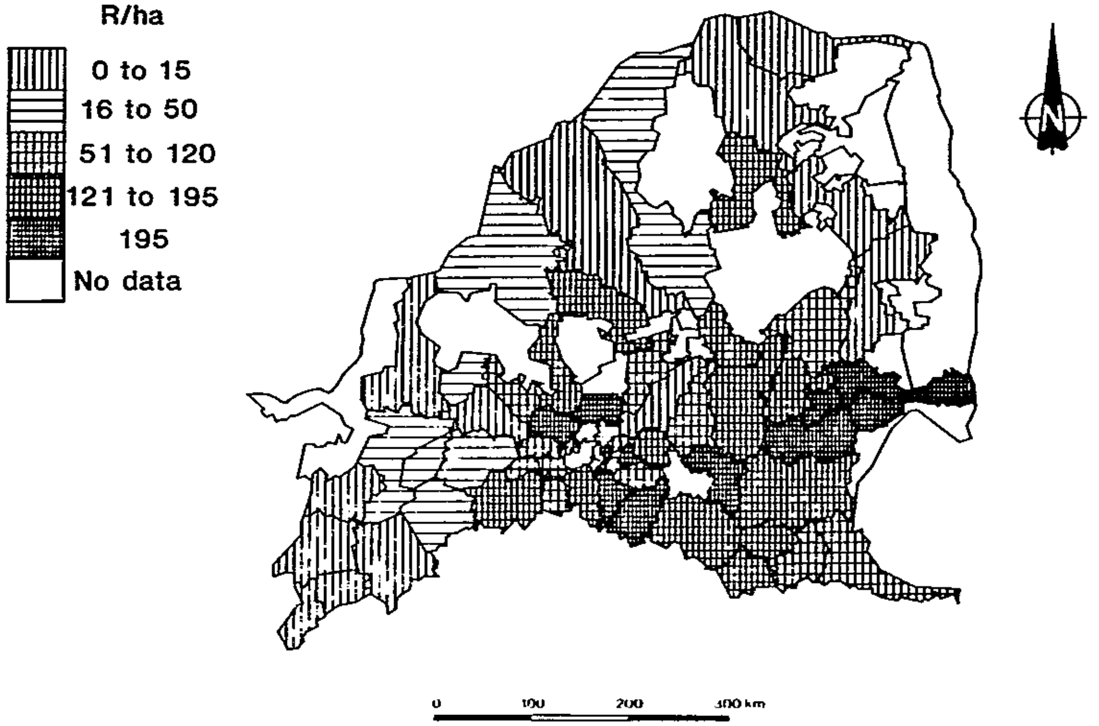

FIGURE 12.3 Relative hail risk for maize in the Transvaal expressed in monetary terms (source: Sentraoes 1982 to 1986).

An important conservation issue for which some data are available concerns the encroachment of noxious and other weeds, but this is not covered in this chapter. Similarly, many specific schemes not listed above have been introduced in an attempt to promote conservation. These include the leycrop and stock reduction schemes implemented during the past two decades.

It is disconcerting to find that the main causes of degradation identified and conservation strategies recommended in all reports submitted to Government have remained more or less the same over a period of almost a century.

AVAILABILITY OF AGRICULTURAL AND RELATED DATA

Effective control over agricultural activities was first attempted in earnest in 1912 when the Department of Agriculture was constituted under the South African Act of 1909. Many organizational changes have come about since then, the most important of which was the creation of two Departments in 1958 to provide improved services in the technical and economic spheres. The latter also included a statistical service aimed at monitoring trends. These two Departments provide agricultural data of many kinds but much remains unpublished or are of a confidential nature.

A bibliography of South African agricultural publications between 1910 and

1972 provides useful reference information (Department of National Education 1978). The more recent advent of computerized information systems popularly and locally referred to as SADAL, SASDI and SABINET all provide access to large volumes of published works. Such systems are not yet fully utilized.

Agricultural data cover many fields but their accuracy and reliability are often suspect. Such data are relevant to macro and micro levels and are presented in many forms, including maps.

Natural resource data

Many kinds of natural resource data are available and often relate to single surveys. Climatic data are, however, collected on a continuous basis and are readily retrievable from data banks such as those of the Weather Bureau, Water Research Commission and Department of Agriculture and Water Supply. Recent moves towards the development of geographic or land information systems by departments and universities holds promise for providing ready access to resource data. For instance, the national resource inventory system (NATIN) established at the Soil and Irrigation Research Institute is a computerized register of maps, reports and published literature concerning climate, soils and terrain forms of the country. Similarly, much information on vegetation is available from the Botanical Research Institute.

Remote sensing products provide a valuable source of agricultural and related data. The country is well covered by high quality aerial photographs dating back over almost five decades and since the early 1970's satellite imagery has enhanced opportunities for gathering data in real time. With improved resolution and analytical systems, such technology could revolutionize the collection and retrieval of land cover and resource data in South Africa. Initial studies in the Highveld Region have shown accuracies of 70 to 80% and over 90% for summer and winter crops respectively (Turner et al 1983).

Agricultural enterprise data

Long-term data on agricultural enterprizes are to be found in numerous publications and reports appearing at various intervals. Examples of these include:

- The agricultural census is available from the Central Statistical Service (Central Statistical Service 1987). This is the prime source of agricultural data. At present the census is undertaken on a four-yearly basis with selected sample surveys carried out during the intervening periods. Legislation ensures that all farmers participate. A wide range of data concerning all enterprises are reported on a magisterial district basis. Limitations of such data are generally acknowledged and, as suggested by Pieterse et al (1986), their reliability is often suspect and they may even be obsolete (see also section on Major Limitations of Agricultural Data).

- The Department of Agricultural Economics and Marketing publishes a valuable abstract of South African agricultural statistics based on census data. Tables reflecting trends in all enterprises over a 30-year period, selected indices and miscellaneous matters are presented. The Directorate of Soil Protection of the same Department is a source of data relevant to conservation legislation but few are widely publicized.

- The Department of Agriculture and Water Supply possesses numerous data sets at both national and regional levels based on census data or specific surveys undertaken. An atlas compiled by Pieterse et al (1986) serves as an example of such data sources. Similarly, development plans for each of the seven agricultural regions, initiated in 1972 and updated on a five-yearly basis contain valuable statistics. Special farm surveys on a region-wide basis have been undertaken (eg in Natal and eastern Cape) using postal and personal interview approaches. The Agriquest survey carried out in Natal in 1980 serves as an example of the former approach and resulted in the production of a computer-generated map of land use in the region (Department of Agriculture and Water Supply 1980).

- Annual reports of the 22 Control Boards and other bodies (eg South African Sugar Association) also provide data reflecting production trends within the relevant commodity. Such data, however, are not always consistent with other sources, but tend to be the most up-to-date. In the case of the Maize Board useful comparisons with production in other countries are usually given (Maize Board 1986).

- Other sources include reports such as those from the Fertilizer Society of South Africa, and the proceedings of congresses and symposia of which those of the annual AGROCON symposium are particularly useful. The South African Agricultural Union and its affiliates are further sources of data but for obvious reasons most are treated as confidential. The South African Yearbook also presents a regular though general overview of South African agriculture (Department of Foreign Affairs 1985).

TRENDS REFLECTED BY LONG-TERM AGRICULTURAL DATA

Very clear trends in agricultural development are reflected by available data, especially over the past two decades (Pieterse et al 1986). Some of these have already been noted (in the section on Considerations of Long-Term Variability). While it may be expected that livestock production off natural veld would follow climatic oscillations such as those presented by Tyson and Dyer (1975), these have not been clearly demonstrated. The complex effects of increasing stocking rates, deteriorating veld condition and responses to seasonal rainfall make it difficult to establish production trends. Agricultural production is also a function of many variables including changing technology. In many cases these tend to mask other effects.

Natural agricultural resources

Selected examples illustrate resource-related trends and further emphasize the urgent need to accurately monitor environmental changes.

Adler (1985) has drawn attention to the rapidly diminishing land resources in South Africa. By the year 1990 the accepted norm of 0,4 ha cultivated land per person will be reached and by 2020 this will drop to 0,2 ha per person.

It is generally accepted that in many instances rates of erosion by wind and water exceed acceptable limits. Despite its importance, trends in wind erosion have not been established. Few studies have accurately detected long-term changes in the rates of accelerated erosion although Roux and Opperman (1986) suggest that erosion in the Karoo was at its worst 40 to 50 years ago. Similarly, Garland (unpublished) found that erosion in Natal increased from colonial times until the mid-20th Century but has tended to abate over the past four decades. Sediment load studies by Rooseboom (1975) have provided valuable insights into erosional trends but care is needed in relating sediment loads to conservation status on farms.

Du Plessis (1986) found that about 100 000 ha of valuable irrigated land has become degraded through the development of hypersaline soils, the so-called 'brak', but little is known of the rate of deterioration.

Appropriate data concerning losses of high potential land to non-agricultural uses are also difficult to obtain. Although rough estimates suggest that losses of such land (excluding that to forestry and conservation) may total almost 40 000 ha yr^{-1}, accurate assessment is rendered difficult by the lack of records. Viewed against South Africa's limited resources of high potential land such losses are serious.

In order to illustrate the need to align policies, the potential impact on agriculture of the current housing policy in Natal may be considered. It is likely that R4 to R5 billion will be made available for low-cost housing over the next 18 months. This implies that it will be necessary to identify, proclaim and service 15 000 ha of land which will no longer be available for food production (Town and Regional Planning Commission unpublished).

Crop production

Trends in crop production over the past two decades are clearly reflected in the atlas presented by Pieterse et al (1986). There are marked differences between crops in both areas planted and total production. Steady increases are reflected for vegetables although marked peaks and troughs are noted for field crops. The influence of drought over the short-term is clearly reflected in production trends for all dryland crops.

Agricultural census data reflect changing cropping patterns. For example, in parts of the Natal Midlands annual cropping in the 1950's gave way to wattles which in turn were largely replaced by sugarcane. Currently sugarcane is being ousted by timber in certain localities. Such trends largely reflect changing economic circumstances.

Livestock production

Trends in livestock populations and production are also clearly reflected by available data. These are greatly influenced by economic and climatic conditions and, especially in the early days, outbreaks of disease. Changes reflected are not as dramatic as with crops since most livestock enterprises take time to establish and respond to external influences. Changes in the purchasing power of the various population groups also influence the demand for specific livestock products.

MAJOR LIMITATIONS OF AGRICULTURAL DATA

Most agricultural data have serious limitations and according to Pieterse et al (1986) it is virtually impossible to paint an accurate picture from available census data. Some of the main limitations may be summarized as follows:

Inaccurate and unreliable data

Such problems are among the most important and involve such issues as:

- changes in land-use categories from one census to the next;
- reluctant participation by farmers and negative attitudes;
- generally poor standard or nonexistence of accurate farm records;
- inadequate definition of items such as farming units, weights and measures;
- lack of explanation and understanding of data collected; and
- user needs not always accommodated by the census schedule.

Geographic considerations

Important limitations concern:

- farm data which cannot be related to the exact geographic location of the property concerned, thus excluding the possibility of computer-generated maps;
- boundaries of farms, magisterial districts, regions and provinces have changed over time making it difficult to compare data sets; and
- granting of independence to TBVC states which has meant periodic changes in farm numbers and provincial sizes.

Timeliness

Despite the need for up-to-date information this is seldom the case with agricultural data. Delays in publishing census data may be four years or more although summary data are made available more frequently. Surveys carried out in addition to the normal agricultural census are seldom if ever repeated.

Availability and confidentiality of data

Users experience difficulties in gaining access to unpublished agricultural data including:

- data which are not readily available to parties outside the institution collecting them;
- individual farm data which are generally confidential;
- high costs which prevent regular updating of special surveys;
- missing data, or those available only for short periods, which do not facilitate comparison of data sets; and
- difficulties in reconciling similar data sets from different sources.

FUTURE NEEDS

There is an urgent need to improve agricultural data. The most important concerns are improving accuracy and reliability, effecting standardization, providing ready access for all users and coordinating efforts to collect information.

Agricultural data needed

It is virtually impossible to list all agricultural data urgently needed but which is not yet analysed, published or even collected. Examples of these include the impact of livestock enterprises on veld condition and hence grazing capacity. Losses of high potential agricultural land and other classes with unique features also deserve more serious attention. Chemical control of weeds, pests and diseases has been practised for decades yet relevant data are virtually unavailable. Similarly, veld management has been facilitated by the erection of fences and the provision of stock watering yet few relevant data have been published. Studies concerning the numbers and effects of farm impoundments are also needed. Changes in the fertility status, including acidification, of South Africa's cultivated soils have not received the attention they deserve. While it is generally accepted that plant succession on fallow lands is slow, few studies have been made of the rates of recovery in different ecosystems.

Agricultural census

The census should remain the prime source of data and should be expanded and refined. Some important needs include:

- flexibility to meet user needs;
- geographic identification of each farm unit to facilitate computer-generated maps for specific areas;
- changing farmer attitudes and dispelling suspicion;
- reducing delays in publication of data;
- greater control through appropriate legislation; and
- research aimed at improving census procedures.

Appropriate computer technology

Full advantage should be taken of developments in computer technology. This implies ready access to data storage/retrieval systems. Various data banks should be linked and made accessible to users and at the same time relaxation of confidentiality should be permitted wherever possible. The application of remote-sensing techniques and the development of geographic information systems should be encouraged. Such activities should be effectively coordinated.

Natural Resource Inventories

It is important that qualified soil scientists play a far greater role in ecosystems research (Scotney and Aucamp 1987).

The ecotope concept and the associated procedures described by MacVicar et al (1986) for inventorizing agricultural resource potential should enjoy countrywide acceptance.

Natural resource registers such as NATIN should be fully supported and extended to include up-to-date land-use information. The production of land cover maps at appropriate scales is a matter of urgency.

Bench Marks

Bench marks and baseline surveys are urgently needed to facilitate long-term monitoring, especially those concerning the natural vegetation.

Human Resources

Studies relating to human resources and attitudes, including those of farmers, should be encouraged. Since agriculture must play a major role in contributing to a rural development strategy, special attention should be paid to developing the required managerial skills of farmers.

Comprehensiveness of data

Data recording must be extended on a multilateral basis to include all independent and self-governing states so as to ensure that joint planning and comprehensive policies are promoted.

Catchment management

Information is required which records and monitors land-use practices on a catchment basis, especially in the upper reaches, and reflects their down-stream effects. This presupposes the management of catchments as a whole and has as a prerequisite effective monitoring systems.

Viability studies

The development of crop production strategies which take account of resource potential and which also address the viability of farming units and their optimum development is of great importance.

Marketing and other strategies

It is essential to relate the agricultural strategy to other national strategies and operational policies. Some of these are marketing strategies, urbanization policy, provision of bulk services and basic infrastructure. Not the least is the aligning of the work of state, semistate, regional and local authorities.

Applicability of policies

It would seem necessary to evaluate existing agricultural and related policies to identify successes and failures and the degree of their present effectiveness.

Linkages between agriculture and other systems

Agriculture impacts forceably on many ecosystems. The study of linkages between agriculture and other systems presents a special challenge for the future. Models describing such interactions should take account of man and his needs, his influence on natural resources, technology and economics as well as the energy sources influencing agriculture. Many agricultural activities affect the various biomes, the ocean, the atmosphere, rivers, estuaries and inland water bodies. These interactions are often complex and not fully understood.

DRIVING FORCES AND CONCLUSIONS

Monitoring changes in agriculture is essential to evaluate progress in implementing policies and production strategies, to effect readjustment of development programmes and to provide warning of approaching undesirable situations. Priorities for research may also be identified.

Improving our ability to make creative decisions within the context of a rapidly changing society and economy should be an important aim. To do this it is important to develop the data sets, storage/retrieval systems and analytical procedures to improve long-range natural resource strategies. It is also necessary to understand the present and future driving forces likely to influence agriculture. Some of the more important of these include:

- Natural resources such as climate, soils and terrain, that largely influence the moisture regime and hence land-use patterns and production levels. These may be modified through practices such as irrigation.

- Economic influences are the prime forces bringing about changes in enterprize selection, especially over the short term. The widespread introduction of incorrect or unadapted farming systems/practices bears witness to the strength of such forces.

- Agricultural policies also influence development and practice but are not as strong as economic forces. Despite dedicated and repeated attempts by the authorities to implement a sound policy of optimal resource utilization progress has been relatively slow.

- Research and advisory services also have a marked influence on agriculture but again the rate of adoption of new practices in most fields is slow and differs between specific enterprises and groups of farmers. New developments in biotechnology could greatly influence agricultural production and its impact on the environment.

- Legislation can be an important influence on agricultural practice but has not always been highly effective in the past.

- A number of cultural and sociological issues can also be regarded as driving forces. The dramatic swing to poultry meat at the expense of red meat is largely the result of demands by the black population. Similarly, particular cultural groups have preferences for certain farming enterprises. Migration of farmers from the rural areas to major urban and industrial centres or to coastal areas is well known and it is clear that many agricultural data sets are strongly influenced by managerial expertise.

Long-term studies of farming practices, including fertilization should be planned and executed continuously on experimental plots, to facilitate future generations making reliable predictions and planning strategies to feed the population.

Several forces including those noted by Theobald (1979) could become more important in the future. These include:

- long-term changes in climate (eg greenhouse effect);
- relations (tensions) between developed and developing agricultural sectors, ie unbalanced socio-economics;
- population growth and demands for specific commodities (Spies 1987);
- migration patterns of the rural population;
- rising costs of energy and resources;
- developments in telecommunications that will greatly influence technological levels. According to Theobald (1979) "free flow of ideas is needed if mankind is to solve the approaching global crises of increasing population, pollution and dwindling resources". Microelectronics could become one of the most important driving forces of the future; and
- as environmental concerns grow, the need for new commitments will arise. Reduced commitments to conservation cannot be afforded but such issues can become confused as the struggle between economic growth and ecological protection continues. The need to develop effective procedures for resolving these conflicts will increase.

It is perhaps appropriate to conclude with a quote from Dennis Gabor, 1971 Nobel prize winner:

"In today's world all curves are exponential. It is only in mathematics that exponential curves grow to infinity. In real life they either break down catastrophically or they saturate gently. It is our duty as thinking men to strive toward a gentle saturation although this poses new and very difficult problems" (Theobald 1979).

REFERENCES

Acocks J H P 1953. Veld types of South Africa. Botanical Survey of South Africa. Memoir 28. Government Printer, Pretoria.

Adler E D 1985. Soil conservation in South Africa. Bulletin 406, Department of Agriculture and Water Supply, Pretoria.

Biesenbach F W 1984. 'n NPK-balansstaat vir die landbougrond van die RSA. Handelinge Stikstof simposium, Tegniese Mededeling Deptartement van Landbou Nr 187, 60-78.

Booysen P de V 1980. The importance of the ecological view of agriculture. Proceedings of the Grassland Society of Southern Africa 15, 7-11.

Botha A D P 1973. Toekomstige ontwikkeling tov die fosformark in SA. Die Misstofvereniging van Suid-Afrika Joernaal 1, 85-90.

Botha J C and Russel B G 1977. The world's potash industry as it relates to South Africa. The Fertilizer Society of South Africa Journal 1977 1, 31-42.

Bruwer J J 1977. Food production: Mechanization and Irrigation. Proceedings of the Agricultural Congress 77, Pretoria.

Burger F P 1983. Kostebeplanning van bemesting as element van bestuursbeplanning van die produsent. Magister Verhandeling, Potchefstroomse Universiteit vir CHO, Potchefstroom.

Carter A E 1977. Hail damage to agriculture and its prevention. South African Journal of Science 73, 327-330.

Central Statistical Service 1987. Census of agriculture 1981: agricultural products, fodder and pastoral products, vegetables, fruit and nuts. Report No 06-01-18, Government Printer, Pretoria.

Department of Agriculture and Water Supply 1980. Agriquest survey. Department of Agriculture and Water Supply (Natal Region), Cedara.

Department of Agricultural Economics and Marketing 1987. Abstract of Agricultural Statistics (RSA). Republic Directorate of Agricultural Economic Trends, Pretoria.

Department of Foreign Affairs 1985. South Africa 1985: Official Yearbook of the Republic of South Africa. 11th edition. CTP Book Printers, Cape Town.

Departement van Landbou en Bosbou 1943. Die heropbou van Landbou. Verslag van die Heropbou komitee. Departement van Landbou en Bosbou, Staatsdrukker, Pretoria.

Department of National Education 1978. Bibliography of South African Government publications. Volume 2, Government Printer, Pretoria.

Drought Investigation Commission 1923. Final report of Drought Investigation Commission. Cape Times, Cape Town.

Du Plessis M C F 1986. Grondagteruitgang. Suid-Afrikaanse Tydskrif vir Natuurwetenskappe en Tegnologie 5(3), 126-137.

Edwards D, de Vos W H, Hartkopf D, Hattingh D J, Scheepers J J and Wilby A F 1983. Monitoring of veld burns using satellite imagery. Proceedings of the Grassland Society of Southern Africa 18, 131-134.

Eisenberg B E, Bennet R J and Farina M P H 1985. The analysis of soil chemical data in Natal: I - Potassium. Proceedings of the Potassium Symposium, Pretoria, 43-50.

Gillooly J F 1978. Agricultural losses caused by adverse weather in South Africa. South African Journal of Science 74, 436-437.

Kassier W E 1987. Trends in agricultural input prices. Proceedings of the Agrocon Conference, Pretoria.

MacVicar C N 1986. A survey of the agricultural resources of South Africa. Proceedings of the Combined Congress of the South African Crop Production, Weed Science and Soil Science Societies, Pretoria.

MacVicar C N, Volschenk J E and Mott R W 1986. Inventorizing the potential of agricultural natural resources. Technical Communication Department of Agriculture and Water Supply No 204, Pretoria.

Maize Board 1986. Report on maize and buckwheat (1/5/85-30/4/86). Report to the Minister of Agricultural Economics, Pretoria.

Pentz J A 1949. An agro-ecological survey of Natal. Department of Agriculture and Forestry, Bulletin 250, Government Printer, Pretoria.

Phillips J 1973. The agricultural and related development of the Tugela Basin and its influent surrounds. Natal Town and Planning Report volume 19, Pietermaritzburg.

Pieterse J S, van Niekerk R J, Botha H J and Ehlers A 1986. Agricultural Atlas 1986. Department of Agriculture and Water Supply, Pretoria.

Ranwell H A 1975. Toekomstige ontwikkeling m.b.t. die stikstofmark in SA. Die Misstofvereniging van Suid-Afrika Joernaal. 1975 1, 37-43.

Rooseboom A 1975. Sedimentafvoer in Suid-Afrikaanse riviere. Water in South Africa 4(1), 14-17.

Roux P W and Opperman D P J 1986. Soil erosion. In: R M Cowling, P W Roux and A J H Pieterse (editors) The Karoo biome: a preliminary synthesis, Part I - Physical environment. South African National Scientific Programmes Report No 124. CSIR, Pretoria. pp 92-115.

Scheepers J J, Smit J A and Ludick B P 1984. An evaluation of the agricultural potential of the Highveld region in terms of dryland cropping and livestock production. Technical Communication No 185. Department of Agriculture, Pretoria.

Schoeman J L and Scotney D M 1987. Agriculture potential as determined by soil, terrain and climate. Proceedings of Conference II of the Association of Scientific and Technical Societies of Southern Africa, Johannesburg. South African Journal of Science 83(5), 260-268.

Scotney D M 1987. Crop production and fertilization in the Republic of South Africa: a futuristic view. The Fertilizer Society of South Africa Journal 1, 31-41.

Scotney D M and Aucamp A J 1987. Soil science and the national grazing strategy. Proceedings of Soil Science Society Congress, Nelspruit.

Spies P H 1987. Die veranderde mark vir landbouprodukte. Handleiding van die Kongres Lanvokon, Pretoria.

Theobald R 1979. Challenges in natural renewable resources - a guide to alternative futures. Report to the United States Department of Agriculture, Government Printing Office, Washington DC, USA.

Theron C B 1983. Conservation chronicle (Part I). Conservation Forum No 2. Department of Agriculture (Division of Soil Protection), Pretoria.

Theron M J, Mathews V L and Neetling P J 1973. The economic importance of the weather and weather services to the South African agricultural sector - a Delphi survey. CSIR research report No 321.

Turner B, Malan O G and Stickler G J 1983. The Heilbron crop mapping project (Part 3). Summer Crops 1981. CSIR Special Report. pp 316.

Tyson P D and Dyer T G J 1975. Mean fluctuations of precipitation in the summer rainfall region of South Africa. Southern African Geographical Journal 57, 104-110.

CHAPTER 13. VETERINARY SCIENCE AND THE STUDY OF DISEASE TRANSMISSION IN SOUTHERN AFRICA

GENERAL OVERVIEW

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INTRODUCTION

"Whoever wishes to investigate medicine properly should proceed thus: in the first place to consider the season of the year, and what effects each of them produces ...... In the same manner, when one comes into a city to which he is a stranger, he should consider its situation, how it lies as to the winds, and the rising of the sun ..... One should consider most attentively the waters which the inhabitants use, whether they be marshy and soft, or hard and running from elevated and rocky situations, and then if saltish and unfit for cooking; the ground, whether it be naked and deficient in water, or wooded and well watered, and whether it lies on a hollow, confined situation or is elevated and cold; and the mode in which the inhabitants lie, and what are their pursuits, whether they be fond of drinking and eating to excess and given to indolence, or are fond of exercise and labour."

Hippocrates: On air, waters and places - trans Medical Classics (1938).

The above quotation demonstrates that more than 2 000 years ago there was an appreciation of the varied and complex factors involved in disease occurrence. However, the extent to which disease, and in particular parasitic (both micro and macro) infections and infestations regulate the distribution and density of animal populations is not clear (Anderson and May 1982). There is little doubt that the dramatic increase in human life expectancy over the last 200 years is due to a decline in deaths from parasitic (the term is used here in its broadest sense) disease (May 1982), but in animals the role of disease in population regulation is a point of contention. It is held, on the one hand, that host-parasite coevolution will tend to produce parasites that are relatively harmless to individual hosts and which therefore have little effect on the dynamics of host populations (May 1982). It is contended by protagonists of this view that habitat constraints are vastly more important than disease in population dynamics. A possible demonstration of this process of host-parasite coevolution is in regions of Africa where trypanosomiasis is endemic. There, indigenous ruminants suffer mild or inapparent infections, domestic ruminants that have been bred in the region for a long time suffer more severely while recently imported ruminants suffer virulent infections which are usually fatal if untreated (May 1982). A similar situation pertains for heartwater *Cowdria ruminantium* in southern Africa (Bonsma 1944).

On the other hand, events such as the African rinderpest pandemic during the last decade of the 19th century and the introduction of myxomatosis into the rabbit *Oryctolagus cuniculus* populations of Britain and Australia demonstrate that the effects of disease on both free-living and domestic animal populations can be cataclysmic (Henning 1956; Ross and Sanders 1987). These effects can have far reaching implications for the structure and stability of ecological communities due to knock-on effects (Anderson and May 1986).

A synthesis of these two viewpoints suggests that populations which are suddenly exposed to highly pathogenic diseases of which they have no previous experience would, initially at least, be severely affected. Later, if a viable population survived the experience, selection towards innate (inherited) resistance and, in the case of infectious diseases, immunity, would increasingly minimize the effect of the condition. In infectious diseases the agents themselves respond to increasing resistance in the population although they do not necessarily all follow the same strategy. For example, in myxomatosis increasing resistance on the part of rabbit populations is countered by increasing virulence and concomitantly greater transmissibility of the virus (Ross and Sanders 1987). Conversely, when African swine fever virus becomes established in domestic pig *Sus scrofa* populations there is evidence that virus isolates become increasingly less virulent (Wilkinson et al 1983). However, in both these infections the tendency is for the host/parasite relationship to evolve along symbiotic or commensal lines.

That new diseases do frequently occur is indisputable although many are anthropogenic, such as those caused by man-made toxic substances. "New" infectious diseases also arise periodically - apparently spontaneously. This is explicable on the basis of the short generation times of viruses and bacteria which may also have a high inherent rate of mutation as well as a tendency to genetic recombination or reassortment. Two recent examples of "new" diseases are canine parvovirus which severely affected dog *Canis familiaris* populations on several continents simultaneously in the 1970's and the current AIDS (acquired immune deficiency syndrome) pandemic in man. Furthermore, the increasingly frequent translocation of animals between countries and continents increases the risk of alien diseases appearing suddenly in unexpected places, eg the recent introduction of type 2 equine influenza to South Africa and African horse sickness to Spain. The African rinderpest pandemic mentioned above probably originated from cattle imports from the Indian subcontinent.

An important point was made recently by May (1986) who emphasized that disease is particularly important in disturbed situations. He used the example of the black-footed ferret *Mustela nigripes* in Wyoming which, after having been thought extinct, was making a successful recovery when the population was virtually wiped out by distemper virus so that today only a handful of individuals exist in captivity. An example closer to home is the recent rabies epidemic in kudu *Tragelaphus strepsiceros* in South West Africa/Namibia between 1977 and 1986. It is contended by some that the disproportionate size of the kudu population allowed kudu to kudu transmission to sustain this epidemic in a way not previously recorded (Hassel 1984). However, the available incidence data suggest that the situation may have been more complex than that because of the possible involvement of other species, eg cattle (Figure 13.1). Conversely, it is known that rabid domestic dogs have frequently entered the Kruger National

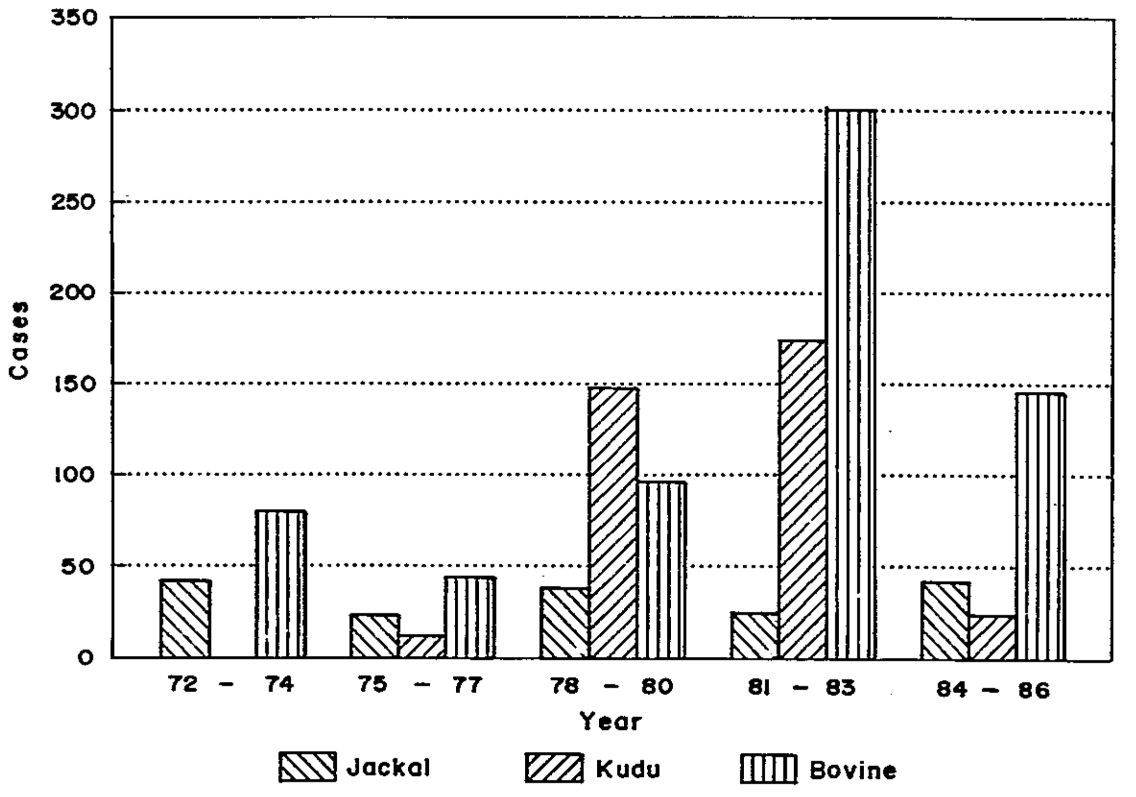

FIGURE 13.1 The reported incidence of rabies in three host species in South West Africa/Namibia from 1972 to 1986.

Park but no case of rabies in a wild animal has ever been confirmed there. It is argued that because of the balance between species (the Park is managed for species diversity) rabies has not been able to sustain itself there.

Thus disturbed situations in conjunction with the remarkable ability of microparasites to generate opportunists (by virtue of their short generation times, high mutation rates and propensity for genetic rearrangement) are likely to produce situations in which animal populations are periodically profoundly affected by disease. Interestingly, mathematical models suggest that infectious diseases are likely to be more important in the population dynamics of invertebrates than vertebrates due to the lack of effective acquired immunity on the part of the former (Anderson and May 1980).

In view of the low predictability of disease occurrence described above, it is not surprising that there has been less concern with long-term data sets on the part of those involved in animal health than is the case with some other branches of biology. Furthermore, the emphasis on domestic animals and attendant economic pressures has resulted in a preoccupation with high resolution, short-term data which are useful in the management of crisis situations which are of frequent occurrence. Furthermore in the control of infectious diseases there has been a tendency to concentrate on vaccine development at the expense of detailed epidemiological investigation which would enable a deeper understanding of the disease in question.

This tendency has now been recognized and steps to rectify the situation have been initiated.

It must be acknowledged that the neglect of long-term data collection within the veterinary field as well as the failure to utilize available data generated by related and even apparently unrelated disciplines has resulted in an inability to determine long-term trends and to apportion our resources accordingly. This situation is particularly unfortunate in the light of the statutory requirement that all controlled (scheduled) animal diseases be reported which should have resulted in the formation of a useful data series. In the event, this has not occurred although an interesting and comprehensive start in this direction began in South West Africa/Namibia in 1986 (Integrated Veterinary Epidemiology Database - Directorate of Veterinary Services, Windhoek) and the incidence of disease throughout the Republic of South Africa has been computerized since the beginning of 1987 (Summary of the Incidence of Livestock Diseases - Directorate of Veterinary Services, Pretoria).

Mathematical modelling is becoming increasingly important in making broad projections about defined host/parasite relationships as well as in detecting critical elements in these relationships (Anderson and May 1986). For example, the importance of the basic reproductive rate of an infectious agent and the host threshold density have been forcefully illustrated with respect to the establishment, persistence and subsequent spread to other species of viral and bacterial agents (Anderson and May 1986). Such parameters are also useful in determining control strategies, eg with respect to immunization (Anderson and May 1982). The definition of such critical elements in the epidemiology of diseases has also provided a means by which infectious diseases with apparently different epidemiological characteristics can be compared (Anderson and May 1986).

Irrespective of the academic debate around the effect of disease on animal populations there can be little doubt that major advances in the control of many economically important diseases of livestock have been made in southern Africa since the turn of the century. Scourges such as rinderpest, east coast fever and a host of other arthropod-borne as well as nutritional diseases have either been eliminated or reduced to manageable levels so that today the raising of livestock in this part of the world is far less risky than was the case in the past. This has not resulted in a void with respect to animal disease, however, because the reduction in the incidence of these highly destructive diseases has revealed underlying erosive conditions (ie diseases which affect the productive capacity of animals other than by causing a high mortality rate) which are becoming increasingly important with the change in and intensification of livestock management practices. This has necessitated the implementation of control strategies for the important erosive conditions of livestock, eg the Tuberculosis (Eradication) Scheme (Figure 13.2). Furthermore some of these conditions have a complex or multifactoral aetiology involving the interaction of a variety of factors such as environmental conditions causing stress as well as infectious agents, eg shipping fever of cattle (Kahrs 1981). It is thus logical to presume that longer-term data series will become more important as the need to determine trends in disease patterns, which are often not obvious, grows. This will be necessary if optimal strategies to counter these diseases are to be devised not only for domestic animals but also with regard to wildlife.

The question is really, what sort of data sets are likely to be most useful in the long term, bearing in mind the constraints of finance and manpower? While most people with some experience in this field are able to venture intelligent guesses the problem is complex enough to bear careful consideration by a body of individuals with wide experience and expertise so as to preclude, as far as possible, what may later be seen to have been obvious mistakes and omissions. Hence we feel that this question cannot be answered adequately until a more considered investigation of the problem has been conducted.

WHAT IS KNOWN ABOUT LONG-TERM VARIABILITY IN ANIMAL DISEASES?

As will be evident from the introduction it is clear that there is a great deal of temporal variability in the incidence and effects of animal diseases. The example of rinderpest demonstrates the point. Not only did it reduce domestic and wildlife populations profoundly but it also led to the disappearance of the tsetse fly *Glossina morsitans* from the area of the present day Kruger National Park (du Toit 1954) and the eclipse of foot-and-mouth disease (FMD) in domestic stock for the 30 years following the turn of the century (Thomson this volume). Unfortunately the quantification of this variability presents a problem because, as stated above, long-term data sets are basically not available in a consolidated form. It can, however, be confidently stated that data on mechanistic aspects and spatial distributions are more comprehensive and reliable than temporal data. Furthermore, the data on controlled (scheduled) diseases are considerably better than for uncontrolled diseases.

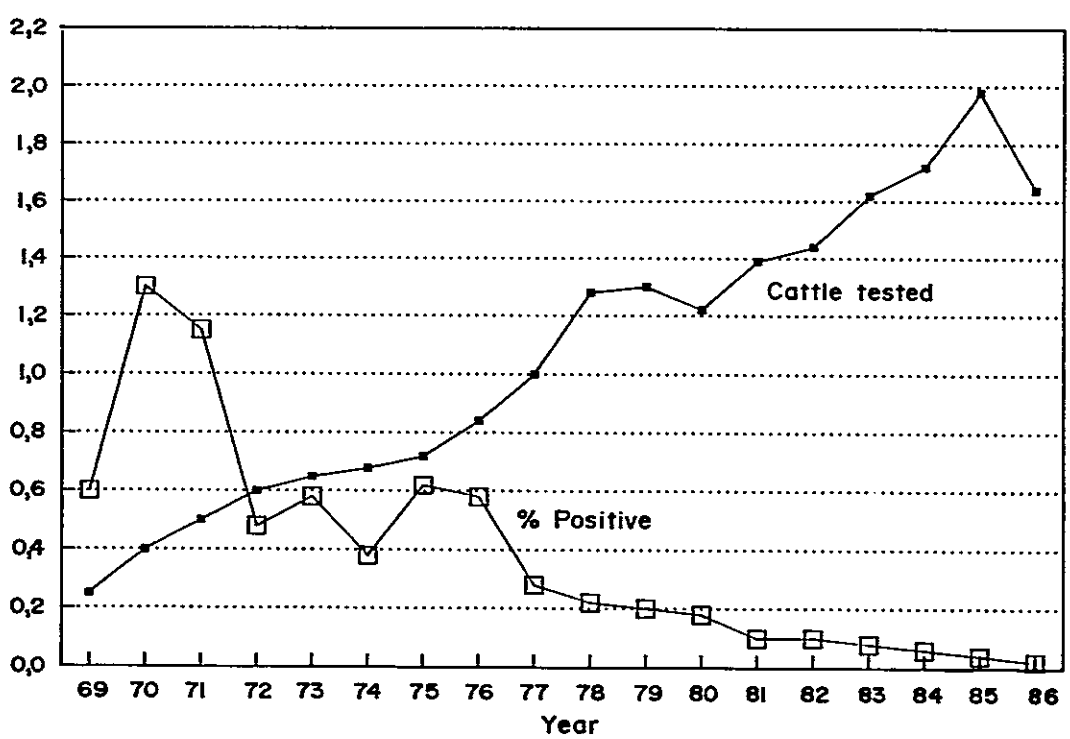

FIGURE 13.2 Results of the Bovine Tuberculosis Eradication Scheme in South Africa, 1969 to 1986/87.

There are five basic sets of epidemiological (disease) data with respect to animals:

1) Incidence and prevalence data. These not only provide information about the diseases themselves but also, in some instances, vectors and macroparasites.

   Information on diseases alone is available on a global, regional and national (approximately 112 countries worldwide) basis from the Office International des Epizooties (OIE) Bulletin which is published monthly. This information is consolidated annually into a publication entitled "World Animal Health". A very similar annual publication "Animal Health Year Book" is published jointly by the WHO, FAO and OIE. The Animal Health Year Book has been published since at least 1957 while World Animal Health commenced in 1986.

   Unconsolidated and sometimes incomplete data on controlled (scheduled) diseases such as rabies and FMD are available from the Directorates of Veterinary Services of countries in southern Africa, usually in the form of annual reports.

2) Data on the spatial distribution of diseases, internal and external parasites and toxic plants. Information in this regard is patchy although, as stated above, usually better than that on temporal incidence. Examples of such data are Howell et al (1978), Kellerman et al (1987) and Hunt and Coetzee (this volume).

3) Data generated as a result of control actions such as dipping of animals, vaccination, vaccine production (eg Potgieter this volume), fencing, stock inspection and disease eradication programmes. These data are usually included in the annual reports of the Directorates of Veterinary Services of all southern African countries.

4) Census data such as annual stock census figures (Annual reports of Directorates of Veterinary Services) and surveys.

5) Mechanisms of disease occurrence. These are usually published as scientific papers in veterinary journals such as the Onderstepoort Journal of Veterinary Research and the Journal of the South African Veterinary Association as well as a number of international journals.

WHAT IS LIKELY TO BE AVAILABLE AND USEFUL BUT WHICH HAS NOT YET BEEN ANALYSED AND PUBLISHED?

This aspect is difficult to quantify but some obvious possibilities are listed below:

1) A considerable amount of information generated by survey and diagnostic activities is never published and is often not even available in a consolidated form.

2) Contributions from primary resource users (eg farmers) are rarely sought although this has changed in South West Africa/Namibia (Integrated Veterinary Epidemiology Database - Directorate of Veterinary Services).

3) Data reflecting the sale of disease control substances (eg drugs, vaccines, acaricides etc). Data such as those presented by Potgieter (this volume) and those available from the SA Agricultural and Veterinary Chemical Association are not readily accessible but could be made so.

4) The fact that the Veterinary Investigation Laboratory at Allerton in Natal and the Veterinary Research Institute at Onderstepoort in the Transvaal have been functional for approximately 100 and 80 years respectively suggests that large amounts of research data are potentially available.

TENTATIVE CONCLUSIONS ON TRENDS AND CYCLES SHOWN BY AVAILABLE DATA SERIES

There is clear evidence of a seasonal periodicity in the occurrence of some animal diseases, especially arthropod-borne diseases such as bluetongue, African horse sickness, ephemeral fever, sheep scab, rabies (Bruckner and Koen this volume), plant poisonings (Kellerman et al 1987) and some external (Nevill this volume) and internal parasites.

Some infections demonstrate irregular periodicity and are prevalent intermittently every few years, eg Rift Valley fever and lumpy skin disease (Davies 1985). This is possibly related to longer-term climatic (rainfall) variability.

There is evidence for a decrease in the incidence of some controlled diseases (eg anthrax and FMD) in South Africa (Thomson this volume).

There is an increase in stock and wildlife losses due to chemical and other poisonings (Nel this volume).

The eradication or effective control of a number of highly pathogenic infections has resulted in the creation of fully susceptible populations which, if the infection were to be reintroduced, would suffer grievously. A prime example here is rinderpest. The overenthusiastic use of acaricides for the control of tick-borne diseases such as redwater, has in some places led to the disappearance of immunity to these haematropic parasites so that "unstable" situations have been generated (Ardington 1982; Norval 1982).

The increasing popularity of 'game farming' favours the occurrence of infections which are harboured by game animals, eg bovine malignant catarrh or snotsiekte. The translocation of wildebeest *Connochaetes taurinus* to game farms adjacent to cattle farms has resulted in numerous outbreaks of snotsiekte on the cattle farms in the recent past.

As mentioned above, the more frequent and more rapid international translocation of animals is increasingly responsible for the introduction of alien diseases to the importing country.

Disease producing organisms are becoming resistant to control substances such as acaricides, anthelminthics and antibiotics (Baker 1982; van Wyk et al 1987).

Residues of substances such as acaricides and antibiotics in food derived from animals (milk, meat etc) is an increasingly important problem.

Anthropogenic changes in the environment such as the building of dams and irrigation projects result in epidemiological changes with respect to diseases or parasites (eg Nevill this volume). Other undesirable effects such as the elimination of oxpeckers *Buphagus* species from large areas of their former range as a result of livestock dipping have also been recorded (Spickett and Bezuidenhout this volume).

DIRECTIONS FOR FUTURE RESEARCH TO FILL MAJOR WEAKNESSES IN LONG-TERM DATA SERIES

Since it is not yet clear what sort of long-term data series are likely to be most beneficial this could be the immediate objective of any research undertaken. It is our opinion that whatever is done in this direction should be approached on a collaborative basis between the organizations involved. Inputs from the Directorates of Veterinary Services of all the countries of southern Africa, from Research Institutes, including those not primarily involved in veterinary aspects, eg those run by the Medical and Agricultural Research Councils, and from universities will all be necessary if a broad and integrated system is to be devised. The diversity of information likely to be required cannot be supplied by any single organization.

Investigation of ways in which data presently being collected could be consolidated and made more generally accessible would be challenging but potentially very rewarding.

TENTATIVE CONCLUSIONS AS TO THE DRIVING FORCES INVOLVED

As far as anthropogenic factors are concerned, these all have a political or socio-economic basis and it is in these areas where the primary driving forces must consequently be sought. Technological developments, particularly in biotechnology, influence our way of doing things and present possibilities which did not exist previously and therefore provide a secondary driving force.

Almost every animal disease (genetic defects are a possible exception) is determined in large measure by the environment and, amongst environmental factors, climate has the most important and immediate effect. Climate, we therefore believe, is a primary driving force in animal disease.

REFERENCES

Anderson R M and May R M 1980. Infectious diseases and population cycles of forest insects. Science, 658-661.

Anderson R M and May R M 1982. Directly transmitted infectious disease: control by vaccination. Science 215, 1053-1060.

Anderson R M and May R M 1986. The invasion, persistence and spread of infectious diseases within animal and plant communities. Philosophical Transactions of the Royal Society, London B314, 533-570.

Ardington P C 1982. The benefit of intensive tide control. Proceedings of a symposium on the ectoparasites of cattle. South African Bureau of Standards, Pretoria, 15-16 March 1982. pp 136-140.

Baker J A F 1982. Some thoughts on resistance to ixodicides by ticks in South Africa. Proceedings of a symposium on the ectoparasites of cattle. South African Bureau of Standards, Pretoria, 15-16 March 1982. pp 52-67.

Bonsma J C 1944. The hereditary heartwater resistance characters in cattle. Farming in South Africa 19, 71.

Davies F G 1985. Rainfall and epizootic Rift Valley fever. Bulletin of the World Health Organization 63, 941-943.

Du Toit R 1954. Trypanosomiasis in Zululand and the control of tsetse flies by chemical means. Onderstepoort Journal of Veterinary Research 26, 317-387.

Hassel R H 1984. Rabies in kudu antelope (Tragelaphus strepsiceros) and cattle in South West Africa. Proceedings of the 13th World Congress on Diseases of cattle. South African Veterinary Association, Durban, September 17-21, 1984.

Henning M W 1956. Animal Diseases in South Africa. 3rd edition. Central News Agency, South Africa.

Howell C J, Walker J B and Nevill E M 1978. Ticks, mites and insects infesting domestic animals in South Africa. Part I. Descriptions and biology. Science Bulletin No 393. Department of Agricultural Technical Services, Pretoria.

Kahrs R F 1981. Viral diseases of cattle. The Iowa State University Press, Ames, Iowa.

Kellerman T S, Coetzer J W and Naude T W 1987. Plant poisonings and mycotoxicoses of livestock in southern Africa. Oxford University Press, Cape Town.

May R M 1982. The impact, transmission and evolution of infectious disease. Nature 297, 539-540.

May R M 1986. The cautionary tale of the black-footed ferret. Nature 320, 13-14.

Norval R A I 1982. Arguements against intensive dipping. Proceedings of a symposium on ectoparasites of cattle. South African Bureau of Standards, Pretoria. 15-16 March 1982. pp 141-148.

Ross J and Sanders M R 1987. Changes in the virulence of myxoma virus strains in Britian. Epidemiology and Infection 98, 113-117.

Van Wyk J A, Malan F S, Gerber H M and Alves R M R 1987. Two field strains of Haemonchus contortus resistant to rafoxanide. Onderstepoort Journal of Veterinary Research 54, 143-146.

Wilkinson P J, Wardley R C and Williams S M 1983. African swine fever. Report EUR 8466 en, pp 74-84. Commission of the European Communities. Luxembourg.

THE SEASONAL AND CYCLIC OCCURRENCE OF RABIES IN SOUTH AFRICA 1976 to 1986

G K BRüCKNER and P KOEN, Directorate of Veterinary Services

The number of positive cases of rabies recorded in domestic animals and wild animal species have shown fluctuations since 1976 (Figure 13.3). This trend manifests itself in spite of the usual control measures for rabies, ie vaccination and movement control. The primary aim of vaccination of dogs *Canis familiaris* and cats *Felis catus* is to create an immune buffer between humans and animals, thereby protecting the human population.

There is evidence of a three-year cycle in the incidence of rabies, which hitherto is still unexplained - mainly due to a lack of concurrent and relevant data. This observation of a cyclic appearance of the disease coincides with observations made on foxes *Vulpes vulpes* in Europe and the USSR (Irvin 1970).

A distinct seasonal variation in the incidence of rabies can be observed in all but the eastern Cape and karoo regions (Figure 13.4). The general

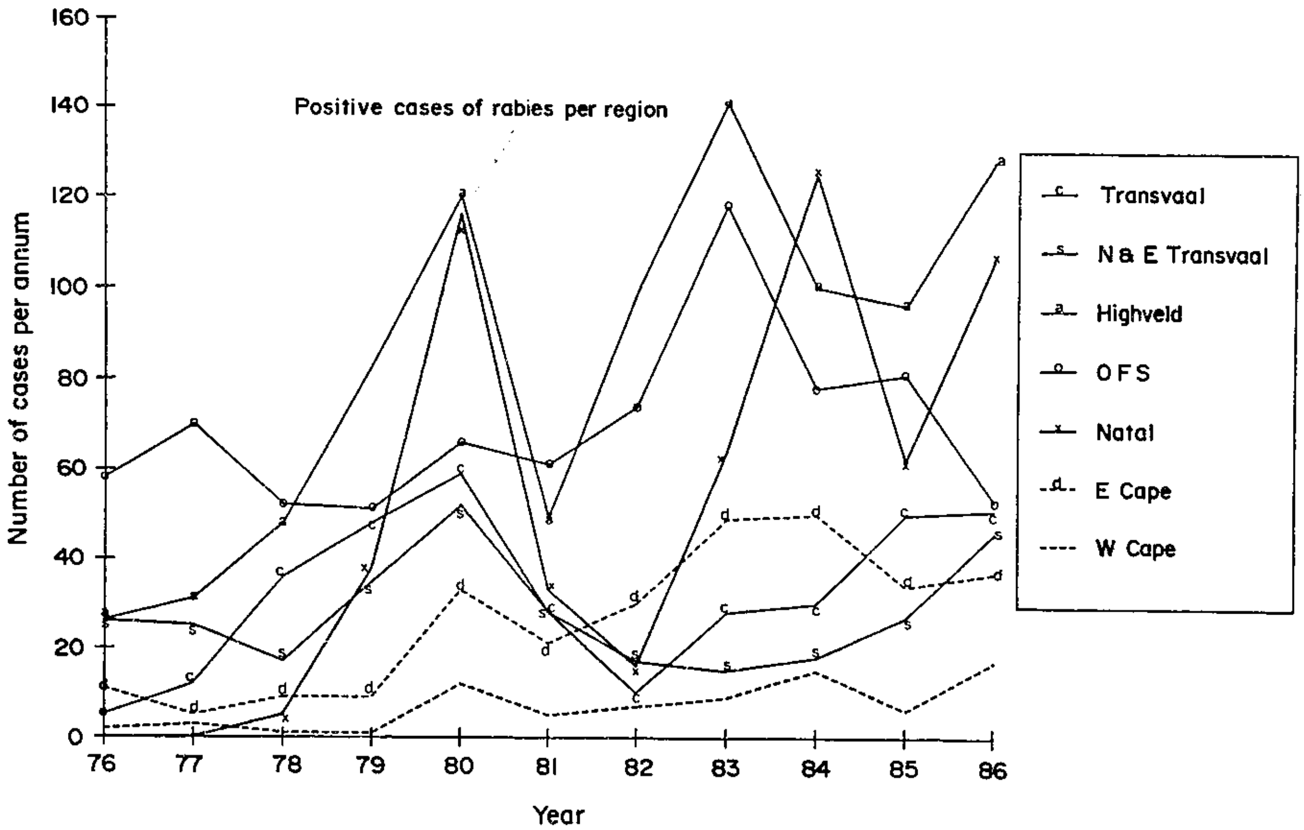

FIGURE 13.3 The number of positive rabies cases recorded per annum in the different regions of South Africa, 1976 to 1986.

trend of this variation indicates peak incidence in spring (August to September) and a low in February. The climate and other ecological factors possibly determine this seasonal pattern; a strong negative correlation with monthly rainfall being manifested in the summer rainfall areas. Other factors are fluctuations in population size of the most important wild animal vectors, infection rate in these vector populations and the breeding pattern of primary vectors (Snyman 1940).

There are distinct differences between regions in the species composition of positive rabies cases (Table 13.1). The domestic dog plays the major role in Natal in the transmission of the so called "street virus", whereas the yellow mongoose *Cynictus penicillata* is the main vector in the Highveld, Orange Free State and karoo regions (Barnard 1979).

Observations in the north-eastern Transvaal and Zimbabwe indicate a four- to five-year cycle in the incidence of positive rabies cases in the black-backed jackal *Canis mesomelas* (Bruckner et al 1978). The black-backed jackal seems to show a longer periodicity in the fluctuating incidence of positive cases in comparison to the yellow mongoose and the bat-eared fox *Otocyon megalotis*. There seems to be a trend towards an increase in the number of cases in the bat-eared fox from the 1976 to 1979 period (Barnard 1979) to the 1980 to 1986 period (Figure 13.5).

TABLE 13.1 Incidence of positive cases of rabies per species per region, 1976 to 1986

	Transvaal	Northern Transvaal	Highveld	Orange Free State	Natal	Eastern Cape	Western Cape
Cattle	122	164	245	104	13	1	10
Other domestic livestock	2	7	13	17	3	8	1
Domestic dog	34	72	52	71	534	7	4
Domestic cat	6	4	31	45	12	20	8
Cynictis penicillata	175	10	551	348	3	112	12
Canis mesomelas	0	37	0	4	0	1	1
Otocyon megalotis	8	0	7	47	0	87	33
Other wild species	10	8	22	125	?	37	9

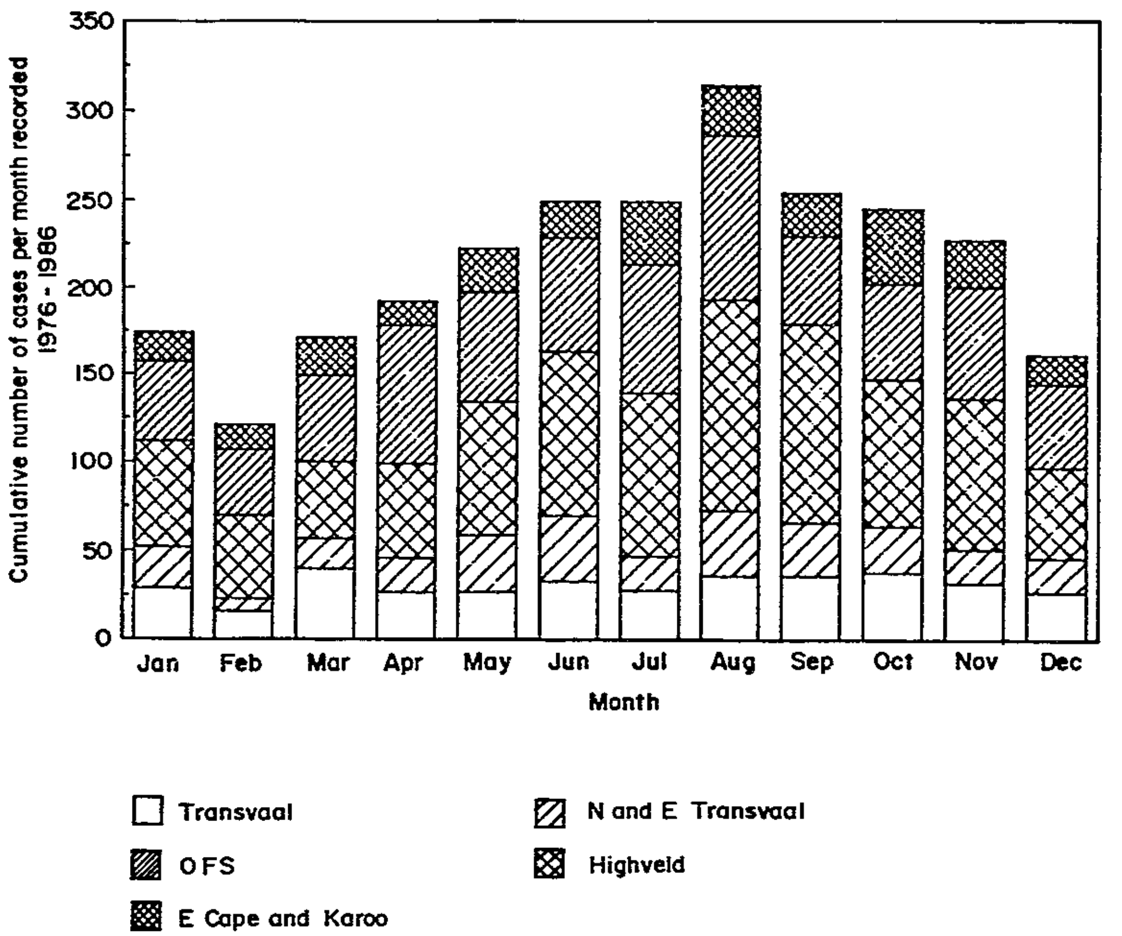

FIGURE 13.4 The seasonal incidence of positive rabies cases in the different regions of South Africa, 1976 to 1986.

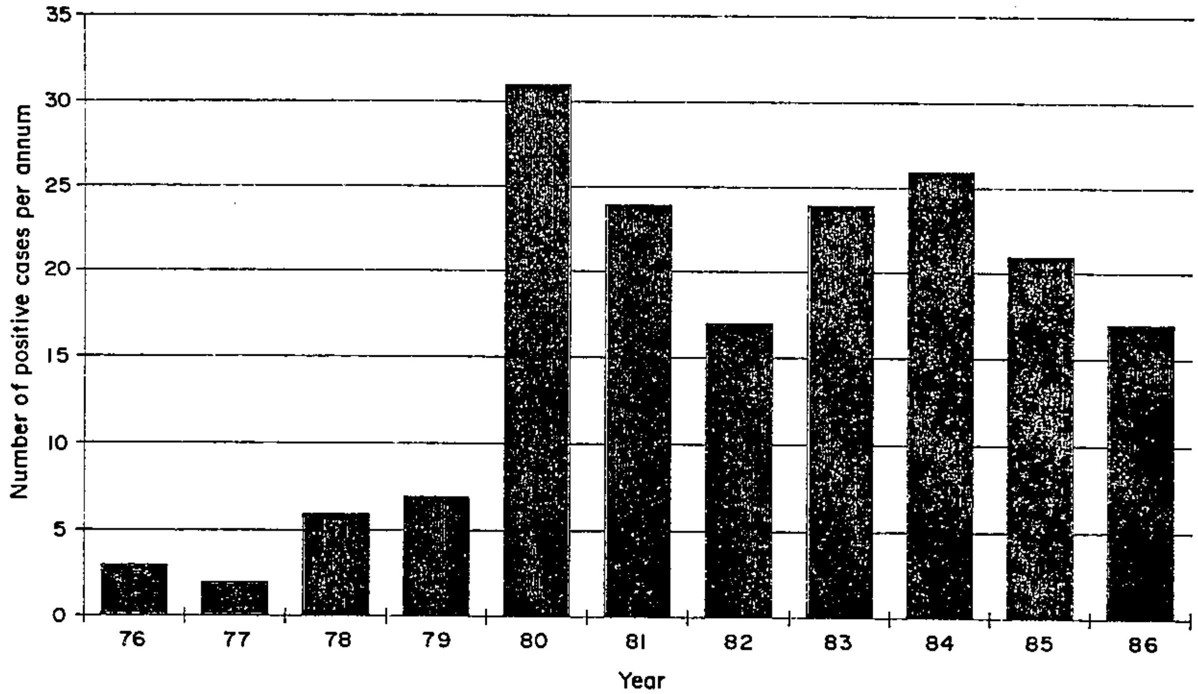

FIGURE 13.5 The number of positive cases of rabies recorded in the bat-eared fox in South Africa, 1976 to 1986.

REFERENCES

Barnard B J 1979. The role played by wildlife in the epizootiology of rabies in South Africa and South West Africa. Onderstepoort Journal of Veterinary Research 46, 155-163.

Bruckner G K, Hurter L and Boshoff J N 1978. Field observations on the occurrence of rabies in cattle in the magisterial districts of Soutpansberg and Messina. Journal of the South African Veterinary Medical Association 49, 33-36.

Irvin A D 1970. The Epidemiology of Wildlife Rabies. The Veterinary Record 87, 333-348.

Snyman P S 1940. The study and control of vectors of rabies in South Africa. Onderstepoort Journal of Veterinary Science and Animal Industry 15, 9-140.

THE ANOPHELES GAMBIAE COMPLEX: AN EXAMPLE OF A GROUP OF CRYPTIC SPECIES OF MOSQUITOES

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Many veterinary and medical diseases are transmitted by insects, mosquitoes being the vectors in many cases. The Culicidae, or mosquitoes, are in general classified by using the oldest tool of taxonomy, ie morphology. However, in the early 1960's it was demonstrated that the important malaria vector *Anopheles gambiae* was in fact composed of a group of morphologically indistinguishable species. The terms species complex, sibling species and, more recently, cryptic species have been applied to such groups (Gillies and Coetzee 1987).

THE *GAMBIAE* COMPLEX

The taxon *A gambiae* has long been known to be a vector of plasmodia (malaria) and filaria nematodes (filariasis, elephantiasis). In 1947 the saltwater tolerant species (*A melas*) in the group was considered to be a variety of *A gambiae*. By 1968 two saltwater breeding taxa, *A merus* and *A melas*, were recognized as good species and three others, at that time classified as species A, B and C, were recognized. The latter three only occurred in freshwater habitats. Lastly, species D, which spends its aquatic stages in mineral springs, was recognized as a species in 1972. Five were formally named in 1977 and the sixth in 1985. They are now known as: *A gambiae* (species A), *A arabiensis* (species B), *A quadriannulatus* (species C), *A bwambae* (species D), *A melas* and *A merus* (Gillies and De Meillon 1968; Gillies and Coetzee 1987).

IMPORTANCE OF CORRECT IDENTIFICATION

The vectorial capabilities of these species are very different. *Anopheles gambiae* and *A arabiensis* are the two most important vectors of plasmodia and filaria in most areas of Africa where these diseases are prevalent. *Anopheles merus* and *A melas* on the east and west coasts respectively, are of relatively minor importance while *A quadriannulatus* is not known to be a vector at all. *Anopheles bwambae*, although a vector, is only of local interest because of its limited distribution. There is no evidence that the poor vectors in the group are in any way refractory to infection with malaria parasites. All evidence points to the biting preferences of the various species as being the limiting factor in their ability to transmit the parasites. *Anopheles gambiae*, the most efficient vector, is known to prefer man as a source of blood. On the other hand, *A quadriannulatus* feeds exclusively on cattle.

Another biological variable between members of the group is the habit of resting in human habitations. As might be expected, *A gambiae* rests indoors while, in general, *A quadriannulatus* and *A merus* do not. *Anopheles arabiensis*, the second most effective vector species, rests both indoors and out. This behaviour has serious implications for malaria control programmes which are usually based on the application of insecticides on the walls of human habitations (Gillies and Coetzee 1987).

IDENTIFICATION METHODS

The present methods used to identify these morphologically similar species are genetic. The most precise method is by recognizing species-specific inversion differences in the polytene chromosomes of the salivary glands of fourth stage larvae and nurse cells of half gravid adult females. They can also be identified by using enzyme electrophoresis. This method relies on electromorph differences between species. However, some of the electromorphs are polymorphic and misidentifications can occur (Hunt and Coetzee 1986).

GENERAL

Several other mosquito taxa have been shown to be species complexes. The following names of African species have been shown to cover two or more species: *Anopheles coustani*, *A hughi*, *A pharoensis*, *A marshallii* and *A funestus*. There is unpublished evidence that *A squamosus* is also a species complex (Gillies and Coetzee 1987).

This phenomenon is not confined to mosquitoes. It has also been demonstrated in the medically important blackfly, *Simulium damnosum*, the vector of Onchocerciasis (river blindness). This is now known to consist of at least 37 morphologically indistinguishable species (Laird 1981).

Cryptic species groups are not confined to the Insecta. Such complexes are known to occur amongst African rodents. The case of the multimammate mouse *Mastomys natalensis* is probably the best known. This was shown to consist of two species (Green et al 1980) whose responses to the plague bacteria are very different (Isaacson et al 1983). There is good evidence that the tree mouse *Thallomys paedulcus* and the pouched mouse *Saccostomus campestris* are also species complexes (Gordon 1986; Gordon and Rautenbach 1987).

SIGNIFICANCE OF THESE FINDINGS FOR LONG-TERM DATA SERIES

Distributional or long-term data are only as good as the accuracy of the species identifications. This is of particular importance where species comprising the group have marked biological differences. In the past, predictive models on the incidence or occurrence of malaria have failed because of the lack of adequate identification (Macdonald 1957).

REFERENCES

Gillies M T and Coetzee M 1987. A supplement to the Anophelinae of Africa South of the Sahara. Publication of the South African Institute for Medical Research 55, 1-143.

Gillies M T and De Meillon B 1968. The Anophelinae of Africa South of the Sahara. Publication of the South African Institute for Medical Research 54, 1-343.

Green C A, Keogh H, Gordon D H, Pinto M and Hartwig E K 1980. The distribution, identification and naming of the Mastomys natalensis species complex in southern Africa (Rodentia: Muridae). Journal of Zoology, London 192, 17-23.

Gordon D H 1986. Extensive chromosomal variation in the pouched mouse, Saccostomus campestris (Rodentia: Cricetidae) from southern Africa: A preliminary investigation of evolutionary status. Cimbebasia (A) 8, 37-47.

Gordon D H and Rautenbach I L 1987. Population cytogenetics of tree rats in southern Africa: evidence for two biological species within the taxon Thallomys paedulcus. 5th Colloquium on Ecology and Taxonomy of African Small Mammals, England. (Abstract only).

Hunt R H and Coetzee M 1986. Field sampling of Anopheles mosquitoes for correlated cytogenetic, electrophoretic and morphological studies. Bulletin of the World Health Organization 64, 897-900.

Isaacson M, Taylor P and Arntzen L 1983. Ecology of plague in Africa: response of indigenous wild rodents to experimental plague infection. Bulletin of the World Health Organization 61, 339-344.

Laird M 1981. Blackflies: The Future for Biological Methods in Integrated Control. Academic Press, London.

Macdonald G 1957. The Epidemiology and Control of Malaria. Oxford University Press, London.

THE INCIDENCE OF ACUTE PESTICIDE POISONING IN DOMESTIC ANIMALS AND WILDLIFE: DIAGNOSES MADE AT THE VETERINARY RESEARCH INSTITUTE, ONDERSTEPOORT, SINCE 1957

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INTRODUCTION

The toxicology section at the Veterinary Research Institute at Onderstepoort receives specimens for toxicological analysis from the whole of South Africa as well as from neighbouring states. Complete records of all cases are kept at the laboratory, including the history, clinical signs, pathology, morbidity, mortality and analytical results. These unpublished data were used to compile the report.

AN ANALYSIS OF TRENDS IN POISONING

Arsenic was the most commonly used acaricide during the 1950's and 1960's. The high incidence of arsenical poisoning during those decades reflects the extreme toxicity of arsenic and the negligent use made of it by farmers. The popularity of arsenic has since declined and it has now been largely replaced as an acaricide by organophosphorous and pyrethroid compounds. Deaths from aresenical poisoning dropped dramatically after the banning of the poison in 1971 and the withdrawal of unused arsenic from farms. During 1957, 296 incidents of arsenical poisoning were diagnosed at the Veterinary Research Institute, Onderstepoort (Figure 13.6). The next year, only 153 incidents occurred, and since then a sharp decline has been evident until 1983, during which only four cases were brought to our attention. Amongst other uses, arsenic is currently applied as an organic herbicide (MSMA) for the control of jointed cactus *Opuntia aurantiaca*. This usage has been responsible for a few serious incidents of poisoning in livestock.

The first diagnosis of organophosphorous and chlorinated hydrocarbon poisoning at our laboratory was made in 1958. Since then, the use of these chemicals as acaricides and insecticides has increased dramatically. This explains the progressive increase in the poisoning of livestock and wildlife (especially birds) with these compounds (Figure 13.7). Initially, from 1967 to 1980, chlorinated hydrocarbons were the most important of the synthetic organic pesticides from a veterinary point of view. DDT, gamma-BHC, dieldrin and toxaphene were responsible for most organochlorine pesticide poisonings. These compounds are highly toxic and are absorbed rapidly from oily solutions. They can all penetrate intact skin when applied in the form of an oily solution, while dieldrin is also absorbed from the dry powder. After absorbtion, chlorinated hydrocarbon insecticides are stored in body fat. This even applies to DDT at dietary levels as low as 1 ppm. These chemicals can give rise to acute toxic effects or chronic poisoning resulting from their persistence in body fat. Because of their slow biodegradation, chlorinated hydrocarbon compounds such as DDT can have a long-term detrimental effect on the environment, eg they can adversely affect the reproduction of raptors. The use of many of these compounds has therefore been banned. Despite being banned in 1981, dieldrin is still a common cause of poisoning of animals, which suggests

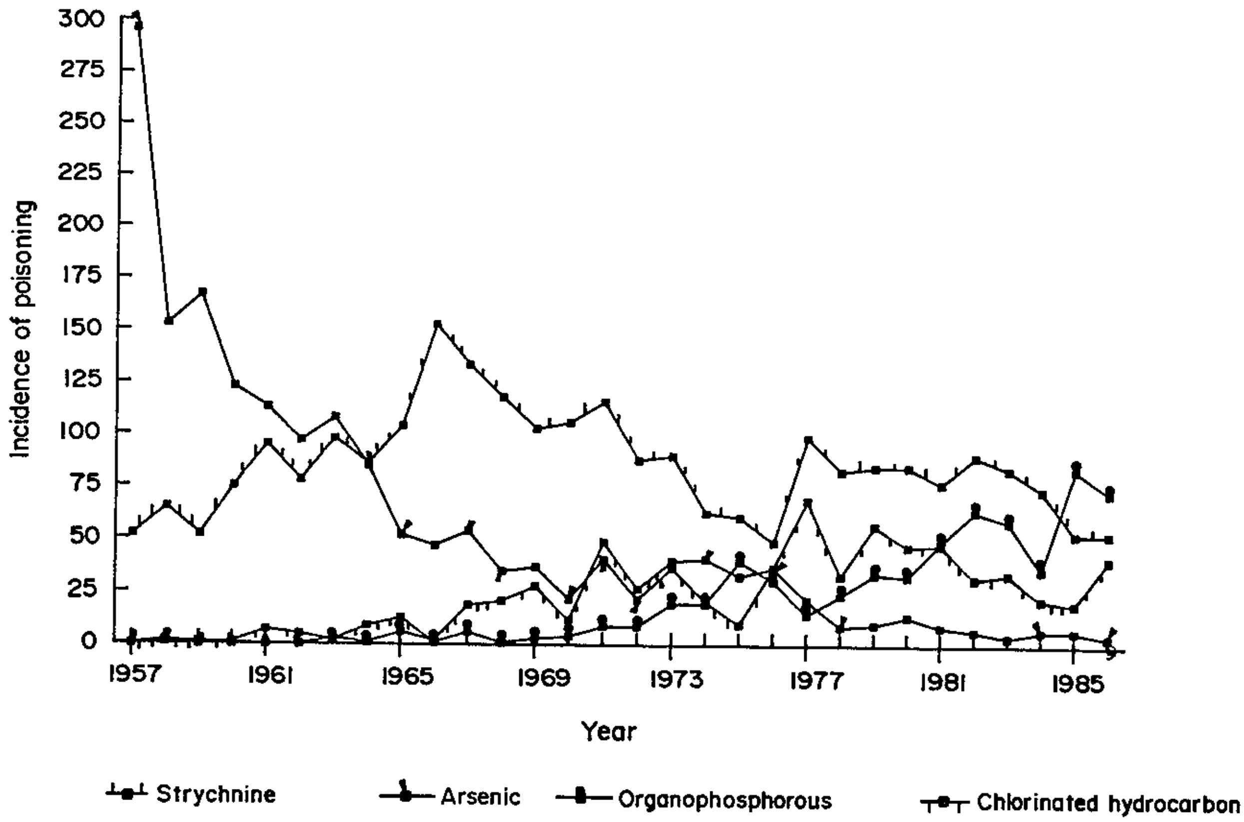

FIGURE 13.6 Incidence of strychnine, arsenic, organophosphorous and chlorinated hydrocarbon poisoning.

that stockpiles of this compound exist. The incidence of poisoning with chlorinated hydrocarbons increased from one in 1958 to a peak of 69 in 1977, while for organophosphates there were only 15 incidents in 1977 (Figure 13.6). Since then, organophosphate poisoning has become more important. The incidence of this poisoning increased progressively to 84 reported cases in 1984 while the incidence of chlorinated hydrocarbon poisoning declined slightly (20 cases in 1984). Parathion was the first organophosphate compound to be identified in an outbreak of toxicosis in 1958, and is still responsible for deaths. The poisoning of livestock with these compounds is usually accidental, whereas that of game animals is mostly intentional by poachers.

Strychnine poisoning, especially of dogs *Canis familiaris*, is a very common diagnosis made at the Toxicology Laboratory, even as long as 30 years ago (Figure 13.6). The highest incidence of poisoning was in 1966, when 153 cases were recorded. Strychnine is still widely used to control 'vermin' (ie wildlife species considered to cause agricultural, veterinary or public health problems) and for the malicious poisoning of dogs. Two peak periods of poisoning are usually experienced each year, namely in spring and autumn. These peaks coincide with the normal heat periods of bitches. The large number of Cape vultures *Gyps coprotheres* that have died of strychnine poisoning after feeding on poisoned carcasses during the past few years is a cause for great concern.

The chronic effects of pesticide residues on animals falls outside the ambit of this communication.

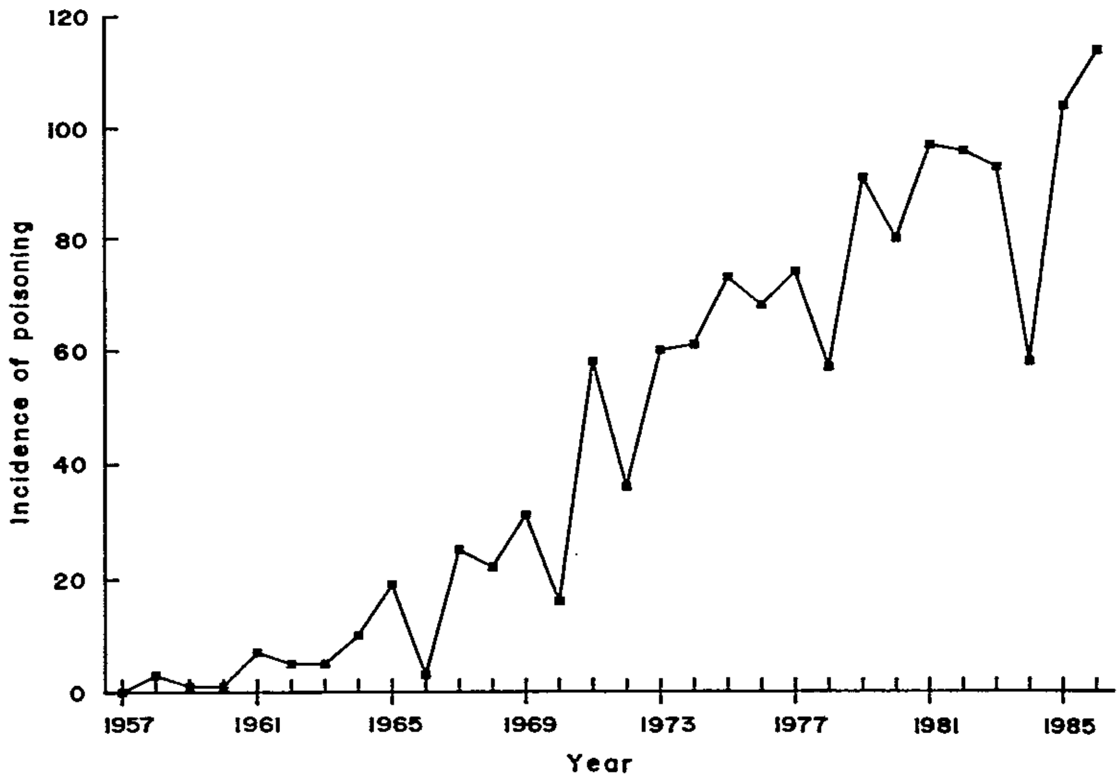

FIGURE 13.7 Incidence of synthetic organic pesticide poisoning.

THE CREATION OF PERMANENT BLACKFLY PROBLEMS BY THE CONSTRUCTION OF DAMS

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INTRODUCTION

The principle goal of this conference is to record how our environment and the renewable natural resources have changed over the years so that we may then be able to predict future change, and hopefully do something to try and avoid the adverse changes.

The purpose of this paper is to point out that controlled water use through the building of dams, weirs, irrigation canals etc, over the past 50 years, has led to both man and animals experiencing serious problems with blood-sucking blackflies (Diptera: Simuliidae). These problems now extend down the Vaal River from Parys to Warrenton; down the Orange River from the Hendrik Verwoerd Dam to Oranjemund, and even along the Great Fish River.

Prior to the construction of these dams, water flow in rivers depended largely on seasonal rainfall so that flow varied from flood levels to complete standstills. Under these circumstances *Simulium* blackflies could not prosper as they require a constant flow of organically enriched water. This also has to flow fast over the rocks to which the larvae are attached by anal suckers in order that they can filter out the food particles using their oral brushes. In a low-flow situation, as has been experienced in the lower Vaal River during recent drought years, only a limited number of larval attachment sites are available and there is competition for these between blackfly species, while predators also keep the blackfly numbers in check. However, under conditions of a constant high volume flow, one *Simulium* species, *S chutteri*, dominates, as it is adapted to using newly submerged rock surfaces, even in the presence of a fairly high level of silt. Its eggs survive in moist silt, until new flows release them, so colonization is almost immediate following release of water from dams. The 'pioneer' characteristics of this species allow it to complete some generations before predators and competitors have a chance to challenge it, and by this time the man-induced changes in water flow may have again made the river unsuitable for other species.

THE HISTORY OF BLACKFLY PROBLEMS

In the mid-1930's the Vaal Dam and Vaalharts Diversion Weir were built. In the 1950's reports of blackfly problems were received and in 1966 to 1967 aerial spraying with DDT was resorted to along the Warrenton-Windsorton stretch of the Vaal River. This was effective in killing the larvae and reduced micro-herbivore populations so severely that all rocks became covered with algae which in turn proved to be highly effective in preventng blackfly larvae from attaching. However, after floods had scoured the riverbed in the early 1970's, the blackfly problem returned (Howell and Holmes 1969).

After the completion of the Hendrik Verwoerd and P K Le Roux Dams in 1972 to 1978 *S chutteri* also became a problem along the Orange River. In 1977 to 1978 a water flow modification system was tested at the Vaalharts Weir and P K Le Roux Dam by weekly closure of these dams so as to expose pupae to dessication and cause larvae to drift, hopefully into still pools where they would not survive. This system was shown to work and has subsequently been implemented twice annually, in about May and again in August (Howell et al 1981).

However, recently the area under irrigation along the Orange River has increased greatly. Whereas, prior to the construction of dams, crops were restricted mainly to lucerne and vineyards which required little or no water in the winter, currently winter crops such as wheat, peas and lentils are important. For these a constant supply of water is required. Superimposed on this is the Electricity Supply Commission's need to generate hydroelectric power, especially at peak times in winter. As a consequence water shut-downs are currently difficult to implement.

Finally, in 1975, water from the Hendrik Verwoerd Dam was released via the Orange-Fish tunnel into the Fish River system. Since this time *Simulium chutteri* has become a serious problem in the Great Fish River (O'Keeffe 1985).

THE AVAILABLE DATA SERIES

To assess the extent of the blackfly problem along the Orange River various workers have undertaken single questionnaire surveys (G J Begemann in 1977 and M Car in 1982). However, since August 1984, L C Jordaan of the Veterinary Research Institute at Onderstepoort has conducted a monthly survey of the pest status of blackflies from P K Le Roux Dam to Oranjemund extending up to 100 km from the river. Two hundred farmers participate in this survey. Simultaneously, along the Great Fish River, 15 farmers participate in a similar blackfly pest status evaluation operated by the State Veterinarian, Grahamstown. This survey started in July 1984 and is still in progress.

The Directorate of Water Affairs maintains detailed daily records of water levels and water releases for both the Orange and Fish River systems. These records allow for the interpretation of fluctuations in blackfly populations, in so far as these are affected by river conditions.

CONCLUSIONS

Blackfly prevention or control would rank low in the planning of new water schemes. However, knowledge of this potential problem may hopefully prevent the implementation of systems favourable for their breeding when other alternatives are available which will not encourage blackfly. Should blackfly build-up still be unavoidable then the inclusion of water fluctuation capabilities should be considered.

REFERENCES

Howell C J and Holmes G W 1969. The control of Simuliidae in the Vaalharts irrigation complex. Journal of the South African Veterinary Medical Association 40, 59-67.

Howell C J, Begemann G J, Muir R W and Louw P 1981. The control of Simuliidae (Diptera, Nematocera) in South African rivers by modification of the water flow volume. Onderstepoort Journal of Veterinary Research 48, 47-49.

O'Keeffe J H 1985. The blackfly problem in the Great Fish River. The Naturalist 29, 3-8.

DEMAND FOR THE ONDERSTEPOORT VACCINES AGAINST TICK-BORNE DISEASES OF DOMESTIC STOCK

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INTRODUCTION

Man-induced changes in the incidence of tick-borne diseases of mammals evolved from his efforts to establish domestic stock in subtropical regions. These valuable resources have to be protected against indigenous and introduced tick-borne diseases (Bigalke et al 1976; Howell et al 1981; Bezuidenhout et al 1986). The general aim is to improve disease control with the use of vaccines and various methods of tick control including the selection of tick-resistant domestic stock. The indigenous fauna of the region also played, and still plays, important roles in the epidemiology of tick-borne diseases of domestic stock in that they act as reservoir hosts for some aetiological agents and are preferred hosts for certain important tick species.

The discovery of the causative organisms of anaplasmosis (tick-borne gallsickness), babesiosis (redwater) and cowdriosis (heartwater) lead to the development of live blood-vaccines to protect cattle, *Bos taurus* and *B indicus*, sheep *Ovis aries* and goats *Capra hircus*. A tick-borne disease, east coast fever of cattle, was introduced into the country in 1902. No vaccine could be developed and the disease ravaged the country for approximately 52 years before it was finally eradicated (Anonymous 1981). It remains the responsibility of the Division of Veterinary Services, in collaboration with the Veterinary Research Institute, to safeguard the country against the possible introduction of any tick-borne diseases that could result in epidemics like east coast fever. For the established tick-borne diseases, vaccination of young animals in endemic disease areas is the only effective long-term control strategy.

THE SUPPLY OF AND DEMAND FOR VACCINES

The first live blood-vaccine was sold in 1912 and for the purpose of this paper an attempt to obtain data series of vaccine sales from the Veterinary Research Institute at Onderstepoort was made. It was postulated that these data could help to evaluate the degree of success of tick-borne disease control through the decades, provided other data series such as domestic stock population records, percentage of total population at risk of contracting disease, mortality and morbidity rates, production losses, environmental conditions, and estimates of what the control of ticks and tick-borne diseases cost this country per annum, were available. However, it was soon found that certain of these data do not exist and those that do, are not readily accessible or are not in a useful form. A joint, well coordinated effort should be made to 'release' relevant data and to identify the need for and the type of information required in order to establish meaningful data-recording systems in future.

The data series available on the tick-borne disease vaccine sales are presented in Figure 13.8. It was disappointing to find that reliable records could only be found for the period since 1970. However, the pattern of vaccine demand over this 16-year period shows a sharp increase followed by a gradual decrease for anaplasmosis and steady increases for both babesiosis and cowdriosis. The anaplasmosis vaccine sales peaked during the decade 1971 to 1980, which can probably be correlated with the above average rainfall received in this decade (Tyson 1986). Had these figures been presented for only the last 10 years, such a phenomenon would probably not have been recognized and a prediction of a possible recurrence in a future high-rainfall period would have been missed. This simple example possibly serves to demonstrate the need for long-term data series. However, in the absence of data on the other factors influencing the demand for vaccines, no attempt can be made to identify any meaningful trends that could be used to predict future patterns.

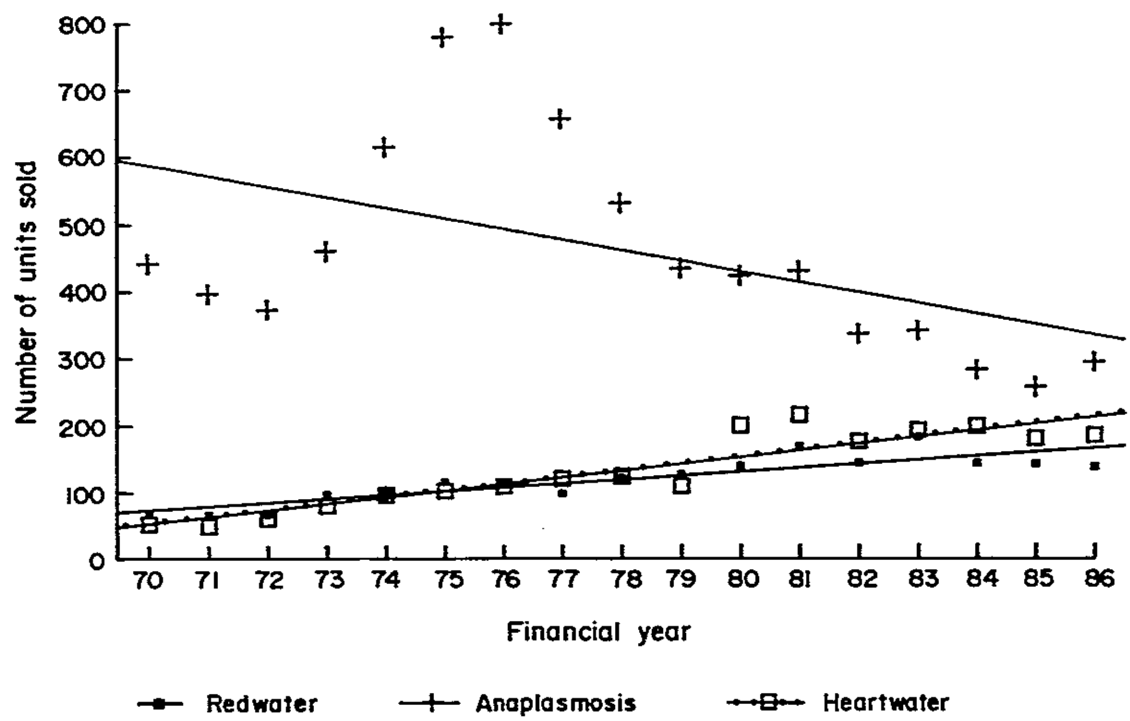

FIGURE 13.8 Trends in the sale of vaccine to winter tick-borne diseases, 1970 to 1986.

THE INTERPRETATION OF CHANGES IN DEMAND

Without ancilliary data the interpretation of changes in the demand for vaccines is difficult. An increase in vaccine sales could mean: improved livestock management where more animals are regularly vaccinated; higher incidence of disease outbreaks as the result of deteriorating epidemiological parameters that control the enzootic stability of disease, eg the influence of environmental conditions on tick survival; introduction of the infection into disease-free areas (epidemics); production of improved vaccines; better marketing of disease control strategies; higher stock prices.

Decrease in vaccine sales could reflect aspects such as: reduction in stock numbers; alternate disease control measures adopted to suit the type of stock management; deterioration of favourable climatic conditions for tick survival; history of regular vaccination creating stable disease situations with little or no clinical disease resulting in termination of vaccine programmes; resistance to using high-care live blood-vaccines; poor livestock management; poor marketing of long-term disease control strategies.

TICK-BORNE DISEASES NOT YET COVERED BY VACCINES

Companion animals, horses *Equus caballus*, dogs *Canis familiaris* and cats *Felis catus*, are also severely affected by tick-borne disease for which there are no vaccines available. Working horses and dogs which are important resources are totally reliant on natural acquired immunity and chemotheraphy to protect them against tick-borne diseases. Wild animals including rare species suffer tick-borne disease under conditions of stress mostly as a result of poor management.

CONCLUSION

This investigation of human-induced changes in tick-borne disease epidemiology indicates that we probably lack the relevant long-term data series that would enable us to accurately predict future changes in this field. It remains a challenge for the relevant sections in veterinary science to assemble these data series in the future.

REFERENCES

Anonymous 1981. The eradication of east coast fever in South Africa. Journal of the South African Veterinary Association 52, 71-73.

Bezuidenhout J D, Potgieter F T and du Plessis J L 1986. Recent developments in the control of tick borne diseases. In: Lötter L L, Pieterse P J S, Kemm E H, Verwoerd D W and Steyn P J J Research Highlights 1986. Animal Production. Department of Agriculture and Water Supply, Pretoria. pp 47-149.

Bigalke R D, de Vos A J and Barrowman R P 1976. The control of some tick-borne diseases in South Africa. Bulletin Office Internasional des Epizooties 86, 89-100.

Howell C J, de Vos A J, Bezuidenhout J D, Potgieter F T and Barrowman P R 1981. The role of chemical tick eradication in the control of tick transmitted diseases of cattle. Proceedings, International Conference on Tick Biology and Control, Grahamstown, 27-29 January 1981. pp 61-66.

Tyson P D 1986. Climate change and variability in southern Africa. Oxford University Press, Cape Town.

LONG-TERM ENVIRONMENTAL EFFECTS OF ACARICADAL USAGE

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INTRODUCTION

Chemical control of ticks has the beneficial effect of preventing direct damage and tick-borne disease transmission by removal of the vectors involved. Without this synthetic aid, animal production in Africa would be so severely reduced that it would not be able to provide the protein requirements of its ever increasing human population. The use of these chemicals, however, have various, well documented, detrimental effects on the environment. With regard to tick control, recent research has raised the principle of integrated control, employing a strategy of "living with the tick" (Sutherst 1981). This involves the use of natural control mechanisms (eg oxpecker birds, *Buphagus* species, and natural host resistance) in combination with vaccination against tick-borne diseases and chemical control of ticks when their numbers reach levels which threaten direct damage and disease transmission. The aims of such a strategy are ultimately cost-effective livestock production where the costs involved in tick control are offset against the losses caused by ectoparasite infestation. This implies that the methods employed in any particular area would be dictated by the specific conditions of vegetation, climate, tick species present, breed of stock involved and immune status, marketing strategy, type of dip used, and vaccinations performed (Howell et al 1981).

THE ENVIRONMENTAL EFFECTS OF PAST PRACTICES

The use of acaricides has mainly influenced three phenomena in the natural control of tick numbers, their direct effects and their transmission of diseases.

The effects on oxpeckers (Stutterheim 1976, 1979).

Toxic dips have drastically affected the incidence and distribution of oxpeckers which are specialized predators of ticks. The current distribution of these birds, especially after the advent of the organo-phosphate era in 1969 (Baker 1982), compares unfavourably with their past distribution. These birds have disappeared from the ranching areas of Zululand, Natal and the central Transvaal bushveld.

The effect of dips on oxpeckers is two-fold in that intake of ticks that have been in contact with chemicals toxic to the birds leads to increased mortality while the depletion of their primary food source results in migration and/or avoidance of the area. Toxicity to the birds is mainly associated with the organo-phosphates, while the new generation of synthetic pyrethroid dips are so effective that they completely deplete the oxpecker's food source if used intensively. Current oxpecker re-establishment programmes are dependent on the full cooperation of all the farmers in a large area, not only in their limiting the use of dips but also in their accepting a philosophy of tolerance of ticks on their animals. The success of these attempts can only be assessed through long-term monitoring of oxpecker distribution and tick incidence. It remains to be seen whether the density of ticks necessary to sustain an oxpecker population is not too high as regards disease transmission. Also in need of measurement are the long-term effects of tick presence on host immunity.

Effects on the immunity of hosts to ectoparasites

Chemical control of ticks prevents the natural selection within the host's genetic pool of host immunity to ectoparasites in general and to ticks in particular. There is a very wide range in the distribution of host resistance indices in herds subjected to different dipping regimes. Indigenous breeds (*Bos indicus* eg Sanga, Nguni) under nondip conditions have more individuals with high resistance indices than do herds subjected to dipping (Figure 13.9).

The expression of host resistance can only be gauged under conditions of tick challenge. Host resistance is a genetically determined factor present in South African indigenous *Bos indicus* Sanga types) and intermediate breed cattle (locally adapted *Bos taurus*, eg Bonsmara) but its extent is presently unknown (Bonsma 1981). The long-term monitoring of experimental cattle herds of intermediate breed would provide invaluable data on this resistance's potential value.

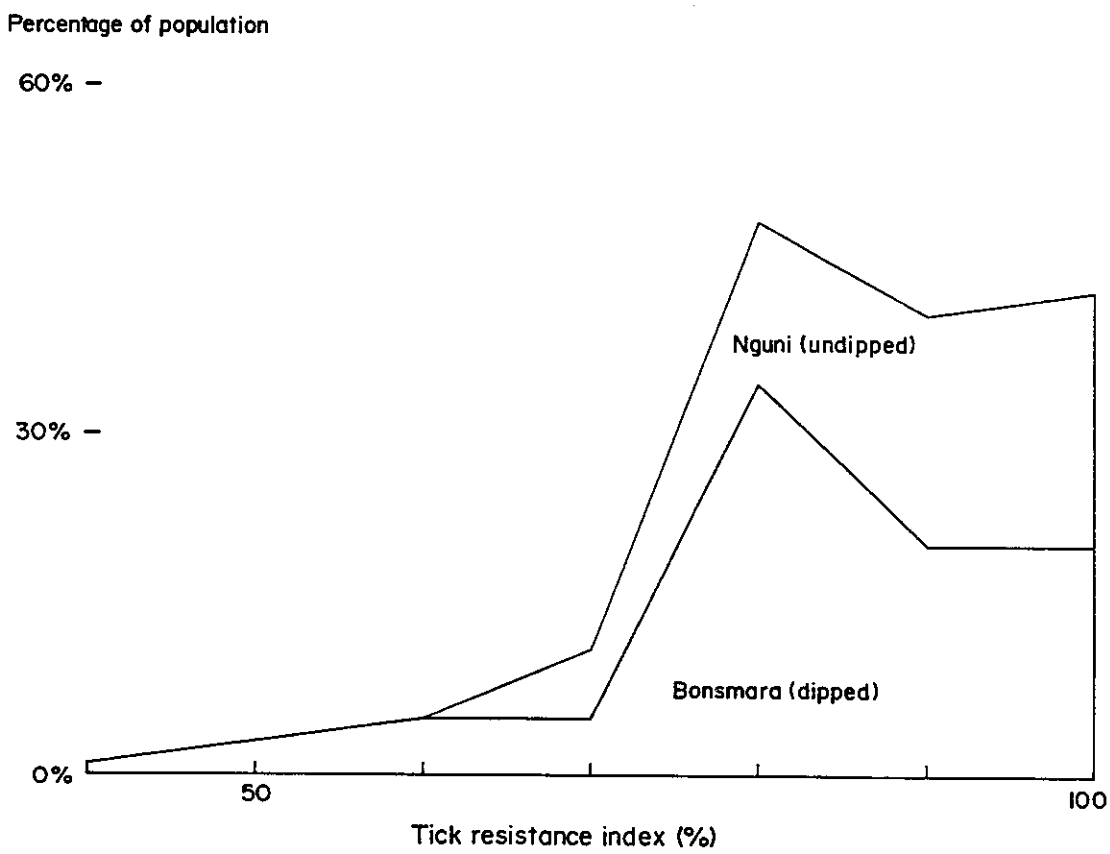

FIGURE 13.9 Percentages of populations of dipped and undipped cattle exhibiting a particular level of resistance to tick infestation.

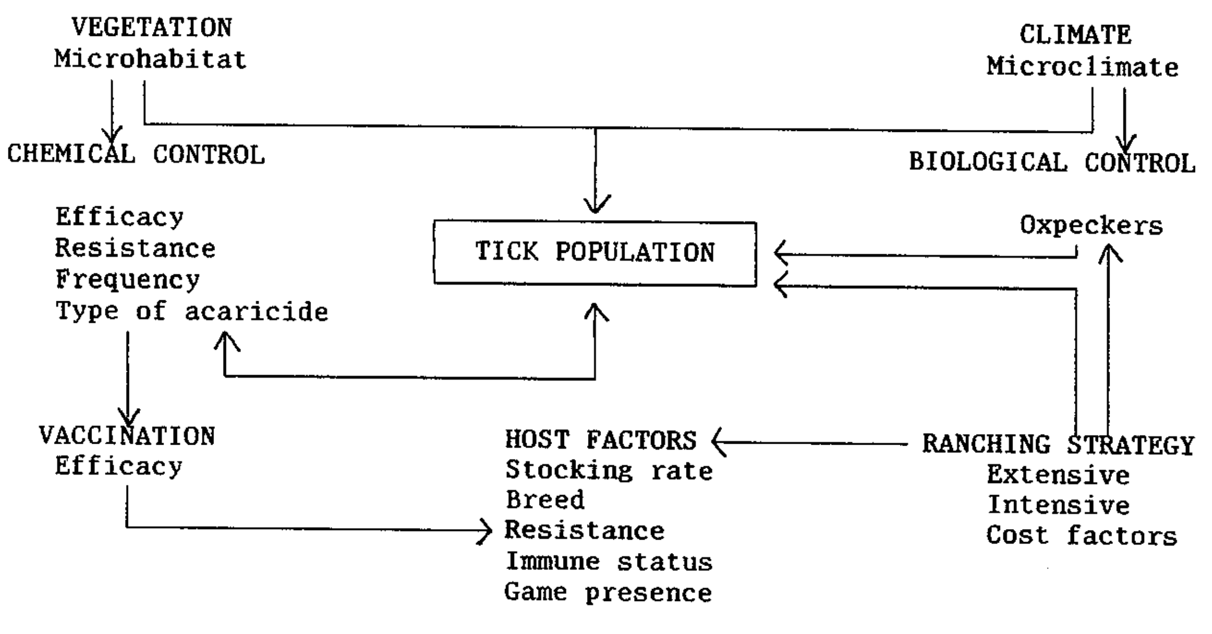

FIGURE 13.10 Direct and indirect factors influencing tick population fluctuations to be considered in integrated tick control strategies.

Effects on host immunity to tick-borne diseases

The natural immunity of hosts to tick-borne diseases remains undeveloped in the absence of tick challenge, creating enzootic instability, subsequently artificially stabilized by vaccination in certain areas. Long-term field data on the immune status of animal populations at risk are virtually nonexistent, but this factor plays an important role in disease control and stability.

The three areas mentioned above represent just some of the phenomena involved in an integrated tick control approach. Figure 13.10 illustrates parameter interactions with regard to integrated tick control.

REFERENCES

Baker J A F 1982. Some thoughts on resistance to ixodicides by ticks in South Africa. Proceedings of a Symposium on ectoparasites of cattle. 15 and 16 March 1982. Pretoria.

Bonsma J C 1981. Breeding tick repellant cattle. In: G B Whitehead and J D Gibson (editors) Tick biology and control. Proceedings of an International Conference on tick biology and control. Grahamstown, South Africa, January 1981. pp 67-77.

Howell C J, de Vos A J, Bezuidenhout J D, Potgieter F T and Barrowman P R 1981. The role of chemical tick eradication in the control and prevention of tick transmitted diseases of cattle. Proceedings of an International Conference on tick biology and control. Grahamstown, South Africa, January 1981.

Stutterheim C J 1976. The biology of the red-billed oxpecker, *Buphagus erythrorhynchus* (Stanley 1814), in the Kruger National Park. MSc Thesis, University of Pretoria. Pretoria.

Stutterheim C J 1979. Die ekologie van die Buphaginae in Suidelike Afrika. DSc Thesis, University of Pretoria, Pretoria.

Sutherst R W 1981. Is the Australian pest management approach to tick control relevant to Africa? In: G B Whitehead and J D Gibson (editors) Tick biology and control. Proceedings of an International Conference on tick biology and control. Grahamstown, South Africa, January 1981. pp 79-85.

SOME ECOLOGICAL FACTORS INVOLVED IN THE OCCURRENCE OF FOOT-AND-MOUTH DISEASE IN SOUTHERN AFRICA

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INTRODUCTION

Foot-and-mouth disease (FMD) is an acute highly contagious virus infection almost exclusively of ruminants and swine which is characterized in domestic livestock by high morbidity, low mortality and vesicular lesions in the mucosa of the mouth and skin of the interdigital spaces and coronary bands. In the southern African subregion FMD tends to occur in areas where either extensive cattle farming is practised or where subsistence agriculture is the predominant activity.

FMD is important because of its implications for agricultural exports to countries in the developed world free of the condition. Since Botswana, South Africa and Zimbabwe all rely heavily on agricultural exports of animal origin, the uncontrolled presence of FMD in any of these countries could have disastrous consequences for such exports. It has been estimated, for example, that uncontrolled FMD in South Africa would impact on approximately R2 billion-worth of agricultural products annually (J Krige personal communication).

THE ROLE OF BUFFALO IN THE EPIDEMIOLOGY OF FMD

Four observations indicate that buffalo *Syncerus caffer* in southern Africa play a central role in the epidemiology of FMD:

1. Endemic FMD areas are confined to regions where buffalo occur (the converse does not always apply, eg Addo Elephant National Park and the Hluhluwe/Umfolozi complex).

2. Buffalo populations in enzootic areas have high infection rates, eg 80% or more of animals aged three or more in the Kruger National Park have been infected with two or more South African Territories (SAT) virus types.

3. There is no evidence that any free-living species other than buffalo can maintain SAT-type infections.

4. In countries such as the Republic of South Africa, Botswana and Zimbabwe it can be accepted that SAT-type infections do not generally persist in cattle (the only other known maintenance host) in periods between epidemics.

Thus understanding the relationship between buffalo and the SAT-type viruses holds the key to appreciating how FMD persists in southern Africa and also the precise way in which these viruses infect domestic livestock.

AN HYPOTHESIS FOR THE PERSISTENCE OF SAT-TYPE VIRUSES IN BUFFALO POPULATIONS

On the basis of buffalo being herd animals, generally becoming infected early in life, being seasonal breeders - most calves arrive in midsummer (Smithers 1983) and being capable of excreting large quantities of virus when acutely infected (Gainaru et al 1986), it is postulated that SAT-type infections are typical 'childhood' infections of buffalo which occur episodically in herds when sufficient susceptibles (generally young animals which have lost their maternal immunity) are present. Furthermore, during these episodes (which are likely to be inapparent because many buffalo infections are subclinical) buffalo herds provide a potential source of infection for other species with which they come into close contact. In periods between infection episodes the virus is maintained within individual herds by carrier animals.

THE OCCURRENCE OF FMD IN DOMESTIC LIVESTOCK IN SOUTHERN AFRICA

Historical records (Henning 1956) indicate that FMD occurred sporadically in what are now South Africa and Zimbabwe prior to 1896.

The great rinderpest panzootic of 1896 to 1903 decimated both cattle and wildlife populations and was undoubtedly responsible for the disappearance of FMD from southern Africa until 1931 (Henning 1956).

TABLE 13.2 The annual incidence of SAT-type FMD outbreaks in domestic cattle in some southern African countries between 1850 and 1986 (based on information in Food and Agriuclture Organizaton, World Health Organization, International Office of Epizooites 1974 to 1976; Pereira 1981)

Country	<-1850-1899->	<-1900-1929->	19 30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
RSA[a]	prevalent	undetected	0	0	0	2*	0	0	0	1*	1*	2*	0	0	0	0	3*	3*	0	0	0	0
Zimbabwe[a]	"	"	0	1	0	0	1	0	2*	1*	1*	0	1*	0	0	1*	1*	1*	0	1	0	0
Botswana[a]	situation unknown	"	0	0	0	1	1	0	0	1	0	0	0	0	0	0	1	0	0	0	1	0
SWA/Namibia[a]	"	"	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1
Zambia[b]	"	"	0	0	0	1	2	0	0	0	0	0	1	0	1	0	1	0	0	0	1	0
Mozambique[c]	"	"	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Angola[c]	"	"	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decade Totals	?	1900-1909-0 1910-1919-0 1920-1929-0	20										20									

Country	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
RSA[a]	0	2	0	0	3	1	0	4	2	2	3	3	0	0	0	1	0	1	3	1	0	1	0	1	2	2	0	1	1	3	1	1	0	1	0	0	0
Zimbabwe[a]	1	1	2	5	3	3	0	3	2	2	2	2	2	0	1	1	4	1	0	0	1	1	4	1	3	5	3	3	3	2	2	3	0	3	1	0	0
Botswana[a]	0	0	0	0	0	0	0	1	1	0	2	2	0	1	1	1	1	0	1	0	0	0	0	0	0	0	0	2	2	2	1	0	0	0	0	0	0
SWA/Namibia[a]	0	0	0	0	0	0	1	0	0	0	1	1	1	0	1	0	0	0	1	1	1	1	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0
Zambia[b]	1	0	0	1	1	1	1	1	1	0	1	0	0	0	1	1	0	0	0	1	0	0	0	1	2	1	1	0	0	1	0	1	1	0	1	0	0
Mozambique[c]	0	1	0	0	0	1	0	0	1	1	1	0	0	0	2	2	1	1	0	1	1	2	1	0	3	1	1	2	2	3	3	3	3	2	2	2	3
Angola[c]	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	2	2	2	2	2	0	0	0	0	0	0	0	0
Decade Totals	51										55										79										35 (7 years) (decade ≡ 50)						

* - outbreaks where virological confirmation was not obtained
[a] - reliable data
[b] - data may be incomplete
[c] - data probably incomplete

A number of factors have affected the incidence of disease between 1931 and the present (Table 13.2). These include:

1) generally increasing cattle populations;
2) decreasing buffalo distribution outside major wildlife reserves and the converse inside some reserves, eg the Kruger National Park (de Vos et al 1983);
3) the use of fences to separate wildlife and cattle populations - experimental and circumstantial evidence suggest that this is an effective measure (Gainaru et al 1986);
4) the prophylactic immunization of cattle populations at risk since the mid-1960's. Improved vaccines have been in use since the beginning of the present decade;
5) possibly climatic factors such as drought; and
6) socio-political upheavals.

CONCLUSIONS

FMD viruses sustained in buffalo populations (the SAT-types) have periodically "spilled over" into domestic cattle populations since records were kept. However, the depopulation of buffalo and cattle caused by the rinderpest pandemic of 1896 to 1903 reduced contact between these two species below an unknown threshold value so that the disease in domestic stock disappeared in southern Africa between the turn of the century and 1930.

Since 1931 the incidence of FMD has increased - presumably due to the recovery of cattle and buffalo populations and despite serious attempts at limiting its occurrence by immunization and other control strategies.

REFERENCES

De Vos V, Bengis R G and Coetzee H J 1983. Population control of large mammals in the Kruger National Park. In: Owen-Smith R N (editor) Management of large mammals in African conservation areas. Haum Educational Publishers, Pretoria. pp 213-231.

Food and Agriculture Organization, World Health Organization, International Office of Epizooites 1974 to 1986. Animal Health Year Books, Rome.

Gainaru M D, Thomson G R, Bengis R G, Esternhuysen J J and Pini A 1986. Foot-and-mouth disease and the African buffalo (Syncerus caffer). II. Virus excretion and transmission during acute infection. Onderstepoort Journal of Veterinary Research 53, 75-85.

Henning M W 1956. Animal diseases in South Africa. Central News Agency, South Africa.

Pereira H G 1981. Foot-and-mouth disease. In: Gibbs E P J (editor) Virus diseases of food animals. Vol II. Academic Press, London. pp 333-363.

Smithers R H N 1983. The mammals of the southern African subregion. University of Pretoria, Pretoria.

CHAPTER 14. PALAEOENVIRONMENTS AND RECENT ENVIRONMENTAL CHANGE IN SOUTHERN AFRICA

GENERAL OVERVIEW

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INTRODUCTION

Environments are continuously changing and thus no clear break is evident between recent change and changes that occurred in earlier times. Modern data sets on environmental change are on the scale of months, years and decades and have high resolution; but they are short relative to those for environmental changes measured on geological time scales. As time scales are lengthened the resolution is reduced. The longer temporal perspective is important because it shows a procession of change leading into modern sets. The most relevant observations for appreciating the full amplitude of environmental changes that characterized the Pleistocene (1,8 Myr to 10 000 years BP) and the Holocene (10 000 to 0 years BP) are those covering the last 18 000 years.

SOURCES OF INFORMATION

The time scale for past environmental data beyond written records is provided by radiocarbon, other chronometric and relative dating methods. These have a precision of half a per cent at best. The available data come from physics (environmental isotopes), palaeobiology (eg palynology, palaeobotany, palaeontology), archaeology and earth sciences (eg stratigraphy and sedimentology, geomorphology, soils, hydrology). These fields of study provide the means for reconstructing past environmental conditions and they provide methods for the measurement of qualitative and quantitative differences from present day values. Inferences about past environmental conditions involve second-order concepts (proxy data). For example inferences drawn from the study of river alluvium (Partridge this volume) must take into account the runoff regime before any conclusions can be drawn; in the interpretation of the fossil faunal record (Avery this volume) it is necessary to consider the ecology of the animals; in isotopic studies (Verhagen this volume) the geochemistry of the deposits must be understood. It is the imprint of palaeoenvironmental conditions in the record of the past that form the database. In most terrestrial situations this record is discontinuous but it may show greater continuity offshore. Major changes in palaeoenvironmental boundary conditions, like the Last Interglacial or the Last Glacial Maxima can be identified more readily than tracking high frequency oscillations around some norm.

OUTLINE OF ENVIRONMENTAL CHANGES ON A GEOLOGICAL TIME SCALE

During the last 2,5 Myr there has been a pulsing of climates related to the effects of planetary orbital forcing (Deacon; Partridge this volume) resulting in the alternate expansion and contraction of continental and sea ice masses at high latitudes and significant climatic fluctuations in lower, unglaciated, latitudes, such as those of southern Africa. Within the last million years there has been a succession of glacial-interglacial couplets of approximately 100 000 years duration, with the warmer interglacial occupying on average 10 000 years. The amplitude of change in mean annual temperature between full interglacial and full glacial conditions were of the order of five to 10°C globally. In the latitudes of southern Africa the range was closer to five degrees Centigrade (Talma and Vogel this volume). The last one per cent of the present interglacial or Holocene (10 000 to 0 years BP) contains the modern environmental data series.

Temperature changes have been related to major changes in ice volumes which have in turn led to fluctuations in sea levels of 100 m and more. Approximately 18 000 years ago the sea was some 120 m below the present level, exposing large areas of the southern African continental shelf. The subsequent transgression has had a marked effect on coastal ecology and coastal dune formation (Illenberger this volume). The Last Glacial Maximum centred on 18 000 years BP is a convenient bench mark because it represents the extreme of coldness and dryness in the latitudes of southern Africa. Climatic amelioration after the Last Glacial Maximum was relatively rapid and a temperature regime comparable to the present was established 10 to 12 000 years ago at the beginning of the Holocene. Temperature variations during the Holocene have been of the order of one to two degrees Centigrade around the annual mean. The main variable driving cycles of environmental changes of 10^2 to 10^3 years duration in the Holocene was precipitation which is reflected in Valley fills and in ground waters. Smaller deviations in all climatic parameters probably characterized the whole period but are largely beyond the resolution of the palaeoenvironmental data. Such fine fluctuations are seen in modern data series.

PALAEOECOLOGICAL CHANGES IN LATER GEOLOGICAL TIMES

The Pleistocene has been a significant period for the evolution of modern biotas. The pulses of Pleistocene changes have caused the ranges of plant and animal taxa to expand and contract. The predominant aridity of the Pleistocene has led to the development of "islands", or centres, of plant species richness. Extinction is best documented for large mammals, and the most recent wave of extinctions took place at the end of the Pleistocene and in the early Holocene.

During the Pleistocene human populations became dispersed through southern Africa. Human activities have compounded the effects of natural forces of change in ecosystems; the most significant of these have been the use of fire, with a documented occurrence of more than 100 000 years, and farming in the last two thousand years. Human effects on the environment have been amplified by industrialization.

FUTURE RESEARCH

There is general agreement that while knowledge of the history of environmental change in the Pleistocene-Holocene has expanded considerably in the last decade, there is a need to acquire records with high temporal resolution from longer continuous sequences. These would include sedimentary sequences (onshore and offshore) that had high deposition rates, corals, speleothems and tree rings. Studies should concentrate on measuring change in a variety of parameters varying from pollen rain to stable isotope ratios. They should be concerned with rates of change across boundaries that relate to some significant periods such as the Last Glacial Maximum or the Pleistocene-Holocene boundary, as well as with calibrating significant fluctuations in intervening periods. The research will have to be designed so that the parameters measured can be translated into the effects of changing environmental factors on terrestrial ecosystems. As palaeoenvironmental data improve in resolution, on both temporal and spatial scales, they will become an even more valuable resource for understanding the processes and causes of observed changes.

CONCLUSIONS

The purpose of this contribution has been to provide a long-term view against which to evaluate recent environmental change. On the longer time scales for example, the Late Pleistocene and Holocene cyclic variation in environmental parameters, measured on a scale of thousands of years, have a greater amplitude than the scale of variations observed in modern data series.

GEOMORPHOLOGICAL PERSPECTIVES ON RECENT ENVIRONMENTAL CHANGE IN SOUTHERN AFRICA

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INTRODUCTION

The present landscape of southern Africa is largely the product of processes that have operated since the fragmentation of Gondwanaland, some 130 Myr ago. The geomorphic evolution of the subcontinent during this period is reasonably well documented from studies of landforms, marine and terrestrial depositional sequences and palaeosols (Partridge and Maud 1987). Although it was influenced by pre-existing lithology and structure, the broad evolutionary picture that has emerged relates chiefly to changing global climate and to a series of tectonic events which appear to have exerted a major influence on regional patterns of temperature and precipitation.

Not unexpectedly, the precision with which key events can be dated improves with time, and the extent and timing of changes is best comprehended over the past two to three million years; reasonably good resolution is, in fact, restricted to the last 30 000 years.

MAJOR EARLY LANDSCAPE CYCLES

The breakup of Gondwanaland was preceded by upwarping and volcanism in the vicinity of the incipient continental margins. Reconstructions based on evidence from kimberlitic diatremes and the subsequent tectonic history of southern Africa (Hawthorne 1975; Partridge and Maud 1987) indicate that at the time of rifting, the interior of the subcontinent had elevations ranging from 2 300 to 2 400 m in Lesotho to about 1 800 m around Kimberley. These high elevations imply that marginal downwarping and scarp formation must have been of considerable magnitude. Energy potentials were, therefore, high, and the resulting cycle of erosion was characterized, in its initial stages, by rapid recession of the marginal escarpments and massive sedimentation of the continental shelf. The thick offshore Cretaceous sequences surrounding southern Africa bear testimony to the vigour of this erosion. Although there is evidence for a number of tectonic interludes, shelf sedimentation showed a generally declining trend throughout the Cretaceous, and by the beginning of the Oligocene accumulation had largely ceased (Dingle et al 1983).

There is thus clear evidence for a major cycle of onshore erosion and offshore deposition which began with the fragmentation of Gondwanaland and was ended by widespread tectonic uplift at the end of the early Miocene. This cycle has been termed the African, following the earlier nomenclature of King (1949). Although evidently multiphase, the African cycle produced a single, well planed landsurface, and cannot be resolved into subcycles on the basis of separate erosional benches of regional extent. This surface occurs at different elevations below and inland of the Great Escarpment; in the interior, elevations at the end of the cycle were of the order of 500 to 700 m above sea level, with a few areas of high ground, such as the highlands of Lesotho, standing above the reduced surface.

The African erosion surface is characterized by a deeply weathered and kaolinized soil profile which relates partly to the length of time which has elapsed since its planation, but chiefly to the generally warm humid, or subhumid, conditions which prevailed over southern Africa during the Cretaceous and much of the early Tertiary (Maud and Partridge 1987). In the eastern part of the subcontinent, including Natal, the Transvaal Highveld and the north-eastern Cape, laterite caps the deeply kaolinized profiles, while in the eastern, southern and western Cape, Namaqualand and southern Namibia the capping is of silcrete. Opinions differ on the climatic circumstances under which silcrete has formed (Summerfield 1983; Twidale and Hutton 1986), but in southern Africa, the presence of solonetzic structures in the B-horizons of many silcretized profiles, as well as the widespread occurrence of 'dorbank', an incipient form of silcrete, in arid areas, suggests that the western parts of the subcontinent were fairly dry (Maud and Partridge 1987). Thus, a well defined east-west climatic gradient seems to have been present across southern Africa by the end of the Cretaceous[1].

The prolonged African cycle was terminated by moderate epeirogenic uplift of the subcontinent some 18 Myr ago towards the end of the early Miocene (Partridge and Maud 1987). Deformation of the African surface, and

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[1]The presence of pebbles of silcrete in marine deposits of Eocene age in the south-eastern Cape (Siesser and Miles 1979; Maud et al 1987), suggest that silcrete formation on the African surface was a Cretaceous, or at latest, earliest Tertiary phenomenon.

divergence between this and the succeeding Post African I surface, indicate that this movement was asymmetrical, ranging from about 300 m in the east to about 150 m inland of the west coast. Larger movements occurred locally along inland axes of warping. It is unlikely that these movements were of sufficient magnitude to cause major climatic shifts on a regional scale, but they appear to have complemented, locally, the effects of changing oceanic circulations in increasing the east-west climatic contrast and the trend towards greater aridity in the continental interior.

Palaeoclimatic evidence for the Neogene is derived from a number of terrestrial sequences on the Post African I surface in the coastal hinterland of the subcontinent. The Knysna lignites of the southern Cape preserve in pollen and wood fragments the remains of a mid-Miocene forest community (J A Coetzee personal communication), while the Tsondab Sandstone Formation, which underlies much of the present Namib sand sea, is widely accepted as reflecting arid conditions (Ward et al 1983). In the past the occurrence of these and other coastal deposits has been ascribed, in the main, to eustatic fluctuations in sea level, but new evidence points conclusively to the dominant role of tectonic movements in constraining the altitudinal distribution of these older deposits (Partridge and Maud 1987; Maud et al 1987). This does not imply that sea level fluctuations were absent during the Cainozoic, but rather that their amplitude and local significance has sometimes been exaggerated. One important marine transgression, dating to the early Pliocene, gave rise to marine deposits and terraces at elevations of 75 to 90 m along the west coast (Hendey 1981; Pether 1986); these can be correlated with widespread deglaciation in Antarctica between about 3,1 and 2,5 Myr (Webb et al 1984; Harwood 1985).

In the continental interior, geomorphic evidence for climatic change during the Miocene is less satisfactory. However, data from the southern Kalahari suggest that the Molopo-Nossob drainage was re-established on top of the sedimentary filling of the Kalahari Basin during Miocene times; this would have been possible only under more mesic circumstances than prevail in this area today (Partridge and Maud 1987).

The Post African I cycle of erosion was brought to an end by an event which contributed more to the present distribution of relief within southern Africa than did any previous tectonic episode since the fragmentation of Gondwanaland. Dating to about 2,5 Myr in the late Pliocene, this was marked by uplift of some 600 to 900 m in the south-eastern hinterland; however, movements declined to about 200 m inland of the southern coast and to 100 m or less in the western areas, thus amplifying the altitudinal asymmetry established in the Miocene (Partridge and Maud 1987). The result of this movement in the elevated eastern areas, which included the interior of Natal and the eastern Cape, the Highveld of the Transvaal and the Orange Free State, and the Lesotho Highlands, would have been a temperature decline at least as great as that which occurred during the Last Glacial Maximum in southern Africa. A roughly simultaneous global decline in temperature, reflected by the onset of ice rafting in the North Sea (Shackleton et al 1984) and by major growth of the East Antarctic ice sheet (Denton 1985), must have greatly increased the ecological significance of this event.

The climatic response to these Late Pliocene changes was generally in the direction of greater aridity. Although earlier dune-building episodes may have occurred, there is little doubt that the maximum extension of the red 'Kalahari' sand, which resulted in the spread of dunes and sand blankets far beyond the limits of the Kalahari Basin into the western Transvaal, western Orange Free State, northern Cape and parts of the Karoo extending as far south as the Cape Fold Mountains, occurred after this event (Maud and Partridge 1987). The oldest terraces of the Vaal River are probably of Late Pliocene age on the basis of limited faunal evidence; their extensive coarse alluviation is essentially a semi-arid phenomenon (Partridge and Brink 1967). Further evidence is forthcoming from the hominid-bearing cave deposits of Makapansgat and Sterkfontein, in which a change in style of sedimentation, from predominantly fine materials, deposited, at least in part, under subaqueous conditions, to more gravelly debris and sheetflood accumulations occurred around 2,5 Myr ago (Partridge 1985a). Of added significance is the fact that approximately concurrent faunal changes indicate a shift to more open vegetation (Vrba 1974, 1975); Tobias (1985, 1986) has pointed to a major nodal episode in hominid speciation at about this time, and there is a wealth of evidence that these evolutionary events were a response to climatic forcing. This is the focus of a series of international conferences (Palaeoclimate and Evolution 1985, 1986).

THE PLEISTOCENE

Lower and middle Pleistocene

No major landscape cycles have occurred in southern Africa since the late Pliocene, and most of the geomorphic evidence for environmental change during subsequent periods comes from local inland depositories and the coastal margins. The latter bear the direct imprint of repeated glacio-eustatic sea level movements which occurred in rather regular cycles in relation to the Milankovitch periods of 100 000 years (eccentricity of the Earth's orbit), 41 000 years (tilt of the Earth's axis) and 21 000 years (precession of the equinoxes) (Hays et al 1976). There is recent evidence to suggest that the 41 000-year period dominated the early Pleistocene, while the 100 000-year cycle was pre-eminent after this time (Ruddiman et al 1986). Dune fields and cordons of various ages, present along this coastal margin and in the immediate hinterland, attest to a series of climatically induced sea level changes throughout the Pleistocene (Davies 1976; Illenberger this volume). According to Maud (1968) the last two glacial maxima at about 150 000 and 18 000 years BP were major periods of dune formation in coastal Natal, with the implication that these periods of major ice-sheet growth in the Northern Hemisphere and in Antarctica (with concomitant decline of global sea levels) were locally both cooler and drier than the intervening times. There is, in fact, considerable evidence for a warm Eemian period of high sea level, around 127 000 years ago (plus six to eight metres along the eastern and southern coasts; plus four to five metres along much of the west coast) (Maud 1968; Hobday 1976; Davies 1980; Shackleton 1982). Shells from near the base of the Middle Stone Age deposits in the Klasies River mouth cave sites have been correlated isotopically with Eemian high sea levels by Shackleton (1982), and ionium dates from stratigraphically higher speleothem deposits are in excess of 100 000 years (J C Vogel personal communication); both overlie a beach deposit at plus six to eight metres. Higher terrace packages around the southern African coast are generally considered older, that at 30 m along the west coast being assigned tentatively by Pether (1986) to the Lower Pleistocene.

In the continental interior, Pleistocene depositional sequences of significant duration are few and isolated. Deposition in the Kalahari Basin continued, albeit at a reduced rate; there is evidence to suggest that dune formation continued intermittently throughout this period, but much remains to be done to resolve this record. It is to be hoped that thermoluminescence dating may help to provide a chronological framework for the principal periods of sand movement. Based on the distribution of linear dunes, Lancaster (1981) has deduced that, at the time of formation of the oldest dunes, the local anticyclonic circulation must have been located about 1 000 km north of its present position; younger dune systems, in the southern Kalahari, which probably date to the Last Glacial Maximum (Lancaster 1986), suggest a smaller shift of 250 to 300 km.

Extended sequences that have been the subject of reasonably detailed investigations are the alluvial terraces of the lower Vaal River and the tufas of the Ghaap escarpment. The former comprise predominantly coarse, gravelly accumulations on the higher terraces; the uppermost of these in the Windsorton area (+30 m and +60 m) are devoid of artefacts, but Acheulian implements have been recovered from deep within the terrace gravels at lower elevations in association with a Middle Pleistocene fauna (Partridge and Brink 1967). Entrenched within these earlier deposits is a cut-and-fill sequence, consisting chiefly of fine-textured deposits, which have yielded Middle Stone Age artefacts and probably belong largely within the Upper Pleistocene (Helgren 1979). Interpretations differ concerning the environmental significance of these deposits; there is little doubt that tectonic events and structural geological controls have influenced the formation of the upper terraces, and it is difficult to isolate these from other environmental effects (Partridge and Brink 1967). It is likely, however, that the younger cut-and-fill sequences are a more direct reflection of climatic fluctuations. A similar alluvial sequence at Cornelia, on a headwater tributary of the Vaal River, contains a Middle Pleistocene fauna and Acheulian artefact in its earliest units (Butzer et al 1974).

Less ambiguous palaeoclimatic evidence is forthcoming from the tufa carapaces of the Ghaap escarpment. Here the application of new dating methods (Vogel and Partridge 1984; Vogel 1985), suggest that, although older accumulations are present at Ulco, the first major tufa deposition at Taung appears to have begun around one million years ago; later carapaces date to approximately 760 000 years, 340 000 to 230 000 years and 103 000 to 30 000 years. Detailed analysis of the local springflow regime (Partridge 1985b) suggests that, contrary to the views of Butzer (1974) and Butzer et al (1978a), tufa deposition was at a maximum during semi-arid interludes, while tufa erosion occurred during the more humid episodes.

It is likely that the deposits of many of the larger pans of the continental interior may also have begun to accumulate before the Upper Pleistocene, but good dating control remains a problem. There is considerable evidence that cycles of pan deflation and formation of lunette dunes alternated regionally with a rise in the phreatic surface, accompanied by pan flooding and the development of beach ridges and marginal terraces.

At Kathu Pan near Sishen, flooding, associated with phases of Acheulian occupation, occurred on several occasions, and the associated deposits may date as far back as the end of the Lower Pleistocene (Butzer 1984). Several such cycles occurred at Haaskraal Pan in the central Karoo between about 240 000 years ago, when the pan floor was occupied by the makers of Acheulian artefacts, and the beginning of the Holocene (Partridge and Dalbey 1986). In similar pan deposits at Rooidam near Kimberley, a lake cycle dating to around 174 000 years BP, marked the transition from Acheulian to Middle Stone Age technologies (Szabö and Butzer 1979). The sequence of spring deposits, with intercalated peaty horizons, at Florisbad in the Orange Free State may, on the evidence of the hominid remains recovered, also date back to the Middle Pleistocene; both the sedimentary sequence and included pollens indicate fluctuations in spring flow in response to changing climate, but there is no chronological control within the earlier part of the sequence (Partridge 1982; Butzer 1984). Equally tenuous is the dating evidence from Elandsfontein, in the western Cape, where Acheulian artefacts and an associated Middle Pleistocene fauna were concentrated by interdune deflation above a shallow groundwater table, under conditions apparently warmer and wetter than today (Partridge 1982; Klein 1983).

Although the data available for the Lower and Middle Pleistocene in southern Africa are sparse, and, with rare exceptions, are insufficiently well calibrated to permit correlation with the Milankovitch cycles whose existence has been so clearly demonstrated in the isotopic records of temperature from deep sea cores, there is ample evidence of changes in precipitation during this period. There are also indications that, as is now clear from the Upper Pleistocene record, changes in humidity were not generally in phase across the entire subcontinent.

Upper Pleistocene and Holocene

Several useful reviews of the southern African evidence for this period have appeared recently (Deacon and Lancaster 1984; Deacon et al 1984; Butzer 1984; Cockroft et al 1987; Deacon and Lancaster 1988). While these have significantly aided our understanding of patterns of climatic variation over, in particular, the last 30 000 years, some notable conflicts are evident between interpretations of humidity based on geomorphological/ sedimentological evidence and some based on biological remains. Problems of correlation are also exacerbated by the clear evidence, highlighted by Tyson (1986) and Cockroft et al (1987), that changes in precipitation were not in phase across the subcontinent; these authors have argued convincingly that changing climatic patterns in the past have been analogous to the patterns evident during extended wet and dry spells documented in recent rainfall records, and that both can be explained in terms of a comprehensive model of surface and upper troposphere circulation variations.

In view of the existence of these previous syntheses, I shall attempt no more than to highlight some of the more significant geomorphological evidence for environmental change during the Upper Pleistocene and Holocene, placing particular emphasis on recent studies which have yielded new evidence in key areas, and to summarize conclusions for specific time intervals.

Evidence from the early part of this period from about 120 000 to 40 000 years BP is fragmentary; in the south-western Cape precipitation appears to have increased initially as temperatures declined (Tankard and Schweitzer 1974), but, in the Kalahari, lake levels appear, on the whole, to have been low, and the Namib was extremely dry (Lancaster 1984).

From about 40 000 BP onwards the resolution improves, chiefly as a result of an increase in the number of deposits within the range of ^{14}C dating. Kalahari lake levels appear to have risen and dunes in the southern areas were fixed by vegetation prior to about 23 000 years BP (Heine 1978, 1982; Helgren and Brooks 1983); sinter formation during the same period at Kwihabe cave also suggests greater humidity (Cooke 1975). The occurrence of roof spall debris in a number of contemporaneous cave deposits in the interior of South Africa has previously been interpreted as the result of frost shattering under conditions of extreme cold (Butzer 1984), but such debris can occur through the action of a number of different processes and cannot be regarded as providing unequivocal evidence of past climatic circumstances. Important evidence is forthcoming from the Namib Desert where speleothem formation in Rossing cave between 42 000 and 26 500 years BP (Heine and Geyh 1984) and calcified root casts (Vogel 1987) provide good evidence for more humid conditions over this period.

The pattern of climatic change between about 23 000 and 15 000 years BP is considerably better documented. With the exception of sites in the southern Cape (Deacon et al 1984) and in the eastern part of the country (Butzer et al 1978b; Price-Williams et al 1982), southern Africa appears to have enjoyed more humid, although cool, conditions during the greater part of this period. It is only during the period of the Last Glacial Maximum (20 000 to 18 000 years BP) that extensive (although not ubiquitous) aridity seems to have occurred. Particularly impressive geomorphological evidence for this desiccation comes from the Namib Desert, where the well dated Homeb silts occur to heights of 37 m above channel level in the Kuiseb Canyon, indicating reduced flow in the Kuiseb River; similar deposits are preserved elsewhere in the area (Vogel 1987; Rust and Vogel in press). It may be asked, with some justification, whether the emphasis which has been placed on this short period is warranted in the context of the more prolonged climatic trends evident during much of the Upper Pleistocene. Humid conditions seem to have followed the glacial maximum until at least 15 000 years BP in most areas, and until 12 000 years BP in many.

Between 12 000 and 10 000 years BP fairly rapid desiccation appears to have characterized most areas, heralding the beginning of the Holocene. That this period was characterized by relatively stable climatic conditions is a common misconception, which is firmly contradicted by recent research in the Karoo and Namib areas. In the former Bousman et al (in press) have shown that, in headwater catchments of the Kikvorsberg range, repeated cut- and- fill cycles with durations of 600 to 3 500 years occurred after about 7 800 years BP. Each cycle began with donga incision into lower fills, followed by pool formation with organic deposition; fluctuations in pool depths are evident, and during the latter part of each pool phase fine alluvial sediments interdigitated with, and ultimately transgressed, the organic pool sequences. Pedogenesis within the alluvia attest to a depositional hiatus at the end of each cycle. It is inferred that these cycles, which are of interest in providing well dated evidence for repeated donga erosion in southern Africa long before the advent of agriculturalists, either of Iron Age or European origin, reflect fairly limited, but significant, climatic shifts whose effects tended to be magnified by fluvial responses in narrow headwater valleys. Palynological evidence generally supports the interpretation that these cycles were initiated by increased precipitation following periods of desiccation, the onset of which was manifested by fine alluviation followed by pedogenesis.

In the Namib Desert the Natab silts document a protracted dry spell from before 8 300 BP to around 4 200 BP, which was marked by shortening of the depositional reach of the Kuiseb River (Vogel 1987). On the basis of these findings and of other evidence summarized by Cockroft et al (1987) it can be inferred that considerable regional variation existed in Holocene climatic responses across the southern African subcontinent. There is little doubt that cyclic variations of the type now documented in the Karoo will be demonstrated increasingly as detailed studies of local depositional sequences proliferate. Of particular importance in this regard are the records forthcoming from pans, valley fills and colluvial mantles.

The last millenium

Evidence for climatic trends over this period are of particular significance for the theme of the present proceedings. In the Namib Desert sedimentary infillings in river mouths, and the death of *Acacia* trees in Sossus Vlei, suggest a period of decreased runoff between about 1 250 and 720 BP (Vogel and Rust 1986; Vogel 1987). Subsequent incision of alluvial sediments is, in contrast, indicative of increased runoff and higher precipitation. In the Blydefontein basin of the Karoo the most recent cycle of incision began sometime after 290 BP (Bousman et al in press); although certainly aggravated by local overgrazing in the present century, there is abundant evidence to suggest that the initiation of this phase of donga cutting was in response to natural environmental circumstances.

It must be emphasized, however, that not all geomorphic events in the recent past were demonstrably related to climatic fluctuations. In their study of changing flow patterns in the Okavango Delta, McCarthy et al (1986) have highlighted the progressive interaction between the growth of riverine sedges and channel sedimentation in producing channel shifts. As vegetation growth decreases the width of the channel, aggradation raises the level of the channel floor and decreases its longitudinal gradient. Once a certain threshold is reached the channel becomes blocked and avulses into a new system. Historical records indicate the effective life of a channel system to be of the order of 100 years.

With the advent of the first Iron Age agriculturalists in southern Africa around 1 700 BP, ecosystems must have been increasingly disturbed in the main areas of settlement, although major anthropogenic effects appear to relate to the arrival of European colonists and are restricted, in the main, to the rapid spread of mechanized agriculture, with concomitant increases in grazing pressures imposed by domestic animals, during this century. In response to these disturbances sediment loads in many major rivers increased dramatically. Martin (1987) estimates conservatively that modern rates of sedimentation from east coast rivers exceed, by a factor of at least twenty, average rates of sedimentation in major offshore depocentres during the past five and 100 Myr. According to

Rooseboom (1978) sediment loss had peaked by 1930, and in the last half century the total average sediment load of major South African rivers has decreased by more than 50%. This decline has, according to Rooseboom, occurred as the result of a reduction in the amount of easily erodible material in the catchments. If this interpretation is correct, even in part, it has grave implications in that substantial volumes of the easily erodible and agriculturally productive upper soil horizons have been lost within a few decades; in comparison, processes of soil formation are extremely slow and cannot, in any event, be effective while severe agricultural disturbances continue. It must be emphasized that in those catchments where erosion has, until recently, been of limited extent, cycles of sheet and donga erosion seem to follow closely the fluctuations in rainfall which have been documented recently (eg Tyson et al 1975). For example, Stromquist et al (1985) have shown that three times as much erosion occurred within a catchment in western Lesotho during the wet decade 1951 to 1961 as occurred during the subsequent two decades; of significance is the fact that this period of accelerated erosion followed the very dry spell recorded during the 1940's.

CONCLUSIONS

All of the foregoing evidence points to the existence of periodicities of varying significance within the southern African geomorphological record. That most of these periodicities are climatically controlled is clear, although the fundamental causes of certain of the more widely spaced events is not. For instance, no generally accepted explanation has yet been offered for the major intensification of Milankovitch cycles around 2,5 Myr ago, nor is it clear why different Milankovitch periodicities dominated different periods of the Pleistocene. Improved resolution in the more recent data series, especially those of the last 30 000 years, indicates the existence of yet shorter cyclical episodes of several hundred to a few thousand years duration, while recent erosional responses reflect, in part, the decadal rhythms in rainfall demonstrated for the last 80 years.

In the longer context of the Neogene, major episodes of tectonic uplift have brought with them equally dramatic environmental changes. The mechanism of these uplifts is, like those governing so much of the earlier palaeoclimatic record, poorly understood. There is no doubt that, as more and more data become available, in the form of long continental and marine records, many of the enigmas which remain will be resolved.

REFERENCES

Bousman C B, Partridge T C, Scott L, Metcalfe S E, Vogel J C, Seaman M and Brink J S (In press). Palaeoenvironmental implications of Late Pleistocene and Holocene valley fills in Blydefontein basin, Noupoort, Cape Province, South Africa. Palaeoecology of Africa.

Butzer K W 1974. Palaeoecology of South African australopithecines: Taung revisited. Current Anthropology 15, 367-382 and 413-416.

Butzer K W 1984. Archaeogeology and Quaternary environments in the interior of Southern Africa. In: Klein R G (editor) Southern African pre-history and palaeoenvironments. Balkema, Rotterdam. pp 1-64.

Butzer K W, Clark J D and Cooke H B S 1974. The geology, archaeology and fossil mammals of the Cornelia Beds, OFS. Memoir National Museum (Bloemfontein) 9, 1-84.

Butzer K W, Stuckenrath R, Bruzewicz A J and Helgren D M 1978a. Late Cenozoic palaeoclimates of the Gaap escarpment, Kalahari margin, South Africa. Quarternary Research 10, 310-339.

Butzer K W, Beaumont P B and Vogel J C 1978b. Lithostratigraphy of Border Cave, Kwazulu, South Africa: Middle Stone Age sequence beginning C 195 000 BP. Journal of Archaeological Science 5, 317-341.

Cockcroft M J, Wilkinson M J and Tyson P D 1987. The application of a present-day climatic model to the late Quaternary in southern Africa. Climatic Change 10, 161-181.

Cooke H J 1975. The palaeoclimatic significance of caves and adjacent landforms in western Ngamiland, Botswana. Geographical Journal 141, 430-444.

Davies O 1976. The older coastal dunes in Natal and Zululand and their relation to former shorelines. Annals of the South African Museum 71, 19-32.

Davies O 1980. Last Interglacial shorelines in the south Cape. Palaeontologia Africana 23, 153-171.

Deacon J and Lancaster N 1984. A synthesis of evidence for climatic changes in southern Africa over the last 125 000 years. Report to National Programme for Weather, Climate and the Atmosphere. CSIR, Pretoria. 283 pp.

Deacon J and Lancaster N 1988. Late Quaternary palaeo-environments of southern Africa. Clarendon Press, Oxford.

Deacon H J, Deacon J, Scholtz A, Thackeray J F, Brink J S and Vogel J C 1984. Correlation of palaeoenvironmental data from the late Pleistocene and Holocene deposits at Boomplaas cave, southern Cape. In: Vogel J C (editor) Late Cainozoic palaeoclimates of the Southern Hemisphere. Balkema, Rotterdam. pp 339-351.

Deacon J, Lancaster N and Scott L 1984. Evidence for Late Quaternary climatic change in southern Africa. In: Vogel J C (editor) Late Cainozoic palaeoclimates of the Southern Hemisphere. Balkema, Rotterdam. pp 391-404.

Denton G H 1985. Did the Antarctic ice sheet influence the late Cainozoic climate and evolution in the Southern Hemisphere? South African Journal of Science 81, 224-229.

Dingle R V, Siesser W G and Newton A R 1983. Mesozoic and Tertiary geology of southern Africa. Balkema, Rotterdam.

Harwood D M 1985. Late Neogene climatic fluctuations in the southern high-latitudes: implications of a warm Pliocene and deglaciated Antarctic continent. South African Journal of Science 81, 239-241.

Hawthorne J B 1975. Model of a kimberlite pipe. In: Ahrens L H, Dawson J B, Duncan A R and Erlank A J (editors) Physics and chemistry of the earth 9, 1-15. Pergamon, Oxford.

Hays J D, Imbrie J and Shackleton N J 1976. Variations in the earth's orbit: pacemaker of the ice ages. Science 194, 1121-1132.

Heine K 1978. Radiocarbon chronology of late Quaternary lakes in the Kalahari, southern Africa. Catena 5, 145-149.

Heine K 1982. The main stages of the late Quaternary evolution of the Kalahari region, southern Africa. Palaeoecology of Africa 15, 53-76.

Heine K and Geyh M A 1984. Radiocarbon dating of speleothems from the Rossing cave, Namib Desert, and palaeoclimatic implications. In: Vogel J C (editor) Late Cainozoic palaeoclimates of the Southern Hemisphere. Balkema, Rotterdam. pp 465-470.

Helgren D M 1979. Rivers of diamonds: an alluvial history of the lower Vaal basin, South Africa. Department of Geography Research Paper, University of Chicago 185. 398 pp.

Helgren D M and Brooks A S 1983. Geoarchaeology at Gi, a Middle Stone Age and Later Stone Age site in the north-western Kalahari. Journal of Archaeological Science 10, 181-197.

Hendey Q B 1981. Palaeoecology of the late Tertiary fossil occurrences in "E" Quarry, Langebaanweg, South Africa, and a reinterpretation of their geological context. Annals of the South African Museum 84, 1-104.

Hobday D K 1976. Quaternary sedimentation and development of the lagoonal complex, Lake St Lucia, Zululand. Annals of the South African Museum 71, 93-113.

King L C 1949. On the ages of African land-surfaces. Quarterly Journal of the Geological Society London 104, 439-453.

Klein R G 1983. Palaeoenvironmental implications of Quaternary large mammals in the Fynbos region. In: Deacon H J, Hendy Q B and Lambrechts J J N (editors) Fynbos palaeoecology: a preliminary synthesis. South African National Scientific Programmes Report No 75. CSIR, Pretoria. pp 116-138.

Lancaster N 1981. Palaeoenvironmental implications of fixed dune systems in southern Africa. Palaeogeography, Palaeoclimatology and Palaeoecology 33, 327-346.

Lancaster N 1984. Aridity in southern Africa: age, origins and expression in landforms and sediments. In: Vogel J C (editor) Late Cainozoic palaeoclimates of the Southern Hemisphere. Balkema, Rotterdam. pp 433-444.

Lancaster N 1986. Pans in the south-western Kalahari: a preliminary report. Palaeoecology of Africa 17, 59-67.

Martin A K 1987. Comparison of sedimentation rates in the Natal Valley, south-west Indian Ocean, with modern sediment yields in east coast rivers of southern Africa. South African Journal of Science 83, 716-724.

Maud R R 1968. Quaternary geomorphology and soil formation in coastal Natal. Zeitschrift fur geomorphologie N.F. Suppl-Bd. 7, 155-199.

Maud R R and Partridge T C 1987. Regional geomorphic evidence for climatic change in southern Africa since the Mesozoic. Palaeoecology of Africa 18, 337-348.

Maud R R, Partridge T C and Siesser W G 1987. An early Tertiary marine deposit at Pato's Kop, Ciskei. South African Journal of Geology 90, 231-238.

McCarthy T S, Ellery W N, Rogers K H, Cairncross B and Ellery K 1986. The roles of sedimentation and plant growth in changing flow patterns in the Okavango Delta, Botswana. South African Journal of Science 82, 579-584.

Palaeoclimate and Evolution 1985. South African Journal of Science 81, 224-275.

Palaeoclimate and Evolution 1986. South African Journal of Science 82, 62-96 and 493-522.

Partridge T C 1982. The chronological positions of the fossil hominids of southern Africa. Proceedings of the 1st International Congress on Human Palaeontology, Nice. Paris CNRS 2, 617-675.

Partridge T C 1985a. The palaeoclimatic significance of Cainozoic terrestrial stratigraphic and tectonic evidence from southern Africa: a review. South African Journal of Science 81, 245-247.

Partridge T C 1985b. Spring flow and tufa accretion at Taung. In: Tobias P V (editor) Past, present and future of hominid evolution. Alan R Liss, New York. pp 171-182.

Partridge T C and Brink A B A 1967. Gravels and terraces of the lower Vaal River basin. South African Geographical Journal 49, 21-38.

Partridge T C and Dalbey T S 1986. Geoarchaeology of Haaskraal Pan: a preliminary palaeoenvironmental model. Palaeoecology of Africa 17, 69-78.

Partridge T C and Maud R R 1987. Geomorphic evolution of southern Africa since the Mesozoic. South African Journal of Geology 90, 179-208.

Pether J 1986. Late Tertiary and early Quaternary marine deposits of the Namaqualand coast, Cape Province: new perspectives. South African Journal of Science 82, 464-470.

Price-Williams D, Watson A and Goudie A S 1982. Quaternary colluvial stratigraphy, archaeological sequences and palaeoenvironments in Swaziland, southern Africa. Geographical Journal 148, 50-67.

Rooseboom A 1978. Sedimentafvoer in Suider-Afrikaanse riviere. Water SA 4, 14-17.

Ruddiman W F, Raymo M and McIntyre A 1986. Matuyama 41 000-year cycles: north Atlantic ocean and Northern Hemisphere ice sheets. Earth and Planetary Science Letters 80, 117-129.

Rust U and Vogel J C (In press). Late Quaternary environmental changes in the northern Namib Desert as evidenced by fluvial landforms. Palaeoecology of Africa.

Shackleton N J 1982. Stratigraphy and chronology of the Klasies River Mouth deposits: oxygen isotope evidence. In: Singer R and Wymer J (editors) The Middle Stone Age at Klasies River mouth, South Africa. University of Chicago Press. pp 194-199.

Shackleton N J et al 1984. Oxygen isotope calibration of the onset of ice rafting and history of glaciation in the North Atlantic region. Nature 307, 620-623.

Siesser W G and Miles G A 1979. Calcareous nannofossils and planktic foraminifers in Tertiary limestones, Natal and eastern Cape, South Africa. Annals of the South African Museum 79, 139-158.

Stromquist L, Lundén B and Chakela Q 1985. Sediment sources, sediment transfer in a small Lesotho catchment - a pilot study of the spatial distribution of erosion features and their variation with time and climate. South African Geographical Journal 67, 3-13.

Summerfield M A 1983. Silcrete as a palaeoclimatic indicator: evidence from southern Africa. Palaeogeography, Palaeoclimatology and Palaeoecology 41, 65-79.

Szabó B J and Butzer K W 1979. Uranium-series dating of lacustrine limestones from pan deposits with the final Acheulian assemblage at Rooidam, Kimberley district, South Africa. Quaternary Research 11, 257-260.

Tankard A J and Schweitzer F R 1974. The Geology of Die Kelders Cave and Environs - a palaeoenvironmental study. South African Journal of Science 70, 365-369.

Tobias P V 1985. Ten climacteric events in hominid evolution. South African Journal of Science 81, 271-272.

Tobias P V 1986. Delineation and dating of some major phases in hominidization and hominization since the Middle Miocene. South African Journal of Science 82, 92-94.

Twidale C R and Hutton J T 1986. Silcrete as a climatic indicator: discussion. Palaeogeography, Palaeoclimatology and Palaeoecology 52, 351-360.

Tyson P D 1986. Climatic change and variability in southern Africa. Oxford University Press, Cape Town.

Tyson P D, Dyer T G J and Mametse M N 1975. Secular changes in South African rainfall: 1880 to 1972. Quarterly Journal of the Royal Meteorological Society 101, 817-833.

Vogel J C 1985. Further attempts at dating the Taung tufas. In: Tobias P V (editor) Hominid evolution: past, present and future. Alan R Liss, New York. pp 189-194.

Vogel J C 1987. Chronological framework for palaeoclimatic events in the Namib. NPRL Research Report CFIS 145. CSIR. 20 pp.

Vogel J C and Partridge T C 1984. Preliminary radiometric ages for the Taung tufas. In: Vogel J C (editor) Late Cainozoic palaeoclimates of the southern hemisphere. Balkema, Rotterdam. pp 507-514.

Vogel J C and Rust U 1986. Environmental changes in the Kaokoveld Namib desert during the present millenium. Madoqua 15, 5-16.

Vrba E S 1974. Chronological and ecological implications of the fossil Bovidae at the Sterkfontein Australopithecine site. Nature 250, 19-23.

Vrba E S 1975. Some evidence of chronology and palaeoecology of Sterkfontein, Swartkrans and Kromdraai from the fossil Bovidae. Nature 254, 301-304.

Ward J D, Seely M K and Lancaster N 1983. On the antiquity of the Namib. South African Journal of Science 79, 175-183.

Webb P N et al 1984. Cenozoic marine sedimentation and ice-volume variations on the east Antarctic craton. Geology 12, 287-291.

PALAEOECOLOGICAL PERSPECTIVES ON RECENT ENVIRONMENTAL CHANGE IN SOUTHERN AFRICA

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INTRODUCTION

This paper is a comment on the significance and validity of modern data series on environmental change from a palaeoecological perspective. There are a number of points that are raised by viewing modern data series from a longer time perspective. This contribution refers to terrestrial ecosystems.

The first and very obvious point that can be made is that modern data series, at best spanning some decades, are short relative to geological time. Different time scales are important because change although continuous is not necessarily linear nor does it progress at a constant rate. Given a limited duration of modern scientific observations there can be a problem in deciding whether an observed change constitutes a significant trend and indeed whether a particular parameter will exhibit real change. Sea levels can be used to illustrate this point. Modern data series (Brundrit this volume) for the South African coast and elsewhere show sea level changes of the order of some tens of millimetres but the length of the record, on a decadal scale, is short. The apparent rise in sea level takes on new importance, however, when it can be shown that sea level changes reflect global ice volumes and have changed at rates as high as a metre per hundred years (Chappell and Shackleton 1986). There is no question that monitoring sea level is very important but it is still not possible to establish whether any observed changes are homeostatic adjustments to the level that stabilized in the late Holocene, the beginnings of a new directional trend, or the result of a secondary (anthropogenic) cause such as increased atmospheric CO_2. The long-term prediction is that sea levels will fall at the end of the present Interglacial and the present Interglacial has run its course if the average duration of 10 000 years is accepted (Imbrie and Imbrie 1979).

The second point is related to the continuity of change. If change is not linear, then reference points are needed. Without anchoring observations to some starting and end point, the observations are floating. Observations need to have reference points otherwise the trajectory of change, observed in any parameter, is perforce unknown. There is a difference in showing change is happening and that change has happened. In this sense modern data series are ahistoric. Palaeoecological studies by contrast are more concerned with scales of change and boundary conditions and are historic. Studies in ecology or any like field are not historical in themselves but disciplines like archaeology and geology are essentially historical because they are primarily concerned with explaining what happened in the past.

A third point has to do with amplitude of any change. Terrestrial ecosystems can be perturbated but may bounce back. This is the quality of resilience. How resilient are ecosystems and to what extent do the kinds of changes observed in modern data series fall within the limits of the ability of systems to bounce back? Extinction, for example, is a real phenomenon and there are thresholds where perturbation causes permanent change. A concern here is that the accumulated effects of particularly anthropogenically induced changes, through simplifying natural ecosystems, may have reduced resilience to future changes.

CHANGE IN ECOSYSTEMS

Modern data series on terrestrial ecosystems are for the most part the product of studies of succession, eg the response after fire or similar disturbance, and other aspects of community ecology. Such research has not been designed explicitly to investigate change over time and extended monitoring of ecosystem changes has only just begun.

The modern data series focus on the change in the relations of the component organisms in ecosystems whereas palaeoecological studies are more concerned with the forces of change, the abiotic factors, than with details of the interplay between taxa. This kind of dichotomy in approaches to the study and explanation of changes in systems is also found in paradigms such as historical materialism where society rather than ecosystem formation is the interest. Borrowing from a historical materialist model (vide Elster 1983 for discussion of the arguments on forms of explanation) it is useful to contrast the elements, abiotic, biotic, and anthropogenic factors that interact to produce observed change in ecosystem (Figure 14.1). The abiotic and biotic, respectively, are the equivalent of the forces and relations of production in historical materialism. Changes in the relationship between taxa through evolution, extinction, migration and interaction processes within communities can be held to be the primary cause of ecosystem change. Under stable environmental conditions the relations in communities would approach a state that is optimal for those conditions and the rate of natural change by natural selection would be low. The effect of introducing environmental changes that are rapid on geological time scales into the equation would be to increase selection and the tempo of change. As the Pleistocene and Holocene are periods of such rapid environmental change it is the environmental forcing that has explanatory as opposed to causal primacy in ecosystem change.

An example may serve to illustrate the argument about primacy (Elster 1983). The example chosen is the Cango Valley (Deacon et al 1984). A reconstruction of the ecological changes in the valley indicates that 18 000 years ago the vegetation was semikarroid shrubland but after 15 000 years ago, under warmer and wetter conditions, the vegetation changed to parkland with *Olea* prominent and there were concomitant changes in the small mammal fauna but not in the more mobile large mammals. At the turn of the Pleistocene, 10 000 years ago and through the early Holocene *Olea* gave way to a thicket which in turn gave way in the later Holocene to an *Acacia karroo* riparian woodland. The fauna reflect the habitat changes and in the Holocene the large mammals are predominantly small browsers. Finally, almost 2 000 years ago sheep were introduced into the valley. This is a scenario of very dynamic ecosystem change and the only one known in such detail from the subcontinent. The Cango Valley ecosystem changes were caused by changes in the relationship between taxa.

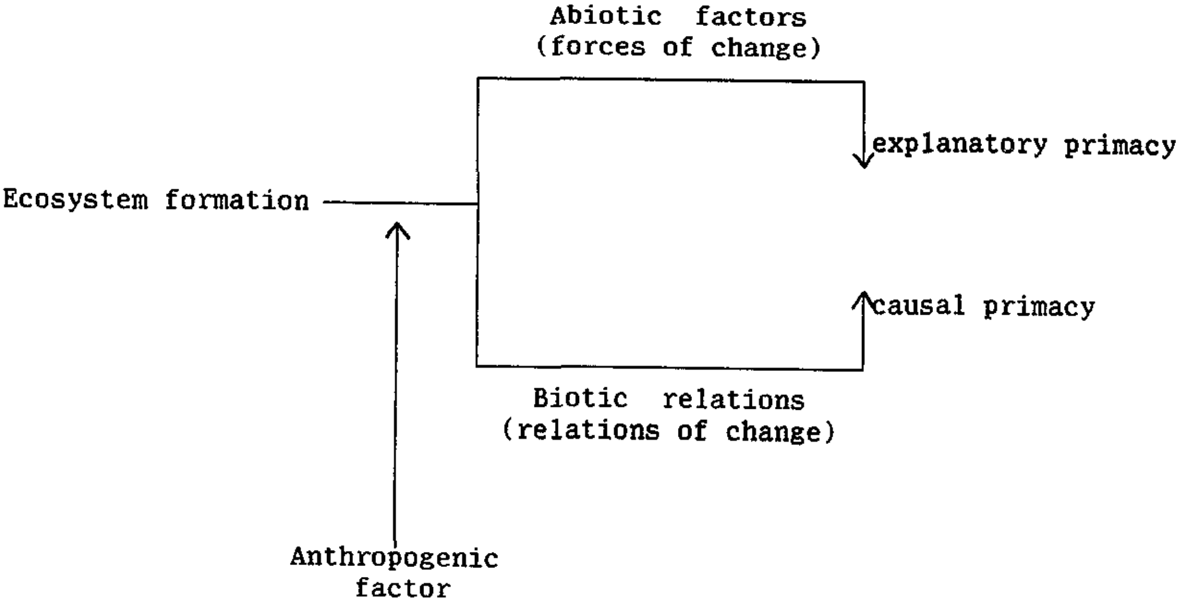

FIGURE 14.1 A model of ecosystem change.

One example of this is the invasion of the valley by *Acacia karroo* in the latter period and this subtropical pioneer was then able to extend its range. An explanation of the ecosystem changes, however, can be given by environmental forcing. The Last Glacial Maximum centred on 18 000 years ago was cold and dry in the Cango Valley and as elsewhere in the Southern Hemisphere (Salinger 1981) there was a rapid amelioration of temperatures thereafter associated with the melting of sea ice around Antarctica. As temperatures approached modern ranges precipitation-related changes tied to changes in synoptic climate patterns became a forcing mechanism (Deacon

1983). The known scale of environmental change is sufficient to explain the observed ecosystem change. The difference between causal and explanatory primacy shown in this example equates with the difference between ahistoric and historic methodologies.

The third part of the equation, the superstructure of change, is the anthropogenic factor. Human behaviour is forged in a socio-economic context and can be considered an independant forcing mechanism with the ability to cause change facilitated by the level of technological sophistication. Through burning, tilling, herding, spreading exotic taxa, irrigating and draining, and construction the tempo of change is speeded up immeasureably. Human management of ecosystems is a prime factor in ecosystem change in the present. It is directed at maintaining a balance that would perpetuate not the present natural biotic relationships but rather those that offer the greater useable productivity. The motivation for management is expediency rather than long-term benefit simply because what the future holds is unknown. That is what the IGBP hopes to find out.

Ahistoric and historic explanations for ecosystem changes are different ways of looking at the same problem. Rates of change in ecosystems through evolution, extinction and recruitment would be very slow in geological time if it had not been for the forcing effects of the rapid and large-scale Pleistocene-Holocene environmental changes. The anthropogenic factor is a separate causal agency promoting change outside the limits of that which would occur naturally. The effects of abiotic, biotic and anthropogenic factors on ecosystem histories are dynamic and compounded over time and postdicting past or predicting future changes is no mean task.

THE SCALE OF ECOSYSTEM CHANGE

Palaeoecology provides numbers of examples of the scale of environmental change between various boundary conditions, points of major change in the Pleistocene. This can best be illustrated in the long continuous records obtained from the oxygen isotope analyses of forams in deep sea cores and the similar analyses of ice cores in the Arctic and Antarctic. Like records of sea level changes these are primarily measurements of ice volumes and are related to global temperature changes. The difference between the glacial and interglacial maxima defines the amplitude of change to which Pleistocene ecosystems have been subjected. The cyclicity that is evident is correlated with the orbital perturbations (Martinson et al 1987).

The boundary conditions that have been investigated in the ocean record are the Last Interglacial and Last Glacial maxima in the CLIMAP programme (CLIMAP Project members 1976, 1984). The results allow some modelling of terrestrial conditions at those times but perforce this is at a very gross level. There have been attempts to compile a similar terrestrial record for the Last Glacial Maximum (Peterson et al 1979) and there are considerable data on vegetation and faunal changes available for the Holocene for Europe and North America. These data have been considered in palaeoenvironmental rather than palaeoecological terms, that is in a geological rather than an ecological framework.

The data that are available for southern Africa for Late Pleistocene terrestrial environments are growing (Deacon and Lancaster 1988) but are still very limited. The example of the Cango Valley serves to show that extreme and harsh conditions pertained at the Last Glacial Maximum in these latitudes and how plant and animal distributions have developed since then. Modern biogeographic patterns pertain only to the late Holocene, within the last some 3 000 to 5 000 years. There is a little evidence which suggests that environmental conditions may have deteriorated since 2 500 years BP but the effects are difficult to distinguish from those related to the introduction of agropastoralism. The spread of agropastoralism into the subcontinent may have an environmental correlate.

ANTHROPOGENIC FACTOR IN CHANGE

There is a danger that in interpreting modern data series the accumulated effects of human activities in the prehistoric past will be underestimated simply because they were not written down. In South Africa there is a history of fire management that may go back more than 100 000 years and a history of agropastoralism that goes back 2 000 years. This impact has escalated with growing populations, the introduction of exotic cultigens and new technology.

There is a good example of the effects of prehistoric range management from Madagascar. In the last 600 years the conversion of a Miombo woodland into a grassland savanna has taken place through the practice of seasonal burning. The changes have been detected in the radiocarbon-dated pollen and charcoal spectra from Lake Kavitaha (Burney 1987) and apart from the pioneering studies of Martin (1968), there is little data of similar quality on the anthropogenic or people-land effect from southern Africa. This is an area needing research.

Knowledge of the long duration of human impacts on terrestrial ecosystems alone is sufficient to indicate that the interpretation of modern data series is complicated by this factor. It is salutory to reflect that it would have been inconceivable for San hunter-gatherers of 2 000 years ago to have predicted the appearance of Khoi herders with stock, domesticated the length of the continent away, and with very different means and relations of product. Equally those Khoi herders could have had no premonition of changes to follow with intensification of agropastoralism, industrialization and urbanization.

CONCLUSIONS

From a palaeoecological perspective the history of ecosystems is dynamic. Change is an inherent property. This is nowhere near as obvious in the study of modern data series. Possibly one of the important products of compiling modern data series will be the greater awareness of the inherency of change. Describing changes on modern data series relating to ecosystems is the initial stage, the explanations of how and why the changes occur are advanced questions to be answered in the future. This does not make the compilation of modern data series any the less important or the less exciting. There is a challenge to find new ways of interpreting available data in historical terms. Qualitative as well as quantitative data are of value and, in the compilation of the longer modern data series, some loss of resolution through the use of qualitative measures of change will be inevitable but this will be offset by the greater length of these records.

Adoption of a palaeoecological perspective in this paper is appropriate because a major input to the IGBP will come from INQUA (International Quaternary Association) members whose concern is with evolving environments through the Pleistocene, over very much longer time ranges than those considered by most authors in this volume. There is some consensus amongst Quaternarists that the broad outlines of environmental changes in the later Cainozoic are known but more emphasis needs to be given to records capable of high resolution. As palaeoenvironmental studies with their focus on the history of change improve in the resolution of temporal and spatial patterns, optimistically they will become more useful to biologists and others concerned with the causes of change in modern data series. There is potential for a greater degree of conjunction in approaches, especially in the testing of models of change. If it is possible to postdict the past then it will be with more confidence that we can attempt to predict the future.

ACKNOWLEDGEMENTS

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REFERENCES

Burney D A 1987. Late Holocene vegetational change in central Madagascar. Quaternary Research 28, 130-143.

Chappell J and Shackleton N J 1986. Oxygen isotopes and sea level. Nature 324, 137-140.

CLIMAP Project Members 1976. The surface of the Ice-Age earth. Science 191, 1131-1137.

CLIMAP Project Members 1984. The Last Interglacial ocean. Quaternary Research 21, 123-224.

Deacon H J 1983. Another look at Pleistocene climates in South Africa. South African Journal of Science 79, 325-328.

Deacon J and Lancaster N 1988. Late Quaternary palaeoenvironments of southern Africa. Clarendon Press, Oxford.

Deacon H J, Deacon J, Scholtz A, Thackeray J F, Brink J S and Vogel J C 1984. Correlation of palaeoenvironmental data from Late Pleistocene and Holocene deposits at Boomplaas cave, southern Cape. In: Vogel J C (editor) Late Cainozoic palaeoclimates of the Southern Hemisphere. Balkema, Rotterdam.

Elster J 1983. Explaining technical change: a case study in the philosophy of science. Cambridge University Press, Cambridge.

Imbrie J and Imbrie K P 1979. Ice ages: solving the mystery. Macmillan, London.

Martin A R H 1968. Pollen analysis of Groenvlei lake sediments, Knysna (South Africa). Review of Palaeobotany and Palynology 7, 107-144.

Martinson D G, Pisias N G, Hays J D, Imbrie J, Moore T C and Shackleton N J 1987. Age dating and the orbital theory of the ice ages: development of a high-resolution 0 to 300 000 year chronostratigraphy. Quaternary Research 12, 47-82.

Peterson G M, Webb T, Kutzbach J E, van der Hammen T, Wijmstra T A and Street F A 1979. The continental record of environmental conditions at 18 000 years BP: an initial evaluation. Quaternary Research 12, 47-82.

Salinger M J 1981. Palaeoclimates north and south. Nature 291, 106-107.

MICROMAMMALIAN EVIDENCE FOR ENVIRONMENTAL CHANGE OVER THE LAST 115 000 YEARS

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INTRODUCTION

Mandibles and maxillae of rodents and insectivores provide the basis for interpretation. These jaws, and other bones, are the accumulated remains of animals thought to have been eaten by barn owls *Tyto alba* in the past. The relationship between the prey sample and the population or community on the ground cannot be established, although it appears to be fairly close. However, if the same predator is involved throughout, the samples are directly comparable with each other and differences between samples are real and interpretable. Small mammals themselves are moderately faithful reflectors of the environment in which they live although, on a very short time scale, one should be aware of the time lag in their response to environmental change.

Although there is still a lack of basic data, which means that the pattern is fairly gross and reliable averages have yet to be obtained, there is good correlation with other databases such as the oxygen isotope curve and the known overall pattern of climatic change during approximately the last 110 000 years (Avery 1982a, 1987; Tyson 1986). There is a danger of circularity caused by comparing observed patterns with patterns from other lines of evidence to provide relative dating of data series but the consistent nature of the pattern indicates that the material provides useful independant information. The greater number of samples for the more recent time period, combined with a ^{14}C chronological framework, already indicates that more precision is possible, although still on a thousand-year scale. During the last 1 000 years chronological control is again more difficult because of the margins of error in the dating methods. At the lowest level, monthly collections of pellets have been made from a roost in the western Cape Province during the last two years, and it should be possible to compare changes in the pellet contents with known climatic changes, thereby obtaining a better understanding of the correlation between the two.

One cannot conduct controlled, repeatable experiments in this type of study but the reliability of the results can be improved by increasing the number of samples on which interpretations are based. It may also be possible to check results by re-excavating a site, using the original excavation units and analysing separately a second column of samples which can be compared with the first. If improved collection techniques are employed the benefits of these can also be assessed. Such a sample has just been excavated and will be analysed shortly.

SOME SOUTHERN AFRICAN EXAMPLES

Attention is here focused mainly on the fynbos biome, partly because more data are currently available for this region and partly to provide a case study. One index that has been found to be a generally useful indicator of patterns of environmental change is the Shannon Wiener index of general diversity (H) which takes into account both the number of species in a community and the extent to which they are represented. It has been observed (Krebs 1972), although not completely explained, that animal life tends to be more abundant and varied in the equable tropics than it is in harsher, less predictable climates. Changes through time at one location can therefore be interpreted in terms of periodic variations in equability and/or predictability of climate at that location. In the present exercise an average (or representative in the case of one) value was obtained for samples within a certain time period variously 100, 1 000 and 5 000 years, and the mean found for all values within the series (Figure 14.2).

There are oscillations about the mean of different periodicity within each of these groupings. During the period 200 to 1 000 years ago, with 100-year averages, the cycles are generally about 200 years (Figure 14.2A) in the only available series, from the northern Cape Province (Arid Savanna). In the postglacial period (Figure 14.2B), based on 1 000-year averages for the fynbos biome, there does not appear to be any regularity to the oscillations. At the level of 5 000-year averages for the fynbos biome (Figure 14.2C) the coincidence of the pattern with the oxygen isotope records is clearly visible. Two troughs, dated to 15 000 to 20 000 BP and estimated to 65 000 to 70 000 BP, equate with cold oxygen isotope stages 2 and 4 respectively; the alternate peaks are referable to stages 3 and 1. Grouping the data may, however, have obscured other patterns that will become clearer with the addition of more samples.

The general pattern of size variation of two different species is similar (Avery 1982a). Since one species (the greater musk shrew *Crocidura flavescens* - Figure 14.3A) is an insectivore that lives above ground and the other (the common molerat *Cryptomys hottentotus* - Figure 14.3B) is a fossorial rodent that eats bulbs and tubers, this is remarkable and must reflect some major environmenal influence. This might be temperature if there is, indeed, a negative correlation between body size and average temperature (Bergmann's rule). It is very likely, however, that the situation is a good deal more complicated; Bergmann's rule is by no means universally applicable, and *C flavescens* exhibits another pattern of size variation at an Arid Savanna site (Avery 1982b). The specific environmental correlates of size variation in individual species must be established.

There are also patterns in variation of the proportion of individual species in different samples (Avery 1982a). The most obvious is that shown by Saunders's vlei rat *Otomys saundersiae* (Figure 14.4C2) which matches very closely the oxygen isotope curve and which it is tempting to equate with temperature fluctuation. It is also possible that this suggestion is supported by the more detailed pattern for the postglacial period (Figure 14.4C1). On the other hand, the vlei rat *Otomys irroratus* (Figure 14.4B) and the forest shrew *Myosorex varius* (Figure 14.4A) exhibit different patterns which require other explanations. In terms of the basic climate forcing mechanisms, it is very likely that changes in predictability and extremes in both temperature and rainfall will prove to have been more critical than changes in absolute values. Effectiveness and seasonality of rainfall are other important aspects. In addition, data are now becoming available which should allow comparison of the superimposed effects of the introduction of farming into different regions.

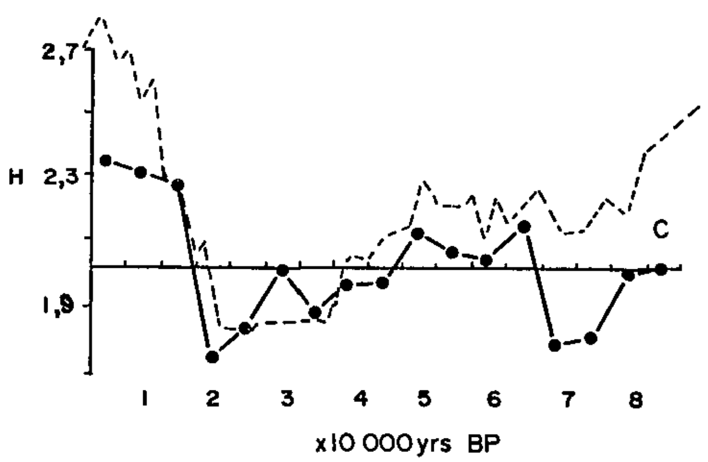

FIGURE 14.2 Oscillations of different periodicity in value of the Shannon Wiener index of general diversity in micromammalian samples for the last 80 000 years. A - the last millenium in the Arid Savanna, based on 100-year averages; B - the post-glacial period in the Fynbos, based on 1 000-year averages; C - the last glacial and postglacial periods in the Fynbos, based on 5 000-year averages, with superimposed oxygen isotope record (dashed line) for subantarctic core RC11-120 (after Shackleton 1977).

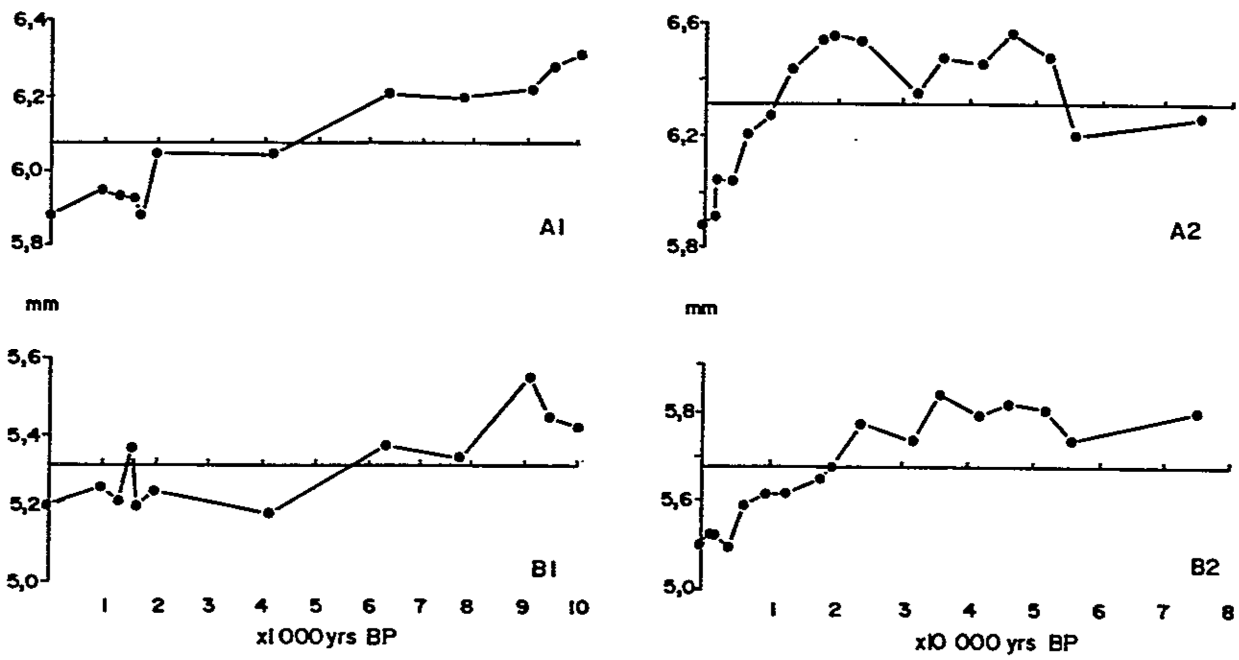

FIGURE 14.3 Size variation in two species of small mammal from Boomplaas, Cango Valley, during the last 10 000 years (A1, B1) and the last 80 000 years (A2, B2). A - the greater musk shrew *Crocidura flavescens*; B - the common molerat *Cryptomys hottentotus*.

CONCLUSIONS

With due regard for the limiations of the database, it is possible to use micromammalian evidence to provide information on changes, both natural and human-induced, in aspects of past vegetation and climate. Additional, rigorously collected, samples and more detailed data concerning the physiological and biological constraints on living representatives of species involved will permit improved precision in the interpretations.

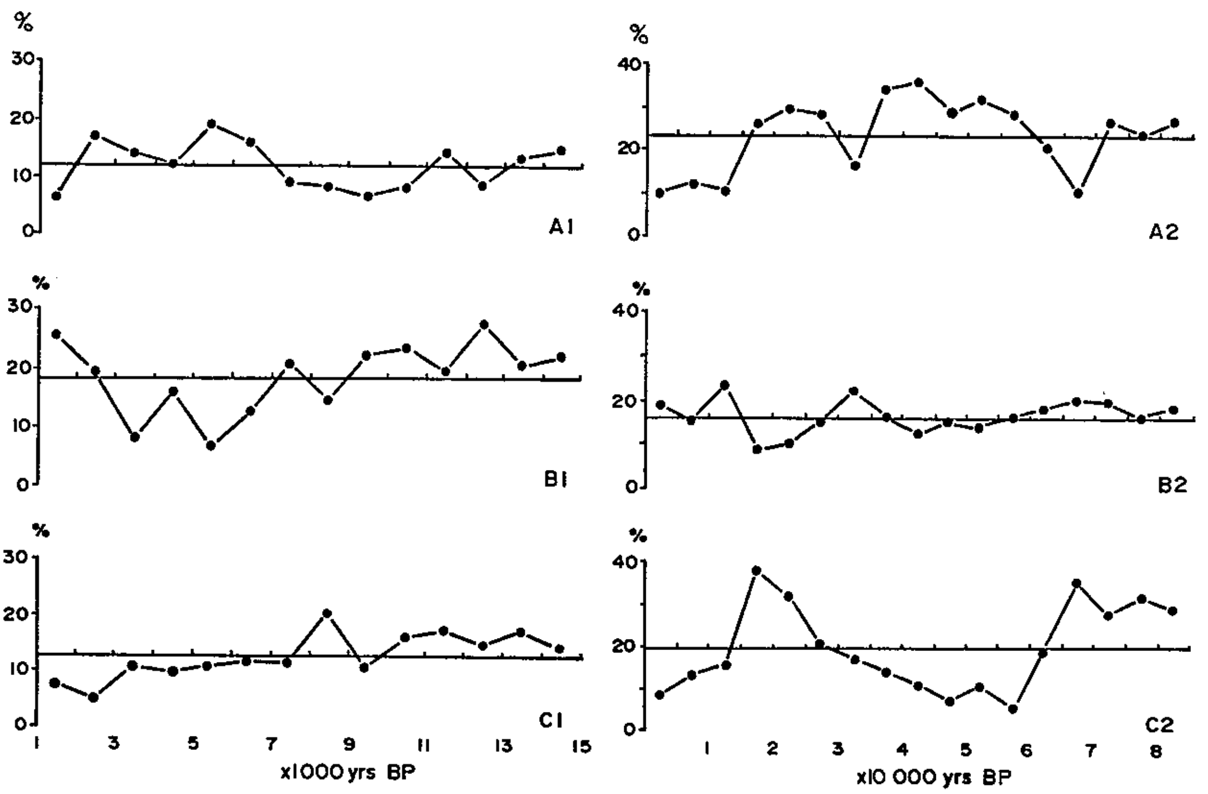

FIGURE 14.4 Variation in the proportional representation of individual species in samples from Boomplaas, Cango Valley, based on 1 000-year averages during the postglacial period (A1, B1, C1) and on 5 000-year averages during the last glacial and postglacial periods (A2, B2, C2). A - the forest shrew *Myosorex varius*; B - the vlei rat *Otomys irroratus*; C - Saunders's vlei rat *Otomys saundersiae*.

REFERENCES

Avery D M 1982a. Micromammals as palaeoenvironmental indicators and an interpretation of the last Quaternary in the southern Cape Province, South Africa. Annals of the South African Museum 85, 183-374.

Avery D M 1982b. The micromammalian fauna from Border Cave, KwaZulu, South Africa. Journal of Archaeological Science 9, 187-204.

Avery D M 1987. Upper Pleistocene coastal environment of the southern Cape Province of South Africa: micromammals from Klasies River mouth. Journal of Archaeological Science 14, 405-421.

Krebs C J 1972. Ecology. Harper and Row, New York.

Shackleton N J 1977. The oxygen isotope stratigraphic record for the Late Pleistocene. Philosophical Transactions of the Royal Society of London B280(972), 169-182.

Tyson P D 1986. Climatic change and variability in southern Africa. Oxford University Press, Cape Town.

PAST AND PRESENT COASTAL DUNEFIELDS IN THE ALGOA BAY AREA

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Rocks (and rocks in the making) represent a very long-term (3 000 million years) data record. The different rock types reflect varying environments of deposition, and conditions at the time of deposition can be inferred from a study of the geological record.

Aspects of the geological record which are relevant to changes in southern Africa's environment and renewable natural resources are represented by active and fossil coastal dunefields. Along the northern shore of Algoa Bay such dunefields range in age from Holocene (the last 10 000 years) to Pliocene (four million years old).

Transgressive coastal dunefields form where a high energy wind regime is directed onshore along a sandy shoreline. The wind regime of Algoa Bay is high-energy and the dominant west - south-west wind blows onshore along the northern sandy shore of the bay (Figure 14.5). These physical conditions are conducive to the formation of coastal dunefields, and have resulted in the Alexandria coastal dunefield, the dunefield of Holocene age which is now active.

The Alexandria dunefield is the largest coastal dunefield in South Africa, extending eastwards from the Sundays River mouth some 50 km in the form of a strip two to three kilometres wide, covering about 110 km^2. It transgresses the hinterland, moving at 0,25 $M.yr^{-1}$. The dunefield has been formed over the past 6 500 years, ie since the sea rose to its present level after the last Ice Age.

There is evidence to suggest that sand was supplied to this dunefield in three main pulses (Figure 14.6). The pulses in sand supply could have resulted from the following: i) small variations in sea level during the past 6 500 years; ii) climatic changes (Figures 14.7 and 14.8); wind variation would affect sand movement rates and also how easily vegetation could establish itself; in addition higher rainfall would favour vegetation. If sand movement is reduced, sand supply would be reduced, and if movement is halted by vegetation, sand supply to the dunefield would cease; and iii) destruction of dune vegetation by prehistoric human (Strandloper) activity or bushfires, which would release sand previously fixed by vegetation (Illenberger in press).

Two pre-Holocene fossil dunefields can be identified on aerial photographs in the area landward of the Alexandria dunefield (Illenberger 1986). The seaward fossil dunefield probably dates from the last interglacial, 120 000 years ago, when sea level on the southern African coast was between five and eight metres higher than present (Hendey 1983). This fossil dunefield is fairly easily recognizable, with eroded parabolic dune remnants. The landward fossil dunefield is much more eroded, and can be identified as only a slight ridge. The landward fossil dunefield is thus probably older, and could have been formed during the second last interglacial or earlier, ie 220 000 years or earlier. The fossil main slipfaces of these dunefields ("main slipface" = landward edge of dunefield) are shown on Figure 14.5.

An area of highland to the east of the Sundays River mouth probably represents the coalition of dunefields formed during the Pleistocene (the last two million years) (Figure 14.5), according to microfossil dating (McMillan unpublished).

A fossil dunefield landward of the 220 000 (?) year old fossil dunefield, and hence probably older than a quarter million years, is recognizable near Alexandria. Individual dune forms are no longer recognizable as the fossil dunes are being dissected by erosion and karst landform development. The fossil dunefield is probably Late Pliocene to Early Pleistocene in age (one to three million years), and may have resulted from the coalescence of dunefields of different ages. This fossil dunefield is termed the Kaba fossil dunefield (Illenberger 1986) (Figure 14.5).

A further fossil dunefield even more eroded in appearance than the Kaba fossil dunefield occurs in the Nanaga area (Figure 14.5). Since this fossil dunefield is at a higher elevation and appears more eroded than the Kaba fossil dunefield, it is probably even older than the latter. According to microfossil dating (McMillan unpublished), this dunefield is about four million years old (mid-Pliocene).

The presently active dunefield is forming on the northern shore of Algoa Bay, where the dominant south-west wind blows onshore. Each fossil dunefield also formed on the northern shore of its palaeo-Algoa Bay, implying that the palaeo-wind regimes were the same as at present during the periods when these fossil dunefields were forming (Figure 14.9).

A vegetation succession is discernible on dunes of increasing age, ranging from largely unvegetated modern dunes, to dense Valley Bushveld developed on the oldest dunes. A corresponding soil development succession is apparent. The high (35%) shell fragment content of the dune sand is instrumental in developing soils on these sands, since these shells consist mainly of calcium carbonate (and also contain other pedogenetically useful elements). It nevertheless takes thousands of years to form soils suitable for agriculture on coastal dunes.

The Namib sand sea has developed over a similar time span to that of the Algoa Bay coastal dunefields (Ward et al 1983). The Namib sand sea is virtually unvegetated, mainly because of the very low rainfall in the area, and also because the shell fragment content of the sand is much lower, although the very low rainfall is obviously by far the major factor.

DISCUSSION

The major factor in coastal dune formation is sea level variation, which controls the sand supply to dunefields. Sea level is at least partly related to major climatic changes, eg the Ice Ages during the Pleistocene. Minor variations in sand supply to the Alexandria dunefield over the past 6 500 years may also result from small climatic changes and damage to vegetation resulting from Strandloper activity or natural bush fires.

The wind regime was similar to that of the present during the periods when the ancient dunefields were forming.

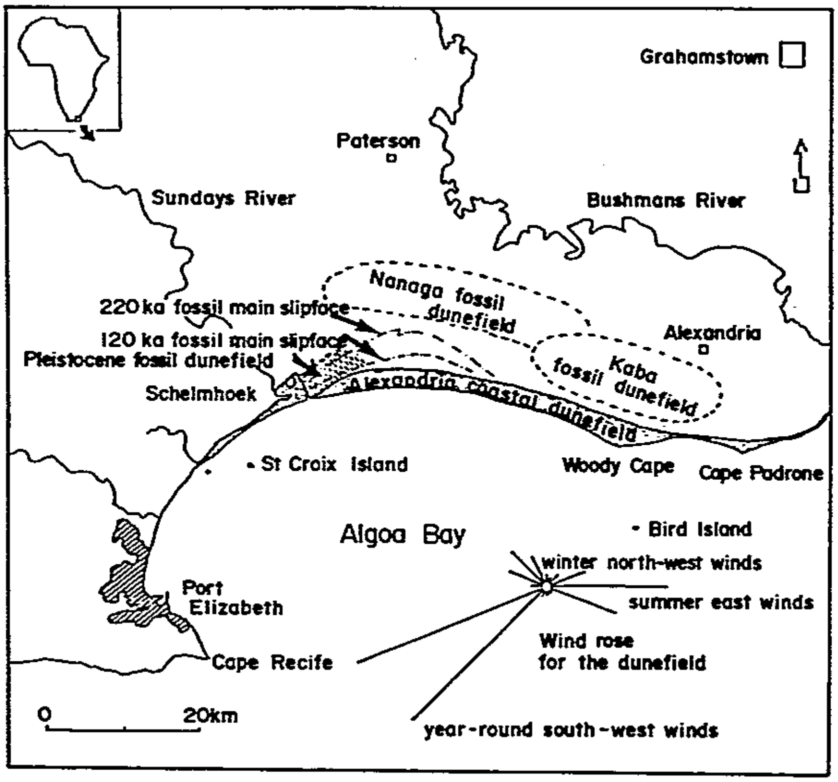

FIGURE 14.5 Coastal dunefields in the Algoa Bay area. The Alexandria dunefield is now active, and the fossil dunefields probably range in age from 120 000 years to four million years. The dunefield dates are tentative, and not exact. The stylized wind rose shows combined data from Port Elizabeth, Aloes and Bird Island. The wind rose arms are plotted in the upwind direction.

FIGURE 14.6 Variation in sand supply to the Alexandria coastal dunefield during the past 7 000 years (from Illenberger in press). Data was inferred from a study of the geomorphology of the dunefield. There are three main pulses, which perhaps correspond with temperature (Figure 14.7) and vegetation changes (Figure 14.8).

FIGURE 14.7 Holocene oxygen isotope temperature curve for the southern Cape from Cango Cave. Temperature lows correspond to pulses in the sand supply (Figure 14.6). (From Talma and Vogel, in Tyson 1986, see Talma and Vogel this volume for derivation of this curve).

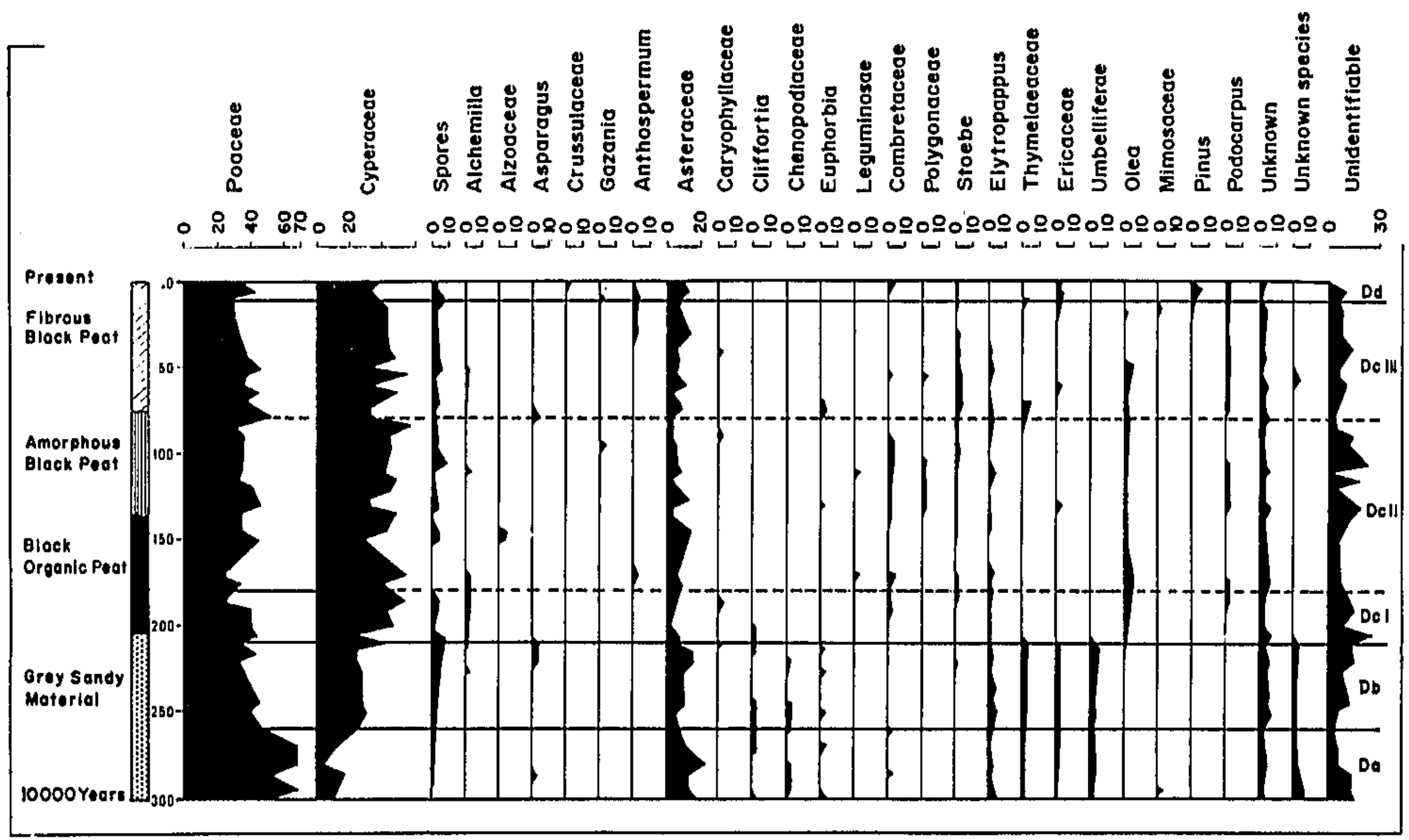

FIGURE 14.8 Pollen record of the past 10 000 years from Dunedin, in the Winterberg mountains, eastern Cape interior. There is much variation, reflecting a complex response to climatic change. The most marked change in this record is the boundary between Db and Dc 1, which represents the end of the last Ice Age, about 8 000 years ago. There is perhaps some correlation with sand pulses in the Alexandria dunefield (Figure 14.6) (from Meadows et al 1987).

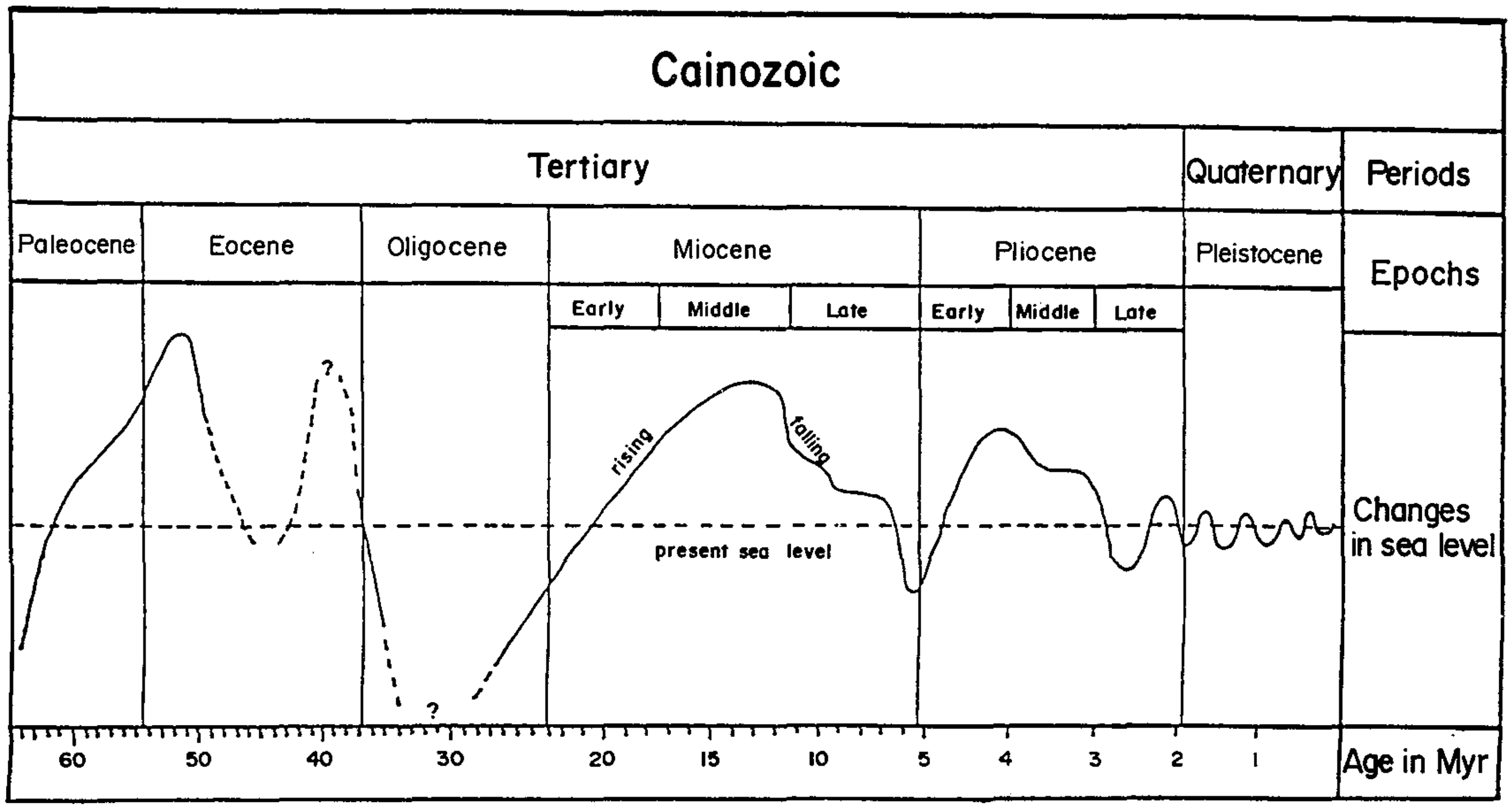

FIGURE 14.9 Cainozoic time scale and a diagrammatic representation of southern African sea level changes. The formation of onshore dunefields corresponds to sea level highs. The Kaba dunefield probably formed in the late Pliocene and early Pleistocene, and the Nanaga dunefield during the early Pliocene. Ma = millions of years (from Hendey 1983).

REFERENCES

Illenberger W K 1986. Alexandria coastal dune field, morphology, sand budget and history. MSc Thesis, University of Port Elizabeth, Port Elizabeth. (Unpublished).

Illenberger W K (In press). The Holocene evolution of the Sundays estuary and adjacent coastal dunefields, Algoa Bay. Proceedings of the Symposium on the geomorphology of southern Africa, UNITRA, April 1988.

Hendey Q B 1983. Cenozoic geology and palaeogeography of the fynbos region. In: H J Deacon, Q B Hendey and J J N Lambrechts (editors) Fynbos palaeoecology: a preliminary synthesis. South African National Scientific Programmes Report No 75. CSIR, Pretoria. pp 35-60.

Meadows M E, Meadows K F and Sugden J M 1987. The development of vegetation on the Winterberg escarpment. The Naturalist 31, 26-32.

Tyson P D 1986. Climatic change and variability in southern Africa. Oxford University Press, Cape Town.

Ward J D, Seely M K and Lancaster N 1983. On the antiquity of the Namib. South African Journal of Science 79, 175-183.

SOUTHERN CAPE ENVIRONMENTAL TEMPERATURES SINCE THE LAST GLACIAL

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INTRODUCTION

Temperature and rainfall are the basic elements of climate that determine the distribution of fauna and flora in an area. Determination of these two elements along a time axis is therefore an important aspect of Quaternary studies. Temperature determination using the ^{18}O content of speleothem carbonate offers a very direct method since the main uncertainties can be recognized (Hendy 1971; Talma et al 1974; Schwarcz 1986).

We have obtained a suitable stalagmite from Cango II Cave, near Oudtshoorn in the south Cape, from which a unique palaeotemperature curve spanning the greater part of the last 30 000 years could be obtained. The first measurements have been reported elsewhere (Vogel 1983) and later versions have been quoted by others (Tyson 1986; Deacon and Lancaster 1988). We hope to publish the detailed data set soon.

BACKGROUND

The principle of the technique is that the $^{18}O/^{16}O$ ratio of carbonate in a deposit depends on the oxygen isotopic composition of the water from which it formed and the temperature during such deposition (Schwarcz 1986). Some requirements regarding water evaporation and chemical/ isotopic equilibrium have to be met (Hendy 1971). We have derived the isotope values of the cave drip water from that of present day drip water and by comparison with old groundwater from Uitenhage, near Port Elizabeth (Heaton et al 1986). With this knowledge the technique is limited by the resolution afforded by low growth rate of the stalagmite to enable close sampling and by the stability of the material to retain its isotope composition with time. Uncertainties in the method are: analytical errors, wrong estimation of water isotopic composition and absence of isotopic equilibrium. We believe that the temperature data derived are a good reflection of actual environmental temperatures during those times.

THE DATA SERIES

The data consist of 162 values of temperature calculated from the $^{18}O/^{16}O$ ratio of the carbonate. Measurements are available in the age range 0 to 5 060 years BP and 13 810 to 30 000 years BP (ages are reported as radiocarbon years Before Present). No stalagmite formation occurred during the 9 000-year gap.

The main temperature features, referred to present day temperatures, are:

1) three to four degrees cooler than present at 30 000 years BP;
2) gradual cooling towards 18 000 years BP;
3) between 18 000 and 15 000 years BP temperatures fluctuated with minimum values at seven degrees below while averaging at five and a half degrees;
4) warming up towards 13 800 BP; and
5) systematic temperature fluctuations during the last 5 000 years within +1 and -2°C

These measurements are not in conflict with worldwide patterns and confirm earlier work using dissolved gases in old groundwater (Heaton et al 1986).

REFERENCES

Deacon J and Lancaster N J 1988. Late Quaternary palaeoenvironments of Southern Africa. Clarendon Press, Oxford.

Heaton T H E, Talma A S and Vogel J C 1986. Dissolved gas palaeotemperatures and ^{18}O variations derived from groundwater near Uitenhage, South Africa. Quaternary Research 25, 79-88.

Hendy C H 1971. The isotopic chemistry of speleothems. Geochimica et Cosmochimica Acta 35, 801-824.

Schwarcz H P 1986. Geochronology and isotopic geochemistry of speleothems. In: Fritz P and Fontes J Ch (editors) Handbook of Environmental Isotope Geochemistry, Vol 1A, 271-304. Elsevier, Amsterdam.

Talma A S, Vogel J C and Partridge T C 1974. Isotopic contents of some Transvaal Speleothems and their palaeoclimatic significance. South African Journal of Science 70, 135-140.

Tyson P D 1986. Climatic change and Variability in southern Africa. Oxford University Press, Cape Town.

Vogel J C 1983. Isotopic evidence for the past climates and vegetation of southern Africa. Bothalia 14, 391-394.

ENVIRONMENTAL ISOTOPE AND HYDROCHEMICAL DATA ON KALAHARI GROUND WATERS IMPOSE CONSTRAINTS ON CONCEPTS OF HOLOCENE CLIMATIC VARIATIONS

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THE KALAHARI: PHYSIOGRAPHY AND CLIMATE

The Kalahari is a vast, aeolian-sand covered region, comprising most of Botswana and the Gordonia District of the northern Cape (Figure 14.10). The region is not a true desert but a semi-arid savanna (traditionally: thirstland). The present ephemeral surface drainage is mainly internal, consisting of 'fossil' river valleys and pans of playas. Sustained surface drainage is brought into the defined region through the Okavango delta in the north. The ephemeral Kuruman, Nossob and Molopo Rivers occasionally carry flood waters in the south.

Present day rainfall in the Kalahari ranges from about 200 mm in the south-west to 600 mm in the north-east. Grey and Cooke (1977) and Brook (1982) postulate the last major humid phase to have lasted from 18 000 BP to 13 000 BP with evidence for more recent minor wet phases.

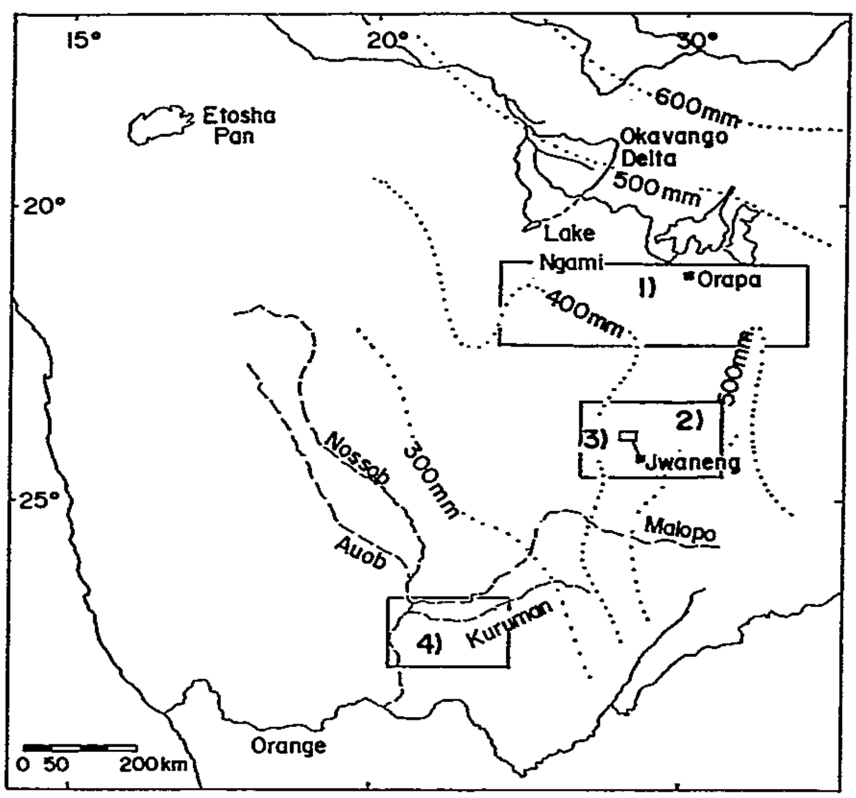

FIGURE 14.10 Location diagram, showing the approximate extent of the four main study areas. Also shown are major drainage features as well as isohyets for the Kalahari region, which extends northwards from the Orange River and westwards to the Nossob. Jwaneng mine and its well field 3) lie in the Kweneng district of Botswana 2).

GROUND WATER

Ground water in the Kalahari was first thought to be largely fossil, the remnant of rain water infiltrated during earlier, 'pluvial' periods. De Vries (1984) assumes only minimal ground water recharge during the past 13 000 years and a gradual decline in piezometric (or ground water rest) levels. Over the past 20 years, environmental isotope measurements, along with hydrochemistry and more refined hydrological observations, have revolutionized thinking about the geohydrology of this area. These observations have shown that the recharge of ground water is an ongoing phenomenon which continues into the present climatological phase (eg Verhagen et al 1974; Mazor et al 1974; Verhagen 1985a,b).

Conversely, the isotope data set on the ground waters of the Kalahari, which is essentially a closed basin, constitutes an often imperfect, but still important, record of ground water recharge and thus of the rainfall and climate over the past 40 000 years. The most meaningful isotope signals cover the Holocene and form a data series from four different study areas on which to base extrapolations of future trends.

ENVIRONMENTAL ISOTOPES

The isotopic ratios of the elements oxygen and hydrogen in the water molecule and carbon in dissolved bicarbonate can give information about the origins and turnover time of ground water.

The values $^{18}O/^{16}O$ and $^{2}H/^{1}H$ undergo small changes during processes such as evaporation and condensation. These changes are expressed as fractional differences (∂) from a sea water standard in parts per thousand (‰). In rain these ∂-values are dependent on a variety of environmental factors, such as geographical position, altitude, temperature and rainfall amount. They can therefore be employed as climatological indicators. Their sensitivity is variable, but for example ^{18}O, the atmospheric temperature response, lies in the range of 0,5% /°C whilst the precipitation (mean monthly) amount response can be as high as -1,5% /100 mm (Yurtsever and Gat 1981).

For precipitation worldwide, a linear plot of $\partial^{2}H$ against $\partial^{18}O$ is obtained, known as the meteoric water line (see Figure 14.17), where cooler, moister conditions produce the more negative values. When an open water body is subject to significant evaporation, its isotopic content will plot on a line of lesser slope. These isotopic signals will be retained, with a degree of weighting, during ground water recharge.

The radioactive isotope ^{3}H or tritium has a half life of 12,4 years. It is cosmic ray - produced and recently present in thermonuclear fallout. It can be used as a "dating" tool for ground water since time of infiltration, over a period of several decades. Its concentration is expressed in TU, or multiples of $^{3}H/^{1}H = 10^{-18}$.

The much longer-lived radiocarbon or ^{14}C ($t_{1/2}$=5730 years), also produced by cosmic rays and in nuclear explosions, finds its way through plant biological activity into bicarbonate dissolved in ground water. This allows "dating" of the ground water over many thousands of years, although complicated by the carbonate chemistry. The ^{14}C concentration is expressed as per cent modern carbon (pmc), prebomb atmospheric CO_2 taken as 100.

Used together, these radioactive and 'stable' isotopes therefore constitute a set of potentially powerful tools for palaeoclimatological investigations.

EVIDENCE FROM INDIVIDUAL STUDY AREAS

Study area 1: Northern Kalahari and Orapa

This area provided the first isotopic evidence of widespread present day recharge to ground waters in the Kalahari (Verhagen et al 1974). These ground waters show levels of the cosmogenic radioactive isotopes ^{3}H and ^{14}C ranging from low values, commensurate with water stored for long periods, up to post-bomb values, produced by rain recharge during the past two decades (Figure 14.11).

In terms of conventional ages, values range from a few tens of years to about 10 000 years for subartesian water in Clarens (locally Ntane) sandstone below basalt and Kalahari Formation cover. ^{2}H and ^{18}O concentrations are similar for the shallow (recent) and deeper (old) ground water at Orapa (Figure 14.12), suggesting similar recharge conditions and similar concentrations in the infiltrating rain. The parallel chemical development in the ground waters goes from HCO_3 (recent) to Cl (old) dominance.

The present climate can be taken to represent an intermediate phase (rainfall 400 to 500 mm yr^{-1}) between arid and pluvial conditions. As rain recharge has been an ongoing process in this subregion over at least the past 10 000 years, this intermediate phase can be taken to be representative of most of the post-glacial period.

Above 80 pmc, significant amounts of short-lived tritium indicate recent (<10 years) water, whilst intermediate ^{14}C values suggest ongoing recharge. This demonstrated for the first time that present day recharge was occurring in the Kalahari. Atmospheric input of the two isotopes, at a maximum due to bomb fallout during the latter 1960's, has since declined substantially.

Study area 2: Kweneng district

In this study area, ground waters are generally encountered in Ecca sandstones, under considerable thickness of Kalahari Formation. Village supply boreholes, often some 100 m deep, penetrate the main aquifer for some tens of metres. The ground water is usually slightly subartesian, depending on local aquifer conditions. These tend to be uniform due to the very gentle northwards dip of the Karoo formations.

Tritium is generally at vanishing concentration, placing a lower limit of about 60 years on the mean age of the penetrated water column. The bulk of the radiocarbon values show a frequency distribution (Figure 14.13) peaking around 55 pmc, indicating a mean age of around 3 000 years. The peak at lower values is for water struck at greater depths, under confined conditions. Values about 90 pmc are mainly for shallower ground waters. The hydrochemistry can be highly variable from site to site (Bath unpublished). Except possibly on a local (≈10 km) scale, there are no hydrochemical (or isotopic) trends suggesting subregional lateral ground water movement at present.

The model ground water ages for the central peak in the distribution are too low to be associated with the main humid phase, which is postulated to have continued up to 13 000 BP. Ground water clearly contains more recent recharge as seen in the distribution which, because of the limited lateral mobility, is to be found at the top of the saturated column. The distribution shows that older, low-^{14}C water is occasionally found in boreholes drilled into deeper downthrown or hydrologically confined sections of the Karoo aquifer. Most boreholes reach this older water through the shallower water layers, which must clearly be much younger than the 3 000 to 5 000 years seen in the pumped mixtures. This, and the variable chemistry, is clear evidence of ongoing diffuse rain recharge.

Major isotopic changes over several years at certain points, show that such recharge continues up to the present (Verhagen 1985b). As infiltrating rain water can take several decades to traverse thick unsaturated zones, tritium is often absent where radiocarbon at more than 70 to 80 pmc suggests the presence of recent water (see also Figure 14.11).

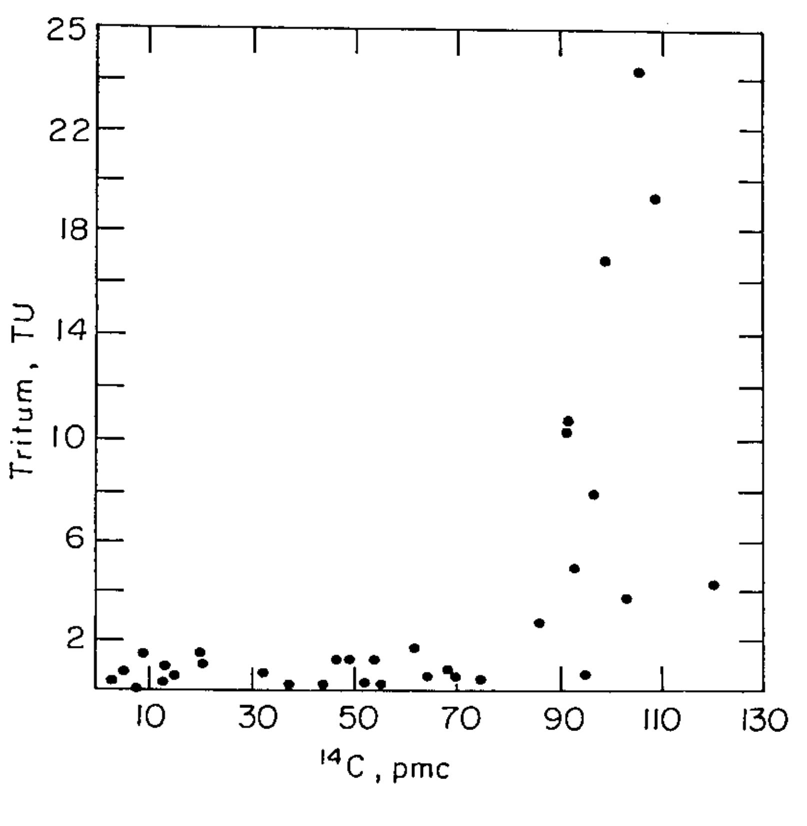

FIGURE 14.11 Tritium concentrations plotted against radiocarbon values for ground water at various locations in the northern Kalahari during 1970 to 1975 (from Verhagen 1984).

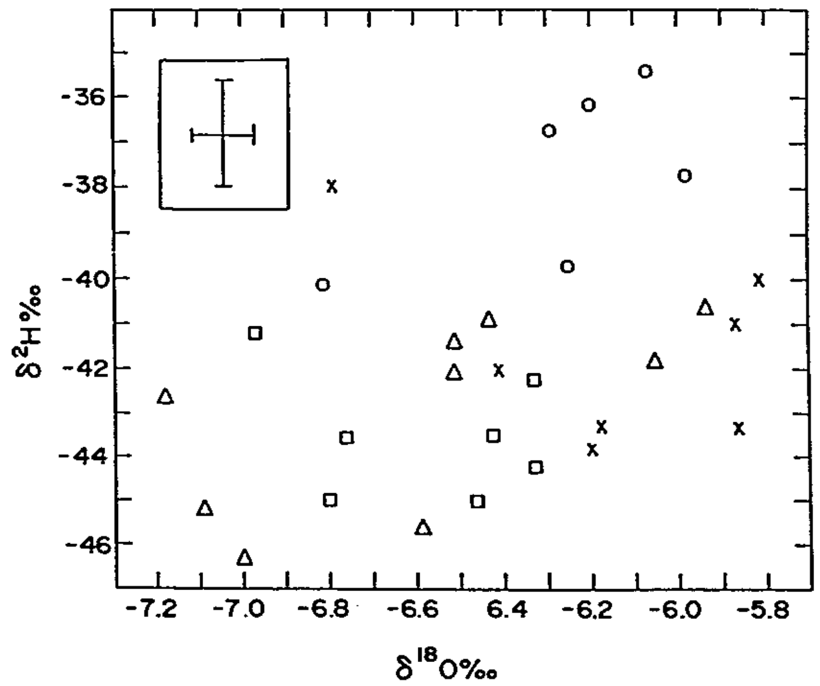

FIGURE 14.12 A plot of $\partial\,^2H$ against $\partial^{18}O$ for various ground water occurrences at Orapa, Botswana (from Mazor et al 1974). The open symbols O, ∂ and Δ are for deep water in the Karoo sandstones (ages up to 20 000 years) and X is for shallow (Kalahari Formation) water derived from present day recharge. The isotopic composition sets largely overlap, suggesting that the infiltrating rain water carried similar mean climatic signals over this dating range.

Study area 3: The Jwaneng mine well field

The well field is situated on a former delta of Ecca age which contains horizons of exceptionally coarse-grained sandstone. Dipping north-westwards, this initially phreatic or open aquifer is progressively confined above by an increasing thickness of mudstone, which in turn is overlain by Kalahari deposits. The ground water is of the low salinity, $Ca/Mg\text{-}HCO_3$ type, distinct from most other Kweneng ground waters. Radiocarbon measurements (Figure 14.14) show that the ground water in the north-west of the well field is surprisingly young (1 000 to 1 500 years), whilst in the south-east, residence times tend towards those found in the rest of the Kweneng District (Figure 14.13).

The well field's performance exceeded expectations in that the drop in water levels during exploitation was much less than predicted by model studies, which suggest a leakage factor. Only minor changes in ^{14}C values over several years (Figure 14.15) and after the abstraction of some 15 x 10^6 m^3, confirm high storage, therefore also of the more recent water. The younger and older water exhibit barely measurable stable isotope differences (cf study area 1), suggesting that they were recharged under much the same conditions. Very recent water (<30 years, based on ^{14}C and ^3H) was encountered in the first water struck (the top-most layer of the saturated zone) during the sinking of a new borehole in the well field.

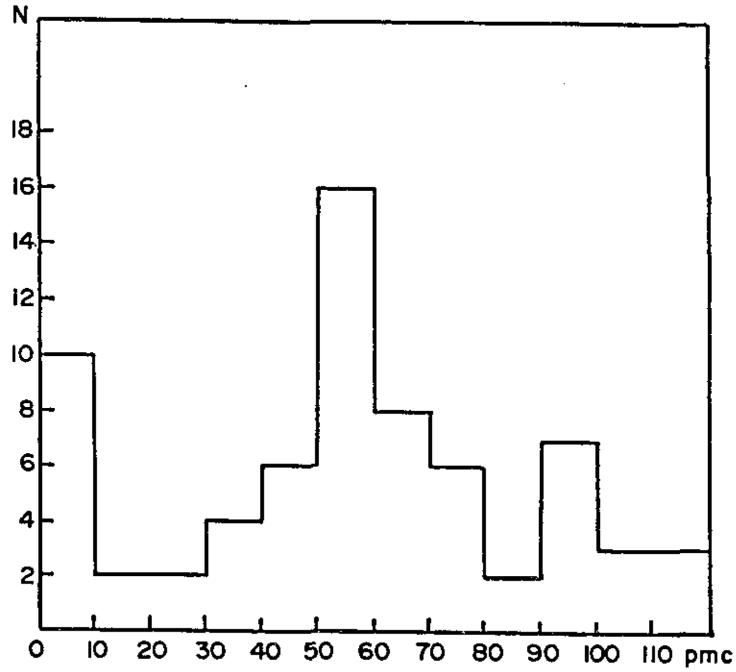

FIGURE 14.13 Frequency diagram of radiocarbon concentrations found in ground water from mainly low-yielding supply wells in the Kweneng district of Botswana (from Verhagen 1985b). The bulk of the samples, mainly from Ecca sandstone, fall in the central maximum centered on 55 pmc. Secondary maxima are seen around 100 pmc, for recently recharged, usually shallow water and below 10 pmc, for deep, usually confined, older water.

The overall picture is one of ongoing diffuse areal recharge by rain over the well field and surroundings, under comparable conditions for at least the past 4 000 years. This might constitute the leakage factor which appears in the model studies. Calculations based on isotope and geohydrological data shown an average long-term recharge rate of two to four millimetres per year.

Study area 4: North-western Gordonia

Traditional models assumed the ephemeral rivers to be principal recharge areas for the ground water in Gordonia. However, no consistent regional ground water movement away from riverbeds could be established on the basis of many isotope observations.

Ground waters in the immediate vicinity of the Kuruman River, which carried water several times this century, are shown by ^{14}C to be recent (<1 000 years) and by ^{3}H to be very recent (<30 years), suggesting recharge in the riverbed. Further away, ^{3}H vanishes and ^{14}C levels are generally lower and variable and, along with the hydrochemistry, show no spatial ageing trends (Figure 14.16).

Stable isotope values for the recent water near the riverbed are more negative than those of the generally older, surrounding ground water (Figure 14.17) as well as for ground water elsewhere in the Kalahari.

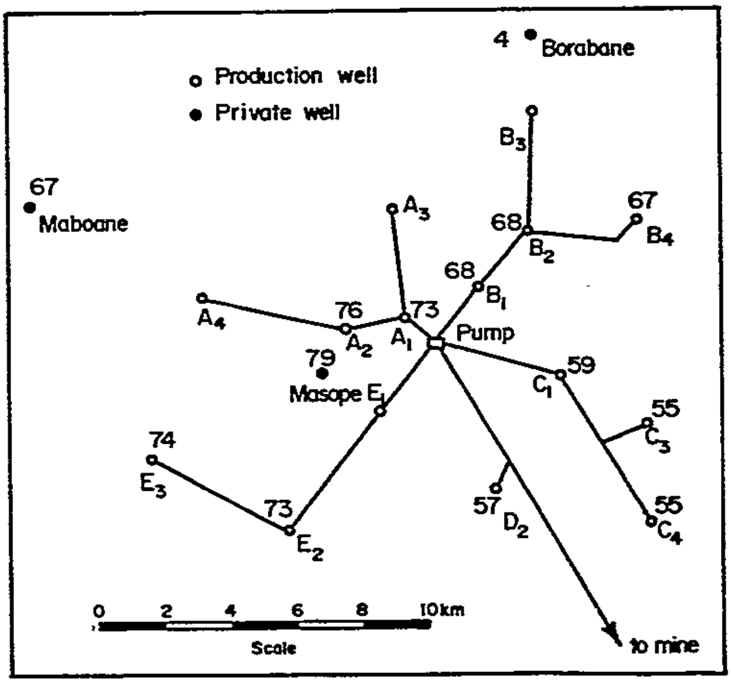

FIGURE 14.14 Diagram of Jwaneng mine well field, showing pipelines, well locations and numbers, and mean radiocarbon concentrations in pmc in the pumped water (from Verhagen 1987). These high-yielding wells are some 200 m deep, tapping the sandstone aquifer under unconfined to partially confined conditions. Also shown are some private or "tribal" wells. Note the low ^{14}C value for Borabane, a low-yielding well intersecting the same aquifer which is here fully confined, at 300+m depth just north of the well field.

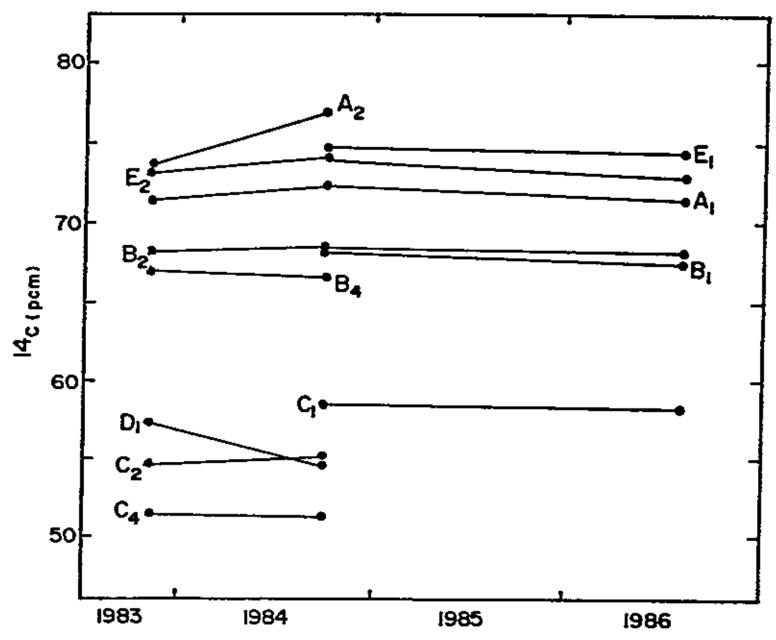

FIGURE 14.15 Radiocarbon concentrations in water pumped from several Jwaneng mine wells over a period of three years. The higher values suggest that a significant proportion of recent water is being pumped from the field. In most of these wells there has been practically no change over this period. This supports the conclusion - from minimal drop in ground water levels during six years of sustained pumping - that the storage in the aquifer is substantial. This storage must include the recent recharge (leakage?) component.

Such isotopically 'lighter' values are conventionally expected in ground water resulting from the higher rainfall and generally moister conditions associated with major humid phases or 'pluvials'. In the present climate, higher rainfall, such as occurred in the mid-1970's and again in the 1987/88 season, caused the Kuruman River to flow and produced isotopically light ground water close to it. The older ground water further from the river has isotopic values closer to, but still lighter than, the present day mean for precipitation. This is interpreted as indicating that these waters originate also from diffuse recharge during less extreme rainfall seasons, with a tendency to select more intense, and thus isotopically lighter rain events.

CONCLUSIONS

Isotopic and chemical signals can be interpreted in terms of the late Quaternary and especially the Holocene history of rain water recharge of Kalahari ground waters. Recharge has clearly continued throughout the period since the end of the Last Glacial Maximum (≈13 000 BP), representing greater aridity.

Isotope methods have proved ongoing rain recharge to deeper ground waters which were often observed to show insignificant changes in piezometric level. From this apparent contradiction it is concluded that recharge should be mainly episodic, produced during periods which constitute statistical "outliers" within the present climate, in which rainfall is exceptionally intense or prolonged. Only recently, after continued observation, have some deep Kalahari ground waters been seen to respond to heavy rain episodes (Verhagen unpublished).

The isotopic information obtained in this way is obviously conditioned by a system which, like most others, responds imperfectly to changing rainfall conditions, in this case, for example, through variable losses in the unsaturated zone, changing vegetation patterns, mixing of pumped water, etc. On the other hand, the usually phreatic (nonconfined) to semiconfined ground water of the Kalahari reflects rain recharge in the general area of observation, providing an ongoing, cumulative signal over the "dating" period.

Some of the other indicators of holocene climate are noncumulative in their nature. Standing alone, geographically and in time, (eg stromatolites in some Kalahari pans; certain erosional features) such palaeohydrological and physiographic phenomena could refer, not necessarily to prolonged humid or pluvial phases, but possibly to shorter periods constituting statistical fluctuations or high rainfall "outliers" within the present climatic regime, referred to above. Such periods could span perhaps no more than several seasons and may even be restricted geographically and could account for some of the minor wet phases of the Holocene that have been postulated by, for example, Grey and Cooke (1977) and by Heine (1982).

There is no evidence in the isotopic record of Kalahari ground water for major changes in the rainfall pattern over the past ≈10 000 years. This suggests a climatic range resembling that of the present. A similar conclusion was recently reached on the basis of an atmospheric circulation model (Cockroft et al 1987). Older Kalahari ground water similarly does

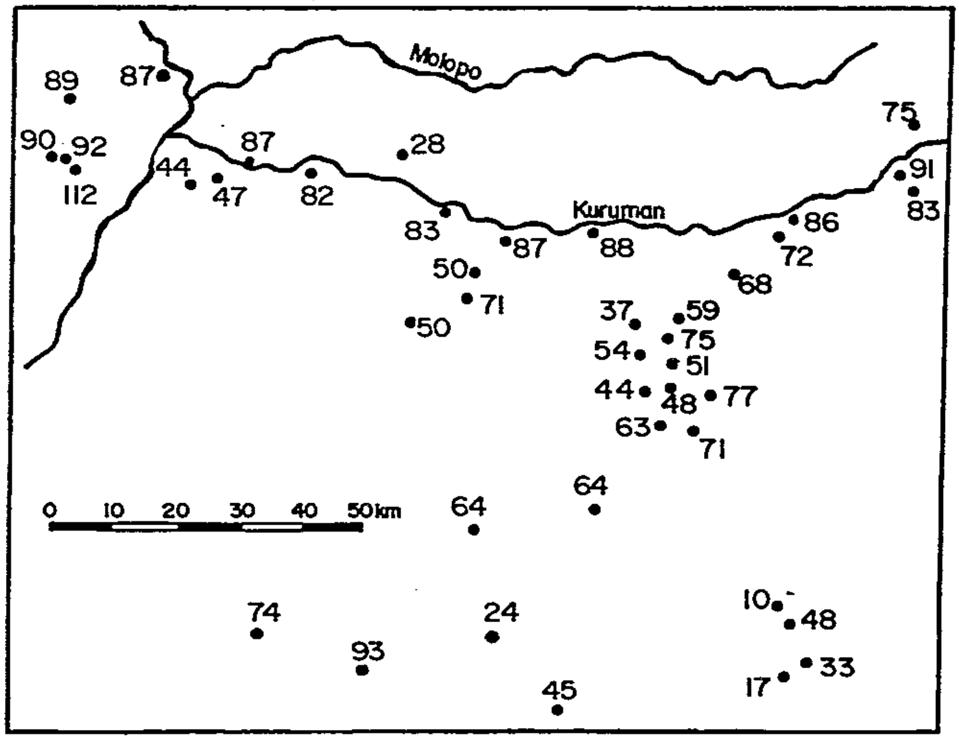

FIGURE 14.16 Radiocarbon concentrations in water from wells in northern Gordonia (from Verhagen 1985a). Close to the Kuruman River all wells show values >80 pmc, indicating mainly recently recharged water. Away from the river, concentrations are generally lower and interspersed with higher values. No systematic trend is therefore seen as would be expected from subsurface flow away from the river in the absence of diffuse areal rain recharge.

not correlate with recharge derived from an earlier, presumably prolonged wetter of pluvial phase as it generally does not show a distinctive stable isotope trend (Figure 14.18). Resolution in signals such as ^{18}O is likely to decrease for older ground water, however, as is seen in the narrowing range of observed values with increasing age.

It is significant that the isotopically "lightest" values found in the entire region thus far are for the very recent ground water close to, and clearly infiltrated from present day flooding in, the Kuruman River bed (Study area 4). Pluvials could be expected to resemble in some ways the high rainfall outliers which constitute the source of the floods at present, but then over much longer time periods. Yet, nowhere in the Kalahari have remnants of older water with such a "light" isotope signal been found. This can be taken to indicate that, on the average, these wetter or pluvial phases achieved neither the same rainfall intensities nor as cool conditions.

The most probable climatic pattern which can be extrapolated into the immediate future is that of the mid-Holocene which extends into the present. As has been demonstrated by extreme weather periods in historical times, the present climatic phase is characterized by large and as yet poorly assessed variability. Whether this observed variability is periodic and thus predictable, has yet to be established.

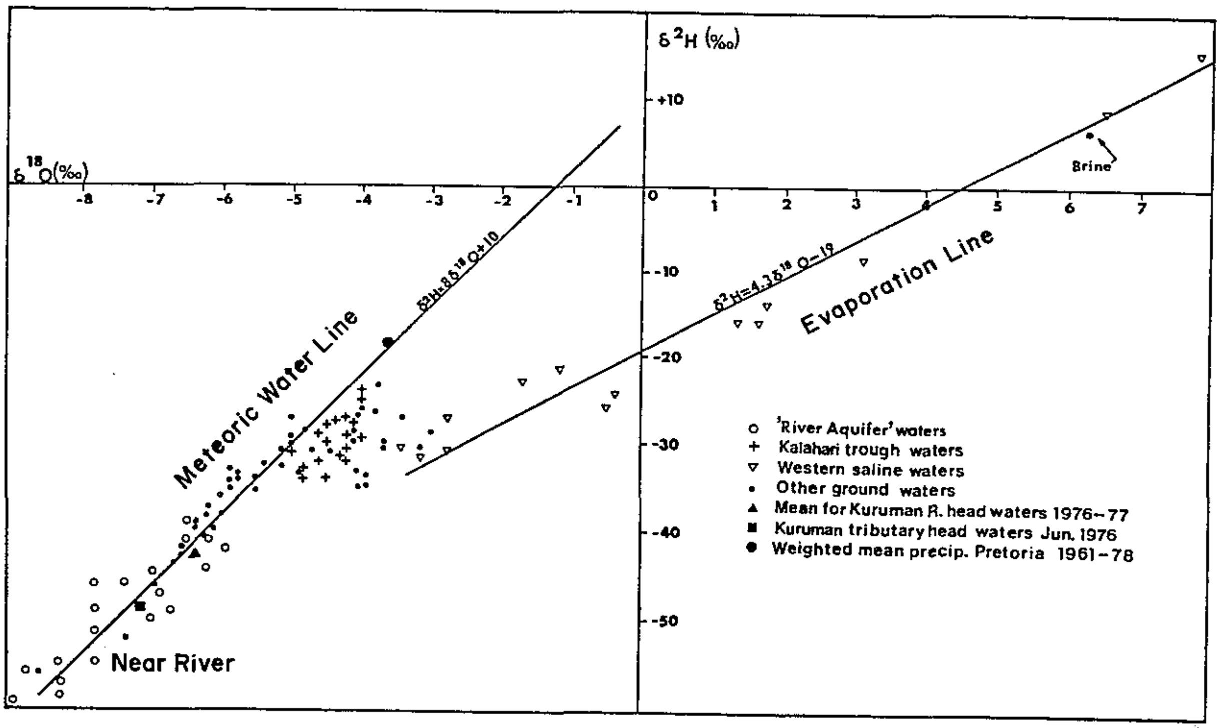

FIGURE 14.17 A $\partial\,^{2}H-\partial\,^{18}O$ diagram of ground water from many wells in Gordonia (from Verhagen 1983). Various categories are shown, the most negative being for recent ground water close to the Kuruman River. Isotopic values for head waters during the 1976/77 floods are shown for comparison. There is practically no overlap with other ground waters, supporting ^{14}C data that these cannot be derived from river infiltration. Also shown are the meteoric water (rain) line and an evaporation line fitting values for saline waters in the west of the area.

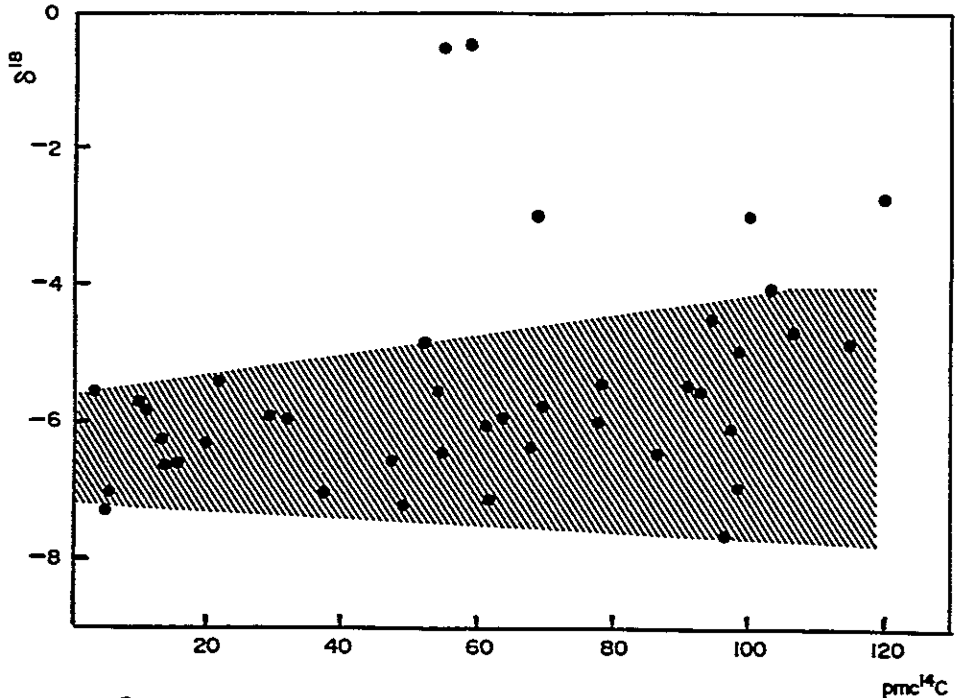

FIGURE 14.18 $\delta^{18}O$ values plotted against ^{14}C in pmc for Kalahari ground water from Botswana, sampled during a general survey. The "heavier" (less negative) values probably represent water which underwent isotopic enrichment due to partial evaporation before recharge. For the bulk of the (nonevaporated) water (indicated by the hatched field) no trend is seen over the past ≈20 000 years, except that the ^{18}O values becomes more uniform, ie loss of resolution. No climatic variations are reflected in this data.

REFERENCES

Brook G A 1982. Stratigraphic evidence of Quaternary climatic change at Echo Cave, Transvaal and a palaeoclimatic record for Botswana and north-eastern South Africa. Catena 9, 343-351.

Cockroft M J, Wilkinson M J and Tyson P D 1987. The application of a present day climatic model to the late Quaternary in southern Africa. Climatic Change 10, 161-181.

De Vries J J 1984. Holocene depletion and active recharge of the Kalhari ground waters - a review and an indicative model. Journal of Hydrology 70, 221-232.

Grey D R C and Cooke H J 1977. Some problems in the Quaternary evolution of the landforms in northern Botswana. Catena 4, 123-133.

Heine K 1982. The main stages of the late Quaternary evolution of the Kalahari region, southern Africa. Palaeoecology of Africa 15, 53-76.

Mazor E, Verhagen B Th, Sellschop J P F, Robins N S and Hutton L G 1974. Kalahari ground waters: their hydrogen, carbon and oxygen isotopes. In: Isotope Techniques in Groundwater Hydrology 1974. International Atomic Energy Agency, Vienna. 1, 203-225.

Verhagen B Th 1983. Environmental isotope study of a ground water supply project in the Kalahari of Gordonia. In: Isotope Hydrology 1983. International Atomic Energy Agency, Vienna, pp 415-432.

Verhagen B Th 1984. Environmental isotope hydrology in southern Africa. In: Challenges in African Hydrology and Water Resources. IAHS Publication No 144, 161-174.

Verhagen B Th 1985a. Isotope hydrology of ground waters of the Kalahari, Gordonia. Transactions of the Geological Society of South Africa 88, 517-522.

Verhagen B Th 1985b. Isotope geohydrology: some hydrochemical and water supply insights into the Kalahari. In: Proceedings of a Seminar on Mineral Exploration of the Kalahari. Geological Survey Department of Botswana. Bulletin 29, 278-293.

Verhagen B Th 1987. Environmental isotopes suggest a recharge model for the well field supplying Jwaneng mine, Botswana. In: Isotope Techniques in Water Resources Development. IAEA, Vienna, pp 170-171.

CHAPTER 15. FORCING MECHANISMS

CLIMATE

THE ATMOSPHERE

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A knowledge of climatic change and variability is central to any understanding of changing environmental conditions and the eventual prediction of global change on the scale of decades to centuries. Since this prediction is the central theme of the International Geosphere Biosphere Programme, it is important, at the outset of the programme, to review the nature of the data series that allow climatic changes over southern Africa to be defined.

The period of meteorological record over South Africa is disappointingly short. Rainfall records in the Transvaal started only near the turn of the century. At a few sites in Natal and in the Cape, reliable rainfall records extend back into the early part of last century. Temperature records have somewhat shorter histories to those of rainfall. Although systematic, upper-level, balloon wind observations were begun in the 1920's, regular radiosonde measurements of temperature, moisture and wind from a network of sites originated only in the 1950's.

In order to extend the record back in time beyond the period of meteorological record, various types of qualitative proxy data may be used. These may be calibrated to produce useful quantitative estimates. To extend the data far back in time requires a variety of geological, geomorphological, palaeontological and palaeobiological sources. Such is the success of these techniques that it has been possible to develop generalized, but valid, temperature records extending back many millions of years. The more recent the records, so the greater the detail. Oxygen isotope studies illustrate this effect (Figure 15.1). Dendrochronology may provide valuable information (Figure 15.2). Documentary evidence, such as reports in explorers journals, missionary records and other historical data may be useful (Figure 15.3).

Perhaps the most immediately evident feature of temperature records on all scales is their variability. Climates have never been and never will be constant. They may change slowly or abruptly; they rarely remain unaffected by more rapidly varying weather patterns. Many of the major longer-term changes in temperature may be ascribed to continental drift, to the break-up of Gondwanaland and to orbital variations. The most characteristic aspect of the record over the past two million years is the irregular fluctuations that have occurred between glacial and interglacial conditions. Southern Africa itself has not been covered by ice since separating from Gondwanaland. Nevertheless, its climates have oscillated in response to global forcing, but with distinctive regional variations.

In the record covering the period back to 30 000 BP, which includes the Last Glacial Maximum, it is possible to identify periods lasting only a

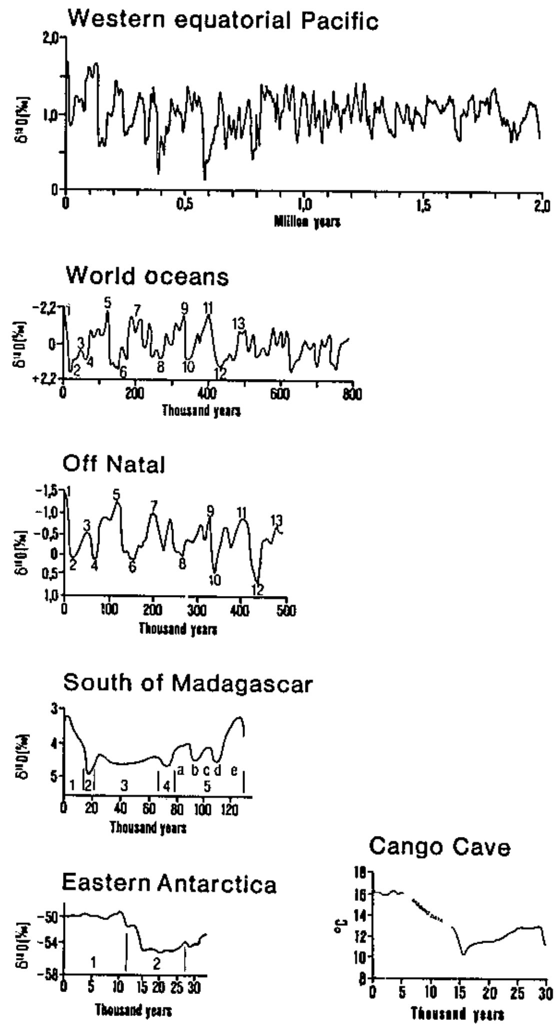

FIGURE 15.1 Oxygen isotope chronologies: for deepsea sediment cores in the western equatorial Pacific (after Shackleton and Opdyke 1973); a world ocean average based on five cores in different oceans (after Imbrie et al 1984); off the Natal coast (after Prell et al 1979); south of Madagascar (after Shackleton 1977); in eastern Antarctica (after De Angelis et al 1984) and in Cango Cave (after Talma and Vogel in preparation). Where numbers are given below the curves these refer to oxygen isotope stages.

few thousand years, during which temperatures and rainfall differed markedly from those in adjoining periods. As the record becomes more modern so the detail in the record increases. Temperature and rainfall variations on time scales ranging from millennia through centuries and decades may be identified. The 18,6-year rainfall variation during the twentieth century over southern Africa is clear (Figure 15.4). Variations of shorter periods may be identified down to the scale of those associated with particular weather systems.

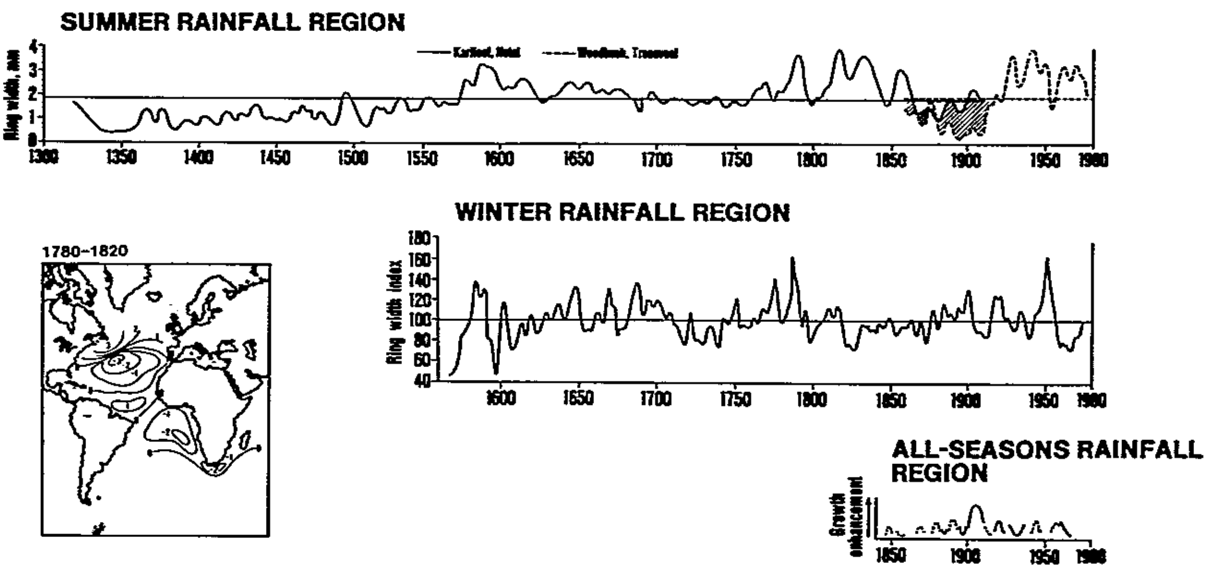

FIGURE 15.2 Variations in tree ring widths in *Podocarpus falcatus* in the summer rainfall region (after Hall 1976; Dyer 1978); in *Widdringtonia cedarbergensis* in the winter rainfall region (after Dunwiddie and LaMarche 1980) and in *Podocarpus falcatus* in the all-seasons rainfall region (after McNaughton and Tyson 1979). Inset: January sea temperatures 1780 to 1820 as departures (°C) from the average values measured between 1887/1899 and 1921/1938 (after Lamb 1969).

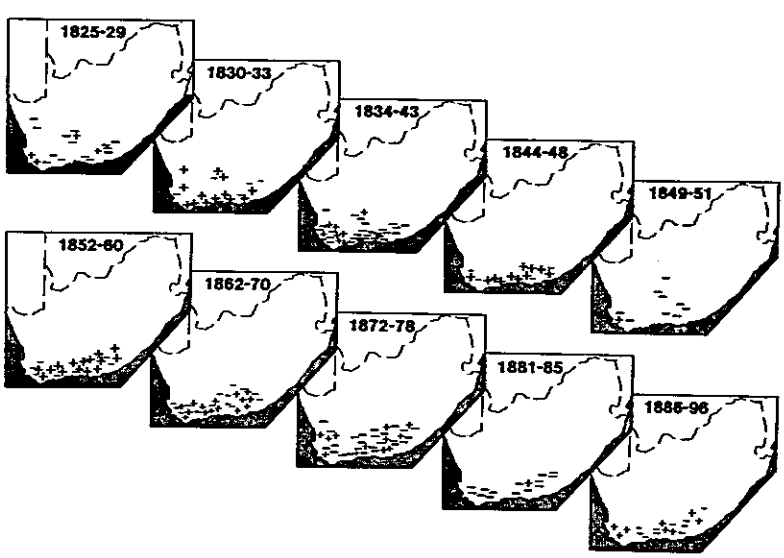

FIGURE 15.3 Precipitation anomaly maps for the nineteenth century as estimated from the analysis of historical documentation (after Vogel 1987). Predominantly wetter (+) or drier (-) conditions are indicated by bold type. Normal type indicates an indeterminate situation as a whole.

Using extensive modern day data and knowledge of mechanisms of short-term climatic variation over southern Africa, it is possible to speculate on mechanisms for past changes. In this type of work it is vital to consider spatial, preferably three-dimensional rather than two-dimensional, aspects of the variations. Modern data enable three-dimensional analyses to be undertaken. Through a variety of techniques which have recently been documented (Tyson 1986) a composite picture has been developed detailing the changes in the atmospheric circulation, both around southern Africa and across the globe, that accompany rainfall variations over the sub-continent. Based on this picture, mechanisms of climatic variation have been proposed, some of which are related to the El Niño/Southern Oscillation. Using climatic modelling it is possible to extrapolate these results back in time to the period before the advent of meteorological records. Analogues become less reliable the further back they are applied. However, with care it is possible to develop heuristic models of differences in circulation across southern Africa during the past 20 000 years.

Thus, through a combination of techniques, it has proved possible, not only to generate an extended record of climate, but also to develop an understanding of mechanisms of climatic variation over decades and of changes extending to thousands of years. Within the context of South Africa's contribution to the IGBP, the important lesson to be derived from experience in climatic research is that much can be gained from data that often appear unpromising initially. Often it may be possible to construct descriptive empirical models that may provide valuable information when compared with output from more complex, mathematical models. The interfacing of results from differing research groups working in this manner may be a useful contribution toward the achievement of the goals of the IGBP.

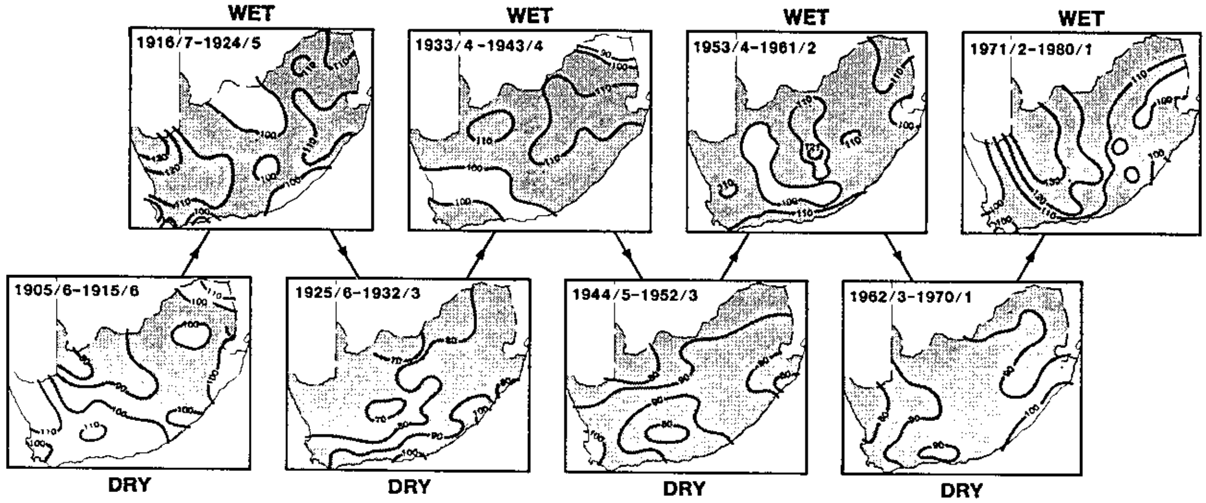

FIGURE 15.4 Percentage of mean rainfall for designated wet and dry spells based on analysis of yearly October to September rainfall data for the period 1905/06 to 1983/84.

CLIMATE AND CLIMATE MODELLING

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Climate is likely to be considered a 'black-box' input in most aspects of the IGBP although, hopefully, feedbacks of ecological processes into the atmospheric circulation will also be considered. Climate itself is, however, the subject of several major international research projects, which have as a common aim the elucidation of mechanisms of climatic change. The major projects are:

1. WCP - the World Climate Programme. The objectives here are broadly the understanding and ultimate prediction of modern day climate variations. The programme has four arms: WCRP (research) - the fundamental atmospheric research programme; WCDP (data) - a programme to identify data requirements, to obtain and archive the data; WCIP (impacts) - to identify and model climate impacts, particularly with regard to human activities; WCAP (applications) - to develop scenarios of appropriate responses to climatic change.

2. WOCE - the World Ocean Circulation Experiment. The objective is an investigation of oceanic circulation with particular reference to its impact on climatic change. Parallel with WOCE is TOGA, the Tropical Oceans and Global Atmosphere Experiment, with emphasis on tropical ocean, and particularly Pacific Ocean, impacts on climate.

Mention should also be made of COHMAP, the Cooperative Holocene Mapping Project, in which the object is to develop detailed global maps of surface climates and properties of the oceans and ecology through the Holocene as a basis for mechanistic studies.

Climate models are fundamental tools in all of the projects. There are several different types of climate models but discussion here is limited to one, probably the most informative, type - the general circulation models. These models are simplified mathematical descriptions of the atmosphere incorporating all major internal dynamic and external forcing mechanisms. They provide a 'laboratory' for atmospheric scientists who are unable, for example, to change the Earth's orbit and subsequently observe resultant changes in global climates. Through experiments in which only one, or perhaps a few, basic parameters are changed it is possible to simulate responses to variations in hypothesized forcing mechanisms. Examples of uses of models to study both modern and palaeoclimate variations include simulations of effects of changed compositions of the atmosphere, changed planetary orbits and solar outputs, changed continental distributions, changed surface properties (such as vegetation cover and soil moisture) and sea surface temperatures and changes resulting from human activities.

In addition to the climate models there exist a number of models of general world ocean circulation which may be used in similar fashion to the climate models to simulate responses in oceanic circulation to changing external forcing mechanisms and internal physical and chemical changes.

Often climate and ocean models are run independently with only simple inputs from the other medium used to force the model. In part this restriction is enforced by the unavailability of computers with sufficient power. This limitation is now being overcome and initial 'coupled' models, which directly simulate the important feedbacks between the two fluid media, have been developed. Undoubtedly these models will in future make vital contributions towards the understanding of climate variations. Many of the inputs to these models come from geophysical and ecological sources. Changing vegetative cover through whatever cause results in adjusted albedos with possible significant impacts on atmospheric circulation - one of the major subprogrammes of WCRP is the development of a spatial and temporal archive of global vegetative cover. Changes in composition of the atmosphere also often result from biological, in addition to anthropogenic, processes. Soil moisture and surface water extents are inadequately incorporated into models through simple 'parameterisations', but have major impacts on atmospheric circulation and climate. The feedbacks between the atmospheric, geophysical and biophysical environments are extensive, complex and fundamental.

The models are now sufficiently advanced to provide valuable input into the debate on relative responses to the various proposed forcing mechanisms, although frequently several mechanisms appear to force similar responses. In this case it is not possible to unequivocally identify the dominant mechanism, should one exist, or the appropriate apportionment of mechanisms. Model simulations of modern day climates are realistic in global terms but are often inadequate on regional scales and thus it is not yet possible to investigate mechanisms of regional climate variations except through specially-designed experiments. Some preliminary simulations of regional Quaternary climate variations over the Northern Hemisphere have been attempted but no equivalent work for the Southern Hemisphere has as yet been undertaken. Climate models provide an effective approach to the problem of understanding mechanisms of climate variations and undoubtedly will become increasingly central in the future.

REFERENCES

De Angelis M, Jouzel J, Lorius C, Merlivat L, Petit J R and Raynaud D 1984. Ice-age data for climate modelling from an Antarctic (Dome C) ice core. In: Berger A L and Nicolis C (editors) New perspectives in Climate Modelling, Elsevier, Amsterdam. pp 23-45.

Dunwiddie P W and LaMarche V C 1980. A climatically-responsive tree-ring record from Widdringtonia cedarbergensis, Cape Province, South Africa. Nature 286, 796-797.

Dyer T G J 1978. Unpublished research, Climatology Research Group, University of the Witwatersrand, Johannesburg.

Hall M 1976. Dendroclimatoology, rainfall and human adaptation in the later Iron Age of Natal and Zululand. Annals of the Natal Museum 22, 693-703.

Imbrie J et al 1984. The orbital theory of Pleistocene climate: support from a revised chronology of the marine ^{18}O record. In: Berger A L, Imbrie J, Hays J, Kukla G and Saltzman B (editors) Milankovitch and Climate, Part 1. D Reidel, Dordrecht. pp 269-305.

Lamb H H 1969. Climatic fluctuations. In: Landsberg (editor) World Survey of Climatology, Vol 2. Elsevier, Amsterdam. pp 173-249.

McNaughton J and Tyson P D 1979. A preliminary assessment of Podocarpus falcatus, in dendrochronological and dendroclimatological studies in the Witelsbos Forest Reserve. South African Forestry Journal 111, 29-33.

Prell W L, Hutson W H and Williams D F 1979. The Subtropical Convergence and late Quaternary circulation in the southern Indian Ocean. Marine Micropalaeontology 4, 225-234.

Shackleton N J 1977. The oxygen isotope stratigraphy record of the late Pleistocene. Philosophical Transactions of the Royal Society, London 280, 169-182.

Shackleton N J and Opdyke N D 1973. Oxygen isotope and palaeomagnetic stratigraphy of Equatorial Pacific Core V 28-239: oxygen isotope temperatures and ice volumes on a 10^5 year and 10^6 year scale. Quaternary Research 3, 39-55.

Tyson P D 1986. Climatic change and variability in southern Africa. Oxford University Press, Cape Town.

Vogel C N 1987. The reconstruction of the nineteenth century Cape climate using documentary evidence. Unpublished MA Thesis, University of the Witwatersrand, Johannesburg.

OCEAN CLIMATE CHANGES AND VARIABILITY FROM A SOUTH AFRICAN PERSPECTIVE

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PALAEO-OCEAN CLIMATE CHANGES

Although a proto system was evidently initiated off Namibia during the late Miocene, about 12 million years ago (Siesser 1980), the present arid-summer, wet-winter Mediterranean climate in the southern Benguela only appears to have been fully established towards the end of the Pliocene, ie about two million years ago (Tankard and Rogers 1978; Hendey 1983). By this time the Agulhas Current was similar to its present form, its quasi-modern flow patterns having been established about five million years ago in the early Pliocene (Martin 1987).

A feature of modern global climatic regimes initiated in the Pliocene and continuing through the Pleistocene has been the characteristic rhythm with a periodicity of about 100 000 years, linked to perturbations in the Earth's orbital characteristics, of cooler climates ie glacials, interrupted by shorter periods of warmer climates, ie interglacials (Deacon 1983). During the past million years there have been 10 major glacials and 40 minor "ice ages" (Pisias and Imbrie 1986). While the data obtained from deep sea cores suggest that changes in the Earth's orbit (tilt of the axis, eccentricity of the orbit, precession of the equinoxes) have played a dominant role in causing climate change during the Pleistocene period, there is growing evidence that changes in the concentrations of carbon dioxide in the atmosphere have also played a part. Figure 15.5 demonstrates the improved fit of a model of ice volume obtained by adding the effects of changing atmospheric carbon dioxide concentrations to those of the orbital inputs to the ice volume record derived from sediment studies (Pisias and Imbrie 1986).

Following the last glacial maximum (16 000 to 18 000 years ago) temperatures approached present values about 12 000 years ago. Over the last 10 000 years global temperatures have fluctuated through about six degrees Centigrade (Figure 15.6a), and there have been concomitant changes in ocean and atmosphere circulation. Van Zinderen Bakker (1976, 1982) and Tankard and Rogers (1978) have discussed the atmospheric and oceanic circulation patterns around southern Africa during glacials and interglacials (see Shannon 1985) and it seems probable that substantial changes in the South Equatorial Counter Current and Angola Current, in the extent and intensity of upwelling within the Benguela on the west coast and in the flux, retroflection and leakage of the Agulhas Current to the south and east, accompanied the transitions between hypo- and hyperthermal times. Recent studies by R Johnson (personal communication) on laminated sediments from the Walvis Bay area suggest that cyclical changes have occurred in upwelling intensity and longshore, cross-shelf currents during the last two thousand years. His work suggests that the temperature at Walvis Bay during the 17th century was colder, approximating the present value at Lüderitz, the principal upwelling centre in the Benguela system. This cold period coincides with, but may not necessarily have been linked to the "Little Ice Age" (Figure 15.6a) when temperatures in high northern latitudes were significantly colder than at present. The Little Ice Age was accompanied by changes in the pattern of global winds and the Gulf Stream followed a more southerly course. The result was that Europe experienced an extended period of severe winters and short summers. The meridional displacement of the two degrees Centigrade and six degrees Centigrade sea surface isotherms during the Little Ice Age is illustrated in Figure 15.6b. Note that the 14°C isotherm was not significantly displaced.

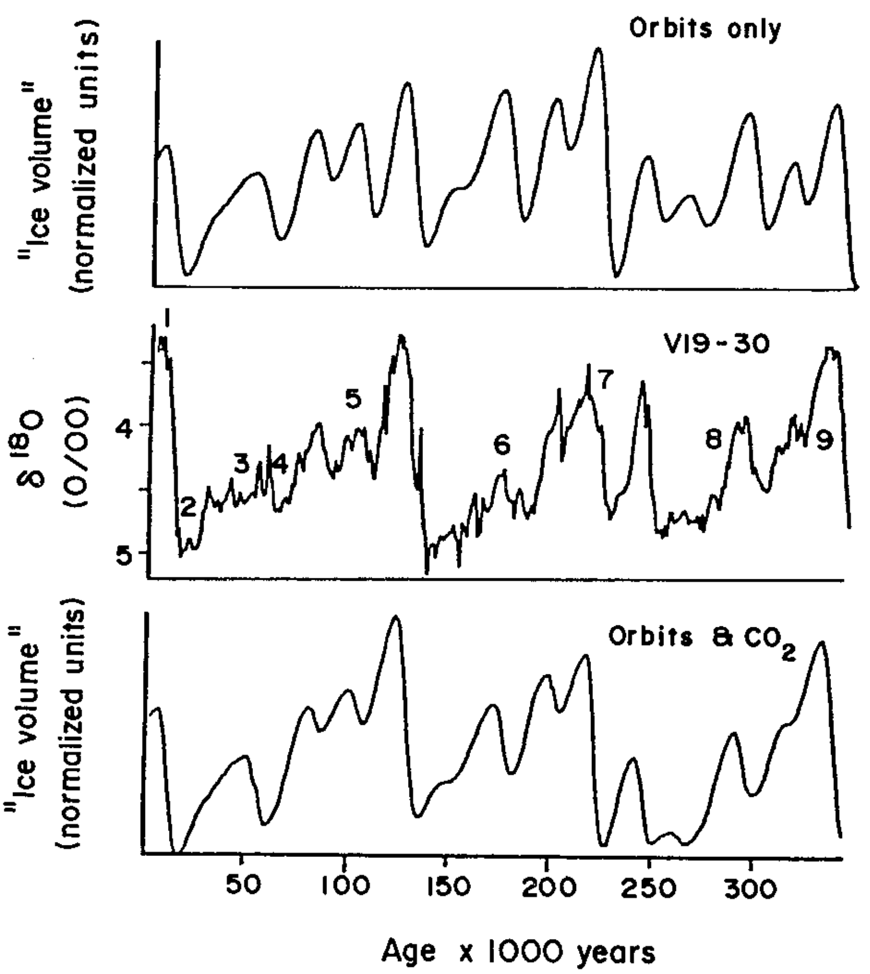

FIGURE 15.5 Global ice volume from deepsea sedimentary record (middle graph) compared with an ice volume model using orbital geometry alone (top) and a model incorporating both orbital and atmospheric CO_2 data (bottom) (after Pisias and Imbrie 1986).

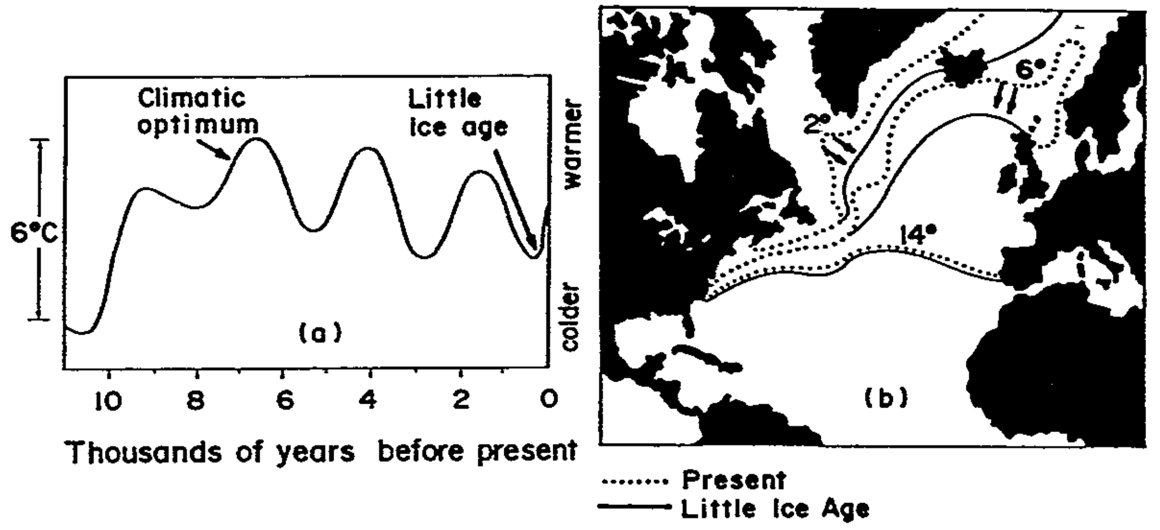

FIGURE 15.6(a) Trends in global climate during the past 10 000 years, as cited by Scavotto (1986)
(b) SST in the North Atlantic during the little ice age compared with present values (after Scavotto 1986).

The sensitivity of the circulation in the North Atlantic to global cooling has been demonstrated by means of a three dimensional prognostic model developed by Sundermann (1987). His model predicts that major changes in the currents, in particular in the Gulf Stream, occurred in the surface and deeper layers during the Last Glacial Maximum. The model, however, predicts relatively little change in the circulation in the South Atlantic.

While the Milankovitch orbital hypothesis accounts for much of the Earth's long-period climatic variability, it does not explain the observed glacial periodicity of 100 000 years, nor does it account for short-period changes. Moreover many of these short-period changes have been regional rather than global and this suggests causes other than changes in the Earth's orbit. Some interesting hypotheses have emerged during the last few years and events such as the ENSO have been linked to changes in the length of day (LOD). Mörner (1987) has stressed that all major short-term paleoclimatic changes and shifts during the last 35 000 years lasted for 50 to 150 years and were only regionally (never globally) induced, for example during the last glacial sea temperatures in the eastern South Pacific were actually higher than at present (Hastenrath 1987). Mörner (1987) argues that only the hydrosphere is capable of storing and redistributing energy in this way on this time scale and that the pulses require the interchange of angular momentum between the solid Earth and the hydrosphere. He claims to have obtained good correlations between LOD and observed changes in coastal temperature, eustatic sea level and continental temperature. In particular during the last decade's El Niño years angular momentum was transferred from the solid Earth to both the atmosphere (increase in westerlies) and the hydrosphere (sea level, upwelling, climate).

DECADAL AND INTERANNUAL VARIABILITY IN SEA SURFACE TEMPERATURE, WIND STRESS AND SEA LEVEL

The change in the ten-year averages of SST (computed at intervals of five years and corrected for instrument change) between 65°N and 40°S for a 120-year period are illustrated in Figure 15.7. What is immediately apparent is the higher variability in the Northern Hemisphere, in particular around 35° and 60°N, than at southern latitudes. Significant changes in SST have occurred this century and an extended warming phase is evident, with the first part of the 20th century being distinctly cooler than the post 1945 period.

Indices of the SST and wind stress suggest that major changes have occurred this century in the region, even allowing for problems due to changes in measuring instruments (eg Folland et al 1984; Wright 1986). The periods prior to 1911 and after 1974 were characterized by significantly higher equatorward wind stress, with lower values during the 1920's, 1930's and immediately after 1945. The data suggest an increasing trend between the early 1950's and the early 1980's. Comparable changes are apparent in SST. An increasing trend in SST this century is suggested in all areas, with the period since 1945 being typically one degree Centigrade warmer than earlier periods. Coherence between SST's is fair, with the monthly anomalies in (3) being significantly correlated with those in the other five areas over the period of record. At times, however, they are out of phase - cf the post 1980 coastal and oceanic anomalies. Cool and warm periods are evident in the record, with Benguela Niños (Shannon et al 1986 - discussed later) having occurred in 1934, 1949, 1963 and 1984 and probably also around 1910, in the mid-1920's and in 1974. Figure 15.7 suggest that climate shunts or jumps occurred during the 1940's and around the mid-1970's (cf observations of Yamamoto et al 1985, 1986 on a climatic jump in Japan around 1950).

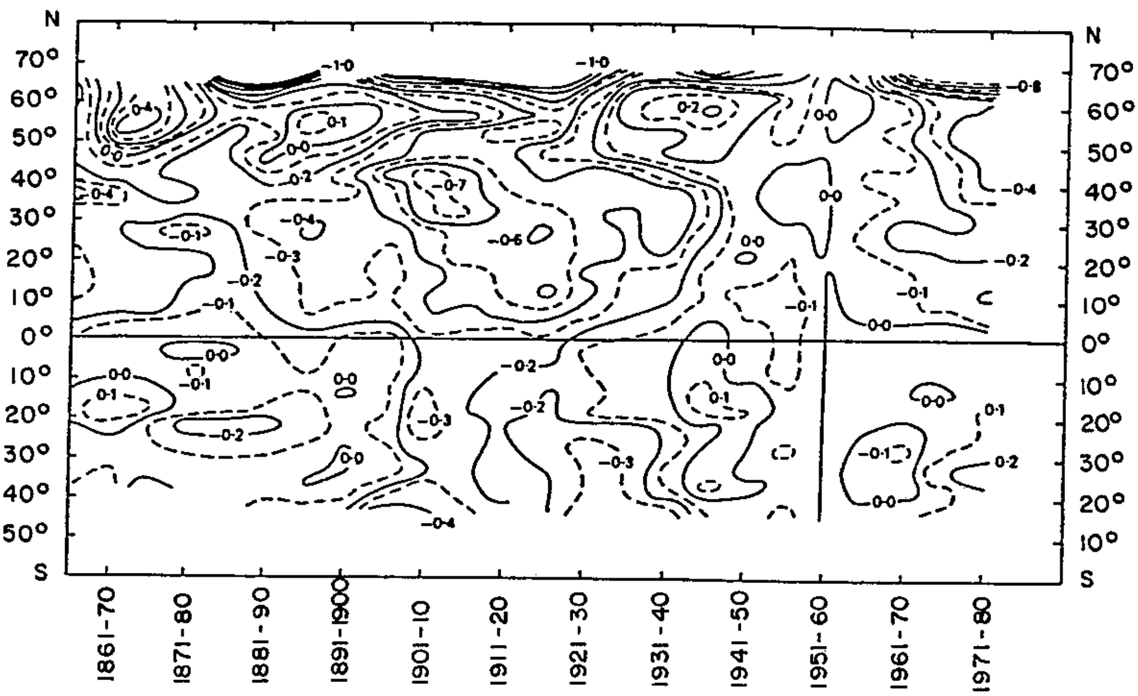

FIGURE 15.7 Zonally averaged SST anomalies relative to 1951 to 1960 (after Folland et al 1984).

A more detailed study of monthly (rather than annual) data using principal component analysis (cf comparable investigations of Taunton-Clark and Kamstra (in press) and Walker (1987) on shorter data sets) suggests a possible, but weak, eight to ten-year cycle (Taunton-Clark and Shannon in press).

The coherency of SST on the event scale over the South-east Atlantic has been demonstrated by Walker (1987), who also found a reasonable correlation between subtropical SST and zonal and meridional winds. Wright (1987) has likewise noted the coherency in SST over the South Atlantic while Nicholson (1987) has reported that Benguela SST and the Southern Oscillation appear to vary coherently.

Sea level records in the South-east Atlantic are short (Brundrit 1984), the longest reliable record being that for a 25-year period from Simon's Bay. The latter record has been constrasted against those for four sites on other continents by Brundrit (this volume). What emerges is that there has been a general increase in sea level world-wide over the last century (at least) of which about 60% can be ascribed to the effect of warming. The records for Sydney, Bombay, San Fransisco and Brest show considerable interannual and interdecadal activity. The positive departures tend to be more pronounced than the negative ones, possibly reflecting El Niño-type events. The Simon's Bay record shows similar features, but less variability (Brundrit this volume).

Viewing the available records for the South-east Atlantic together it can be concluded that the interannual variability in the region is small compared to that, for example, in the Pacific, although the seasonal effect may be more pronounced, as in the case of SST (Taunton-Clark and Shannon in press). Nevertheless it is possible that changes locally in, for example, SST, although in themselves small, may reflect to some extent changes in currents (eg flux of Agulhas water into the Atlantic), which for marine fauna and flora could be extremely important.

It is appropriate at this stage to examine the more obvious causes of interannual variability in the ocean systems around South Africa (numbers on Figure 15.8 refer to arabic numerals in parentheses in the following text):

1. Changes in regional wind stress associated with shifts in pressure belts and changes in pressure gradients. Stronger trade winds will result in increased Ekman transport off the west coast and intensification of upwelling (1), while increased westerly winds could favour advection of surface water of the Agulhas Current onto the Agulhas Bank (2) and into the Benguela region (3). Moreover, model studies by De Ruijter (1982) and De Ruijter and Boudra (1985) suggest that westward penetration of the Agulhas Current (eg Walker 1986) is sensitive to the position of the zero of wind stress curl. Changes in the frequency of cold fronts passing through the southern Benguela and of coastal lows will impact on upwelling and shelf waves in the region. Changes in regional atmospheric circulation associated with different phases of the Southern Oscillation, ie a regional response to a global phenomenon, have been shown schematically (Harrison 1986; Tyson 1986; Figure 15.9).

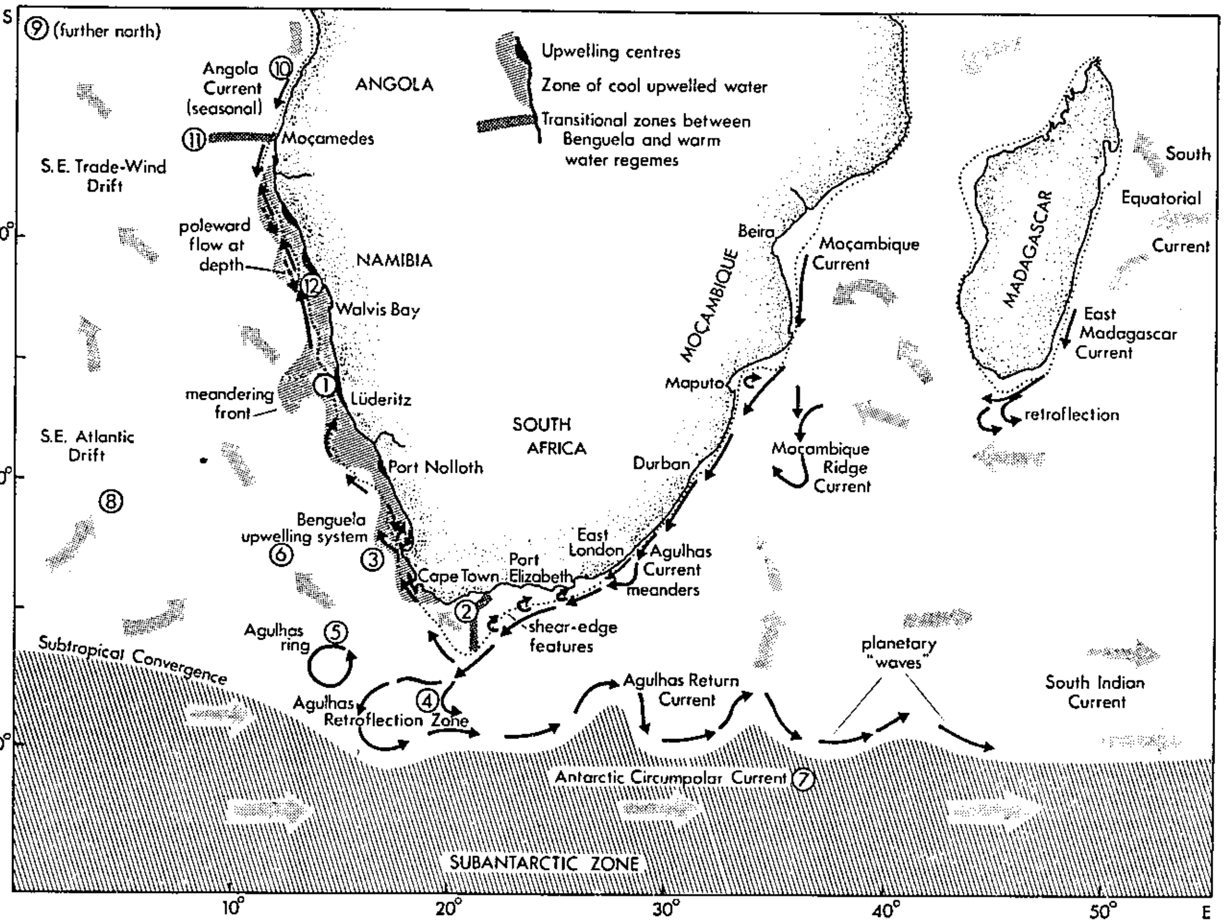

FIGURE 15.8 Schematic representation of some key features of the ocean systems around southern Africa. Numbers in parenthesis refer to components mentioned in the text (modified from Shannon in press).

2. Changes in the position and character of the retroflection (4) of the Agulhas Current, the shedding of rings (5) and their fate ie leakage of Agulhas Current water into the Atlantic (6). These factors are likely to be important and, although the causes of the changes are poorly understood, they may be associated with changes in the Antarctic Circumpolar Current (7), large-scale changes in wind stress, and pressure adjustments in the South Indian and South Atlantic oceans. A major perturbation in the retroflection of the Agulhas Current occurred in 1985 and 1986 (Agenbag and Shannon 1987) which was expected to have a significant impact on local fish populations (Shannon and Agenbag 1987).

3. Changes in the South Atlantic Gyre (8) and the Antarctic Circumpolar Current (7). These could be important for ocean dynamics on the west coast shelf at various time scales.

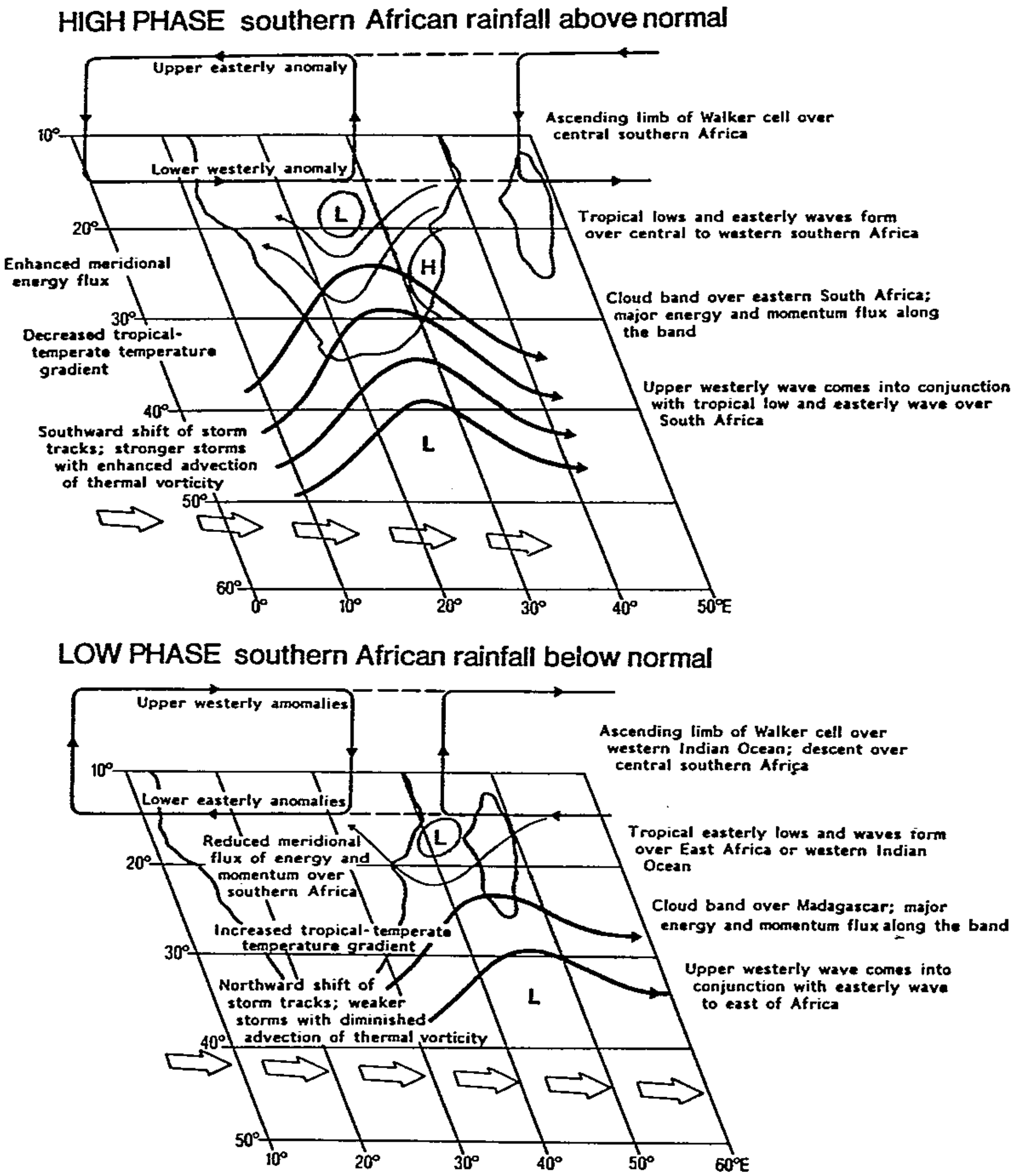

FIGURE 15.9 Schematic representation of Walker circulation over Africa during high and low phases of the Southern Oscillation - after Harrison (1986) and Tyson (1986). Light lines denote surface flow; heavy lines denote upper-tropospheric conditions.

4. Changes in the South Equatorial Counter/Under Current (9) and Angola Current systems (10). The position of the Angola-Benguela front (11) is normally at latitude 16°S (Shannon et al 1987), although seasonal shifts over two degrees of latitude and mesoscale changes in the front occur. During some years the front is displaced polewards through several degrees of latitude, and warm tropical water invades the northern Benguela region (12). These events, viz Benguela Niños (Shannon et al 1986), are less intense and less frequent (average period is ten years - Taunton-Clark and Shannon in press) than their Pacific counterparts, and are accompanied by changes in SST, sea level and local winds. They appear to be caused by changes in the current system in the tropical Atlantic caused by sudden relaxation in the equatorial wind stress off Brazil (cf Horel et al 1986). Benguela Niños tend to be preceded by cold periods on the northern Benguela shelf.

Some of the above "causes" may be regional responses to global perturbations (eg Figure 15.9), as a result of adjustments within the atmosphere and hydrosphere. While there is evidence for teleconnection with the Pacific, eg Nicholson's (1987) work suggests that Benguela SST's and the Southern Oscillation vary coherently, it is far from conclusive (eg Pan and Oort 1983; Taunton-Clark and Kamstra in press). There is even some suggestion that the Atlantic may lead the Pacific (Wright 1987). What is clear, however, is that global changes are likely to influence the heat, fresh water and salinity budgets in the Atlantic. The effect of changes in the global heat budget is particularly pronounced at high latitudes. In the Atlantic sector, the resultant changes in the rates of formation of Antarctic Bottom Water and North Atlantic Deep Water are likely to have a major impact on deep circulation. Moreover the South Atlantic is the only ocean basin in which there is a net equatorward transport of heat, and Hastenrath (1987) has suggested that changes in Atlantic SST and upwelling could have important implications for global climate. Changes in SST in the South Atlantic certainly appear to be linked to African rainfall and droughts (eg Hirst and Hastenrath 1983; Nicholson 1987).

CONCLUDING REMARKS

Change and variability in the oceans is the norm rather than the exception. "Trends" inferred from marine data series (which, excluding the sediment record, are generally short) are more likely to reflect the length of the data series rather than real long-term trends. However, if the unprecedented build-up of greenhouse gases in the atmosphere is maintained, major changes in the atmosphere-hydrosphere within the next century are likely, in what Prof Roger Revelle (former Director of Scripps Institution of Oceanography) has termed "Man's greatest geophysical experiment". If the present rate of build-up of CO_2 in the atmosphere is maintained, there will be a doubling in its concentration before the middle of the next century. Models predict a two to three degree Centigrade global warming (with a five to 10°C warming at higher latitudes) and major changes in rainfall patterns. Contrasted against this, changes over the last millennium pale into insignificance.

REFERENCES

Agenbag J J and Shannon L V 1987. A preliminary note on a recent perturbation in the Agulhas Current retroflection area. Tropical Ocean-Atmosphere Newsletter 37, 10-11.

Brundrit G B 1984. Monthly mean sea level variability along the west coast of southern Africa. South African Journal of Marine Science 2, 195-203.

Deacon H J 1983. An introduction to the Fynbos region, time scales and palaeoenvironments. In: Deacon H J, Hendey Q B and Lambrechts J J N (editors) Fynbos Palaeoecology: A Preliminary Synthesis. South African National Scientific Programmes Report No 17. CSIR, Pretoria. pp 1-20.

De Ruijter W 1982. Asymtotic analysis of the Agulhas and Brazil Current systems. Journal of Physical Oceanography 12, 361-373.

De Ruijter W P M and Boudra D B 1985. The wind-driven circulation in the South Atlantic-Indian Ocean. I. Numerical experiments in a one-layer model. Deep-Sea Research 32, 557-574.

Folland C K, Parker D E and Kates F E 1984. Worldwide marine temperature fluctuation 1856-1981. Nature 310, 670-673.

Harrison M S J 1986. A synoptic climatology of South African rainfall variability. PhD Thesis, University of the Witwatersrand, Johannesburg.

Hastenrath S 1987. The role of the Atlantic in the global heat budget. International Union of Geodesy and Geophysics XIX General Assembly. Vancouver, August 1987, (Paper U18-2), Abstracts Vol 1, p 176.

Hendey Q B 1983. Palaeoenvironmental implications of the late tertiary vertebrate fauna of the Fynbos region. In: Deacon H J, Hendey Q B and Lambrechts J J N (editors) Fynbos Palaeoecology: A Preliminary Synthesis. South African National Scientific Programmes Report No 17. CSIR, Pretoria. pp 100-115.

Hirst A C and Hastenrath S 1983. Atmosphere - ocean mechanisms of climate anomalies in the Angola - tropical Atlantic sector. Journal of Physical Oceanography 13, 1146-1157.

Horel J D, Kousky V E and Kagano M T 1986. Atmospheric conditions in the Atlantic sector during 1983 and 1984. Nature 322, 248-251.

Martin A K 1987. Evolution of the Agulhas Current and its palaeoecological implications. South African Journal of Science 77, 547-554.

Mörner N-A 1987. Ocean circulation changes, eustatic sea level and continental climate. International Union of Geodesy and Geophysics XIX General Assembly, Vancouver, August 1987, (Paper U18-3), Abstracts Vol 1, p 177.

Nicholson S E 1987. Sea surface temperature variability in the South-east Atlantic and its relationship to African rainfall and the Southern Oscillation. International Union of Geodesy and Geophysics XIX General Assembly, Vancouver, August 1987, (Paper U17-p.38), Abstract Vol 1, p 167.

Pan Y H and Oort A H 1983. Global climate variations connected with sea surface temperature anomalies in the eastern equatorial Pacific Ocean for the 1958-73 period. Monthly Weather Review 111(6), 1244-1258.

Pisias N G and Imbrie J 1986. Orbital geometry, CO_2, and pleistocene climate. Oceanus 29(4),43-49.

Scavotto E D 1986. The Little Ice-Age. In: Bryan K (editor) Man's great geophysical experiment: can we model the consequences? Oceanus 29(4), 38-39.

Siesser W G 1980. Late Miocene origin of the Benguela upwelling system off Northern Namibia. Science 208, 283-285.

Shannon L V 1985. The Benguela ecosystem Part I. Evolution of the Benguela, physical features and processes. Oceanography and Marine Biology Annual Review 23, 105-182.

Shannon L V (In press). The Physical Environment. In: Payne A I L and Crawford R J M (editors) Southern Africa's Open Sea - Its Living Resources. Vlaeberg Publishers, Cape Town.

Shannon L V and Agenbag J J 1987. Notes on the recent warming in the South-east Atlantic, and possible implications for the fisheries of the region. Collection of scientific papers. International Commission for South-east Atlantic Fisheries 14(II), 243-248.

Shannon L V, Boyd A J, Brundrit G B and Taunton-Clark J 1986. On the existence of an El Niño-type phenomenon in the Benguela system. Journal of Marine Research 44, 495-520.

Shannon L V, Agenbag J J and Buys M E L 1987. Large- and mesoscale features of the Angola-Benguela front. In: Payne A I L, Gulland J A and Brink K H (editors) The Benguela and Comparable Ecosystems. South African Journal of Marine Science 5, 11-34.

Sundermann J 1987. An Atlantic circulation model for the last glacial maximum. International Union of Geodesy and Geophysics XIX General Assembly, Vancouver, August 1987, (Paper U18-4), Abstracts Vol 1, p 177.

Tankard A J and Rogers J 1978. Late Cenozoic palaeoenvironments on the west coast of southern Africa. Journal of Biogeography 5, 319-337.

Taunton-Clark J and Kamstra F (In press). Aspects of marine environmental variability near Cape Town, 1960-1985. South African Journal of Marine Science 6.

Taunton-Clark J and Shannon L V (In press). Annual and interannual variability in the South-east Atlantic during the 20th century. South African Journal of Marine Science 6.

Tyson P D 1986. Climatic change and variability in southern Africa. Oxford University Press, Cape Town.

Van Zinderen Bakker E M 1976. The evolution of late Quaternary palaeoclimates of southern Africa. Palaeoecology of Africa 9, 160-202.

Van Zinderen Bakker E M 1982. In: Vogel J G, Voigt E A and Partridge T C (editors) Palaeoecology of Africa and the Surrounding Islands, Vol 15. Balkema, Rotterdam. pp 77-99.

Walker N D 1986. Satellite observations of the Agulhas Current and episodic upwelling south of Africa. Deep-Sea Research 33(8), 1083-1106.

Walker N D 1987. Interannual sea surface temperature variability and associated atmospheric forcing within the Benguela system. In: Payne A I L, Gulland J A and Brink K H (editors) The Benguela and Comparable Ecosystems. South African Journal of Marine Science 5, 121-132.

Wright P B 1986. Problems in the use of ship observations for the study of interdecadal climate changes. Monthly Weather Review 114(6), 1028-1034.

Wright P B 1987. On the possible role of the equatorial Atlantic SST in forcing the Southern Oscillation. International Union of Geodesy and Geophysics XIX General Assembly, Vancouver, August 1987, (Paper U17-p.44), Abstracts Vol 1, p 169.

Yamamoto R, Iwashima T, Kazadi S-N and Hoshiai M 1985. Climatic jump: a hypothesis in climate diagnosis. Journal of the Meteorological Society of Japan 63(6), 1157-1160.

Yamamoto R, Iwashima T, Kazadi S-N and Hoshiai M 1986. Journal of the Meteorological Society of Japan 64(2), 273-281.

GEOMAGNETIC DATA RECORDED IN THE SOUTHERN CAPE SINCE 1932

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INTRODUCTION

The purpose of this paper is to present an overview, with examples, of the nature and extent of long-term geomagnetic data series that are available for southern Africa. The examples were selected in such a way that they illustrate various aspects of magnetic field variability. Two different types of long-term data series will be dealt with, namely long-term continuous recording at a fixed location (ie magnetic observatories) and regular but intermittent observations done nearly concurrently at a number of fixed locations (ie regional magnetic surveys).

CONTINUOUS RECORDING OF THE GEOMAGNETIC FIELD

The first systematic magnetic observations in South Africa resulted from the establishment in 1841 of a worldwide network of observation stations, one of which was built in the grounds of the Royal Observatory at the Cape of Good Hope. Observations of magnetic declination (D) and horizontal intensity (H) were made at hourly intervals from the middle of 1841 to the middle of 1846. Hourly observations of the magnetic vertical intensity (Z) were commenced in January 1842 and also continued until the middle of 1846. Although these data are readily available, they have not been included in the examples presented here, because they require a significant amount of reprocessing.

The first South African magnetic observatory worthy of the name, was established at the University of Cape Town in 1932. Continuous observations commenced on 5 August of that year. As a result of electromagnetic interference experienced in Cape Town, the magnetic observatory was moved to Hermanus where it officially commenced operation on 1 January 1941. However, simultaneous observations were made at Hermanus and Cape Town during the last few months of 1940 to preserve the continuity of the data during the transfer.

Magnetic recording stations were later also established at Tsumeb (1964) and at Hartebeesthoek near Johannesburg (1972). Both of these continuous recording stations are still in operation. A summary of the data available from the three recording stations is presented in Table 15.1. However, only examples of the Cape Town/Hermanus data are presented here because this station has the longest continuous data series.

Monthly mean values of magnetic horizontal intensity, vertical intensity, total intensity and declination recorded at Cape Town and Hermanus since 1932 are shown in Figure 15.10, and a magnetic disturbance index derived from horizontal intensity at Hermanus in Figure 15.11. Superimposed on the latter are periods of minimum and maximum sunspot numbers. A lagged relationship between magnetic activity and solar activity is clear.

TABLE 15.1 Continuous magnetic recordings made in southern Africa

Station	Commencement of recording	Field components recorded	Nature of data
Cape Town/ Hermanus	1932 (Cape Town) 1941 (Hermanus)	Horizontal intensity (H) Vertical intensity (Z) Declination (D) Total intensity (F) (since 1973)	Analogue records. Hourly, daily, monthly and annual means. One minute spot values (since 1973)
Tsumeb	1964	H, Z, D	Analogue records. Hourly, daily, monthly and annual means.
Hartebeesthoek	1972	H, Z, D and F	Analogue records. Hourly, daily, monthly and annual means. One minute spot values.

REGIONAL MAGNETIC SURVEYS

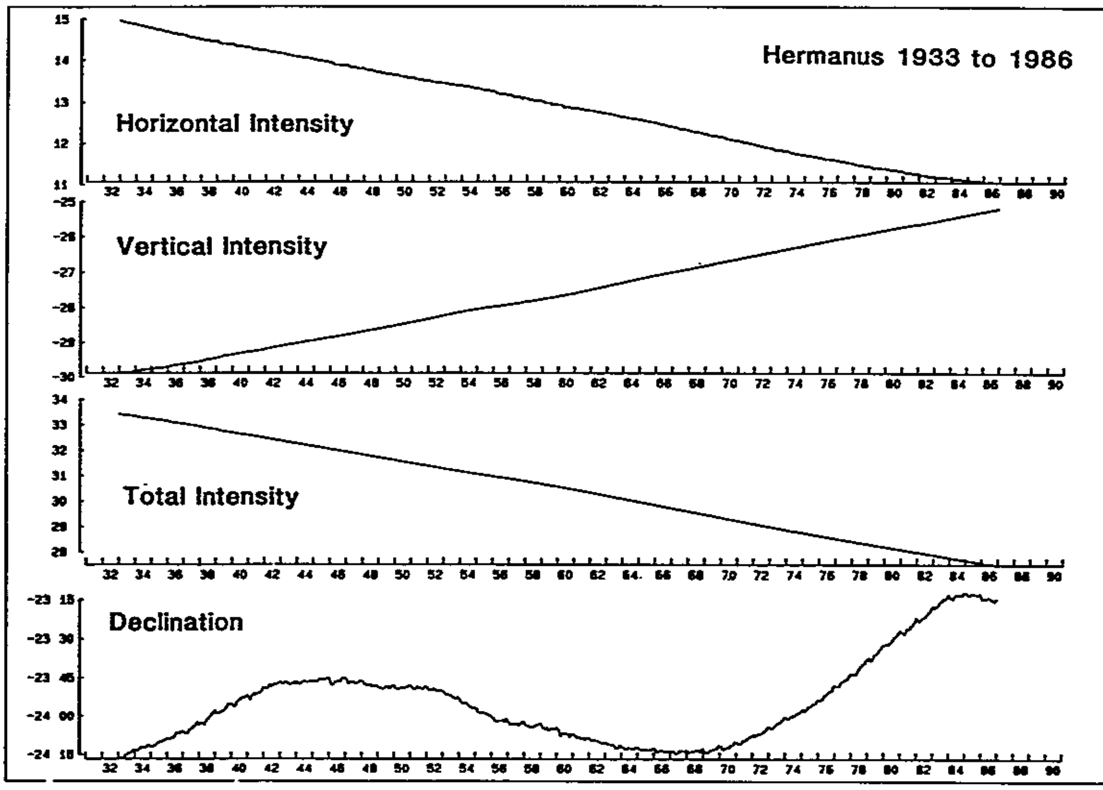
The first magnetic survey covering a major part of southern Africa was executed during the period 1898 to 1906, when Beattie and Morrison occupied some 400 observation stations. The results of this survey are readily available.

A long-term magnetic secular variation observational programme was only instituted in 1938/39. The programme consisted of magnetic field observations done on a network of 44 permanent field stations covering the whole of South Africa, South West Africa and what was then Bechuanaland. Exact reoccupation during subsequent surveys was ensured by erecting concrete beacons at each station to mark the position of instruments during observations. In the course of time, the network was expanded somewhat to optimize the coverage and to improve the results from anomalous areas. At present the network consists of some 62 field stations. Information about all the magnetic field surveys executed since 1938 is presented in Table 15.2.

The network *inter alia* may be used to examine the geographical extent of magnetic phenomena. For example, an abrupt and very large change of the annual rate of change of magnetic declination since 1983, known as a geomagnetic jerk, recorded at Hermanus (Figure 15.12), was also observed over the whole southern African region (Figure 15.13).

FIGURE 15.10 Monthly mean values of the magnetic horizontal intensity (H), vertical intensity (Z), total intensity (F) and declination (D) as recorded at Cape Town (1932 to 1940) and Hermanus (since 1941). H, Z and F are presented in units of 1 000 nT and D in degrees and minutes of arc. The more noisy appearance of D is caused by the fact that a more sensitive scale has been used than for H, Z and F. The "noise" is therefore in fact the short period variations caused by magnetic disturbances.

FIGURE 15.11 A monthly magnetic disturbance index derived from the Hermanus H-component data. The standard deviation of the daily mean values around the monthly mean is used here as a disturbance index. Downward pointing arrows indicate the years of minimum sunspot numbers and upward pointing arrows the years of maximum sunspot numbers in the eleven-year sunspot cycle. The relationship between magnetic activity and solar activity, as represented here by the sunspot numbers, is clear, although the years of maximum magnetic activity do appear to lag sunspot maxima.


Hermanus 1933 to 1986
Horizontal Intensity
Vertical Intensity
Total Intensity
Declination

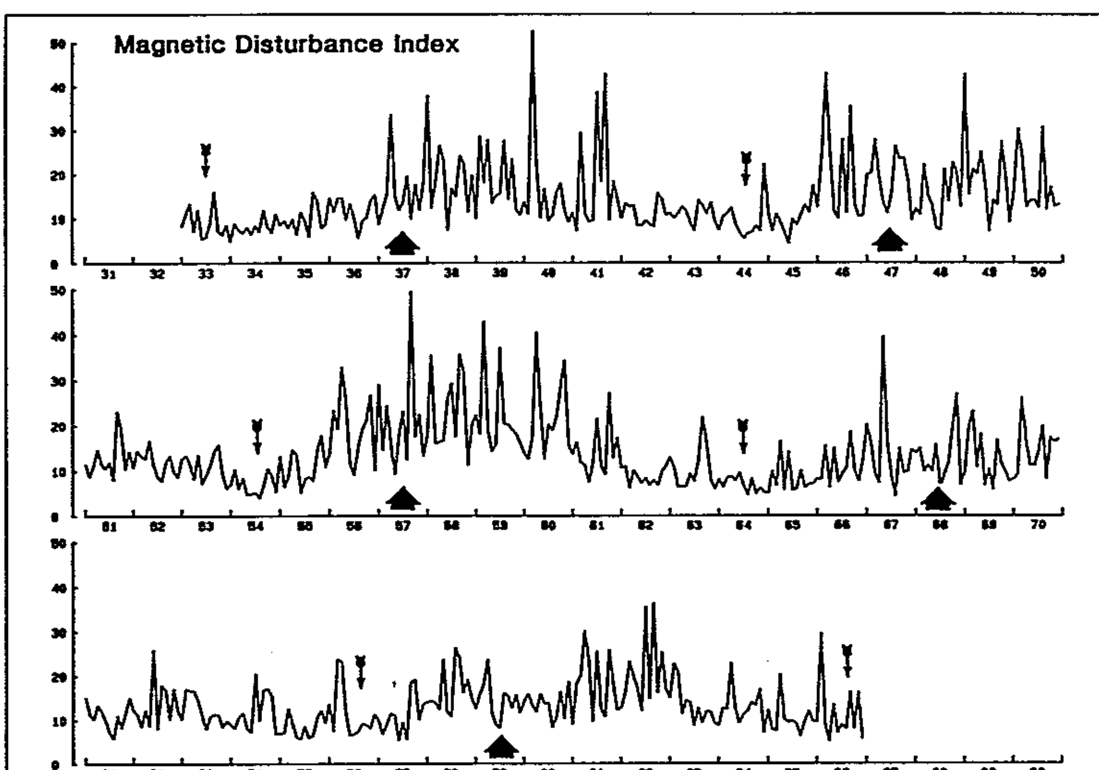

Magnetic Disturbance Index

TABLE 15.2 A list of magnetic field surveys executed by the Hermanus Magnetic Observatory sonce 1938

Survey epoch	Field elements measurements	Area covered by survey	Total number of field stations
1938/39	D, H and Z	South Africa, Namibia	44
1947/48	D, H and Z	South Africa, Namibia and Zimbabwe	48
1952/53	D, H and Z	South Africa, Namibia and Zimbabwe	52
1961	D, H and Z	South Africa, Namibia and Zimbabwe	59
1966	D, H and Z	South Africa, Namibia and Zimbabwe	57
1969-1972	D, H and F	South Africa, Namibia and Zimbabwe	72
1973-1975	D, H and F	South Africa, Namibia Zimbabwe and Botswana	70
1977-1980	D, H and F	South Africa, Namibia and Botswana	61
1982*	D, H and F	South Africa, Namibia	20
1984/85	D, H and F	South Africa, Namibia and Botswana	62
1987*	D, H and F	South Africa, Namibia	20

* Special Purposes Limited Surveys

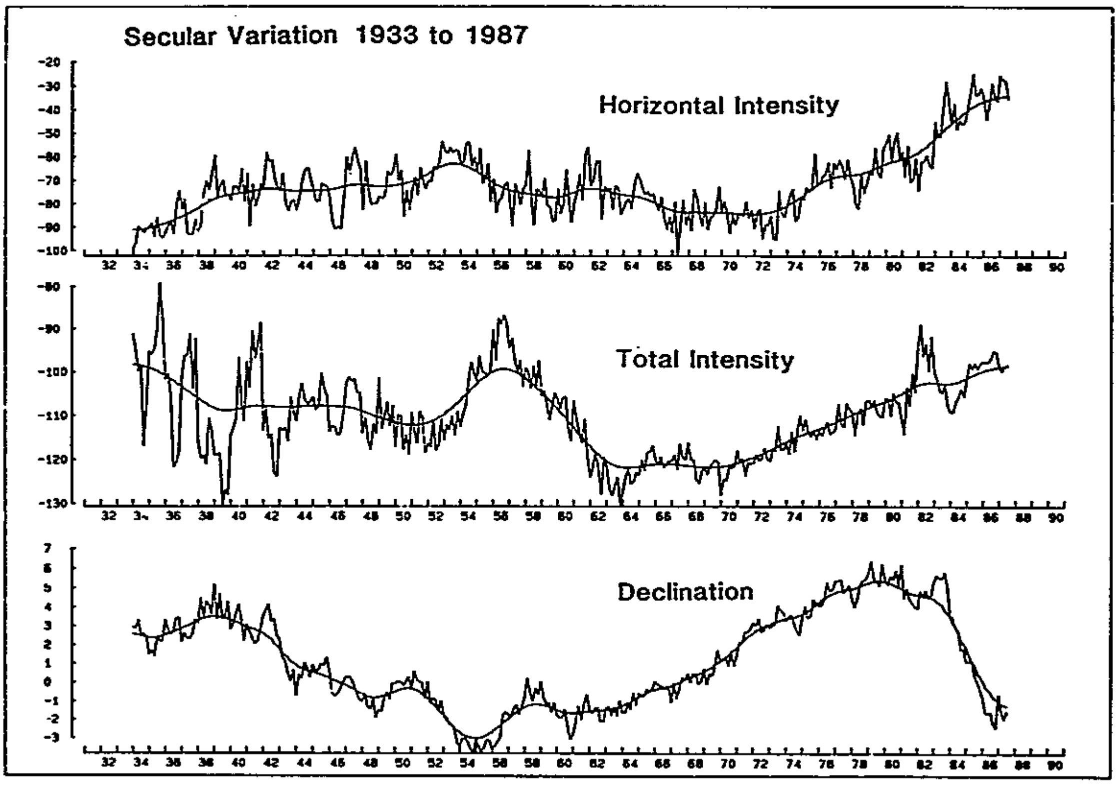
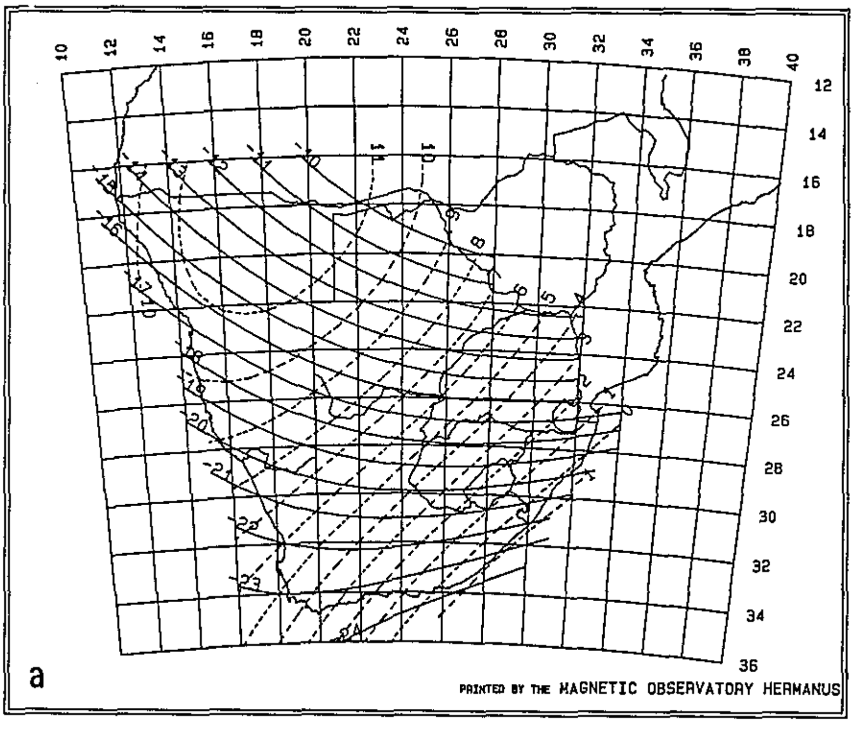


FIGURE 15.12 The mean annual change (secular variation), derived on a month-to-month basis, of the horizontal intensity (nT/a), total intensity (nT/a) and declination (minutes of arc/a), recorded at Cape Town and Hermanus. The noisy appearance is again caused by external sources such as magnetic disturbances. The smooth lines, which were derived from the scattered data by means of data adaptive filtering, are probably a more correct representation of the long-term rate of change for the main geomagnetic field with its source in the core of the earth. The rather abrupt and very large change of the annual rate of change of magnetic declination since 1983, is real and is known as a geomagnetic jerk. Figure 15.13 illustrates that it was observed over the whole southern African region.

FIGURE 15.13 Regional charts of the magnetic declination isogonals derived from the 1984/85 and 1987 field survey data. The isogonals (solid lines) are in degrees of arc west of true north and the secular variation, or mean annual change, (broken lines) are in minutes of arc eastward per year. The dramatic change in secular variation from 1985 to 1987 was caused by the geomagnetic jerk illustrated in Figure 15.12. Similar regional charts and mathematical models are available for H, Z, D and F for all the field surveys executed since 1938.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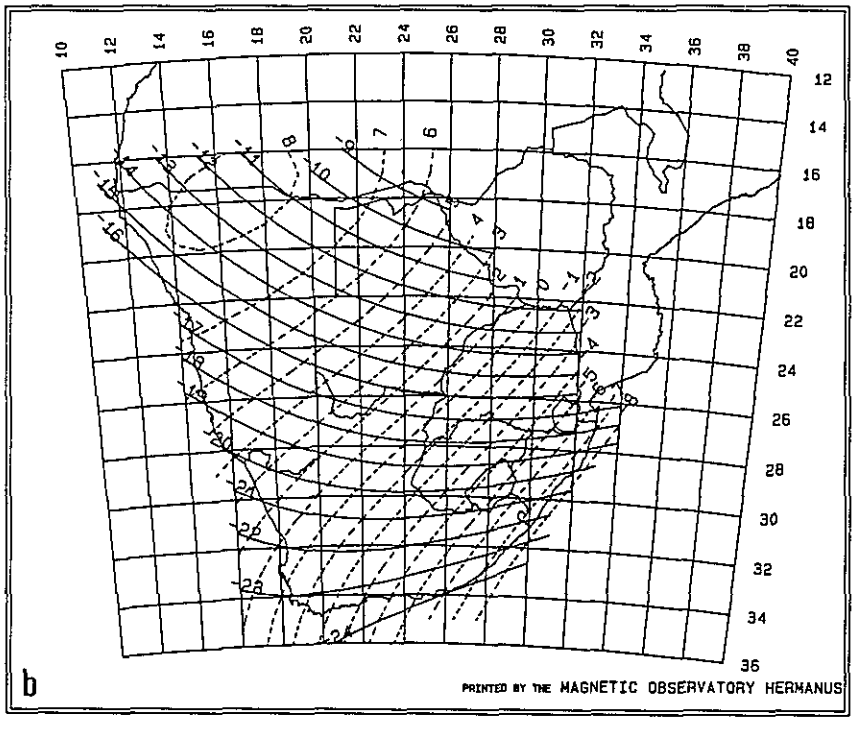
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AIR POLLUTION DATA AND RELEVANT METEOROLOGICAL OBSERVATIONS IN SOUTH AFRICA

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Ever since the creation of the Air Pollution Research Group (now Atmospheric Sciences Division - ASD) as part of the National Physical Research Laboratory (NPRL) in 1961 its staff have been involved in monitoring various kinds of air pollution levels and relevant meteorological parameters. Specific sites, parameters monitored and measuring periods have been published in the National Register for Weather, Climate and Atmosphere Numeric Data Sources (Brunt et al 1985). Man-made air pollution is mostly contained within the first few hundred metres of the atmosphere and can thus have an immediate impact on the ecology of a region. Since the boundary layer, ie approximately the first two kilometres of the troposphere, is subjected to a number of meteorological processes which determine its stability or instability and which display distinct diurnal, seasonal and year to year variations, it is of utmost importance to simultaneously observe meteorological conditions if one wants to understand the complex processes governing the dispersion of pollutants in the atmosphere. Although it is realized that the data series presented here are relatively short, it is felt that they could form a useful contribution to environmental studies. It should also be remembered that many pollution measurements now being conducted and which will continue in the future could not have been made ten years ago.

The first regular measurements of air pollutants were those of smoke and sulphur dioxide which commenced in 1958 and are still continued in various South African cities and towns. There are now 160 and 115 stations monitoring smoke and sulphur dioxide, respectively, consisting of city centre, industrial, residential, non-white residential and other sites (Brunt et al 1985). The survey is still expanding, with particular emphasis being placed on establishing further stations in non-white areas. The data accumulated from the survey are documented (eg Walker et al 1987) and plotted for both long- and short-term periods of analysis. More than half of the sites, viz 56%, showed a decrease of smoke concentrations, while for 39% of the sites no long-term trend was apparent. The corresponding figures for sulphur dioxide were 33 and 53%, respectively. All of the data have been computerized since October 1980 and are stored on the CDC Cyber 750 mainframe computer of the CSIR. Complete sets of data from 1958 onwards for selected sites in Cape Town and Pretoria are also available on the computer.

Many short- and medium-term projects have been undertaken by the ASD on a contract basis, mostly for the purpose of optimal siting of planned industries or urban settlements. Thus, a vast number of surface wind measurements (10 m above ground level - AGL) as well as a limited number of vertical profiles of wind and temperature are available for numerous regions in South Africa (Brunt et al 1985).

Two large projects which have been ongoing since 1979 and 1984, might be of particular interest to ecologists and will thus be briefly discussed here. The first one concerns air pollution levels and dispersion mechanisms in the eastern Transvaal Highveld, while the other one is monitoring background levels in the relatively unindustrialized northern Orange Free State. Sites and periods of observations are listed by Brunt et al (1985).

Surface winds (10 m AGL) have been continuously observed since 1 April 1979 at eight sites in the eastern Transvaal Highveld and are available in the form of hourly averages on the CSIR's computer. Concurrent SO_2 ground level concentrations were monitored at nine sites by ESKOM during the period 1 April 1979 to 30 April 1983 and hourly averages are also available on the CSIR's mainframe computer. A total of about 2 400 balloon soundings made since 1979 provide information on the variation with height of temperature, wind speed and direction. Based on these data, the climatology of the boundary layer in the eastern Transvaal Highveld was compiled and its impact on sulphur dioxide concentrations at ground level investigated (Pretorius et al 1986). ESKOM refurbished its SO_2 monitoring network from January 1984 onwards and monthly data reports have been published (eg Turner 1984). Particulate matter (sulphate, nitrate, phosphate, chloride and fluoride concentrations) has been monitored at three metres AGL at various sites in the eastern Transvaal Highveld since 1982 (Snyman et al 1987 and data reports). Daily mean concentrations are available on the CSIR's mainframe computer. These pollutants can be related to rain chemistry and the long-term risk of acidifying the environment. Ground-level concentrations of particulate sulphate and nitrate correspond to areas of the USA experiencing medium to low pollution. However, measurements made at 300 m AGL show episodes of high pollution rivalling the most polluted areas of the USA. These episodes suggest that a strongly stratified zone of secondary acidic pollutants may exist above the Transvaal Highveld (Wells et al 1987). Such a layer would have serious long-term implications for the environment in South Africa and for future pollution control. The phenomenon will be intensively studied both meteorologically and chemically to determine its significance.

Similarly to the measurements made in the eastern Transvaal Highveld, monitoring sites for particulates and wind (5 and 2, respectively), have been established in the northern Orange Free State with the main purpose of determining background levels to optimize future development of the region. However, it was found that levels of surface pollution rise more or less simultaneously in the Orange Free State and eastern Transvaal Highveld and are of similar magnitude. A mechanism linking the two areas still has to be found.

Among the numerous short-term projects which are conducted by the ASD to investigate meteorological conditions (surface winds, vertical temperature and wind profiles) relevant to the dispersion of pollutants, only three, which are thought to be of possible interest to ecologists, are briefly mentioned below. The circulation pattern and temperature distribution with height including the interaction with sea/land breezes and berg winds, was investigated in the vicinity of Mossel Bay during the period June 1982 to July 1983 (Langenberg et al 1984). Detailed studies of the mechanism and occurrences of the escarpment breeze (as analogy to land/sea breezes) have been conducted in the Graskop region during the summers of 1983/84 and 1984/85. An easterly flow across the escarpment was found to occur during the day, while at night westerly drainage from the Highveld into the Lowveld took place. This flow reversal takes place in a layer up to 500 m thick with the compensating flow above it. It is most pronounced on fine weather days and when synoptic-scale forcing of the flow pattern is minimal (Held 1985a). A microclimatological investigation was conducted during the winters of 1983 and 1984 in the vicinity of a power station (Grootvlei, between Heidelberg and Villiers) to investigate possible impacts on meteorological conditions in its environment, but these were found to be minimal (Held 1985b). Data from all three experiments are stored on the CSIR's computer.

Finally, the proposed establishment of a database for air pollution and related meteorological observations should be pointed out. It will be managed by the Weather Bureau under contract to the Foundation for Research Development (FRD) and will contain all the relevant data from ASD, ESKOM and other organizations concerned with air pollution measurements.

REFERENCES

Brunt A G, Chalmers L and Heten J E 1985. National Register for Weather, Climate and Atmospheric Numeric Data Sources. Compiled for the Foundation for Research Development, CSIR Report CSTI/88. Pretoria. 210 pp.

Held G 1985a. Study of the escarpment breeze and its influence on the ventilation potential of the eastern Transvaal Highveld. Final report to the Foundation for Research Development. CSIR Report ATMOS/85/21. 28 pp.

Held G 1985b. Study of air flow and convection in the immediate vicinity of a power station. Final report to the Foundation for Research Development. CSIR Report ATMOS/85/22. 16 pp.

Langenberg H M, Held G, von Gogh R S, Brassel K H and Danford I R 1984. Meteorological observations in the vicinity of Mossel Bay. Report to the Department of Constitutional Development and Planning: Physical Planning. CSIR Report ATMOS/84/18 (Restricted). 149 pp.

Pretorius R W, Auret I, Held G, Brassel K H, Danford I R and Waldie D D 1986. The climatology of the boundary layer over the eastern Transvaal Highveld and its impact on SO_2 concentrations at ground level. Report to the Foundation for Research Development. CSIR Report ATMOS/86/16. 212 pp.

Snyman G M, Turner G S M, Wells R B, Ellerbeck R I and Dos Santos A 1987. Seasonal variations in airborne sulphate pollution on the South African Highveld. Accepted for publication in South African Journal of Science.

Turner C R 1984. Air pollution monitoring network - data for January 1984. ESCOM Report TRR/N84/004 (subsequently issued monthly).

Walker N, Ellerbeck R and Marinus N 1987. Statistics on smoke and sulphur dioxide pollution in South Africa. Period: October 1984 to September 1986. CSIR Special Report ATMOS/87/13. 73 pp.

Wells R B, Snyman G M, Held G and Dos Santos A 1987. Air pollution on the eastern Transvaal Highveld. Report to the Foundation for Research Development. CSIR Report ATMOS/87/23. 147 pp.

TROPOSPHERIC BACKGROUND MEASUREMENTS OF $CFCl_3$ (F-11) CONDUCTED AT CAPE POINT, SOUTH AFRICA, SINCE 1979

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INTRODUCTION

The environmental threat of atmospheric $CFCl_3$ (F-11) lies in its ability to destroy stratospheric ozone and to absorb infrared radiation reflected back into space by the earth's surface (greenhouse effect). Recent interest in stratospheric ozone research has been stimulated by the so-called 'ozone hole' that has been observed over Antarctica. International research is still being conducted to find a plausible explanation for this phenomenon.

Freon-11, which is solely man-made, has been extensively used internationally as aerosol propellants, refrigerants and solvents. When scientific evidence showed that chloro-fluoromethanes (such as F-11) are photolysed in the stratosphere thereby releasing ozone destroying Cl atoms, the USA followed by other countries, placed a ban on the non-essential uses of F-11. However, the major application of this gas now lies in the production of rigid closed-cell polyurethane foams, which constitute a growing reservoir from which F-11 is released to the atmosphere. The 'freon problem' is hence still with us.

METHODS

Tropospheric background measurements (1979 to 1987) of F-11 have been made at the CSIR's global baseline station at Cape Point utilizing an automated GC/ECD system. Measurements made in 'polluted air' derived from local sources have been filtered out of the data set and have not been used in determinations of the secular trend. Halocarbon standards have been obtained from Professor Rasmussen, Oregon, USA. The precision of the F-11 data is estimated at one per cent.

RESULTS

The filtered F-11 data collected over the past eight years are presented in the form of monthly means (Figure 15.14). As can be seen, the period January 1980 until December 1986, produced an increase in the F-11 level from 168 pptV to 229 pptV, an overall growth of 36% within seven years. The average annual increase over this period amounted to 8,8 pptV per year (3,8% per year). Excellent agreement exists between this trend and growth rates estimated at other global baseline stations such as Cape Grim (Tasmania) and Palmer station (Antarctica). At present there are no indications that the rise in atmospheric F-11 is abating. Hence it is of vital importance to maintain a watchful eye on the changing chemistry of the atmosphere.

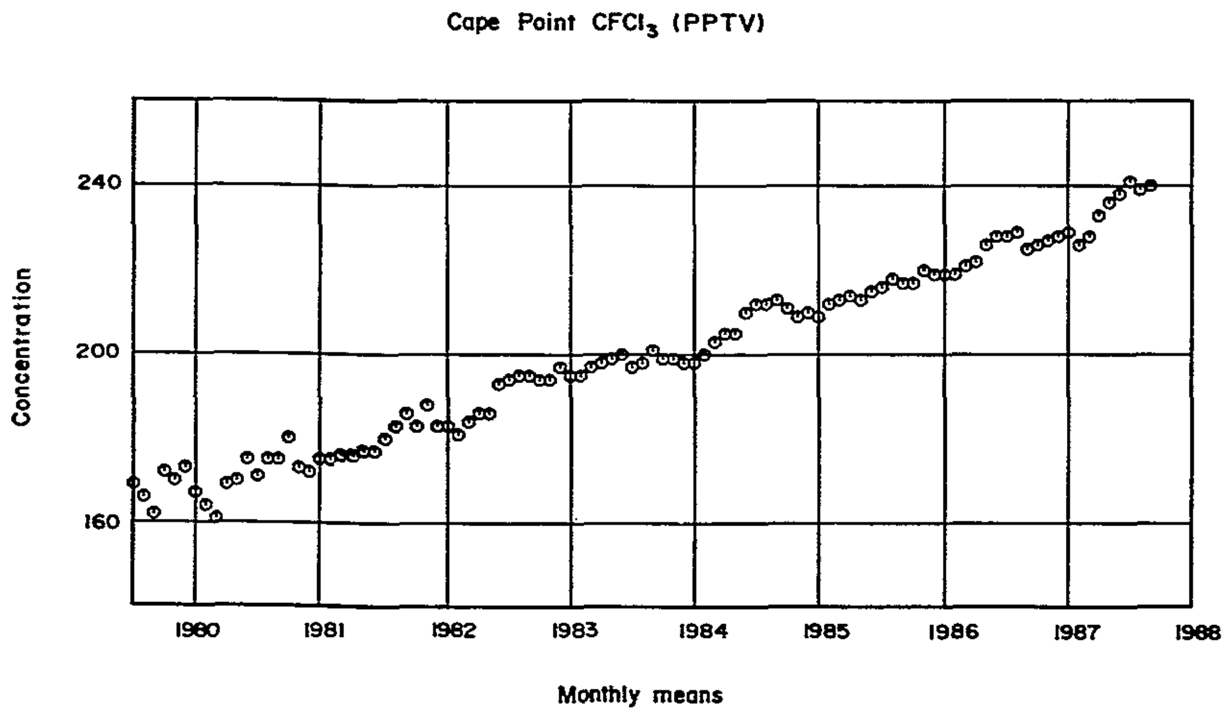

FIGURE 15.14 Concentration of $CFCl_3$ in parts per trillion (10^{12}) plotted against time in months.

CHAPTER 16. LINKAGES

LINKAGES BETWEEN DATA SETS FROM THE SAME AND DIFFERENT ECOSYSTEMS

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INTRODUCTION

There has been considerable recent interest in relationships between biological data series. Such relationships have been observed both within and between ecosystems, and are often of value in elucidating causes of change in the distribution or abundance of species. For example, Shepherd et al (1984) consider the occurrence of good year-classes of fish in the same year in widely separate parts of the ocean to be evidence of climatic influence, because no other cause could act over ocean basins. Similarly, Tont and Delistraty (1980) cite Moran (1953) as concluding that, although the snowshoe hare-lynx (*Lepus americanus-Felis lynx*) cycle in North America is a classic predator-prey relationship, strong synchronization of oscillations over all of Canada indicates that large-scale meteorological factors influence the oscillations. Because description and understanding of interactive physical, chemical and biological processes that regulate the total earth system is an important aim of the International Geosphere-Biosphere Programme (IGBP) (Risser 1985), it seemed appropriate that South Africa's first contribution to the IGBP should include a preliminary examination of the possibility that relationships exist between data sets.

EXAMPLES OF RELATIONSHIPS BETWEEN DATA SETS FROM THE SAME ECOSYSTEMS

Terrestrial ecosystems

Macdonald (1982) concluded that numerous species of the southern African savanna, especially those dependent on its variable herbaceous component, change their distributions in response to short-term fluctuations in climate. For example, migrations and altered rates of survival result in most blue wildebeest *Connochaetes taurinus* being located in higher-rainfall savannas after periods of below average rainfall and in drier savannas after wetter periods (Figure 16.1). Bat-eared foxes *Otocyon megalotis* are abundant in arid savannas during periods of above-average rainfall, but expand into wetter areas in dry periods (Figure 16.2). A dense herbaceous layer apparently prevents bat-eared foxes from successfully locating prey. In addition, following periods of high rainfall the termite *Hodotermes mossambicus*, an important prey of bat-eared foxes, becomes scarce in wetter areas but remains plentiful in at least some lower-rainfall savannas. Similarly, in periods when rainfall is above-average the zorilla *Ictonyx striatus* appears to expand into lower-rainfall savannas, where food may be limiting during drier periods. Many other examples have been documented (Macdonald 1982).

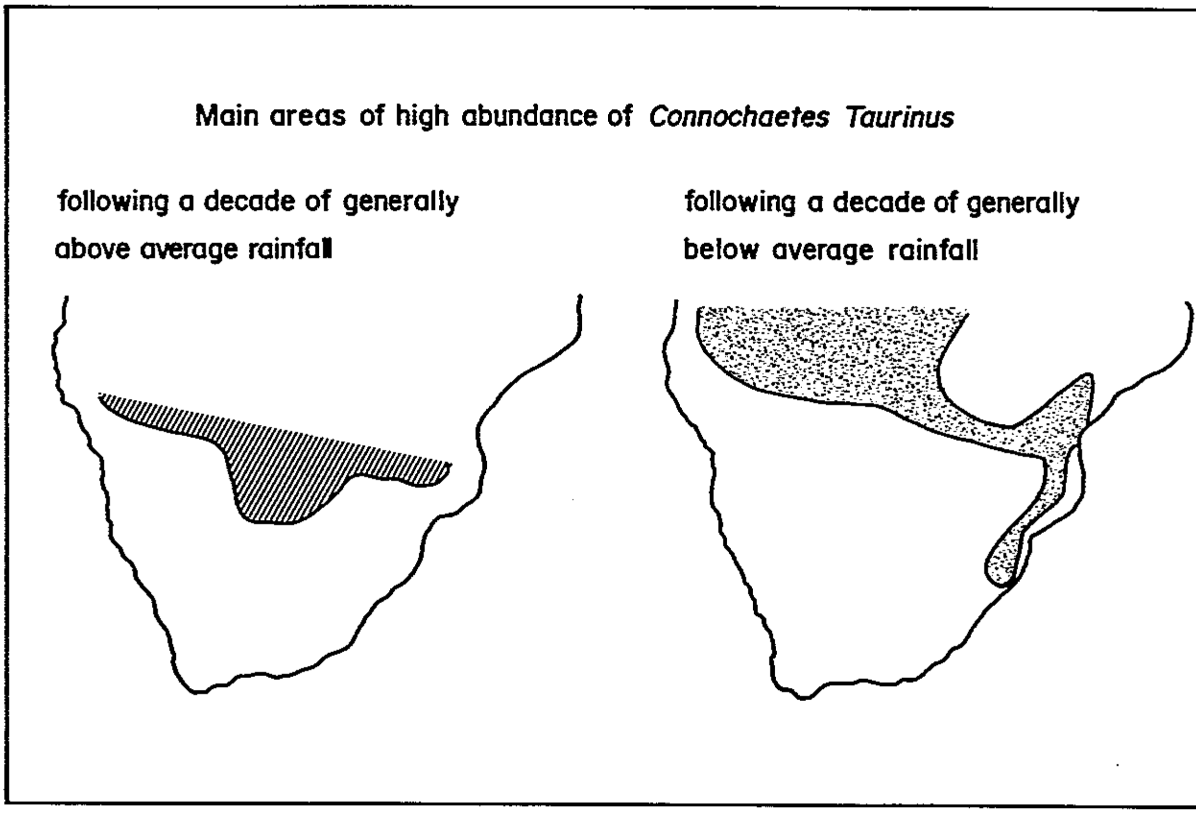

FIGURE 16.1 Schematic illustration of shifts in the areas of main abundance of blue wildebeest resulting from changed patterns of rainfall (from Macdonald 1982).

Marine ecosystems

For marine ecosystems, Koslow (1984) has shown that in the North-west Atlantic significant positive correlations occur in the recruitment of demersal, offshore-spawning fishes, but that recruitment of such species tends to be negatively correlated with that of pelagic species spawning inshore. Preliminary observations suggest that a similar situation may prevail in the South-east Atlantic (Shannon et al in press). In both regions the extents of the patterns have led authors to suggest that large-scale physical forcing predominantly regulates recruitment to the fisheries.

EXAMPLES OF RELATIONSHIPS BETWEEN DATA SETS FROM DIFFERENT ECOSYSTEMS

Biologically-exported relationships

Underhill (1987 and this volume) demonstrated that during 1969 to 1985 the percentage of first-year curlew sandpipers *Calidris ferruginea* at Langebaan Lagoon was positively correlated with the percentage of first-

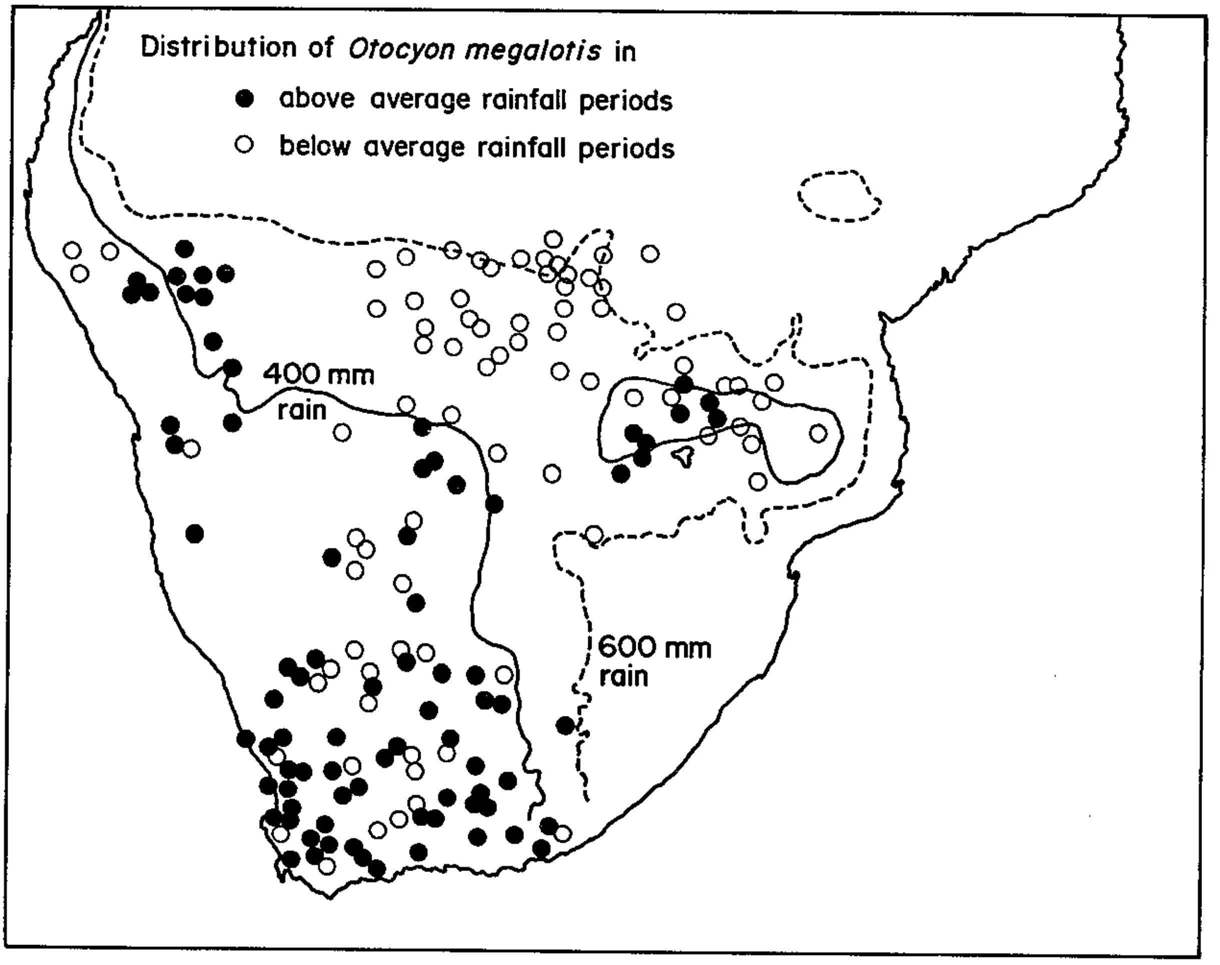

FIGURE 16.2 Records of the distribution of bat-eared foxes in southern Africa during periods of above and below-average rainfall (from Macdonald 1982).

year brent geese *Branta bernicla bernicla* in Britain. Both species breed in the Taimyr Peninsula in northern Siberia, and Underhill (1987) and others have suggested that survival of first-year birds is related to the abundance of lemmings *Lemmus sibiricus* and *Dicrostonyx torquatus* in this peninsula (Figure 16.3). Lemmings are the main prey of Arctic foxes *Alopex lagopus*, but when lemmings are scarce, foxes increase predation on the eggs and young of waders and geese. Breeding success of these birds is significantly related to the abundance of lemmings (Underhill 1987). It is clear that in this instance the related observations in widely separate ecosystems result from the export of biological parameters from one ecosystem to the others.

Abiotically-exported relationships

Very often the effect of the environment on an ecosystem is not that of the ecosystem's immediate environment. An example is the importance of rainfall in the catchments of rivers that later flow through the Namib Desert. This is not closely related to rainfall falling in the Namib itself but has profound influences on the functioning of its ecosystems (Seely and Ward this volume). A further example is provided by the utilization of southern African waterbodies by aquatic birds. Although in some cases the environmental factors pertaining in the waterbody explain observed changes in the avifauna (Heyl this volume), in others, such as Barberspan, it is rainfall elsewhere which is the critical determinant of the pan's volume and hence of its environmental characteristics (Morgan this volume). In dry periods, good rainfall elsewhere may cause avian dispersion from Barberspan to more favourable habitats. These few examples serve to illustrate that biological data series from a particular ecosystem can often not be adequately interpreted without reference to the relevant abiotic data series from other ecosystems.

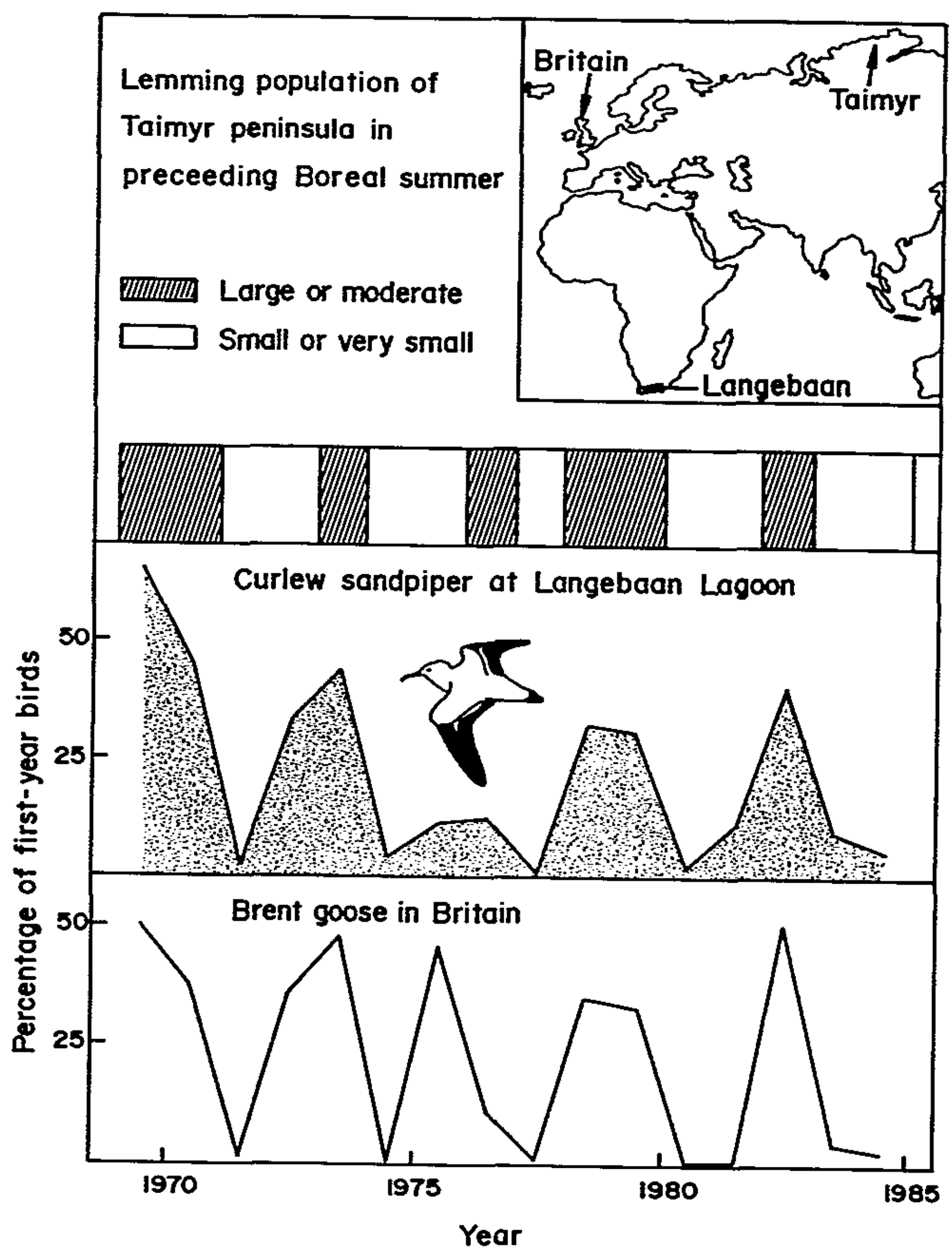

FIGURE 16.3 Relationship between abundance of lemmings in the Taimyr Peninsula and contributions of first-year birds to populations of curlew sandpipers at Langebaan Lagoon and brent geese in Britain (from data in Underhill 1987).

Man-induced relationships

Fluctuations in lemming abundance, in the reproductive success of geese and waders, in flow of rivers through the Namib Desert and in avifauna at water bodies are seemingly natural events. By contrast Sherman et al (1981) suggested that heavy fishing of herring *Clupea harengus* and mackerel *Scomber scombrus* had been responsible for strikingly similar trends in some fish resources on each side of the Atlantic. In both the North Sea and the North-west Atlantic, biomasses of herring and mackerel declined at more or less the same time, and were followed by increased abundances of small, fast-growing, plankton-feeding fishes such as sandeels *Ammodytes* species (Figure 16.4). It was argued that removal of a large biomass of mid-sized predators had made available increased amounts of forage to the smaller, opportunistic species. The response was thus a biological one to man-induced perturbations.

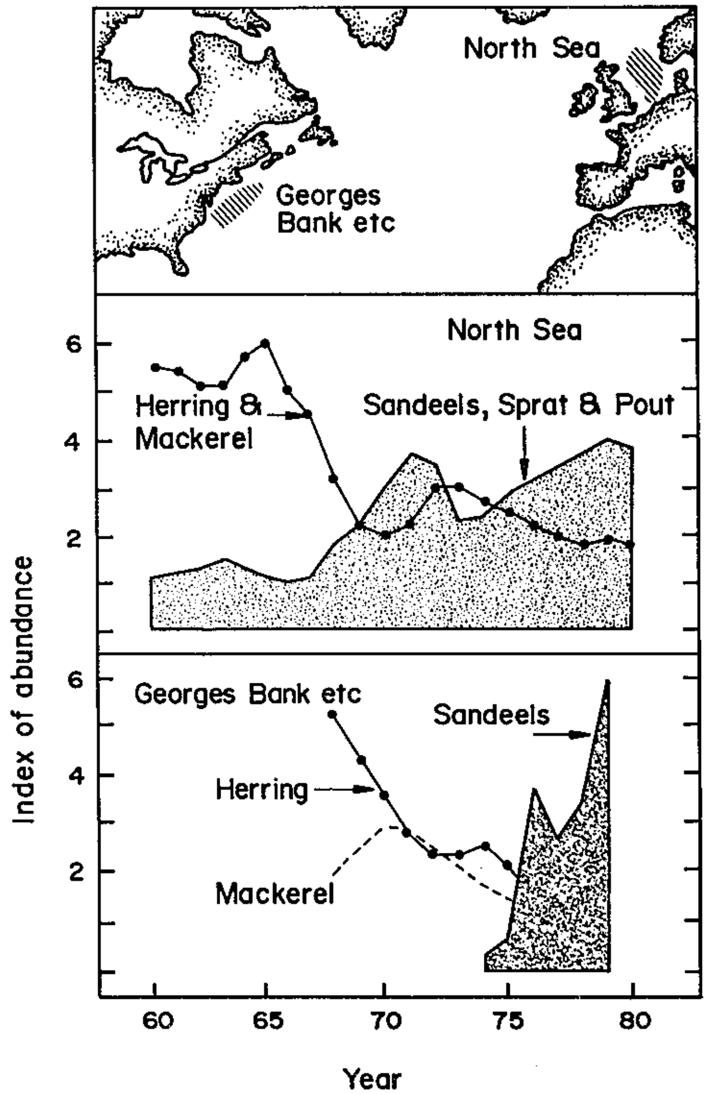

FIGURE 16.4 Congruent shifts in the abundances of herring, mackerel and sandeels on two sides of the North Atlantic Ocean (from data in Sherman et al 1981).

An African terrestrial example of man influencing different areas is provided by the effects of the introduced mammalian pathogen Rinderpest at the turn of the century (Thompson this volume). This viral disease swept down the continent decimating herds of susceptible ungulate species. Resultant reductions in herbivore grazing and browsing are thought to have set in motion large-scale oscillations in herbivore-plant relationships in areas as widely dispersed as the Serengeti Plains of Tanzania (Sinclair 1979) and the savannas of South Africa (Joubert et al this volume). Although these oscillations are unlikely to be in absolute synchrony between such widely differing systems, viewed on geological time scales the effects of this man-induced disease outbreak are virtually simultaneous throughout the continent.

Environmentally-induced relationships

Global-scale environmental processes may influence many different ecosystems. Droughts in Australia and altered weather patterns over North America have been linked to floods off the west coast of South America and El Niño conditions in the South- east Pacific (Kerr 1983). The coupled ocean-atmosphere changes are referred to as El Niño-Southern Oscillation (ENSO) events.

Kawasaki (1983) noted similarity in trends in catches of sardines *Sardinops* species in three widely separate parts of the Pacific (Figure 16.5). He postulated that increased solar radiation resulted in larger stocks of phytoplankton, an important food of sardines, and increased populations of sardines.

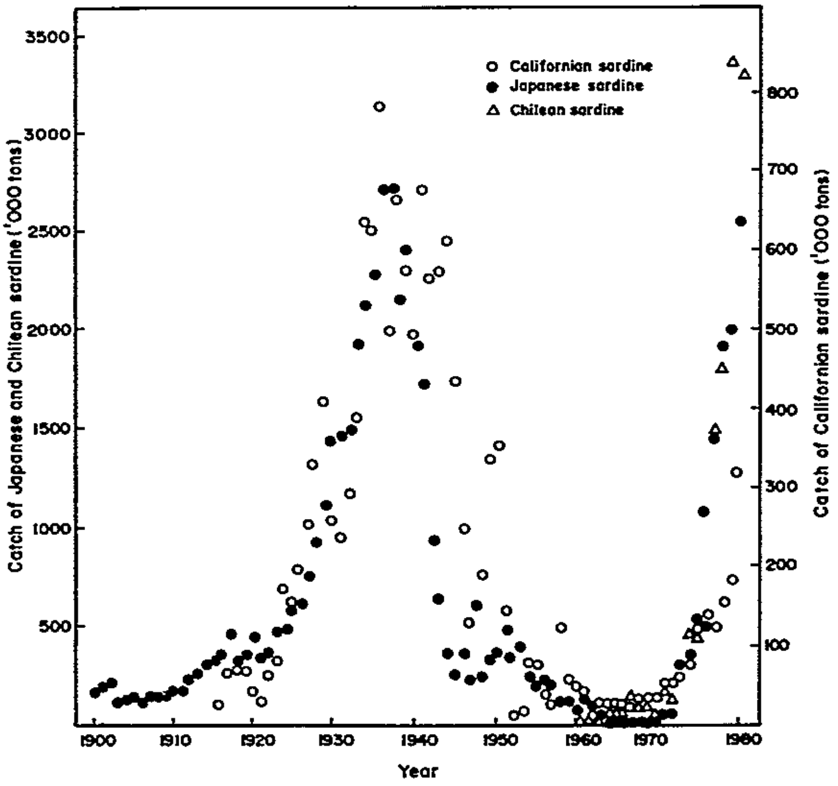

FIGURE 16.5 Similarities in catches of sardines from three widely separate parts of the Pacific Ocean (from Kawasaki 1983).

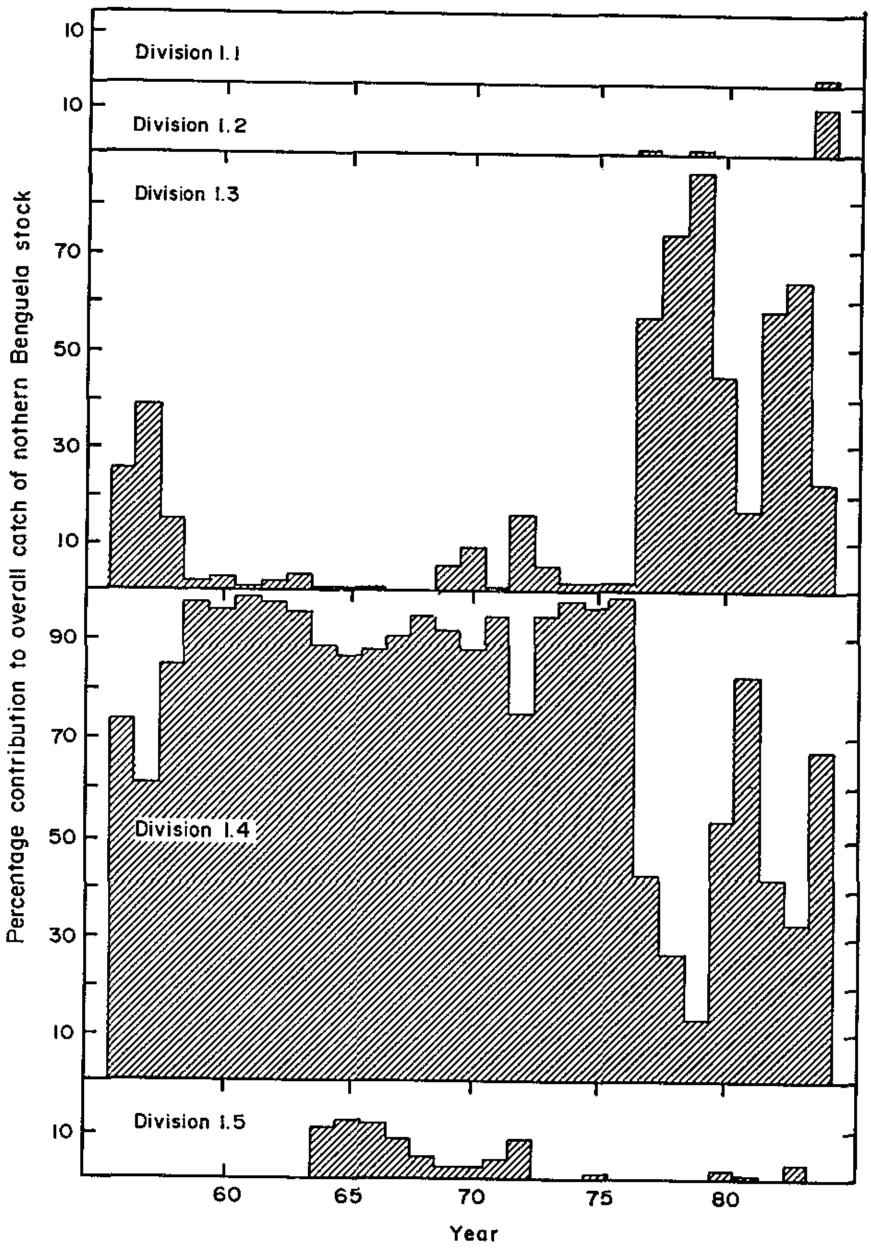

FIGURE 16.6 Proportions of the overall annual catches of pilchard in the northern Benguela contributed by different data-recording divisions of the International Commission for the South-east Atlantic Fisheries, 1956 to 1984. Divisions are numbered from north to south and an initial southward displacement of catches was followed by a return to the north (from Crawford and Shannon in press).

Global-scale environmental processes may also influence the distributions of fish stocks. In the South-east Atlantic there have been congruent shifts in the distributions of a number of stocks, including those of pilchard *Sardinops ocellatus*, anchovy *Engraulis japonicus*, sardinellas *Sardinella* species, horse mackerel *Trachurus* species, chub mackerel *Scomber japonicus* and large-eye dentex *Dentex macrophthalmus* (Crawford and Shannon in press). Between the late 1950's and mid-1970's the displacements were to the south; from the mid-1970's to the mid-1980's they were to the north (eg Figure 16.6). There was good agreement in the timing of the displacements (eg Figure 16.7), which also appear to have influenced the distributions of predators (Crawford and Shannon in press). There were simultaneous geographic shifts in the same directions in the distributions of a number of fish stocks off north-west Africa (eg Figure 16.8), indicative that both systems were being influenced by the same environmental mechanisms. The altered feeding migrations of juvenile Cape gannets *Morus capensis* proposed by Oatley (this volume) may well be attributable to changes in the distributions of fish stocks off north-west Africa.

DISCUSSION

It appears that trends in different ecosystems may be related as a result of the export of biological or abiotic phenomena from one ecosystem to others, or as a result of man or large-scale environmental processes influencing more than one ecosystem in the same way. It is also possible that similar trends in different ecosystems may arise purely by chance.

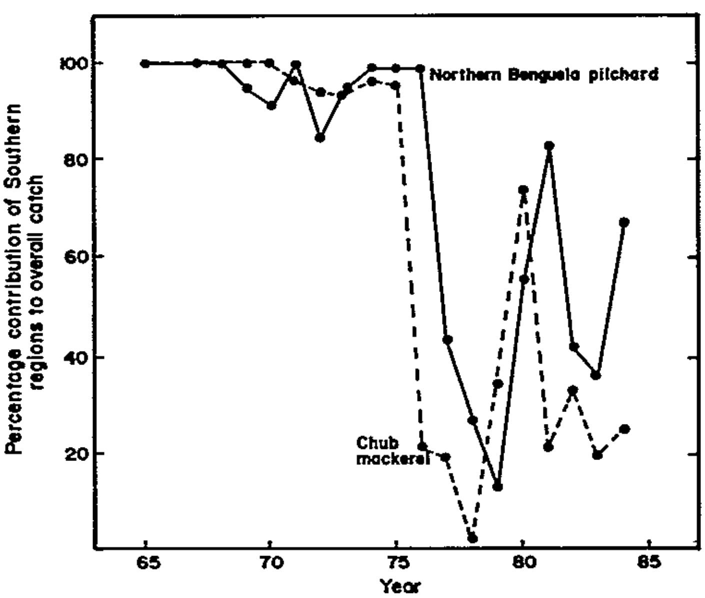

FIGURE 16.7 Proportions of the overall catches of chub mackerel in the Benguela as a whole, and of pilchard in the northern Benguela, which were contributed by the southern fishing areas, 1965 to 1984, illustrating similarity in the trends (from Crawford and Shannon in press).

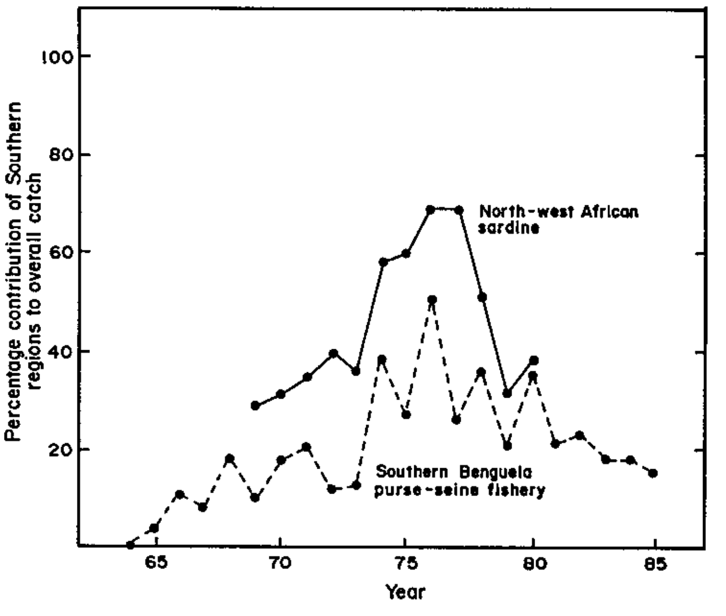

FIGURE 16.8 Proportions of the overall annual catches by purse-seine boats in the southern Benguela and of sardine *Sardina pilchardus* off north-west Africa contributed by the southern fishing areas, 1964 to 1985, illustrating similarity in the trends (from Crawford and Shannon in press).

Relationships which result from the export of biological phenomena to other ecosystems must in a large measure be dependent on the migrations of species, and hence on the presence in ecosystems of highly mobile organisms, as in the examples concerning the blue wildebeest, the brent goose and the curlew sandpiper. A southern African marine equivalent of the blue wildebeest may well be the snoek *Thyrsites atun*. Data in Crawford et al (1987) and Venter (this volume) suggest that this migratory fish alternates between the northern and southern Benguela ecosystems. Catches by handline fishermen are generally high in one of these ecosystems, but not in both simultaneously (Figure 16.9).

Environmental processes are important in influencing the distributions and abundances of both terrestrial and marine organisms (Tont and Delistraty 1980). Examples concerning bat-eared foxes, termites and zorillas in the southern African savanna and fish populations in the North-west and South-east Atlantic have been listed above. The environment may affect organisms directly, as when mortality rates of blue wildebeest are changed (Macdonald 1982), or indirectly, as with the postulated influence of climate on the availability of food to sardines in the Pacific Ocean. It may not always be reasonable to look for a one-to-one correspondence between the environment and biological parameters. Parameters such as the biomass or abundance of long-lived organisms may integrate the effect of the environment over a number of years. For example, a favourable environment in one year may give rise to formation of a strong year class, and this in turn may lead to high biomasses in subsequent years. In the Benguela system, strong year classes have often supported fisheries over a period of years (Crawford et al 1987), as was the case with horse mackerel off the western Cape Province of South Africa (Figure 16.10; Geldenhuys 1973).

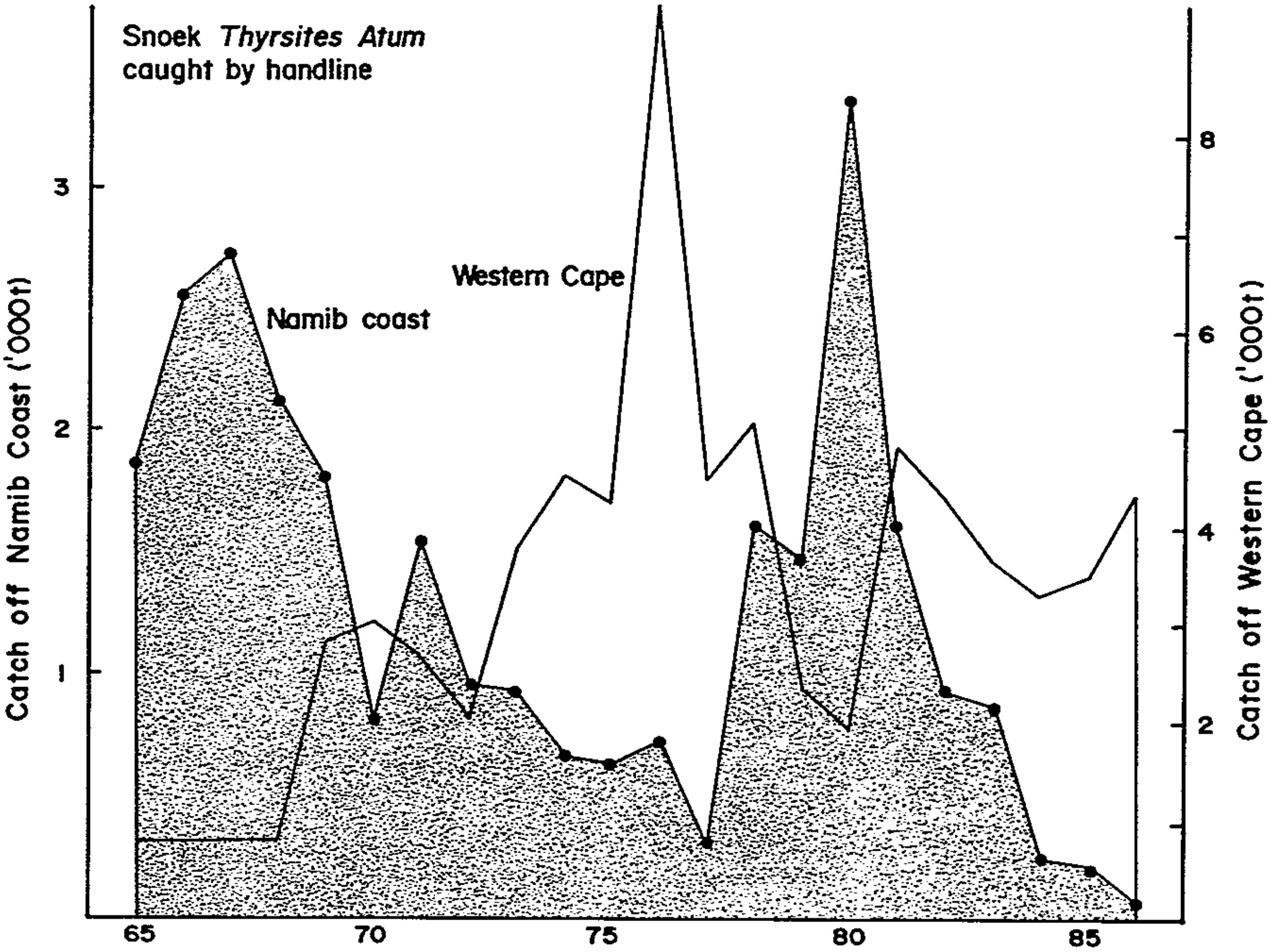

FIGURE 16.9 Annual catches of snoek made by handline off the Namib coast and off the western Cape Province of South Africa, 1965 to 1986. Catches have generally been high in one of the regions but not in both simultaneously, suggesting migration between them (from data in Crawford et al 1987; Venter this volume).

Some ecosystems state, however, eg those in which sardines are abundant in the Pacific (Figure 16.5), persist for many years - longer than might be anticipated to result from formation of a few good year classes. Extended favourable, or unfavourable, periods appear to occur and these may be best investigated through the study of long-term and large-scale averages and processes.

Man's impact on ecosystems may persist for many years, as the effect of heavy fishing on some fish resources in the North Sea and North-west Atlantic (Figure 16.4; Sherman et al 1981). Off southern Africa, commercial exploitation reduced first Cape fur seals *Arctocephalus pusillus pusillus* and then jackass penguins *Spheniscus demersus* to low levels of abundance. Seals have subsequently recovered, but not jackass penguins (Figure 16.11), a nonintuitive result as controlled exploitation of seals has continued but the collection of penguin eggs has been terminated. Commercial exploitation of the main prey of penguins has, however, been intense (Crawford et al 1988).

A dramatic example of man's long-term impact on a terrestrial system concerns the Chilean fur trade (Iriarte and Jaksic 1986). Chinchillas, mainly *Chinchilla lanigera* but also *C brevicaudata*, contributed the bulk of the early exports but they had been hunted to near extinction by 1915 (Figure 16.12). Thereafter pelts of European rabbits *Oryctolagus cuniculus* and hares *Lepus capensis* rapidly assumed increased importance, reflecting their growing status as pests after escape from cages at the turn of the century (Iriarte and Jaksic 1986). This, and the Rinderpest example mentioned earlier demonstrate that man, through introductions as well as through removals, can influence ecosystems.

A southern African illustration of the long-term impact of introductions is provided by the spread of alien trees and shrubs in the fynbos of the south-western Cape Province. Bird species which require trees for nesting sites, such as the hadeda ibis *Bostrychia hagedash* and the pied barbet *Lybius leucomelas*, have shown progressive expansions of their ranges into the fynbos biome as a consequence of this proliferation of alien trees (Macdonald 1986; Macdonald et al 1986).

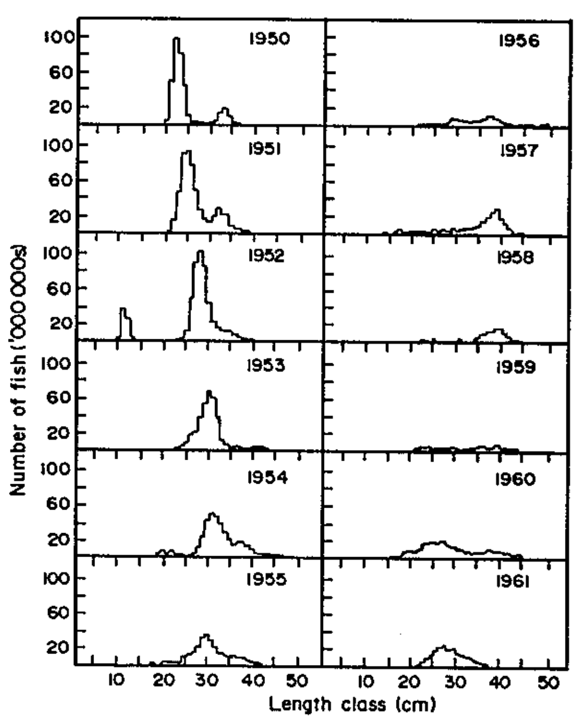

FIGURE 16.10 The contribution of different size classes to purse-seine catches of Cape horse mackerel *Trachurus trachurus capensis* off the western Cape Province of South Africa, 1950 to 1961, illustrating progression of year classes formed during the late 1940's (from Crawford et al 1987).

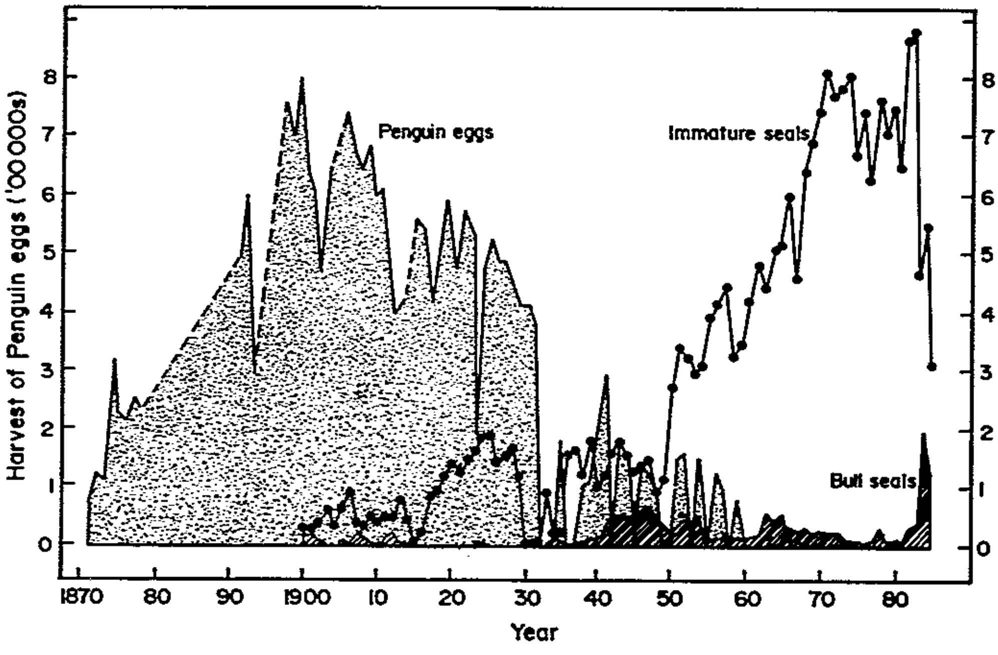

FIGURE 16.11 Annual harvests of penguin eggs and of immature and bull seals off southern Africa, 1871 to 1985, showing the decreased harvests of eggs and increased harvests of seals during the 20th century (from Crawford et al 1988).

In conclusion it can be stated that relationships between data series may arise from a variety of causes and that the establishment of relationships may be of value in elucidating mechanisms causing ecosystem change. In particular, comparative studies between different ecosystems may substantially advance the aims of the IGBP. As influences of episodic environmental or man-induced effects may persist in ecosystems for a number of years, an understanding of biological processes will generally be necessary when searching for relationships between these effects and biological data sets.

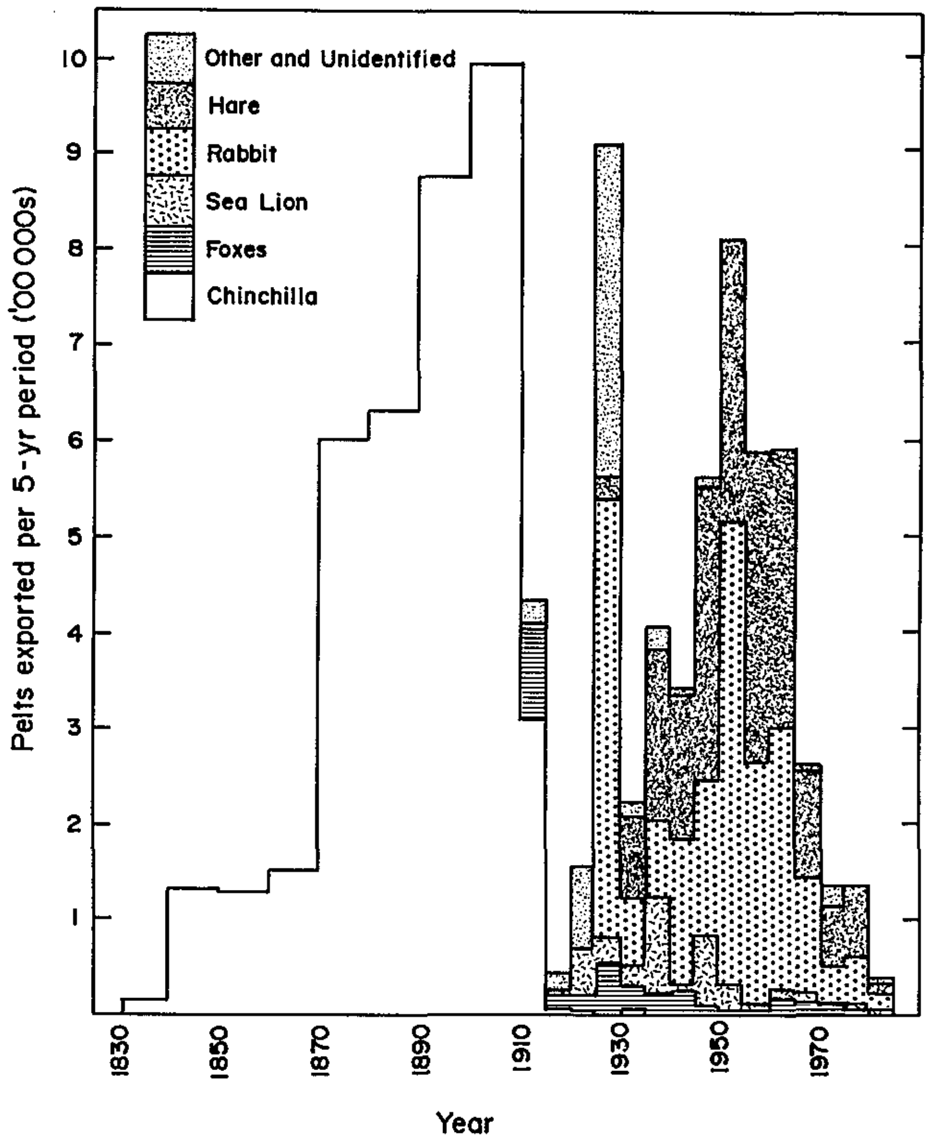

FIGURE 16.12 Trends in the export of various pelts from Chile, 1830 to 1985 (from information in Iriarte and Jaksic 1986).

REFERENCES

Crawford R J M and Shannon L V (In press). Long-term changes in distributions of fish catches in the Benguela. In: Proceedings of the International Symposium on Long-term Changes in Marine Fish Populations, Vigo, Spain, November 1986.

Crawford R J M, Shannon L V and Pollock D E 1987. The Benguela Ecosystem. Part IV. The major fish and invertebrate resources. Oceanography and Marine Biology Annual Review 25, 353-505.

Crawford R J M, Shannon L V and Shelton P A 1988. Characteristics and management of the Benguela as a large marine ecosystem. In: Sherman K and Alexander L M (editors) Biomass and Geography of Large Marine Ecosystems. American Association for the Advancement of Science, 171-221.

Geldenhuys N D 1973. Growth of the South African maasbanker Trachurus trachurus Linnaeus and age composition of the catches, 1950-1971. Investigational Report Sea Fisheries Branch South Africa 101, 1-24.

Iriarte J A and Jaksic F M 1986. The fur trade in Chile: an overview of seventy-five years of export data (1910-1984). Biological Conservation 38, 243-253.

Kawasaki T 1983. Why do some pelagic fish have wide fluctuations in their numbers? Biological basis of fluctuation from the viewpoint of evolutionary ecology. In: Sharp G D and Csirke J (editors) Proceedings of the Expert Consultation to examine Changes in Abundance and Species Composition of Neritic Fish Resources, San Jose, Costa Rica, April 1983. Food and Agriculture Organisation Fisheries Report 291, 1065-1080.

Kawasaki T (In press). Fluctuations in the three major sardine stocks in the Pacific, and global trends in temperature. In: Proceedings of the International Symposium on Long-term Changes in Marine Fish Populations, Vigo, Spain, November 1986.

Kerr R A 1983. Fading El Niño broadening scientist's view. Science 221, 940-941.

Koslow J A 1984. Recruitment patterns in North-west Atlantic fish stocks. Canadian Journal of Fisheries and Aquatic Science 41, 1722-1729.

Macdonald I A W 1982. The influence of short-term climatic fluctuations on the distribution of savanna organisms in southern Africa. MSc Thesis, University of Natal.

Macdonald I A W 1986. Range expansion in the pied barbet and the spread of alien tree species in southern Africa. Ostrich 57, 75-94.

Macdonald I A W, Richardson D M and Powrie F J 1986. Range expansion of the hadeda ibis Bostrychia hagedash in southern Africa. South African Journal of Zoology 21, 331-342.

Moran P A P 1953. The statistical analysis of the Canadian lynx cycle. Australian Journal of Zoology 1, 291-298.

Risser P G 1985. Report of a workshop on the spatial and temporal variability of biospheric and geospheric processes: research needed to determine interactions with global environmental change. St Petersburg, Florida, USA, October-November 1985, 52 pp.

Shannon L V, Crawford R J M, Brundrit G B and Underhill L G (In press). Responses of fish populations in the Benguela ecosystem to environmental change. Journal du Conseil International pour L' Exploration de la Mer.

Shepherd J G, Pope J G and Cousins R D 1984. Variations in fish stocks and hypotheses concerning their links with climate. Rapports et Procès-verbaux des Réunions Conseil International pour L' Exploration de la Mer 185, 255-267.

Sherman K, Jones C, Sullivan L, Smith W, Berrien P and Ejsymont L 1981. Congruent shifts in sand eel abundance in western and eastern North Atlantic ecosystems. Nature 291, 486-489.

Sinclair A R E 1979. Dynamics of the Serengeti Ecosystem. In: Sinclair A R E and Norton-Griffiths M (editors) Serengeti: dynamics of an ecosystem. University of Chicago Press, Chicago. pp 1-30.

Tont S A and Delistraty D A 1980. The effects of climate on terrestrial and marine populations. California Cooperative Oceanic Fisheries Investigations Reports 21, 85-89.

Underhill L G 1987. Changes in the age structure of curlew sandpiper populations at Langebaai Lagoon, South Africa, in relation to lemming cycles in Siberia. Transactions of the Royal Society of South Africa 46, 209-214.

LINKAGES BETWEEN OCEAN AND CONTINENTAL CLIMATE: A GLOBAL AND LOCAL PERSPECTIVE

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The linkages between ocean and continental climate are through weather and climate processes in the atmosphere (Woods 1985). In the ocean-atmosphere-land chain, the weak link where least is known and understood lies in the ocean. The importance of the link to the ocean increases on longer time scales as weather becomes climate. The corresponding spatial scales of important processes and their influence grows cumulatively so that on the interannual scale, processes of local and regional and global extent are all important. It is intended to illustrate these points with examples on various scales and with information on research which is being planned both internationally and nationally.

The first examples are of climate variability on the interannual scale. In some localities, there are profound differences in the climate experienced in a particular season in different years. A normally wet summer season can be replaced by a severe drought. In the years when this occurs, similar droughts can affect such regions as Australia, Brazil and the Sahel region of west Africa, which are far afield. The most recent and most severe occurrence of this failure was in 1983 when the summer rainfall region of southern Africa was also in the grip of severe drought.

Can there be a common cause for such severe conditions and how can it influence climate at so many localities on a global scale around the world? The link appears to be the Southern Oscillation of the global atmosphere, first described by Walker (1923) and now intensely studied (Hastenrath 1985).

The Southern Oscillation has a profound effect over the tropical South Pacific and on the coastal waters off Ecuador and Peru in South America. These coastal waters are normally somewhat cooler than the oceanic surface waters, which remain well offshore to the west. In the so-called El Niño years, the seasonal summer warming of the coastal waters is greatly enhanced as a thick layer of much warmer oceanic surface water impinges on the coast. The Southern Oscillation in the atmosphere involves a major redistribution of pressure systems, and hence of winds and weather, on a global scale. In the low phase of the Southern Oscillation, the south-easterly trade winds over the tropical South Pacific substantially weaken. There is a remarkable correlation between the years of the warm sea surface temperatures off South America and the low phase of the Southern Oscillation. The mechanism which links the two lies in the trade winds which normally keep the warm surface waters of the tropical Pacific well to the west, particularly so when the trade winds are strong. When the trade winds weaken, the warm surface waters slop back and deepen on the Pacific coast of South America. The realization of this linkage between the El Niño phenomenon in the equatorial Pacific Ocean and the Southern Oscillation in the atmosphere has been a major breakthrough in geophysics in the last decade (Philander 1983).

The influence of the Southern Oscillation extends far beyond the Pacific. Tyson (1986) has stated "The Walker circulation plays a significant, but by no means dominant role in modulating climate variability over southern Africa. The Southern Oscillation appears to account for about 20% of the variance of summer rainfall". More recent work (Harrison 1987; van Heerden 1987) suggests even stronger correlation with Pacific atmospheric indicators. The search for mechanisms to explain these distant teleconnections continues.

The second examples are concerned with climate variability and indeed prediction on the seasonal time scale. The influence of the ocean on the seasonal climate over the North American continent has been established to the level where successful predictions can be made (Namias and Cayan 1981). Sea surface temperature anomalies over the North Pacific are both consistent over the region and persistent through the season. There is also a correlation with air pressure anomalies. In the winter of 1978, the prediction of temperature over North America from the sea surface temperature anomaly field over the North Pacific was excellent, whilst the prediction of rainfall was good especially over the eastern seaboard (Namias and Cayan 1981).

In the Benguela region of the South-east Atlantic Ocean, the sea surface temperature anomalies are both consistent and persistent (Walker 1987). It is also the case that the Agulhas retroflection region to the south of South Africa is a region of intense flux of heat and moisture from the ocean into the atmosphere (Walker and Mey 1986). Air approaching from the south-west moves over this region and there is an indication that midlatitude low pressure systems and their attendant cold fronts intensify (Harrison et al in preparation). The first steps towards understanding the influence of sea surface temperature anomalies on weather over South Africa have been taken.

Turning now to plans for future research, it is important to discuss the World Climate Research Programme. This was established in 1980 by the World Meteorological Organization and the International Council of Scientific Unions (WCRP 1983). It has twin objectives of determining the sensitivity of climate to changes due to man, and of finding ways to make useful predictions of climate on time scales of weeks to years. The scientific approach is through coupled models of the different parts of the climate system, identification of key processes, the design of the observing network for the data required, and statistical analyses of climate variables. Significant processes have been identified and one is the controlling influence of the oceans on the global cycles of heat, water and carbon in the climate system. A major scientific problem limiting climate prediction over decades is the inability to describe and model the circulation of the world ocean. The World Ocean Circulation Experiment (WOCE) is the principal activity of the World Climate Research Programme on the decadal time scale (Woods 1985).

On present knowledge, South Africa lies at a crucial position in the global circulation of heat and water in the world ocean. There is continual flow of heat from the Southern Ocean up the entire Atlantic Ocean (Woods 1985) which provides ocean pathways from the equatorial Pacific to all the oceans of the world. Both the surface and deep water circulation pass South Africa. Transport in the Agulhas current and possible interbasin exchange from the Indian Ocean into the Atlantic Ocean are also of vital interest to WOCE.

In recent years, there has been an increasing interest in the Agulhas retroflection region. It has been shown to be a region of high variability (Lutjeharms and van Ballegooyen 1984), with the position of retroflection lying between 12°E and 21°E. In addition rings of warm surface water from the Agulhas Current can break off (Lutjeharms and Gordon 1987) and be carried equatorwards at the outer edge of the Benguela Current (Agenbag and Shannon 1987; Shannon and Agenbag 1987).

To conclude, WOCE sees South Africa as a focal point of its observational effort in providing proper data for its predictive climate models. The new South African national programme for WOCE and open ocean science will, over the next decade, be liaising with the international WOCE community (Lutjeharms and Anderson 1987; Lutjeharms and Grundlingh 1987). Already an indication of acceptance of South African involvement in the TOPEX/POSEIDON mission for remote sensing studies of the world's ocean has been received. It is anticipated that further involvement will be forthcoming in respect of international efforts on sea level and hydrographic sections.

In addition the national programme will be addressing in depth many issues of specific interest to South Africa. In this way, knowledge and understanding of ocean variability will enable its influence on climate variability over southern Africa to be established, and the impact on renewable natural resources can begin to be assessed.

REFERENCES

Agenbag J J and Shannon L V 1987. A preliminary note on a recent perturbation in the Agulhas Current retroflection area. Tropical Ocean-Atmosphere Newsletter 37, 10-11.

Harrison M S J 1987. Rainfall from tropical-temperature troughs and the Southern Oscillation. Third Annual Conference of the South African Society for Atmospheric Sciences, CSIR, Pretoria, October 1987.

Hastenrath S 1985. Climate and Circulation of the Tropics. D Reidel, Dordrecht.

Lutjeharms J R E and van Ballegooyen R C 1984. Topographic control in the Agulhas Current system. Deep Sea Research 31, 1312-1337.

Lutjeharms J R E and Anderson F P 1987. The World Ocean Circulation Experiment (WOCE); a South African perspective. South African Journal of Science 83, 10-14.

Lutjeharms J R E and Gordon A L 1987. Shedding of an Agulhas ring observed at sea. Nature 325, 138-140.

Lutjeharms J R E and Grundlingh M L 1987. Die Wêreld Oseaansirkulasie-eksperiment (WOCE). Suid Afrikaanse Tydskrif vir Natuurwetenskap en Tegnologie 6, 64-71.

Namias J and Cayan D R 1981. Large-scale air-sea interactions and short-period climatic fluctuations. Science 214 (4523), 869-876.

Philander S G H 1983. El Niño Southern Oscillation phenomena. Nature 302, 295-301.

Shannon L V and Agenbag J J 1987. Notes on the recent warming in the south-east Atlantic and possible implications for the fisheries of the region. Collection of Scientific Papers for International Commission for South East Atlantic Fisheries 14(II), 243-248.

Tyson P D 1986. Climate change and variability in Southern Africa. Oxford University Press, Cape Town.

Van Heerden J 1987. Results achieved by using the Southern Oscillation to predict South Africa's 1986/1987 rainfall. Third Annual Conference of the South African Society for Atmospheric Sciences, CSIR, Pretoria, October 1987.

Walker G T 1923. Correlation in seasonal variations of weather, VIII. A preliminary study of world weather (World weather I). Memoirs of the Indian Meteorological Department 24(4), 75-131.

Walker N D 1987. Interannual sea surface temperature variability and associated atmospheric forcing within the Benguela system. In: Payne A I L, Gulland J A and Brink K H (editors) The Benguela and comparable ecosystems. South African Journal of Marine Science 5, 121-132.

Walker N D and Mey R D 1986. Heat fluxes of the Agulhas-preliminary observations of seasonal retroflection region. Proceedings of the Second International Conference on Southern Hemisphere Meteorology, 396-399.

World Climate Research Programme 1983. Large-scale oceanographic experiments in the WRCP. World Climate Research Programme Publication Series Vol I.

Woods J D 1985. The World Ocean Circulation Experiment. Nature 314, 501-511.

RELATIONSHIPS BETWEEN LEMMING AND PREDATOR CYCLES ON TAIMYR PENINSULA, SIBERIA AND THE BREEDING PRODUCTIVITY OF GROUND-NESTING BIRDS, MEASURED IN EUROPE, AFRICA AND AUSTRALASIA

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University of Cape Town

DATA SERIES

The following data series are presented (Table 16.1):

i) Abundance of lemmings *Dicrostonyx torquatus* and *Lemmus sibiricus* in the Taimyr Peninsula during the boreal summer for the period 1969 to 1986 (Dorogov 1983; Tomkovich in Pienkowski 1983 and in litt to R W Summers) and the inferred predator pressure on ground nesting birds by Arctic foxes *Alopex lagopus* and other lemming predators (Dhondt 1987; Summers and Underhill 1987). The lemming abundance was rated on a four point ordinal scale: the relationship between actual lemming density and the ratings are not known. The inferred predator pressure was rated on a two point scale: "high" if the population of lemmings had decreased since the previous boreal summer and "low" if the lemming population had increased. Years in which the lemming population remained small or very small were rated years of low predator pressure.

ii) Percentage of first-year darkbellied brent geese *Branta bernicla bernicla* in Britain and western Europe in the boreal winter for the period 1954 to 1986 (Prokosch 1984; Summers 1986; Summers and Underhill 1987), and percentage change in the size of the wintering population, calculated from Prokosch (1984) and R W Summers (personal communication). The percentage of first-year birds was based on large visual samples throughout the winter range of the sub-species and the size of the wintering population on comprehensive counts.

iii) The percentage change in the January index for grey plovers *Pluvialis squatarola* in the United Kingdom during 1971 to 1986, calculated from Salmon et al (1987). This index is based on counts of grey plovers at estuaries in the United Kingdom.

iv) Percentages of first-year sanderlings *Calidris alba*, curlew sand-pipers *C ferruginea* and knot *C canutus* in ringing samples, mainly at Langebaan Lagoon, in the austral summers of 1969 to 1986 (Summers and Underhill 1987; Summers et al 1987; Underhill 1986, 1987a,b,c; Underhill et al in preparation). The sample sizes vary from very small (less than 10) to several hundred. Details of the sample sizes in each year are given in the references listed above.

v) Percentages of overwintering Turnstones *Arenaria interpres* and curlew sandpipers at Langebaan Lagoon for 1972 to 1987 (Summers and Underhill 1987; Summers et al in preparation; Underhill 1987a). Since it is mainly first-year birds which overwinter (Elliott et al 1976; Summers et al in preparation), these percentages provide an index of breeding productivity in the previous boreal summer. The figures are based on single summer and winter counts by the Western Cape Wader Study Group at Langebaan Lagoon.

TABLE 16.1 Annual variations in temperature and the abundance of lemmings and predators on the Taimyr Peninsula and in the breeding productivity of ground-nesting birds from the Taimyr Peninsula as measured in Europe, Africa and Australasia. (% 1Y = percentage of first-year birds, pn = percentage change in population size, % o-w = percentage overwintering)

Year	June temperature °C	Lemming abundance	Inferred predator pressure	Brent goose % 1Y	Brent goose pn	Grey Plover pn	Sander-ling % 1Y	Curlew Sandpiper % 1Y	Knot % 1Y	Curlew Sandpiper % o-w	Turnstone % o-w	Grey Plover no.	Curlew Sandpiper no.	Sander-ling no.	Turn-stone no.	Curlew Sandpiper no. or %
Note	1	2	3	4	5	6	7	7	7	8	8	9	9	9	9	10
1954	1,9			40,5												2[a]
1955	1,5			25,8												5[a]
1956	-0,1			6,5	+0											6[a]
1957	1,7			52,8	+19											10[a]
1958	-1,8			0,4	-3											15[a]
1959	1,8			21,6	+8											13[a]
1960	1,0			45,0	+12											16[a]
1961	-0,2			5,1	+1											12[a]
1962	—			0,2	+4											16[a]
1963	0,8			35,0	+3											43[a]
1964	0,8			34,7	+8											35[a] 0% o-w[b]
1965	-1,4			6,9	+7											18[a] 0% o-w[b]
1966	-2,0			39,7	+15											30[a] 20% o-w[b]
1967	-0,8			5,6	-2											23[a] 0% o-w[b]
1968	-2,3			0,4	-11											12[a]
1969	1,9	Moderate		49,7	+32			65								150[a]
1970	-0,4	Large	Low	37,7	+12			45				100 o-w				
1971	-0,9	Small	High	0,7	-17	-4	0,0	2	0			2	7	0	0	
1972	0,0	Very small	Low	35,5	+50	+16	36,9	33	42	21	55	27	numerous	13	15	
1973	-0,7	Large	Low	48,5	+66	+40	30,0	44	41	35	180	9	313	20	6	18% o-w[c]
1974	-1,4	Small	High	0,04	+16	+14	7,1	4	0	<0,1	11	2	5	3	11	
1975	1,6	Small	Low	46,2	+68	+1	12,2	11	45	8	39	68	many	28	20	
1976	0,2	Large	Low	11,6	-8	+11	25,4	12	24	2	96	4	many	32	18	73% 1Y[d]
1977	1,8	Small	High	2,0	-6	-48	6,5	0,2	-	0,5	13	4	193	11	4	
1978	-0,3	Moderate	Low	35,0	+35	+46	22,7	32	61	19	51	27	351	48	12	
1979	0,3	Large	Low	33,0	+21	+32	34,5	30	32	20	69	22	widespread	19	28	
1980	-0,4	Small	High	0,2	-14	-10	low	1,7	3	4	11	3	89	1	2	very few o-w[e]
1981	-0,1	Very small	Low	4,0	-12	-13	27,3	11	0	7	15	1	38	2	2	2,1% o-w[f]
1982	0,4	Large	Low	50,0	+58	+22	48,9	40	39	30	71	3	80	24	3	12,0% o-w[f]
1983	1,4	Very small	High	3,0	-8	-1	5,9	9	5	3	29	20	56	18	4	10,9% o-w[f]
1984	0,6	Small	Low	<1	-20	+4	14,0	5	7	7	36	7	42	5	10	1,7% o-w[f]
1985	2,7	Large	Low	35,0	+27	+19	30,0	58	high	26	80	6	many	5	3	many 1Y[g]
1986	-0,9	Small	High	0,02-0,1			0,0	1	5	0,6	3	2	200	0	7	

NOTES:
1. Ostrov Dikson, Taimyr Peninsula; 2. Taimyr Peninsula; 3. Taimyr Peninsula; 4. Percentage first-year brent geese in Britain and western Europe; 5. Percentage change in estimated size of darkbellied brent goose population in Britain and western Europe; 6. Percentage change in population index for grey plovers in Britain, as computed by the Birds of Estuaries Enquiry of the British Trust for Ornithology; 7. Percentage of first-year birds in ringing samples caught by members of the Western Cape Wader Study Group in southern Africa during the austral summer, mainly at Langebaan Lagoon; 8. Austral winter populations of curlew sandpipers and turnstones at Langebaan Lagoon in the following year, expressed as a percentage of the summer population; 9. The total number of sightings recorded in Zambia, August to November; 10. Information about curlew sandpipers from Australasia: (a) Numbers of curlew sandpiper sightings in New Zealand (Sibson 1970); (b) Percentage overwintering in south-eastern Tasmania (Thomas 1970); (c) Percentage overwintering in Westernport Bay, Victoria (Loyn 1978); (d) Percentage of first-year birds in ringing samples at Werribee Spit, Victoria (Paton et al 1982); (e) Percentage overwintering in Australia, obtained by comparison of summer (Martindale 1981) and winter counts (Martindale 1982); (f) Percentage overwintering in Australia, as determined by the counts of the Australian Wader Studies Group of the Royal Australasian Ornithologists' Union (Lane and Starks 1985); and (g) B A Lane (in litt).

vi) Monthly temperature and precipitation data at Ostrov Dikson (73°30'N, 80°14'E) in the Taimyr Peninsula are available. Only the mean monthly June temperature is presented for 1954 to 1986. It is used as a surrogate for snow conditions on the breeding grounds when the birds arrive (Boyd 1987). These data were obtained by R W Summers from the British Meteorological Office (Summers and Underhill 1987).

vii) Total number of sightings of grey plovers, curlew sandpipers, sanderlings and turnstones in Zambia between August and November for 1971 to 1986 (Dowsett 1980; Taylor 1979; data extracted from Zambian Ornithological Society Newsletters). The distribution and number of contributing observers varied considerably over the years.

viii) Percentage of overwintering or first-year curlew sandpipers in Australia and total number of curlew sandpiper sightings in New Zealand. Data sources are listed below Table 16.1.

DISCUSSION

When predators were abundant the breeding productivity of ground-nesting birds in the Taimyr Peninsula was low and vice versa. For example, inferred predator abundance accounted for 60% of the variance in brent goose productivity. June temperature, a surrogate for timing of snow melt, accounted for only a further three per cent of brent goose productivity (Summers and Underhill 1987).

P Tomkovitch (in litt to R W Summers) indicated that lemming numbers fluctuate synchronously across the entire Taimyr Peninsula, with some deviations in the western, northern and eastern parts. This near synchronous cycling of lemming abundance is the key factor in producing the boom or bust breeding productivities observed at migration destinations on three continents (Table 16.1). Further research on the Taimyr Peninsula is required to investigate these relationships (Greenwood 1987).

REFERENCES

Boyd H 1987. Do June temperatures affect the breeding success of dark-bellied brent geese? Bird Study 34, 155-159.

Dhondt A A 1987. Cycles of lemming and geese: a comment on the hypothesis of Roselaar and Summers. Bird Study 34, 151-154.

Dorogov V F 1983. Nesting of the rough-legged buzzard (Buteo lagopus) on Taimyr. In: Ecology and rational use of land vertebrates of north central Siberia. Sbornik Nauchaykh Trudov Sibirsk Oldel VASHKhNIL, Novosibirsk, 118-126.

Dowsett R J 1980. The migration of coastal waders from the Palaearctic across Africa. Gerfaut 70, 3-35.

Elliott C C H, Waltner M, Underhill L G, Pringle J S and Dick W J A 1976. The migration system of the curlew sandpiper Calidris ferruginea in Africa. Ostrich 47, 191-213.

Greenwood J J D 1987. Three-year cycles of lemmings and Arctic geese explained. Nature 328, 577.

Lane B A and Starks J 1985. Report on the winter 1985 national wader count. Stilt 7, 2-7.

Loyn R H 1978. A survey of birds in Westernport Bay, Victoria, 1973-74. Emu 78, 11-19.

Martindale J 1981. AWSG wader counts in Australia. Stilt 1, 9-11, 15-26.

Martindale J 1982. National winter count, 1981. Stilt 2, 2-9.

Paton D C, Wykes B J and Dann P 1982. Moult of juvenile curlew sandpipers in southern Australia. Emu 82, 54-56.

Pienkowski M W 1983. A poor breeding season in 1983 for some waders on the Taimyr Peninsula. Wader Study Group Bulletin 39; 34.

Prokosch P 1984. Population, Jahresrhythmus und traditionelle Nahrungsplatzbindungen der Dunkelbäuchigen Ringelgans (Branta b. bernicla, L. 1758) im Nordfriesischen Wattenmeer. Ökologie der Vögel 6, 1-99.

Salmon D G, Moses M E and Kirby J S 1987. Wildfowl and wader counts 1985-86. Wildfowl Trust, Slimbridge.

Sibson R B 1970. Curlew sandpipers in New Zealand 1969-70. Notornis 17, 291-296.

Summers R W 1986. Breeding productivity of dark-bellied brent geese Branta bernicla bernicla in relation to lemming cycles. Bird Study 33, 105-108.

Summers R W and Underhill L G 1987. Factors related to breeding production of brent geese Branta b bernicla and waders (Charadrii) on the Taimyr Peninsula. Bird Study 34, 161-171.

Summers R W, Underhill L G, Waltner M and Whitelaw D A 1987. Population, biometrics and movements of the sanderling Calidris alba in southern Africa. Ostrich 58, 24-39.

Taylor P B 1979. Palaearctic and intra-African migrant birds in Zambia: a report for the period May 1971 to December 1976. Zambian Ornithological Society Occasional Paper 1, 1-167.

Thomas D G 1970. Fluctuations of numbers of waders in south-eastern Tasmania. Emu 70, 79-85.

Underhill L G 1986. A successful breeding season in 1985 for brent geese, curlew sandpipers and sanderlings. Safring News 15, 15-18.

Underhill L G 1987a. Waders (Charadrii) and other waterbirds at Langebaan Lagoon, South Africa, 1975-1986. Ostrich 58, 145-155.

Underhill L G 1987b. Changes in the age structure of curlew sandpiper populations at Langebaan Lagoon, South Africa, in relation to lemming cycles in Siberia. Transactions of the Royal Society of South Africa 46, 209-214.

Underhill L G 1987c. A poor breeding season for ground-nesting birds in the Taimyr Peninsula in 1986. Safring News 16, 13-16.

CHAPTER 17. DATA ANALYSIS AND STORAGE

STATISTICAL CONSIDERATIONS IN THE DIFFERENTIATION BETWEEN TRENDS, CYCLES AND NOISE IN LONG-TERM DATA SERIES

Is the data set trying to tell me something, or am I telling it?

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University of Natal

GROUP MEMBERS: P Fatti, J S Galpin, L G Underhill

INTRODUCTION

Data concerning natural phenomena are measurements made on those phenomena, sometimes continuously, but usually intermittently at discrete instants usually as a time series. There are two main sources of trends, discontinuities and inhomogeneities that appear in data; either the phenomenon is nonstationary, or the method of measurement is changing with time, or both. Consistent measurement error is more difficult to detect, since it usually only adds noise to the data, and it is only by controlled comparative experiments that one can estimate the amount of noise polluting the data. For example, two rain gauges mounted near each other may have a typical difference on daily reading of up to 20%. This chapter will not address the problem of measurement noise.

What you can do with a data sequence depends on its length. A very general rule of thumb, that may be used as a rough guide, is that there should be at least five data points for each parameter estimated, such as means, variances, regression slopes etc. Therefore even if the data series is too short for the classical methods of statistical inference to be appropriate, the scientist can usually draw some information from the data set. Short data series may be used to suggest models which longer data series could confirm.

The general philosophy of statistical data analysis embodies four basic steps:

Step 0 Planning or experimental design. Before collecting the data, think about what the questions are. What data are required and how they should be collected? Consult a statistician.

Although highly desirable, this step does not always arise, as you may be looking at data already collected. Do not despair, much can still be done - move on to Step 1.

Once you have data, there are three basic steps: identification, estimation and verification.

Step 1 The objective is to *identify* a possible model from the available set which not only explains the data but also makes physical sense and hopefully has predictive ability. We call this identification via exploratory analysis of the data. Some candidate models are: Autoregressive Moving Average models (which are the subject of the remainder of the article), Regression models and the novel Generalized Linear Model (McCullagh and Nelder 1983).

The basic approach to modelling time series is firstly to identify perceived deterministic components such as trends, seasonality and discontinuities (Figure 17.1). Having removed the deterministic component, the residuals are subject to analysis. A plot of the residuals may draw attention to any component that has possibly been omitted from the deterministic model.

The model of the error process is just as important as that of the deterministic component. Most standard analyses assume that the errors are normally distributed (Gaussian) but in many cases their distribution may be skewed or long-tailed, reflecting occasional extreme departures from the deterministic component. In these cases, the statistical analysis must either be tailored to the particular form of the error distribution, or the data must be transformed to normality. Note that a transformation of the raw data will also affect the form of the deterministic component of the model. For example, a log transformation of the raw data will transform a multiplicative model to an additive one.

Step 2 The method of *estimation* of the parameters of the chosen model is almost dictated for the distribution of the residuals by the model chosen, although it may, for some models, be quite complicated and require extensive computer analysis.

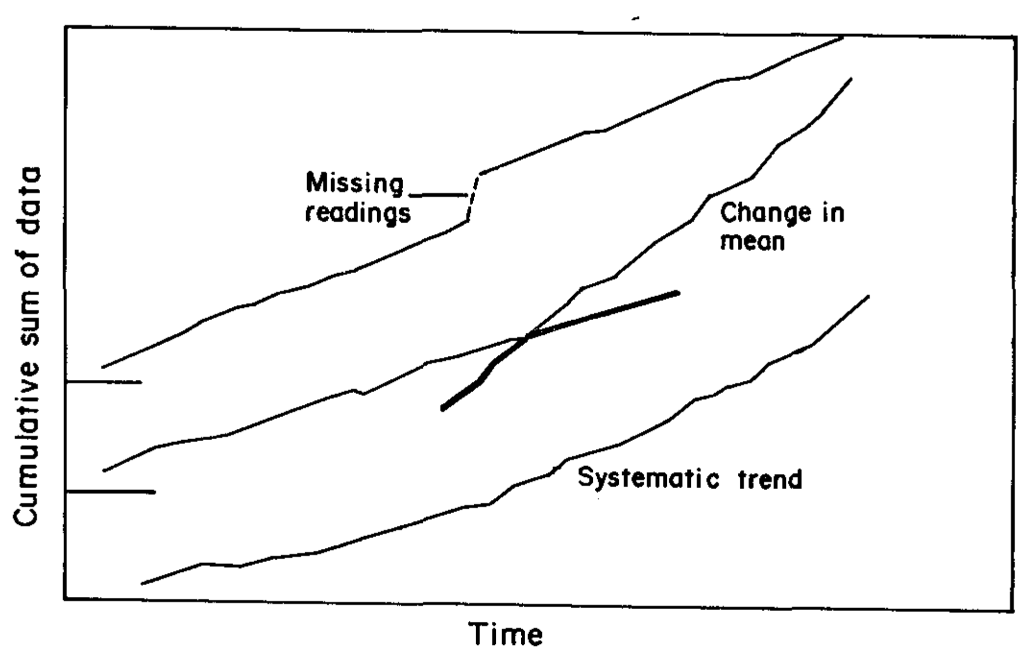

FIGURE 17.1 Plot of cumulative data versus cumulative "trusted" data (double-mass plot) showing types of inhomogeneities that typically plague time series.

Step 3 *Verification* of the model is an essential step in the process of modelling, because it is only as a result of this that one knows if one has gone far enough in describing the behaviour of the data. The residuals that come from the time series model should be checked visually and statistically.

It is important to identify change of regime, where a model is no longer valid, and the methods of quality control can be used for identifying the points of possible departure from the model, which could indicate an intervention to the basic phenomenon. These ideas are an extension of the simple techniques elucidated later in the section "Detection of inhomogeneities".

Where outliers (points that do not fit the rest) are detected, they should be carefully examined to decide whether they are due to measurement error or some extreme event (Figure 17.2). These extreme events may be precisely what is sought to explain changes in regime.

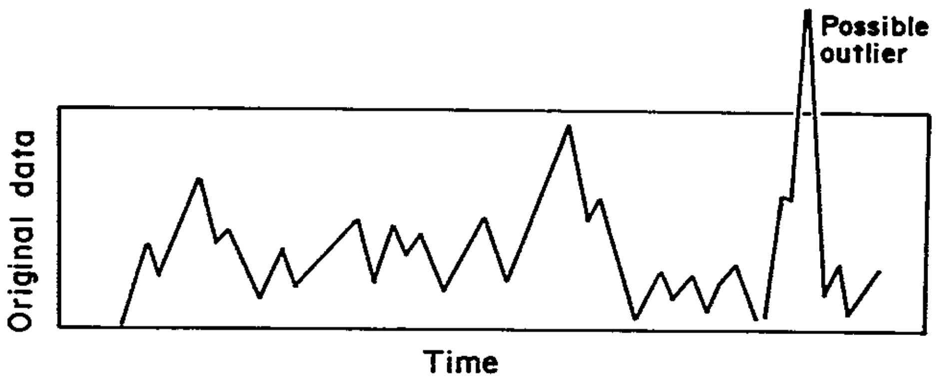

FIGURE 17.2 Plot of the data showing a possible outlier.

Here follow some handy watch-points when analysing time series.

Gaps are often a problem in the data series and it depends on the need as to what approach is adopted:

(a) Are the missing data of interest in themselves? If so, they can be estimated, on the basis of the model fitted to the available data, using for example the following procedure:

- (i) fit the model on the existing data alone and use this model to estimate the missing points;
- (ii) reestimate your model based on the infilled set and go to (i) until convergence, (which is guaranteed in the E-M algorithm, of which this is a particular application); and
- (iii) use correlation with other variables to fill in data, or to help check filled in values.

(b) Are the missing data just a nuisance, from the point of view of the parameterization of the model? If yes, ignore them, in for example, calculation of the spectrum. If the model cannot be used with missing data, fill them in as in (a).

When computing cross-correlation with other series, use only the intact data sets.

The purpose of the remainder of this chapter is to outline the approach one should adopt when analysing time series of a particular type, specifically, that class of stochastic processes that can be modelled by the ARMA (autoregressive, moving average) model popularized by Box and Jenkins (1970). Excluded from the analysis are more exotic types of time series such as compound Poisson processes, which can be used to describe phenomena like hourly rainfall. ARMA models have been used with considerable success by stochastic hydrologists to model such processes as annual streamflow and rainfall totals where the climate is not too arid (so that there is a zero probability of zero flow in monthly totals). Evidently there are many data sets which fall into the class of time series which can be modelled by ARMA or even ARIMA (autoregressive integrated moving average) models. Clearly, this article cannot do more than summarize the approach, so for exposition purposes it has the nature of a primer (even a recipe), so as the Romans used to say, "caveat emptor".

DETECTION OF INHOMOGENEITIES

Plot the data

There is no substitute for "eye-balling" the data: trends, discontinuities and outliers can often be picked out by eye (Figure 17.2). However, one should always approach data with a healthy scepticism. Beware of your own subjectivity: "if you cannot see it, it probably is not there; if you think you can see it, it may not be there".

Plot the data in many ways, for example with different symbols or colours for different groups; against other variables (eg temperture); plot the data spatially etc.

If the data are a single variable use histograms, box-and-whisker and stem-and-leaf plots (Underhill 1987); for two variables use scatterplots and for multivariable data, dimension reduction techniques such as biplots and correspondence analysis techniques (Digby and Kempton 1987).

Plot the cumulative data against time

Because the eye is good at detecting any deviation from a straight line, the cumulative chronological plot is a valuable tool for indicating the possibility of a change in the mean value of the data (Figure 17.3). It also indicates when the change is likely to have taken place because of the change in the slope.

Plot the cumulative data against trusted data

This is commonly called the "double-mass plot" and is a standard technique for checking rain gauge data. A sudden change in measurement (moving a gauge for example) will show as a break in the line. A linear trend will show as a quadratic curve. A discontinuity in the gauging will show as a break (Figure 17.1).

Student's T-test for means

Once a possible shift in means has been detected, it can be tested statistically by splitting the sample at the point suggested by the plots and computing the Student's T statistic, either assuming equal variances or more generally, unequal variances. To remedy the error, if there is one, the offending subsequence may be adjusted by a suitable factor to bring it into line.

Fisher's F-ratio for variances

There may be a suspicion that the variance has changed from one part of the data set to the other. Maybe the measurement has become more precise, eliminating some measurement noise. To test this, one computes the ratio of the variances and tests the statistic against the F-ratio. Adjusting variances requires more care, but in principle, it is a matter of scaling the standardized values by a factor to ensure homoscedasticity.

The above remarks apply to nonseasonal data, typically annual data. This section has described the tedious, boring but essential task of cleaning the data.

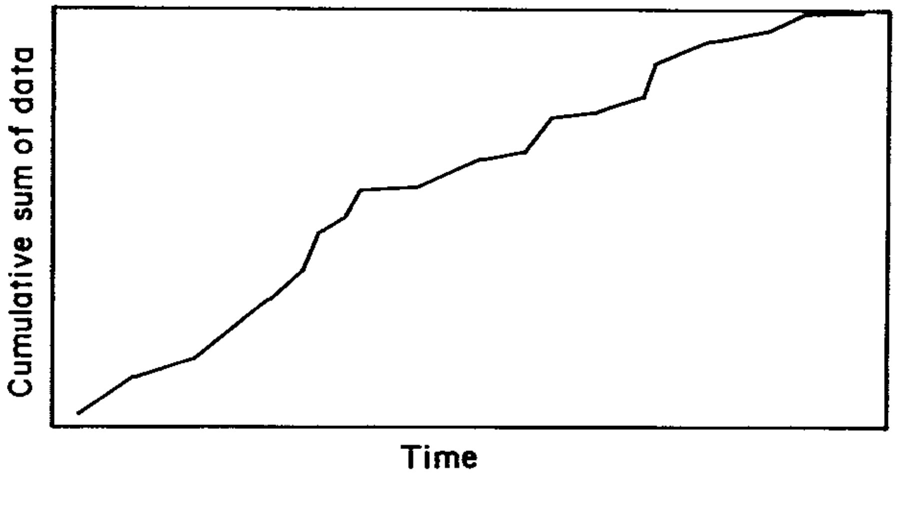

FIGURE 17.3 Plot of cumulative data versus time.

REMOVAL OF SEASONAL PERIODICITIES

This section applies to daily, weekly or monthly data, but not to annual (ostensibly stationary) data which will be treated in the next two sections.

There are two models which are commonly used to explain the "deterministic" element of periodicity apparent in some data. The more usual assumes that the deterministic mean is additive, the other that it is multiplicative. The first favours standardization after estimation of the mean and variance of each of the "seasons": the other favours the modelling of the periodicity as a factor described by a trigonometric (finite Fourier) series of a few terms. For example, in the case of monthly streamflows (Figure 17.4), the standard deviation increases and decreases, following the mean throughout the year. In this case standardization is straightforward, but a multiplicative Fourier series is possibly more parsimonious. There is no difficulty in modelling the periodic mean and variance by Fourier series before standardization. There are evidently many variants, and which is employed will depend on its success, ease of implementation and the taste of the analyst.

NORMALIZATION AND STANDARDIZATION

By now the data-set should be clean and free of periodicity. It may even have been standardized, if it came through the treatment suggested in the section: Removal of Seasonal Periodicities. Before meaningful time series analysis of the Box-Jenkins type can be employed, the data need to be transformed to normality, and then standardized, so that by the end of this section the set should be Gaussian (possibly serially correlated) with zero mean and unit variance. There are several steps.

Plot the histogram

Again the principle of "eye-balling" the data comes into play, because the eye can judge skewness and lack of fit fairly well. If the eye judges that the data are normal, then the tests are unlikely to contradict its judgement.

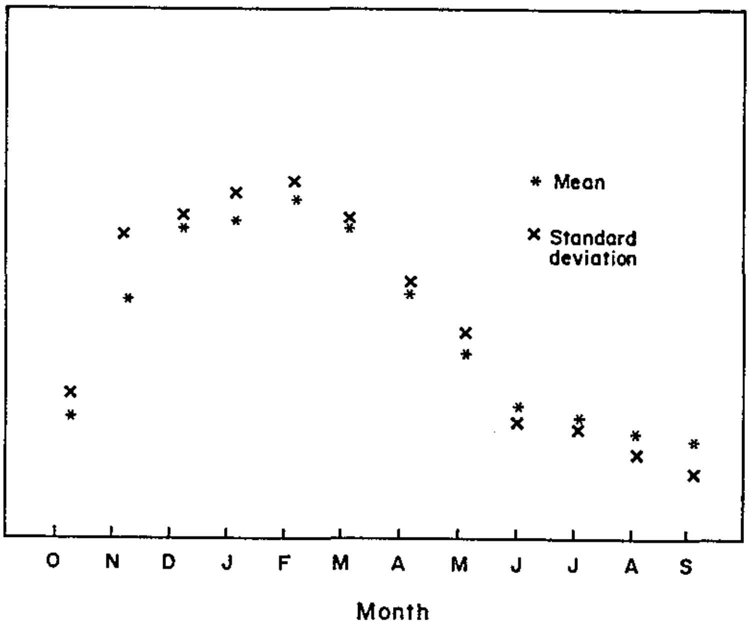

FIGURE 17.4 Example of annual variation of mean and standard deviation measured from a riverflow record for Gemsbokhoek Wier on the Komati River.

Plot the cumulative histogram

This is particularly useful when plotted on probability paper, ie the abscissa is transformed so that a cumulative normal will plot as a straight line (Figure 17.5).

Tests for normality

The chi-square goodness of fit test is applicable to the histogram (use cells of equal probability not with equal intervals - it saves the problem of grouping) while the Kolmogorov-Smirnoff test is a natural with the cumulative histogram. In addition, check the skewness and kurtosis against their allowable deviations from 0 and 3, the values for the normal.

Transformation to normality

To identify the marginal distribution of the data and decide whether they come from a particular parent distribution may be possible from a knowledge of the natural phenomenon. For example, annual streamflow totals must be nonnegative; in addition, they are notoriously positively skewed in the more arid parts of the country. Thus a natural choice of distribution functions to describe annual streamflow is the 3-parameter log-normal distribution; some analysts favour the Gamma (or Pearson type III), and there are others.

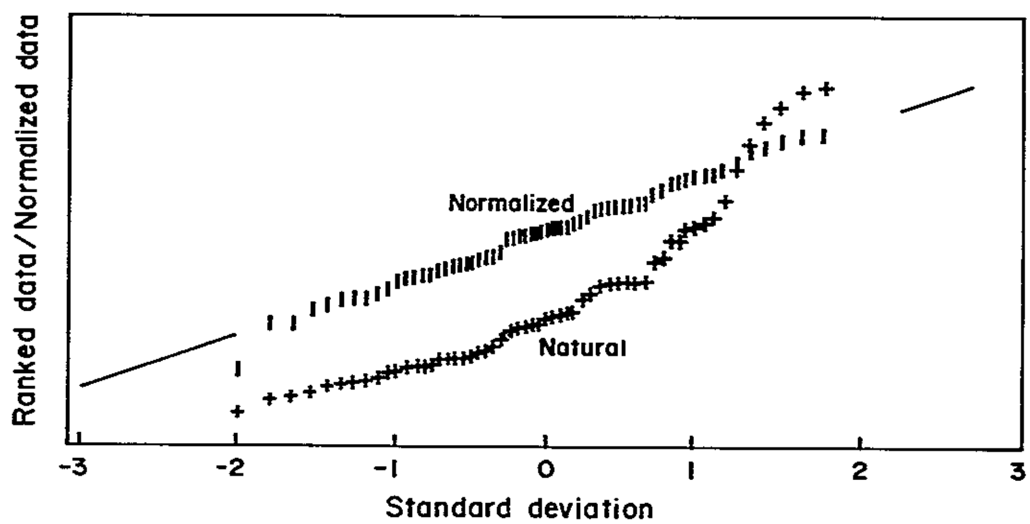

FIGURE 17.5 Plot of cumulative histogram on probability scale. The example is the Gladdespruit Weir on the Komati River.

A family of distribution functions which contains the normal, exponential, log-normal and gamma as special cases is the Johnson family. An algorithm exists (Hill et al 1976) for its computation and transformation to normality. Another attractive contender, that is so new it has not had much exposure, is the target distribution and polynomial approximation idea of Elphinstone (1986). These algorithms take the data set and attempt to transform it to normality. The success of the transformation depends on whether the new variates pass the tests outlined in the section: Tests for normality above. Experience shows that good data usually transform successfully because they come from a consistent set. The "mavericks" usually have a rotten family background.

The final step is standardization. This is useful, because it considerably speeds up the correlation/frequency analysis of the next section.

CORRELATION AND FREQUENCY ANALYSIS

The emphasis is again on visual presentation of the derived statistics. The first step is to compute and plot the correlogram (Figure 17.6a), the sequence of serial correlation coefficients, and its companion, the partial correlogram (Box and Jenkins 1970). From it one may compute the spectrum (Figure 17.6b) by cosine transform of the correlogram (Jenkins and Watts 1969). Both of these should have confidence limits (usually 95%) plotted to help judge the size of the correlation coefficient or the frequency as the case may be.

The candidate ARMA models

The autoregressive, moving average model is a simple idea to model time series with as few parameters as possible - this is called parsimony.

For example, an ARMA(2,2) model is written as :

$$x_t = a_1x_{t-1}+a_2x_{t-2}+w_t-b_1w_{t-1}-b_2w_{t-2} \quad (t=2,3,..) \qquad (1)$$

Equivalently, by defining the backward shift operator as

$Bx_t = x_{t-1}$, (1) can be written as :

$$(1 - a_1B - a_2B^2)x_t = (1 - b_1B - b_2B^2)w_t \qquad (2)$$

Note that these real polynomials in B can have real or complex roots, so that (2) can equivalently be written as :

$$(1 - c_1B)(1 - c_2B)x_t = (1 - d_1B)(1 - d_2B)w_t \qquad (3)$$

and the values of the various "c"s and "d"s can be real or imaginary. If they are imaginary, they can model pseudo-periodic behaviour.

Another example is an ARMA(1,1) model :

$$(1 - a_1B)x_t = (1 - b_1B)w_t \qquad (4)$$

In the above expressions, $[x_t]$ is assumed to be a set of Gaussian, zero mean (and conveniently unit variance) variates. $[w_t]$, being a linear transform of the $[x_t]$, must also be Gaussian, zero mean with a variance that depends on the a and b parameters, but with the special distinction of being serially uncorrelated and therefore, because of normality, independent. The intervention process $[w_t]$ is called a White Noise process, because its theoretical spectrum has all frequencies equally represented at the same variance, so it plots as a straight line with

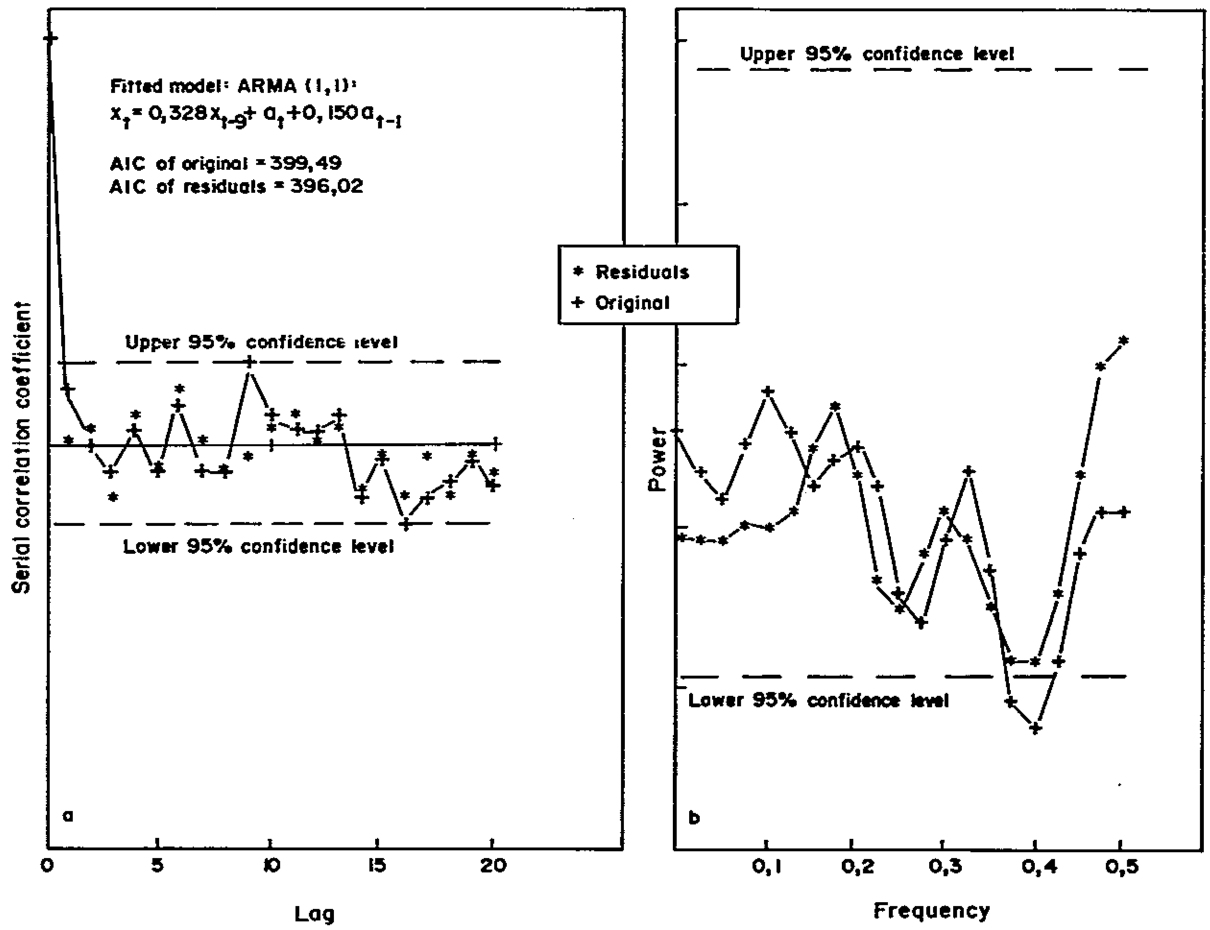

FIGURE 17.6 Sample correlogram (a) and sample spectrum (b) for annual rainfall totals at Stellenbosch for normalized data and the residuals of the fitted model.

value 2 over the range $(0,\frac{1}{2})$. Correspondingly, the theoretical correlogram of White Noise is zero for all lags one and greater. A model is deemed to have fitted the data properly when the correlogram of the residuals w_t does not differ significantly from zero; or equivalently when the spectrum of w_t does not differ significantly from 2.

There are three classical steps in the business of time series analysis as enunciated by Box and Jenkins (1970); they are identification, estimation and verification.

Identification

The correlogram and spectrum are good indicators of the type and order of model to fit. The strategy should be to keep the model as simple as possible while ensuring that the derived residuals are White noise. Over-fitting is wasteful of computing time as well as parameters. For detailed descriptions of how to read the correlogram or the spectrum, consult Box and Jenkins (1970) or Jenkins and Watts (1969), respectively.

Estimation

There are two philosophies in parameter estimation (or model fitting); the one is a variant of Gauss's Least-squares technique, the other is maximum likelihood. Both require the computation of the sum-of-squares of the residuals w_t, but the latter has some extra bits added for precision. When the data series is "long", the methods yield very similar results. When the series is "short", maximum likelihood has the edge. The additional computational burden is not large; it requires the computation of determinants of order p, q and p+q for an ARMA(p,q) model.

Verification

The only verification test is that the residuals w_t should be White Noise, ie serially independent normal variates.

There are two equivalent checks. The correlation coefficients should not differ from zero, and equivalently the spectrum should not differ from two, by more than that which may occur by chance.

Model selection

To choose between competing models which seem to be fitting the data equally well (eg without overfitting, it is conceivable that an ARMA(1,1) and an AR(2) model both seem to be able to explain the correlation structure), one must have some fitting criterion. A useful one, that incorporates the maximum likelihood function and penalizes overfitting because it incorporates a term equal to the number of parameters, is Akaike's Information Criterion (AIC) (Akaike 1974). The strategy is to accept the model with the minimum AIC. Because the AIC is an asymptotic criterion, it works particularly well on long data sets whose confidence bounds become so narrow that quite a few of the correlation coefficients/ frequencies appear significant. Using the AIC, one can devise automatic model selection from a suite of candidate ARMA(p,q) models with each of p and q varying over a range (eg 0, 1, 2) and picking the model with the lowest AIC.

However, the suite may not contain the "best" model, so the analyst must be vigilant and examine the correlograms (Figure 17.6a) and spectra (Figure 17.6b) of the residuals produced by the various models and decide if a different order of model is necessary.

CONCLUSION

The modelling procedure described in the above sections is standard ARMA modelling, and will enable the analyst to cope with the bulk of time-series problems. There are other variants, such as the ARIMA models, which include a differencing term to accommodate quasi-nonstationary behaviour, and SARIMA models which incorporate seasonality explicitly. Both are described by Box and Jenkins (1970). However, natural processes usually produce data sequences which are unlikely to wander away from an established mean, so ARMA models are usually adequate in those cases. ARMA models also have an intuitively appealing structure, because they are allied to linear (storage) systems, which are often used in the modelling of natural processes (Pegram 1980).

The last word is on cyclicity. The use of the term "cycle" has been deliberately avoided in this chapter because to some it conjures up the idea of a fixed-period driving force which influences the behaviour of the phenomenon from which the data are derived. The term "periodic" is preferred. Seasonal data exhibit periodicity and one can identify the forcing mechanism in such phenomena. Note, however, that ARMA models exhibit a pseudo-periodicity which is evident from an inspection of the spectrum of, eg an AR(2) model with imaginary roots. The spectrum will exhibit a peak at low frequencies, perhaps in the 0,05 to 0,15 range which may lead one to search for a nonexistent causal phenomenon with a period between six and 20 years, when the true cause of the peak in the spectrum is a storage related one. This can be called pseudo-periodic behaviour, and should not be confused with the signatures of truly periodic phenomena, which may exhibit vaguely similar spectra, especially when the periodic signal is buried in a fair amount of noise.

REFERENCES

Akaike H 1974. A new look at the statistical model identification, IEEE. Transactions on automatic control, Vol AC 19, No 6.

Box G E P and Jenkins G M 1970. Time series analysis, forecasting and control. Holden Day.

Digby P G N and Kempton R A 1987. Multivariate analysis of ecological communities. Chapman and Hall, London.

Elphinstone C D 1986. Parameter estimation for the target distribution estimator. Technical report TWISK 488, CSIR, Pretoria.

Hill I D, Hill R and Holder R L 1976. Algorithm AS 99, Fitting Johnson Curves by Moments, Applied Statistics 25, 180-189.

Jenkins G M and Watts D G 1969. Spectral Analysis and its Applications. Holden Day.

McCullagh P and Nelder J A 1983. Generalized Linear Models. Chapman and Hall, London.

Pegram G G S 1980. A Continuous Streamflow Model, Journal of Hydrology 47, 65-89.

Underhill L G 1987. Introstat. Juta, Cape Town.

DATA STORAGE

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At the 1987 conference it was felt that data for environmental sciences in southern Africa were generally not well curated. A particular shortcoming was that useful data inventories were not available, even with respect to the conference. A need was felt for databanks to store data, as data are a valuable resource and should be cared for as part of corporate strategy.

The concept of overall data administration was raised, implying a reduction in redundancies, better communication and usage possibilities, overall view of available data, and sharing of predefined programs and software packages. Such data banks as exist or may come into existence should be able to be linked to one another. This need not imply physical links, or even logical 'system' links, which generally could be considered to be unfeasible, but would require some degree of cooperation and overall planning. A difficulty at present is that several systems exist (all usable by means of different networks, computers, languages etc) that are often effectively private to a limited group of individuals.

The role of the South African Data Centre for Oceanography (SADCO) was dealt with, and its successes and shortcomings highlighted. Amongst the former was the accepted superiority of SADCO with respect to 'end-user computing' (the accessibility to the various databases by nonexpert users) and the availability of relatively flexible basic analytical routines, all based on well designed and implemented data bases. Shortcomings have included the unavailability of recent data, especially with respect to Voluntary Observing Ships meteorological data. It was highlighted that the role of SADCO was likely to change under the restructured CSIR, and furthermore that SADCO was in 1987 heavily involved in a complete re-implementation based on a different computer and a new (to SADCO) database management system. As part of the re-implementation, the shortcomings had been taken into account, and planning is such as to attempt to reduce them. L V Shannon (Sea Fisheries Research Institute) pointed out that the original motivation for SADCO was to serve the oceanographic community, and that its 'national facility' nature should be continued.

It was felt that a crucial need existed for an inventory of raw data sets and that this should be addressed by the whole community, both in terms of which body would be responsible for the inventory and how the information would be acquired and kept current. It was pointed out that SADCO had identified this need and intended to implement such a system, but that CSIR policy may affect this, and also that the limited SADCO staff, being data management/computing personnel are not in a position to carry out the task of obtaining the information.

The usefulness of two recently initiated storage systems, the southern African Bird Atlas Project and the National Marine Linefish system, are addressed in the following two sections. Data storage systems are also considered elsewhere in these proceedings (eg Held et al this volume).

THE POTENTIAL OF THE SOUTHERN AFRICAN BIRD ATLAS PROJECT FOR LONG-TERM POPULATION MONITORING

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INTRODUCTION

Regional bird atlasses have been ongoing in southern Africa since the mid-1970's (eg Cyrus and Robson 1980; Tarboton et al 1987). In January 1987 the regional schemes became integrated into one Southern African Bird Atlas Project (SABAP) based at the University of Cape Town.

Birds are one of the most readily observed faunal groups. This attribute, coupled with their mobility, renders them particularly valuable as integrators and indicators of changing environmental conditions. Quantitative historical data for comparison with the present-day situation are few. The primary objective of SABAP is thus to describe quantitively the spatial and seasonal distribution and abundance of southern African birds, and so provide a basis against which future change can be monitored. It will greatly facilitate future analyses of changes in bird distribution, and, for example, overcome the severe problems encountered by Macdonald (1986) and Macdonald et al (1986) in mapping the range expansion of the pied barbet *Tricholaema leucomelan* and hadeda ibis respectively (scientific names are given in Table 17.1, unless the species is mentioned only in the text).

DATA COLLECTION AND PROCESSING

The spatial resolution is 15' latitude x 15' longitude, the quarter degree square, and the temporal resolution is one month. Data are recorded in such a manner that both finer and coarser resolution are possible. Data are collected primarily by amateurs and submitted in the form of species lists recording the presence or absence of species and their associated breeding activities, if any. Observers are not requested to assess abundance. Relative abundances (seasonal, spatial, intra- and inter-specific) are determined by reporting frequency. In motivating participation in atlas projects, emphasis has been placed on the importance of data collection on a spatial and seasonal scale. Thus, the target for the Cape Bird Club atlas of the birds of the south-western Cape Province, for example, was to obtain a list of more than 75 species in each "square" in each month. There was no incentive to atlas in each year.

The data processing systems and computer programs used for the south-western Cape atlas has been adapted for SABAP. These programs provide a wide spectrum of methods of data analysis and presentation, some examples being presented in Hockey and Ferrar (1985). The programmes, written in FORTRAN 77, are available for use by other atlas projects.

DATA VOLUME

The southern African subregion contains approximately 5 000 quarter degree squares, and the degree of coverage will vary dramatically between squares. For the Cape Bird Club atlas of the birds of the south-western Cape, 8 321 field cards (species lists) were submitted, containing 421 000 records of about 400 species from the 76 quarter degree squares in the region. It seems likely that the final total of records to be processed by SABAP will exceed five million.

DATA LIMITATIONS

Atlas data lack absolute spatial and temporal resolution, although the recording precision is clearly defined. There are variations in observer competence (SABAP currently has some 4 000 participants), and hence the risk of misidentification exists. There are, however, checks built into the system at various levels to ensure that the final data sets are as 'clean' as possible. The concentration of observers in urban areas leads to grossly uneven geographical coverage. However, several of these limitations are swamped by data volume and are less serious than it would at first appear. One limitation which is difficult to overcome is the relative crypticity of species, which means that inter-specific comparisons of abundance are, in many cases, totally unrealistic.

SHORT-TERM TRENDS

Even though the objective of the atlas project is to provide a baseline for assessing future change in bird distribution and abundance, several short-term trends can be observed over the five-year period of the atlas of the south-western Cape. This is an unexpected by-product of the atlas, and is explored further in this paper.

Table 17.1 shows some selected statistics from the south-western Cape atlas. The total number of field cards submitted each year varied in a narrow range (1 561 to 1 770). The total number of records ("ticks") on these field cards also showed relatively little variation (79 133 to 89 386). However, the average number of records per field card increased steadily, from 45,0 in the first year to 54,6 and 54,5 in the final two years. This increase is attributable to two factors, improved skill in identification and, probably more importantly, a change in the attitude of atlassers. In the first years, there was a tendency for individuals to try to get some data from a large number of squares; in the last years, there was an attempt to achieve indepth coverage in a few squares.

There was also a tendency to stop atlassing in squares in which the "target" of more than 75 species for the month had been reached. For example, the number of cards received for "3318CD Cape Town" dropped from 159 in 1982 to 77 in 1986, and similar patterns were observed for "3318AA and 3317BB Saldanha" and "3318AB and AD Simonstown". Through *Promerops*, the Cape Bird Club newsletter, the Atlas Committee attempted to redirect effort to poorly covered squares. Thus the number of field cards for squares such as "3118CA Papendorp" steadily increased. There was also a tendency for a square to be "adopted" for a year; "3319AA Groot-Winterhoek" was the most extreme example (Table 17.1). However, all 76 squares in the south-western Cape atlas were visited at least once in each year. Of the 380 (5 x 76) "square years", only 94 (25%) received fewer than 10 field cards.

In spite of these limitations, and the shortness of the data collection period, trends in population abundance are evident in the raw data. Hadedas and forktailed drongos are known to be expanding their range in the south-western Cape. Table 17.1 and Figure 17.7 provide quantitative evidence of this. The number of records for hadeda increased from 67 in 1982 to 209 in 1985, an increase of 212%. Similarly, forktailed drongo increased from 103 records to 173, a 68% increase (Table 17.1; Figure 17.8). In comparison, note the relative stability in the number of records for cattle egrets, African black oystercatchers, whitefronted plovers, crowned plovers, Cape robins and ground woodpeckers. Blackheaded canaries erupted in the south-western Cape in 1982 and 1984. These were years of drought in Namaqualand and the Karoo, and it is likely that these eruptions were related to this event.

The three-year cycles in breeding productivity for certain species of waders can also be discerned in Table 17.1. The boreal summers of 1982 and 1985 were years of successful breeding for waders such as curlew sandpipers, sanderlings, turnstones and grey plovers which breed in the Taimyr Peninsula (Summers and Underhill 1987). After years of successful breeding, these species tend to be more widespread, and occur in more marginal habitat. Young birds also overwinter. One would thus expect more records for these species in 1983 and 1986, the years following the

TABLE 17.1 Selected statistics from the Cape Bird Club atlas of the south-western Cape

Year	1982	1983	1984	1985	1986
Number of field cards	1762	1770	1591	1637	1561
Number of records ("ticks")	79133	83423	83868	89386	85086
Average number of records per field card	45,0	47,1	52,7	54,6	54,5
Number of field cards for:					
3118CA Papendorp	5	8	7	15	13
3318AA and 3317BB Saldanha	54	55	38	31	38
3319AA Groot-Winterhoek	3	5	27	7	1
3318CD Cape Town	159	139	65	77	77
3418AB and AD Simons' Town	156	162	142	129	130
Number of field cards recording:					
Hadeda *Bostrychia hagedash*	67	74	87	166	209
Cattle egret *Bubulcus ibis*	1058	1093	1062	1057	1112
African black oystercatcher *Haematopus moquini*	372	430	393	381	368
Turnstone *Arenaria interpres*	130	176	143	149	168
Ringed plover *Charadrius hiaticula*	108	150	172	136	159
Whitefronted plover *Charadrius marginatus*	369	439	401	366	364
Grey plover *Pluvialis squatarola*	84	159	147	112	179
Crowned plover *Vanellus coronatus*	742	790	789	791	786
Curlew sandpiper *Calidris ferruginea*	299	416	355	324	387
Sanderling *Calidris alba*	123	175	157	136	148
Ruff *Philomachus pugnax*	129	202	186	157	169
Marsh sandpiper *Tringa stagnatilis*	84	112	115	82	75
Whimbrel *Numenius phaeopus*	117	140	157	137	142
Forktailed drongo *Dicrurus adsimilis*	103	98	114	165	173
Ground woodpecker *Geocolaptes olivaceus*	185	148	163	180	152
Cape robin *Cossypha caffra*	1141	1071	1032	1078	1043
Blackheaded canary *Serinus alario*	42	26	61	28	14

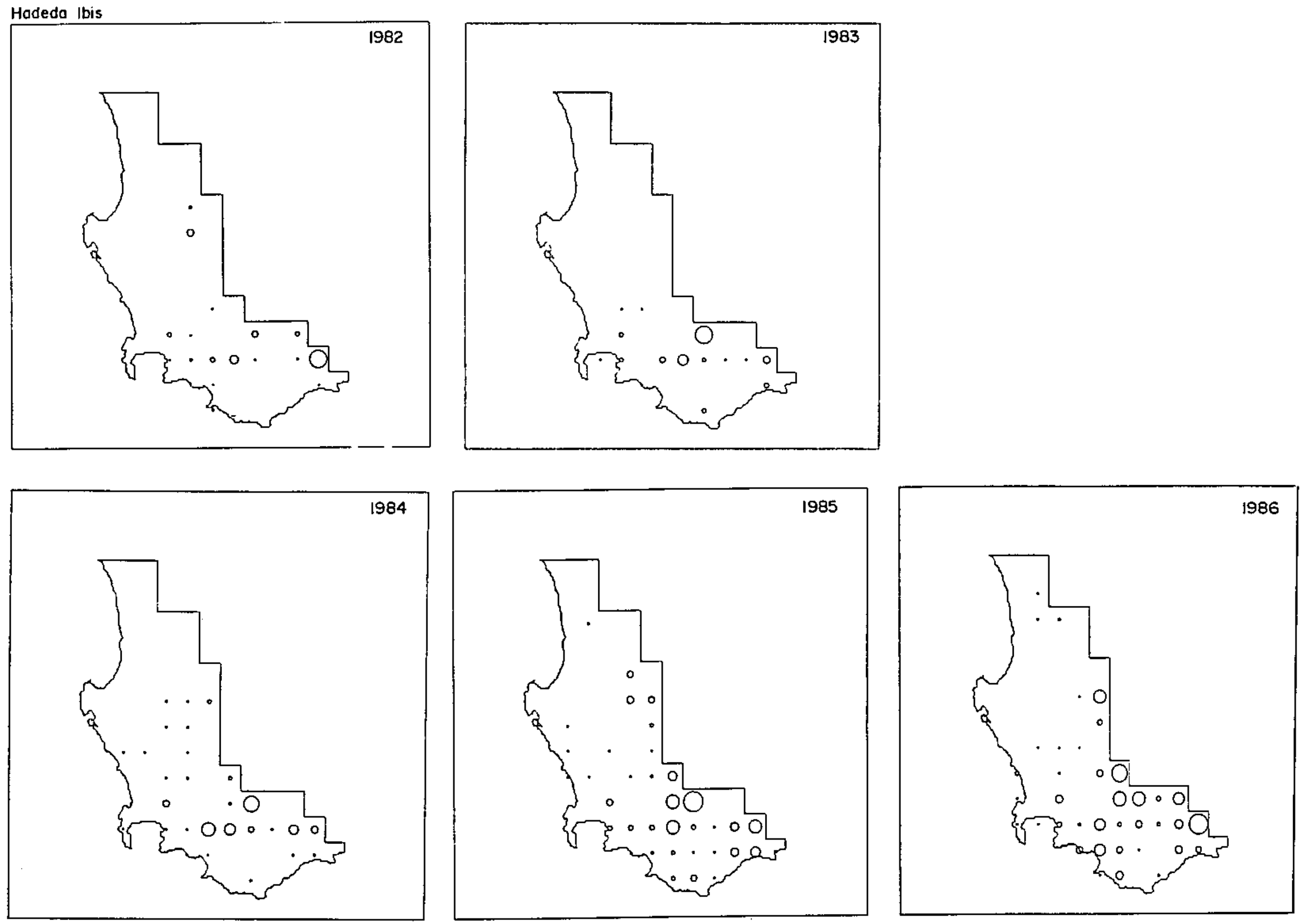

FIGURE 17.7 The distribution of the hadeda ibis in the south-western Cape, 1982 to 1986. The diameter of the circle within each quarter degree square is proportional to the number of cards for the square which reported hadeda ibis.

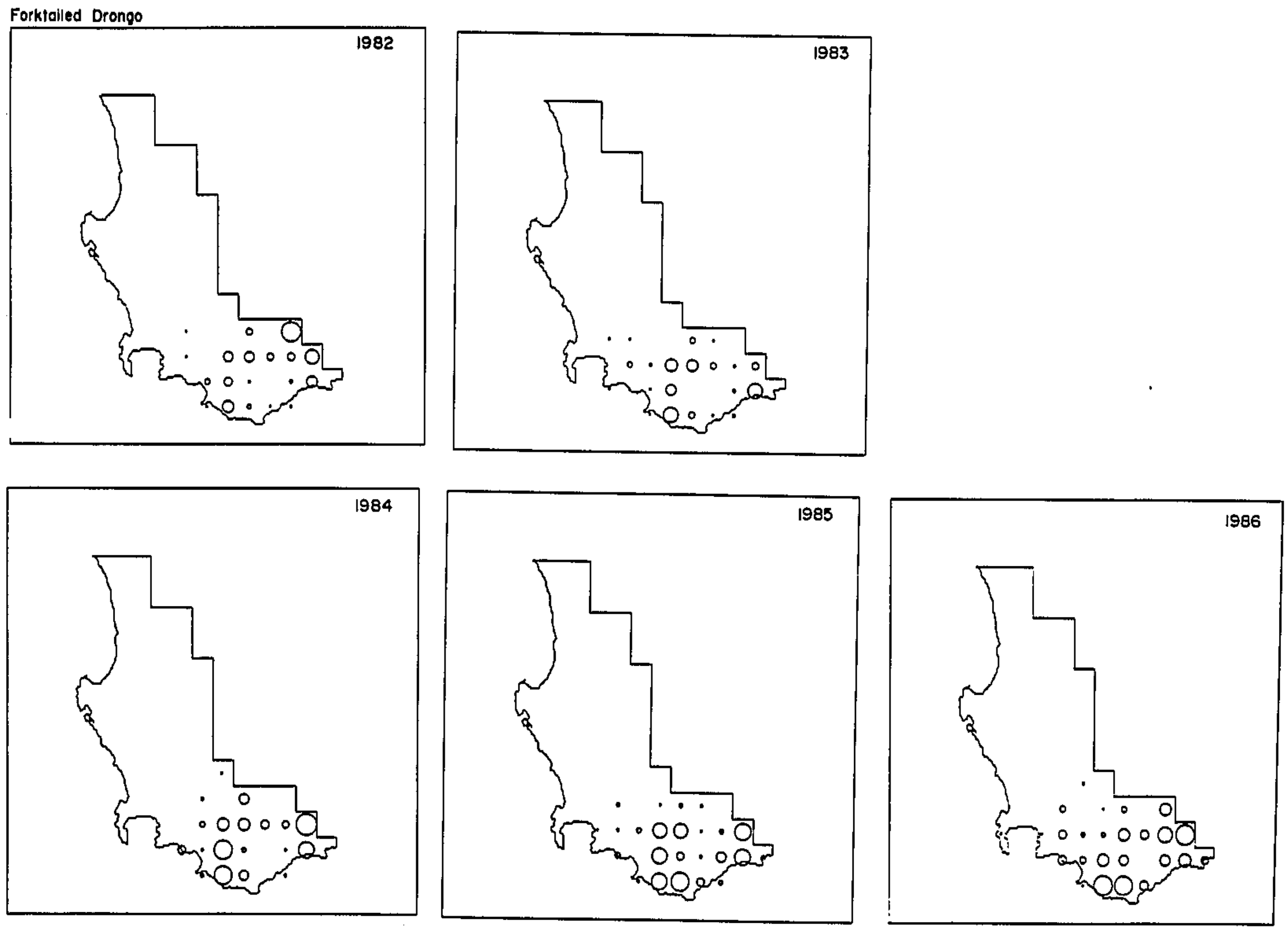

FIGURE 17.8 The distribution of the forktailed drongo in the south- western Cape, 1982 to 1986. The diameter of the circle within each quarter degree square is proportional to the number of cards for the square which reported forktailed drongo.

successful breeding years. This pattern occurs in Table 17.1. In contrast, waders such as ringed plovers, ruffs, marsh sandpipers and whimbrels, which breed farther south in the taiga, are not expected to show any such annual variation in their abundance.

AN INDEX OF CHANGE IN ABUNDANCE

The discussion above was based on the raw data. More sophisticated analyses are required which would compensate, not only for variation in the number of field cards received each year, but also for the inter-year variation in numbers of cards in each square, and the number of ticks on those cards. The following index might prove suitable for measuring inter-year change in abundance.

Let n_{ij} be the number of cards received in year i $(i = 1...I)$. Let t_{ijk} be the number of records in year i, square j, for species k $(k = 1...K)$. Let π_{ijk} be the probability that an atlasser in year i, square j, records species k. Assuming that atlassers operate independently, $p_{ijk} = t_{ijk}/n_{ij}$ is an unbiased estimator of π_{ijk}. Using the normal approximation to the binomial distribution, p_{ijk} has approximately the normal distribution N $(p_{ijk}, p_{ijk}(1 - p_{ijk})/n_{ij})$.

Consider two years i_1 and i_2. For an index of change in abundance, one needs to estimate the differences $\pi i_2jk - \pi i_2jk$ and, in some way, average these differences over the J squares. For each square, $pi_1jk - pi_2jk$ estimates this difference and has a normal distribution. One now finds the weighted sum of these estimated differences which has minimum variance. It is easy to show that

$$A_{i_1i_2}(k) = \sum_{j=1}^{J}\left(\frac{\left(\frac{p_{i_1jk}(1-p_{i_1jk})}{n_{i_1j}} + \frac{p_{i_2jk}(1-p_{i_2jk})}{n_{i_2j}}\right)^{-1}}{\sum_{j=1}^{J}\left(\frac{p_{i_1jk}(1-p_{i_1jk})}{n_{i_1j}} + \frac{p_{i_2jk}(1-p_{i_2jk})}{n_{i_2j}}\right)^{-1}}\right)(p_{i_1jk} - p_{i_2jk})$$

has this property, so that $Ai_1i_2(k)$ may be used as an index of the change in abundance of species k between years i_1 and i_2. Note that both sums in the above equation must only be taken over those squares for which there are cards in both years i_1 and i_2. A confidence interval for $Ai_1i_2(k)$ can readily be devised. If the confidence interval does not include zero, a possible change in abundance is indicated.

It must be emphasized that this is only an index of change in abundance, and does not measure even relative change in abundance in the same way as is achieved by the indices of the Common Bird Census or the Birds of Estuaries Enquiry schemes run by the British Trust for Ornithology (Mountford 1982). Because atlassers record only the presence of a species in a square, regardless of numbers observed, the index $Ai_1i_2(k)$ is likely to be relatively inelastic so that small changes in abundance are unlikely to be detected. It is thus likely that even a 20% change in the proposed index for a species could represent a major change in its absolute abundance.

The proposed index overcomes the problem of uneven coverage of the squares in the different years. It does not compensate for improvement in identification skills of individual observers, nor does it compensate for changes in observer attitude to atlassing. It might prove necessary to compute the index using only a subset of selected observers. The SABAP database records observer information, and thus selection of observers will be possible.

It is also possible to adapt the data so that the index computes changes in abundance between groups of years.

RECOMMENDATIONS FOR USE OF THE BIRD ATLAS FOR LONG-TERM MONITORING

Atlassers who are unable to travel widely to under-atlassed areas should be encouraged to continue faithfully in atlassing their home regions, month by month and year by year.

Atlassers should be encouraged to concentrate on returning comprehensive field cards for a few squares in preference to superficial field cards from a large number of squares.

Inexperienced observers should be identified and receive training to enable them to stabilize their bird identification skills as soon as possible. Cards received from these observers should be excluded from the computation of the abundance index.

The atlas project should not be seen as a five-year project, but as an ongoing long-term monitoring operation.

REFERENCES

Cyrus D and Robson N 1980. Bird atlas of Natal. University of Natal Press, Pietermaritzburg.

Hockey P A R and Ferrar A A (editors) 1985. Guidelines for the bird atlas of southern Africa. Occasional Report No 2. FRD, CSIR. 55 pp.

Macdonald I A W 1986. Range expansion in the pied barbet and the spread of alien tree species in southern Africa. Ostrich 57, 75-94.

Macdonald I A W, Richardson D M and Powrie F J 1986. Range expansion of the hadeda ibis Bostrychia hagedash in southern Africa. South African Journal of Zoology 21, 331-342.

Mountford M D 1982. Estimation of population fluctuations with application to the Common Bird Census. Applied Statistics 31, 135-143.

Summers R W and Underhill L G 1987. Factors related to breeding production of brent geese Branta b bernicla and waders (Charadrii) on the Taimyr Peninsula. Bird Study 34, 161-171.

Tarboton W R, Kemp M I and Kemp A C 1987. Birds of the Transvaal. Transvaal Museum, Pretoria.

THE NATIONAL MARINE LINEFISH SYSTEM - A LINEFISH CATCH AND EFFORT DATABASE

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A number of independent collection systems for data on linefish catch and effort existed in South Africa prior to 1982. The Oceanographic Research Institute (ORI) collected returns for fishing competitions and voluntary catch cards from all sectors of the recreational fishery in Natal. In cooperation with the Natal Parks Board they developed a shore patrol data collection card for monitoring shore angling catch and effort. In the Cape, the Sea Fisheries Research Institute (SFRI) developed monthly catch return systems for monitoring catches by commercial linefishing vessels, linefish landings at all fisheries harbours and purchases by major linefish dealers. In 1982 these various data systems were merged to form the National Marine Linefish Systems (NMLS).

The NMLS has been designed to provide a long-term database and analysis facility for data on linefish catch and effort from all sources, both current and historic. Sources monitored during 1986 provided information for approximately 75 000 recreational and 472 000 commercial angler days. The commercial returns represent 90% of registered linefishing vessels in South Africa and the recreational data were collected from skiboat, light-tackle, shore and spearfishermen in Natal.

Two summary systems are available for analysis of data on the NMLS. A "feedback" system produces summaries of catch and effort data for participating anglers, thereby encouraging increased participation and improved data quality. A "scientific" system provides detailed analyses of catch, effort and CPUE. If information on length-frequency distributions and growth rates is provided, the "scientific" system will be able to produce summaries of catch-per-length-class and catch-per-age-class for use in dynamic pool models.

CHAPTER 18. CONCLUDING REMARKS

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It is appropriate at the end to address three questions:

1. Why the conference?

2. What did the conference achieve?

3. Where to next?

WHY THE CONFERENCE?

You all are familiar with the rationale for the International Geosphere-Biosphere Programme (IGBP), as described in several ICSU-sponsored documents. It is not my intention to reiterate here the arguments in favour of the IGBP and, hence, our conference. Rather, I want to start with the question: why is it that South African science and scientists so frequently need the stimulus of some form of international collaborative effort to prompt them into responding efficiently to matters of serious national concern? Such matters often have been staring South African science and scientists in the face, persistently, and with full recognition, for many years with little or no action being forthcoming. I could go on to substantiate this contention with several examples but, within the context of this conference, it suffices to refer to the problem of the country's natural rangelands or *veld*. These rangelands, occurring mainly in the semi-arid regions, cover more than 80% of the area of South Africa. The *veld* is South Africa's main and most economic source of food for the domestic livestock industry, and it is the last defence against soil erosion. Perhaps only some 10% of the *veld* is in a good condition and, according to the Department of Agriculture, more than 50% is in a poor condition. Currently, approximately 25 million small-stock units (mainly sheep and goats) depend on the *veld* for food, and it is estimated that the country will need some 40 million small-stock units by the turn of the century. How might these animals be supported? The national farming debt is about 14 billion Rands and the plight of the grazier is a disgrace. Let me digress and tell you about the two graziers who were discussing what they would do if they won a jackpot of one million rands. The one said he would sell up and retire to Durban, and the other one said he would continue farming until all the money was used up.

Without going into detail here, it is true to say that most informed South Africans, in most walks of life, know at least something about the problems, both economic and ecological, that beset the grazier and the *veld*. This is not surprising, given that there have been several official committees of enquiry that have reported on the matter. The public media, high-school curricula and the writers of both popular and scientific texts, have repeatedly given prominence to the subject. There have been crusaders. Think of T C Robertson who has devoted the better part of his life to making all South Africans, but especially decision-makers in organized agriculture, economics, science and politics, aware of the problems. It would be wrong to say that generally South Africa's poor response to the problems is a consequence of insufficient advertisement. More particularly, nor can South African corporate science shelter behind such an excuse. The fact is that South Africa still lacks a respectable, scientifically-grounded, statistically-rigorous national monitoring facility to assess properly, changes in the physical and biological make-up of its rangeland ecosystems and their productivity, both ecological and economic. In the absence of such a facility, it is puerile to think about making predictions with any confidence, let alone attempting strategic planning. This is not a novel conclusion. It has been said repeatedly by many eminent persons for several decades. However, if ever there was a need for South Africa to plan strategically for the future use of its renewable resources it is now.

So, if not lack of awareness of the problems, what else is there that might be responsible for the dismal record of progress in this matter to date? There are scientists who might say, "Do not blame us, do not blame South African science". You might argue that funds for science have been, and are, limiting and that had funds been available the job would have been properly done by now. With respect, I reject this argument. There are some that know, as I know, that it is not so much a shortage of funds for supporting science, as rather a shortage of dedicated and innovative scientists in positions of authority in the organizations that are responsible for much of the spending of public monies on science in South Africa. In effect, this is a microcosm of the macrocosm that is the bloated and, on balance, mediocre and slothful government bureaucracy that has contributed in so many ways to South Africa's stagnation during the last 20 years or so. If South Africa's science and scientists are to be more effective and efficient, then they need to be freed from bureaucratic shackles and sheltered employment. There should be no rewards for indolence. But, I have strayed somewhat from answering directly the question I posed earlier. In concluding this, the first section, I suppose that it is fair to say that there is substance in the claim that people choose not to listen to prophets in their own land. That being so, South African science and scientists should welcome, and be thankful for, the initiatives of the IGBP. I cannot, however, escape from expressing my regret over the apparent inability of much of South African science to independently break out of its inertia regarding matters of strategic national importance.

WHAT DID THE CONFERENCE ACHIEVE?

Turning now to the second question: did the conference achieve its principal goal? Before I deal with this, I must say that a single-theme conference involving scientists of different disciplines, who work in different ecosystems - marine, freshwater and terrestrial - is in itself a rare event. The cooperation and collaboration between these scientists augur well for the future of a South African contribution to the IGBP. To say that I was both encouraged and impressed by the commitment of the scientists to the objectives of the IGBP would be an understatement.
Reverting now to the goal of the conference which was stated as: "to document what is known about how the environment and the renewable natural resources of southern Africa have changed over historical time, so as to provide a basis for improving the prediction of future change". To be noted is that the preceding wording "... predict future change" is that of

the conference organizers and not mine. In this context, I remind you of Niels Bohr's statement: "It is always difficult to make predictions, especially about the future". My response to the question "did the conference achieve its principal goal" is a qualified both yes and no. Proceeding first to the good news, or my qualified yes, I submit that the conference has succeeded in revealing, but not always documenting (at least not yet), major elements of ignorance. This, perhaps paradoxically, represents a significant advance. Indeed, it provides a springboard for the development of the next phase of South Africa's contribution to the IGBP and, concomitantly, and more importantly, a rationale for a scientific research programme whose results should provide the framework for a national environmental monitoring scheme.

The bad news is that, while some interesting correlations between different historical data sets emerged in the conference, very little, if any, proof was found for cause-and-effect relationships. The conference hardly strengthened confidence in attempts at making predictions. To be sure, some informed guesses were made which facilitated projections of trends, but proper predictions with attendant levels of statistical variance were conspicuous by their absence. Perhaps, however, this was too much to expect of the conference, or any other conference of this nature in the foreseeable future. Hence, it might be fair to conclude that the South African scientific community at present can offer at best some primitive scenarios for the strategic planners who advise both the private-sector entrepreneurs and the governmental regulatory bodies which are concerned with the exploitation of the country's renewable natural resources.

WHERE TO NEXT?

Which brings me to the last of my three questions: where do we go from here? First, and most importantly, a firm commitment to proceed with the IGBP both nationally and internationally is needed. By this I mean more than just another national 'limp-along' and 'do-it-within-the-present-set-up' exercise. The existing organization of scientific effort and deployment of funds (note deployment and not necessarily the amount of funds) are not good enough for doing the job properly. A new dispensation is needed, to use the vogue jargon, and I can think of no better organization, in spite of its sometimes imperfect nature, than the CSIR's Foundation for Research Development.

The international nature of the IGBP is crucial to South Africa. Only one example is needed to substantiate this point. It has to do with anticipating the so-called "greenhouse effect". No country can any longer safely ignore the possible alteration of the earth's climate by this effect, in spite of its still controversial nature. Temperature changes, changes in rainfall patterns and a rising sea level could have profound impacts in the foreseeable future. What, for instance, might be the consequences of such changes for the productivity of South Africa's rangelands within the next 25 or 50 years? South Africa should now be investigating options available to it in responding to the threat of global climate change. To do this, South Africa needs access to the best state-of-the-art environmental data sets and prognoses that should become available throughout the IGBP. South Africa cannot expect to receive IGBP-generated data unless it contributes to the programme. There has to be an exchange of information.

The pace of environmental change in South Africa, driven by economic and political realities and engineering skills, far outruns the pace of research on how to confidently measure and project all such change. However, without such a projection, albeit crude, integrated strategic planning is barely possible. South Africa cannot afford not to incorporate environmental scenarios into a strategic national plan. The consequences of not doing so could be catastrophic. And, this is the point that has not yet been understood and accepted as fully as it deserves to be by the nation's captains of industry, commerce and politics. If you doubt me, I recommend that you read, if you have not already done so, Clem Sunter's book (The World and South Africa in the 1990's) which exemplifies the short thrift that crucial environmental factors receive in the development of scenario-based forecasts of South Africa's future. This important neglect needs to be highlighted and remedied, and this should be done by scientists as part of the South African national IGBP. If not scientists, then who else? I, frankly, see no viable alternatives.

In summary, the conference has been successful in providing a springboard for (a) greater awareness of a national need of vital importance, and (b) the development of a national scientific programme to help meet that need. The springboard should also be used to launch a properly packaged public relations campaign, to convince the vanguard of the national mindset both of the need for a suitable environmental monitoring programme and the imperative of incorporating environmental factors into integrated strategic plans.

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