# Monitoring in South African Grasslands

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A Report of the Committee for Terrestrial Ecosystems
National Programme for Environmental Sciences

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## Preface

The National Programme for Environmental Sciences is a cooperative undertaking of scientists and scientific institutions in South Africa concerned with research related to environmental problems. The National Programme includes major research activities in inland water and terrestrial ecosystems, in all aspects of nature conservation and in the field of human needs, resources and the environment.

The Committee for Terrestrial Ecosystems has developed its programme within the five major biomes of South Africa - fynbos, karoo, grassland, savanna and forest. In each of these systems research designed to develop a predictive understanding of their structure and functioning is being coordinated within both site specific and extensive research projects.

The Grassland Biome Project has recently been initiated to coordinate existing and stimulate new research on the grasslands of South Africa. The valuable body of information developed during the last half century by range and pasture scientists will serve as a base from which new work will be initiated in order to fill gaps in our understanding of significant components and processes. While most of the work to be undertaken will be financed by participating organizations, research by universities and other indpendent reseach groups will be supported by the National Committee for Environmental Sciences from funds contributed largely by the Department of Environment Affairs.

## Acknowledgements

This report is based on a workshop held at Cathedral Peak from 30 January to 1 February 1984. The workshop was organized and funded by the National Programme for Environmental Sciences' Grassland Biome Project. The cooperation and aid provided by the Department of Agriculture and Nature Conservation (SWA/Namibia), Department of Agriculture, Department of Environment Affairs, and the Natal Parks Game and Fish Preservation Board enabled participants of widely ranging interests in resource management to attend.

Messrs C S Everson, M B Hardy, N P le Roux, R S Walker and Dr J S B Scotcher drafted background documents which served as the basis for discussion at the workshop. Working groups at the workshop concerned community change (O J H Bosch, P Colvin, C S Everson, J H Fourie, M T Mentis (convener), T Nott, J C Scheepers, N M Tainton, F Truter and F van Rensburg), selected species (D Scott, P G H Frost (convener), M D Panagos, J S B Scotcher and R Yeaton), selected issues of process and structure (R H Drewes, J E Granger, M B Hardy, N P le Roux, F J Kruger (convener), D R MacDevette, F R Smith, D N S Tomlinson and R S Walker) and monitoring benchmarks (P F du Toit and B J Huntley).

Like other workshops of NPES's Terrestrial Ecosystems group, it would not have flourished without the industry and inspiration of Brian Huntley and his able team. Minja Martin was largely responsible for engineering the assembly and accommodation of grassland workers at Cathedral Peak. Diana Banyard supervised the smooth running of the workshop and the trout-sampling of the wilderness-streams which, incidentally, were infested with coarse native fishes. Claire McKinnon extracted a workshop-report from a tardy writer whose scrawl was quickly and accurately transformed - despite the odds - into a typescript by Ruth Viljoen.

Although this document is called a report on a workshop, it would be quite wrong to suggest that the actual proceedings are accurately recorded here. Nor is this a manual that sets out in the style of a recipe how monitoring should be done. Rather, the discussions at Cathedral Peak have served as a basis to proposing techniques that invite testing. The bad thing about this is possible criticism of bias, distortion, plagiarism or simply scant regard for words of wisdom. The benefit however, it is hoped, is that the presently proposed techniques - and especially those about community-change - might actually be tested, found wanting, and perhaps improved upon.

## Synopsis

The main purpose of this document is to propose how ecological monitoring might be developed in the Grassland Biome of South Africa.

Monitoring is defined as the maintenance of regular surveillance to test the null hypothesis of no change in predefined properties of a system which is vulnerable to impacts, the nature, timing and location of which are not necessarily known. Monitoring is an integral part of scientific management whereby the objectives for the system are spelled out. They are translated into operational goals, tests are designed and performed to assess goal-attainment, and remedial measures are devised and applied as necessary.

Grassland users have a variety of objectives. Commercial pastoralists aim to gain economically from selling animal produce derived from livestock feeding on live herbage. Interests focus on maximizing absolute profit in the short-term, although longer-term views and non-sustainable practices do arise. Subsistence graziers use livestock as a source of draught power and manure for crop production, and as producers of milk, meat and other animal products, and exchangeable benefits. Such livestock of course depends primarily on native grassland. The State administers areas set aside to preserve samples of dynamic communities of the native biota, to provide ecological baselines and, in cases, to produce a sustained flow of clean stream-water. The conservation objectives championed by the State are typical of these kinds of aims in that they are poorly falsifiable - it is difficult or impossible to assess the degree of their attainment.

Community-composition seems to be an appropriate focus of attention in trying to develop operational goals from untestable objectives. For pastoralism the abundance values of the grass species strongly influences animal performance. For conservation, community-composition is a central issue since the significance of environmental impact is judged, almost by definition, on whether it affects the composition of the community. It is of course hardly conceivable that any given impact would affect all species equally - there are bound to be differential effects which, if large enough, will be reflected in community composition. An appropriate null hypothesis for monitoring then is that there is no difference in community-composition between some specified or baseline situation and a follow-up survey.

No cookbook procedure is offered here for the worker to proceed immediately with monitoring. Rather a system is proposed whereby a procedure tailored for local objectives and conditions might be devised - the worker can establish for himself the appropriate sampling design, the number of sample plots to locate, the intensity of observation on each plot, and so on for whatever the chosen degree of sensitivity to change. And the proposals made in this regard are not intended to be definitive recipes, but rather to invite testing.

Monitoring can serve only to test the null hypothesis of no change. The cause of change need not and usually will not be self-evident. Indeed, quite explicitly monitoring applies when the nature, location and timing of the impact are unknown - if these details are known then so is the cause and the study becomes an environmental one other than monitoring. There is no certain way of establishing cause-and-effect, not without 'wasted' effort. Discovery itself is born of inspirational hunches - science cannot produce these, but only test them. These tests might involve (semi-) permanent quadrats subjected to various treatments at several intensities, and observed over time.

Certain species and biospheric processes might be selected for special study. Rare, invasive, indicator and keystone species are likely candidates, as are issues concerning soil loss, hydrological regime, water quality, primary production, biogeochemical cycles, biogeographic processes and community structure. Again the null hypothesis is that of no change between specified or baseline conditions and follow-up surveys.

Monitoring in the Grassland Biome would be facilitated by a national network of benchmark sites consistently managed in specified ways and assessed periodically. The data obtained would aid in interpreting constancy or change revealed by routine monitoring studies.

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# 1. INTRODUCTION

This introduction deals with the objectives of the Grassland Monitoring Workteam (GMW), an explanation and justification of these objectives and the proposed means by which they might be achieved. This is followed by a statement of the aims of the workshop on which this document is based.

## 1.1 Objectives of Grassland Monitoring Workteam

The primary objective of GMW is to develop procedures to monitor and evaluate the state of grassland ecosystems in relation to the main uses to which they are put, and in relation to their potential to satisfy future needs.

A secondary objective is to identify gaps in our knowledge of the structure and functioning of grassland ecosystems relevant to interpreting monitoring results and their application to present and foreseeable uses.

At this early stage it is imperative to define monitor. It is here defined as maintaining regular surveillance to test a null hypothesis of no change in predefined properties of a system which is vulnerable to impacts, the nature, timing and location of which are not necessarily known.

GMW's concern with monitoring is in the context of the objectives of the Grassland Biome Project (Mentis and Huntley 1982) and in relation to those main uses to which local grasslands are put, namely, pastoralism, nature conservation and water production. There is of course an infinite array of parameters of grassland ecosystems which are more or less relevant to an equally infinite range of conceivable scientific studies. It is not possible to monitor everything, and GMW is not intended to address general issues for which guidance is obtainable from standard texts on statistics, sampling theory, environmental study design and fundamental ecology (Siegel 1956, Snedecor and Cochran 1967, Colinvaux 1973, Barnett 1974, Green 1979, May 1981, Greig-Smith 1983). Nor is there a need to prepare yet another general treatise on monitoring (see Grimsdell 1978, Ferrar 1983). Rather the deficiency concerns what our use and management of local grasslands do to the state of these ecosystems. At present procedures for doing this are poorly developed and little applied. GMW is intended to remedy this. It aims to look at monitoring in the kind of management context illustrated in Figure 1. It is appropriate that the main steps in this procedure be considered.

A prerequisite to anything other than aimless activity is a statement of objective (step 2 in Figure 1). Purposeful management derives not from science but rather as an expression of value judgements - what we like or want. (The common objectives in using local grasslands, for example, are considered in section 2.) Often these statements of purpose are so generally phrased or so conceived as to be hardly or not amenable to quantification. Clearly the more exact we can be in stating what we want or expect, then the more readily is it possible to measure whether we are getting this. Thus these general expressions of intent (objectives) need to be translated into precise goals, or written in operational terms (step 3 in Figure 1). Often the goals will specify target dates, deadlines, thresholds or maxima and/or minima. It is important at this stage that communication be maintained between the policy-makers, who set objectives, and the persons who develop the goals. It is almost inevitable that paraphrasing is necessary, but whatever the 'scientific licence' the principles of policy must be faithfully reproduced in the goals. Having satisfied these requirements the system must be examined to ascertain whether the target dates, deadlines, thresholds or maxima and/or minima are observed (step 4 in Figure 1). That there is no departure from our goals is the appropriate null hypothesis ($H_o$) which step 4 must be designed to test (see Green 1979: especially pp 1-64). In the event of there being no significant departure from the goals the system is simply kept under regular surveillance (the loop involving steps 4 and 5 in Figure 1).

The monitoring might however reveal a deviation from the intended behaviour of the system (stage 6 in Figure 1). Usually it will be possible to generate a solution (step 7). Indeed, there are likely to be numerous more or less plausible solutions. The selection and application of one (step 8) might involve an evaluation of the alternatives and choice of the one which has the least apparent weaknesses. This screening of alternatives might resort to either deferred action or adaptive management (Walters and Hilborn 1978) the details of which are beyond the scope of the present report.

It is possible, particularly after numerous executions of the loop involving steps 4, 6, 7 and 8 in Figure 1, that the stock of plausible solutions may become exhausted. The goals might then be reviewed (step 9). Perhaps they are not operational after all, and redrafting might be worth considering. In the extreme event it might be warranted to appeal to the policy-makers for a change in objectives (eg it was intended to design a perpetual motion machine but now that the second law has come to light our purpose might be restyled as to design an efficient machine).

The centrality of monitoring (step 4 in Figure 1) to scientific management might now be emphasized. The practice of allegedly managing without periodically assessing the degree of goal attainment is a contradiction in terms. Further, the scientific management of which monitoring is a part must be designed and executed as a sequence of interdependent procedures. Developing goals must anticipate how things are to be measured in the field, what kinds of results will be yielded, what degree of confidence might be attached to them, how they might be interpreted, and whether their expensive acquisition and analysis can be rewarded by their positive input into goal-attainment.

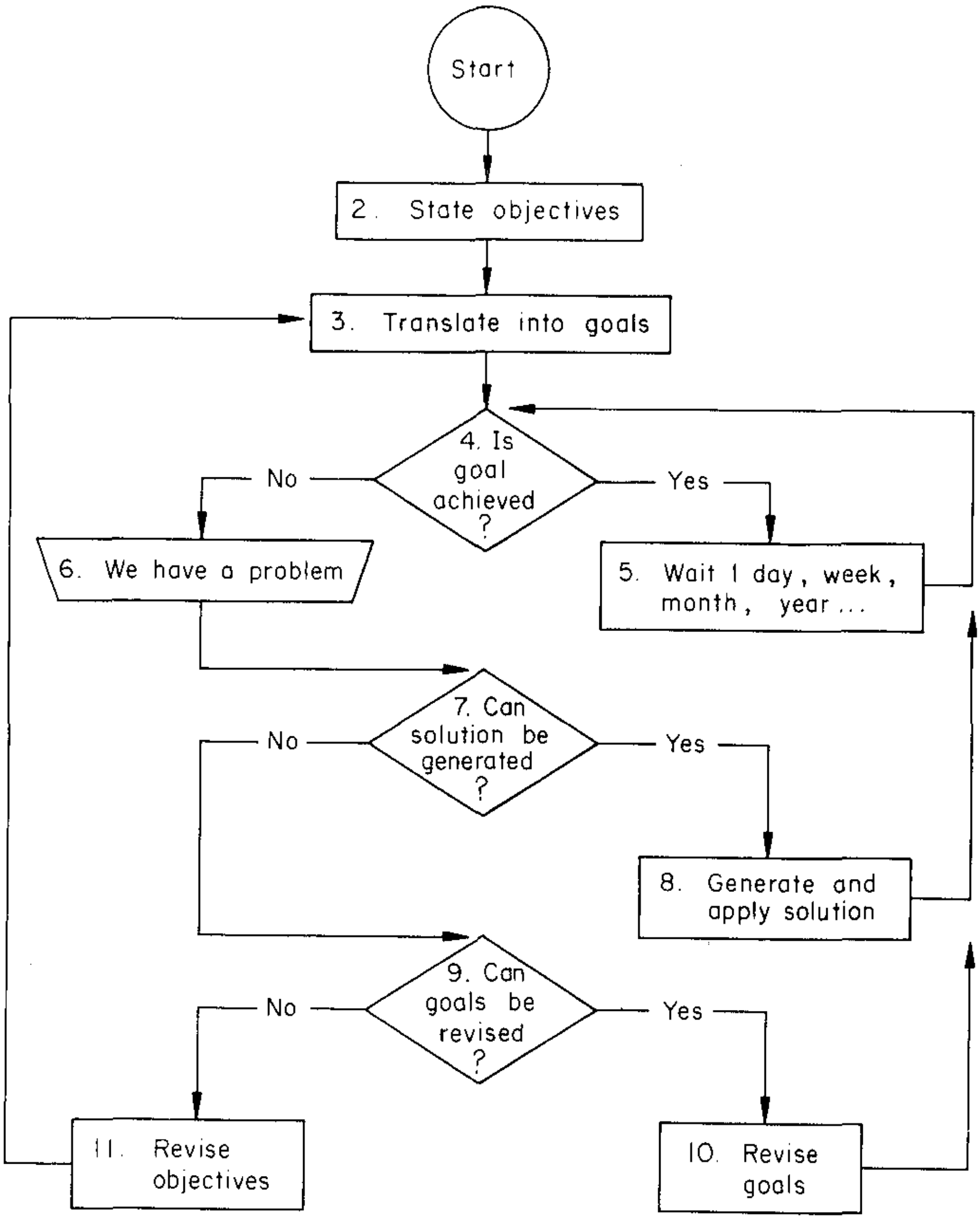


Figure 1. A generalized algorithm for scientific management

Having now broadly defined GMW's terms of reference the question arises as to how the aims might be achieved.

In regard to its primary objective, GMW might

1. synthesize relevant knowledge on the objectives of local grassland utilization, the objectives of monitoring our grassland ecosystems, the monitoring techniques, and how the monitoring results might be interpreted and used;

2. identify topics of research which will improve the appropriateness and efficiency of monitoring techniques, and facilitate the drawing of inference from the results of monitoring;

3. publicize the monitoring techniques and the benefits of using them; and

4. assemble interested workers to initiate momentum and then periodically reconvene to maintain the momentum of the programme.

Turning to the secondary objective, knowledge of how the structure and function of the system relate to how we want to use grassland facilitates our choice of parameters to monitor, our interpretation of the results and our selection of remedial measures. In striving to achieve its primary objective, GMW ought therefore to try to identify those kinds of studies of structure and function which stand to benefit monitoring effectiveness. Several procedures are proposed by which progress in this direction might be made.

5. GMW should identify those parts of management objectives which are difficult to write operationally. For instance, objectives which specify the maintenance of soil are poorly falsifiable because of such issues as our vague knowledge of the rate of soil genesis, the difficulties in measuring it, the poorly corroborated state of soil loss models, and so on. Rigorous search for highly predictive independent variables, and comparison of the outputs of competitive models (eg Universal Soil Loss Equation vs Soil Loss Estimator for Southern Africa) with reality could, for example, revolutionize local environmental legislation. Rather than soil conservation laws being used punitively in retrospect of the loss, the laws might be written prescriptively and thereby guide grassland users to help them minimize soil loss.

6. GMW might identify those results of monitoring which are of uncertain interpretation. By this it is not meant results for which there is a wide confidence interval. Rather the uncertainty concerns ambiguity. For example, does the statistically significant increase of, say, a certain karoo bush in arid grasslands reflect competitive superiority of this plant in the face of heavy grazing, or is it essentially a response to a succession of dry years? We have here a case for research, perhaps using permanent quadrats (Austin 1981), to complement monitoring.

7. Problems with no obvious remedy ought also to be identified. For example, no amount of veld resting or regular burning or whatever might prevent the development of crescent-shaped so-called slip-scars on some hillslopes in the Natal Drakensberg. Study might reveal however a high incidence of these scars on convex hillslopes (with a dispersing soil profile) and it might be concluded that while soil loss can be minimized by excluding domestic livestock, the process is to an extent unavoidable except by unreasonable expenditure of funds.

1.2 Aims of the Workshop

The objectives of the first workshop for GMW were to:

8. develop the objectives of GMW (see section 1.1);

9. pursue the issues 1, 2, 5, 6 and 7 enumerated under section 1.1 above as procedures by which to attain GMW's objectives; and

10. prepare a workshop report which will record GMW's progress under 9 above, and represent a first effort at publicizing appropriate monitoring techniques and the benefits of using them (item 3 in section 1.1).

## 2. OBJECTIVES OF GRASSLAND USERS

The point was previously made (section 1.1) that without objectives, human activity cannot be other than aimless. There is now overwhelming evidence to refute the free-market economists view that the blind forces of supply and demand will always allocate resources in the best interests of present and future generations. In respect of natural resources and posterity this is especially so (Randall 1981). If we are serious in managing our affairs in the interests of present and future human welfare then universal frames of references are needed. The World Conservation Strategy (WCS 1980) is the most ambitious attempt to date to set global goals in the field of environmentalism. The document was political and ethical rather than economic or scientific, and, rather than its proposals be lifted verbatim for application around the world, it was intended to offer a framework by which individual countries (or other organizations) might develop specific policies and strategies tailored for their individual circumstances.

It is appropriate then to summarize the main tenets of WCS and thereafter, with this general philosophy in mind, to consider how and why local grasslands are used.

### 2.1 World Conservation Strategy

The main aim of WCS was to foster sustainable development through the conservation of living resources. Conservation was defined as the management of human use of the biosphere so that it may yield the greatest sustainable benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations.

The objectives of conserving living resources were described as:

1. maintaining essential ecological processes and cycles without which no life can exist on earth; ie the sustained yield of clean water, the generation and maintenance of soil, the disposal of waste products and the recycling of soil nutrients and atmospheric gases;

2. maintain plant and animal communities (or ecosystems) that are essential for the maintenance of the life supporting processes and cycles outlined above;

3. conserving genetic diversity; ie to ensure that no plant and animal species become extinct and to maintain genetic variation both within and between populations of existing species; and

4. ensuring the sustainable utilization of species and ecosystems; ie to utilize natural resources for the benefit of present and future generations of mankind.

Despite its laudable aims and it prestigious achievement in attracting wide interest, WCS must not be thought to be necessarily definitive. It is a document drafted by ecologists (rather than by or with economists) and it presupposes that the world can or indeed should be persuaded to behave altruistically, with the best interests of posterity in mind. The operationality of some of the ideals is questionable, and alternate stances are not only possible but of course practised.

## 2.2 Pastoralism

The most widespread use of local grasslands is for grazing by domestic livestock. Two broad types of pastoralism might be recognized, namely commercial and subsistence.

### 2.2.1 Commercial pastoralism

Broadly, commercial pastoralism might be described as the practice of trying to gain economically from selling animal produce derived from livestock feeding on live herbage. Within this there are several alternate objectives.

#### 2.2.1.1 Maximizing short- or long-term profit

The grazier may elect to maximize immediate return on his investment. However shortsighted this might be regarded, the strategy has the merit of pragmatism. Embodied is the optimization of circumstances as currently perceived. These circumstances are less likely to change in the short-term than in the long-term. Thus the grazier maximizing immediate profit is in an important sense a realist and might reasonably be assured of reward for his efforts. Furthermore, this reward is eminently predictable.

Maximizing profit in the long-term is fancied in conservation circles. It is however an ideal which cannot be strictly implemented. In order to maximize cumulative gains indefinitely into the future it is necessary to be able to predict future circumstances with certainty or at least accuracy. Of course such prediction is not possible. What will beef cost to produce 200 years hence? Will people have the money or even the inclination to buy it? A strictly quantified resource economics of the future does not exist.

However, the spirit of the conservation ethic might be salvaged if the degree of idealism is relaxed. To wit: in terms of WCS (section 2.1) it is intended that greatest sustainable benefit be enjoyed now, but the needs and aspirations of future generations not be prejudiced. Economists for example see some difficulty in how this trade-off might be achieved since conflict might arise between present and future interests (Tisdell 1983). However, conservationists might place emphasis on <u>sustainable</u> benefits and the retained <u>potential</u> to satisfy future needs. A practice might be regarded as sustainable if its effect is not some systematic change leading to a state where output becomes low. (Words are carefully chosen here so as not to discredit the case where initial harvesting of a previously unharvested population might bring about initially a stock reduction - systematic change - but where the final output - optimum sustained yield - is not low). Such change, probably with ultimate equilibration, might well be poorly reversible, in which case the potential to meet future needs would be impaired. The simplistic view, perhaps fostered by the doctrines of classical succession, that mother nature is globally stable has of course long since been disbanded (May 1977). Rather, it is plausible that biotic communities possess multiple alternate stable states. Thus the pastoralist caring for posterity might aim to maximize benefits in the short-term provided no thresholds are crossed into domains out of which there is little or no chance of escape. Entering such domains might be regarded as a foreclosure of options for the future and thus in conflict with the ideals of WCS. This reduces but does not invalidate Tisdell's point. Who knows what domains of attraction will be preferred in the distant future? They need not be those that we now find beneficial. It is these uncertainties which render WCS-type objectives poorly falsifiable. This is so far as long as they are interpreted literally and almost regardless of how we attempt to translate them into goals.

Thus, the conservation philosophy poses some vexing problems. It might be proposed in response that, in view of GMW's secondary objective, the stability and dynamics of local grassland ecosystems are deserving of special study. Such research would be extremely useful in the immediate term. Its relevance to the distant future would however depend on the unknowns of how grasslands will be valued in future and what will be the main factors (which might be very different from those of today) which determine the state of the system.

#### 2.2.1.2 Maximizing absolute or percentage profit

Maximizing percentage profit might be regarded as efficient in terms of the energy input : energy output ratio. This efficiency is however what preoccupies academic thermodynamicists and is of little concern to modern pastoral or agricultural practice. At least in terms of energy (and money might be regarded as symbolic energy) the input : output ratio in agriculture has increased over time. A contemporary view of modern agriculture is that it is an exercise in converting fossil fuel energy into food energy, with some entropic losses. Maximizing absolute rather than percentage profit seems the prevalent objective.

#### 2.2.1.3 Other objectives

There is a miscellany of objectives, other than those already mentioned, that pastoralists might have. A common feature of many of these is a more or less aimless attitude toward managing the veld. Some examples illustrate the point.

First, the grazier might not be profit-motivated. Owning a property with a potentially large productive capacity, the grazier might be moved to earn no more than that which enables a comfortable existence. That the veld might slowly lose its capacity to support and produce livestock might come to the notice of the grazier only when the comfortable existence is threatened.

Second, the landowner's disinterest in realising the productive potential of the land might arise also from capital appreciation of the property. Such continual appreciation, and therefore added security for repeated borrowing, might far exceed the potential earnings from livestock production (Danckwerts and King 1984). Under these circumstances the landowner might quite understandably have little incentive to farm 'properly'. Thus his strategies might be whimsical and he might stock at rates higher (or lower) than those that maximize return on costs.

Third, the grazier's interest might focus on the animals rather than on the veld or the plant-animal system as a whole. It might be his ambition to maintain, say, a pedigreed herd of 300 Bonsmaras, quite regardless of the capacity of the veld to support such a herd in the long term.

At this stage, it is perhaps prudent to caution against the outright condemnation of the above miscellaneous uses of grasslands. To be sure they contravene the ethics of WCS by virtue of their disregard for the vegetation, and hence because of their non-sustainability. This corrected, however, it is only the value judgement of a paranoic capitalist that insists that every farm must always maximize absolute profit. After all, what ecologist works to maximize his take-home pay?

### 2.2.2 Subsistence pastoralism

Subsistence pastoralism might be defined as that form of landuse practised by peasants primarily dependent in their subsistence on their livestock as a source of draught power and manure for crop production, and as producers of milk, meat and other animal products.

Subsistence herdsmen apparently have a hierarchy of values for livestock (Colvin 1983). First are the basic needs satisfied by cattle providing draught power, manure for crop production and the like. Next is the provision of animal products for home use. Third, with these basic needs met, livestock play a role in social considerations and transactions. If there are sufficient stock they might be regarded as a source of cash as in a market economy. The positioning of these several values in the hierarchy is variable.

## 2.3 Nature Conservation

Discussion of the objectives of nature conservation seems to be bedevilled by two issues. First, there is a wide range of categories of land which come under consideration (eg national parks, game and nature reserves, wilderness areas, mountain catchments, state plantations, private nature reserves, privately owned rural land, communally owned subsistence land, etc). Second, there is a wide range of activities varying in emphasis on the protection, use and control of natural resources, which falls within the broad definition of nature conservation. The possible combinations have been admirably handled by Miller (1983).

At the risk of oversimplifying this desirable complexity of nature conservation, it is necessary to try to identify central issues to serve as a basis for discussion of monitoring. Suppose for the moment that attention is focused on the kinds of areas formally designated for nature conservation in the South African grassland biome. The main objectives might be summarized as to maintain samples of dynamic communities of the native biota (WCS 1980) and to use the areas in which these communities occur as ecological baselines (Sinclair 1983).

## 2.4 Water Production

Portions of the South African grassland biome (eg Natal Drakensberg) have been set aside as wilderness areas and nature reserves in which the sustained yield of clean water is a joint primary objective together with those stated for nature conservation (Section 2.3) and to retain an essentially wild character to the environment.

# 3. OBJECTIVES OF MONITORING

The general reason for monitoring, namely to ascertain the degree to which the objectives of management are achieved, has already been considered (section 1.1). The aim of this section, then, is to consider specifically why each of the various categories of grassland user would wish to monitor the area of grassland of concern.

## 3.1 Individual Grassland User

Graziers, both commercial and subsistence, might be regarded as individuals potentially interested in the state of the grassland ecosystems they as individuals use. Of course not every grazier does monitor (except in a trivial sense or in a superficial way) but the approach must here be taken of the so-called rational individual (ie where the decision process is coherent and logically consistent).

It is suggested that there might be two main kinds of use to which the individual grazier would put information on the state of his plant-animal system.

First, the grazier might want to be guided on decisions, which have implications mostly in the medium- and long-term. For example, if he knows the current state of his veld he might be aided in deciding at what rate to stock and what systems of grazing and resting management to apply. Similarly, a knowledge of both the state of the veld and the amount of rain over the last year (assuming an area where precipitation is limiting on livestock production) might aid in deciding whether to buy on or sell off stock.

Second, there are issues with short-term implications. An example is whether, on an individual grazing area or paddock, grazing or resting is to be initiated, continued or terminated.

## 3.2 Government Agencies

As with individual graziers, government agencies must be treated normatively. What is it logically consistent for them to monitor given the aforegoing objectives of grassland users?

First, there would be a close interest in the state of grazing lands as it applies strictly to pastoral use in the immediate- and long-term. This applies equally in the case of both commercial and subsistence grazing.

Being informed through regional monitoring, a government might respond to favourable or unfavourable changes by policy decisions involving taxations, incentives, disincentives, price structures or legislation to curtail abuses, conserve resources, encourage use of previously unexploited ones, and so on. Regional monitoring would aid in detecting the effects of such policy changes, and might be used to highlight issues deserving study or requiring remedy by available techniques.

Second, having designated areas for nature conservation and as mountain catchment, government, through the respective local controlling agencies, is obligated to assess routinely whether the objectives for these areas are being achieved, or whether public money is not being used for its ostensible purpose.

Third, government agencies might have yet wider obligations in monitoring. Suppose that a national policy incorporates the WCS ethic of sustainability for civilization and concern for the welfare of posterity. A government would then have to monitor biospheric conditions and processes if it were not to lay itself open to accusations of non-management in the affairs of state.

## 4. MONITORING TECHNIQUES

Having identified the likely reasons for which grassland systems might be monitored, it is appropriate to consider suitable techniques of field measurement. The choice of technique is faced with two kinds of problem. First is what to measure, and second is how to measure. Both issues are constrained by the need for the data to be informative and tractable in analysis and interpretation.

If a general guide is to be given as to which of the infinite variety of parameters of a grassland ecosystem are to be monitored, then it might be said that attention should be focused on the objective function, and/or those independent variables which vary sufficiently to materially affect it. The objective function is that factor, determined by our statements of management objectives and goals, which we aim to maximize, minimize or, in general, optimize. Usually, it is not possible to optimize more than one thing at a time, although the objective function might, as in 'environmental quality' or 'veld condition', be a joint expression of many things. Sometimes the objective function is masked by variables that are incidental to the main focus of interest. For example, data on the absolute profits enjoyed by commercial graziers do not reflect simply the condition of the grazing lands but are coloured by economics as well. The environmental conservationist would thus wish to monitor those of the independent variables which environmentally (as opposed to economically) determine the objective function. Such independent variables are not necessarily only those factors which can be manipulated managerially. For example, elements of community-composition influenced by invasion by alien species (section 4.2), or by biogeographic processes might generally be beyond the control of any individual grassland manager.

Having chosen the parameters the techniques subsequently selected ought to qualify on the basis of superior efficiency (ie high precision per unit cost).

The sequence of discussion hereafter is rationalized as follows. The subject matter is essentially that of the study of communities and ecosystems. It is appropriate then that most attention be devoted to monitoring at the so-called higher levels of organization. Nevertheless, environmental conservationists do find it necessary to consider individual species of special importance, and certain properties and processes of ecosystems which are of special interest. Some attention is therefore directed at these special issues.

## 4.1 Community Change

There are several lines of argument which lead to measurement of the (relative) abundances of species represented in a community as useful indicators of the state of a community. These several arguments will be presented. They will be followed up firstly by proposals regarding field procedure, and then suggestions on how the data might be analysed and interpreted.

### 4.1.1 The parameters

It is convenient to start discussion with the relatively concrete issues of pastoralism and then to move to the more abstract problems of nature conservation. Despite separation of the argument under two headings the subject matter of each complements the other.

#### 4.1.1.1 Pastoralism

Suppose for the moment that attention is focused on the graziers who are profit-motivated, and that consideration of the problems of the other kinds of graziers be postponed. Suppose further that the objective function of the profit-motivated grazier is short- or long-term absolute profit, and that we are concerned for the moment with decisions of medium- to long-term consequence. In the present case the profit might be conceived to comprise two things: the amount of animal production and the cost of producing it. For the moment it is appropriate to direct attention at the animal production, and this will, in the following discussion, be regarded as the objective function.

What, then, determines animal production? There are of course a number of factors (Bransby 1981), but those of particular relevance are the quality and quantity of herbage.

At any given site, herbage quality would appear to be affected in two important ways. First, grasses become more fibrous and less nutritious as they mature. In South Africa the words 'sour' and 'sweet' have been coined to denote respectively rapid and slow rates or large and small degrees of such decrease in herbage quality. Second, grasses vary not only in their nutritional quality but also in their palatability and capacity to tolerate grazing. The quality of herbage at a given site is thus a complex function of time of year, immediate past defoliation regime, and the proportional species composition of the veld as influenced by abiotic and biotic factors including defoliation history (Mentis 1982).

The quantity of herbage at a given site varies largely as a function of time of year, recent rainfall and defoliation, and also in relation to the abundance values of the plant species (Innes 1978, Tainton, Foran and Booysen 1978, Mentis 1982).

It is thus the community-composition of the veld which is considered as indicative of its capacity in the medium- to long-term to sustain animal production. Such an evaluation is deliberately in disregard of the immediate capacity of the veld to support livestock (viz it might only recently have been grazed or burnt and there might temporarily be insufficient forage for animals).

This parameter, community-composition, now identified as of interest, is multivariate since at any given site abundance values will be recorded for each of a number of species. Further, since a number of sites will likely be involved in considering the state of any given grazing area, we will typically be dealing with a two-way, species-by-samples matrix:

| | $SM_1$ | $SM_2$ | $SM_3$ ... | $SM_j$ | ... $SM_c$ |
|---|---|---|---|---|---|
| $SP_1$ | | | | . | |
| $SP_2$ | | | | . | |
| $SP_3$ | | | | . | |
| . | | | | . | |
| . | | | | . | |
| . | | | | . | |
| $SP_i$ | . . . . . . | . . . . . . | . . . . . . | $a_{ij}$ | |
| . | | | | | |
| . | | | | | |
| . | | | | | |
| $SP_r$ | | | | | |

where there are r species and c samples (or stands or sites), and $a_{ij}$ is the abundance value of species i in sample j.

4.1.1.2 Nature conservation

A problem mentioned at the outset (section 1.1) was that objectives are often rather general and imprecise, and defy easy quanitification. WCS asserts, for instance, that genetic diversity ought to be conserved (section 2.1). Yet how is the genetic diversity of a community measured? How would the measurements be interpreted? The previously proposed way around this problem of objectives being non-operational is to paraphrase them and yet faithfully retain their intent (section 1.1). The particular translation (and summary) of the objectives of WCS (section 2.1) and nature conservation (section 2.3) now suggested is to maintain biotic diversity. At first sight this might seem simplistic and narrow, but by defining the components of this statement of purpose it will be argued that it goes a long way towards meeting the intentions of its more long-winded predecessors.

First, why is maintenance rather than some other maxim like maximizing, increasing, optimizing or creating the natural diversity not chosen? All these alternatives suffer the weaknesses that (1) the utopian condition of a maximal, increased, optimal or natural diversity (however diversity be defined - but see below) is not known, and (2) there is therefore no automatic yardstick by which to assess goal-attainment. Despite the difficulties this imposes, some standard by which to judge has to be decided. It seems that maintaining present diversity (among the alternatives mentioned) minimizes the imposition of sheer arbitrariness, whim or artificiality to the park. Inevitably there might be exceptions, for example, sites that have been greatly disturbed, denuded of vegetation or eroded to bedrock. Here increasing diversity is not without merit, and we may wish to modify our summary objective to something like maintaining or, in special cases of heavily disturbed communities, increasing biotic diversity.

Second, how do we define biotic diversity? A cluster of concepts is involved and each of the various meanings must be considered in relation to WCS-type objectives and the demands of operationality.

1. Intraspecific genetic diversity. Individuals of a population may be genetically variable, similar or identical depending on such factors as whether reproduction is vegetative or sexual, and, in case of the latter, the degrees of in- and out-breeding. While it can hardly be argued that this type of intraspecific variation is of no consequence, it is not practicable to monitor, and - special cases aside - measurement is possibly unwarranted. Changes to intraspecific genetic diversity which are critical in terms of WCS-type objectives are likely to accompany abnormal changes (especially decreases) in population sizes. Thus, monitoring the numbers (or indices of abundance) of individuals in populations might be reasoned to be a convenient warning system.

2. Alpha-diversity. Biotic communities vary in terms of their constituent species. Traditionally there are three types of alpha- ($\alpha$-) diversity (Peet 1974). First there is species richness ($\alpha_r$) which is the number of species occurring in the community of concern. Second is equitability ($\alpha_e$) which measures the evenness of the distribution of numerical importance among species of a community. Third is the combination of richness and equitability that expresses so-called heterogeneity ($\alpha_h$). Quite explicitly, $\alpha_r$ is relevant to WCS-type objectives since loss of species or extinction is to be prevented. Estimating this parameter alone is however insensitive since changes in $\alpha_e$, without change in $\alpha_r$, can conceivably have far-reaching effects. For instance a change in the proportion of palatable and unpalatable plants might influence the size of the herbivore populations maintained, the rate at which fuel to carry fire accumulates, the frequency and intensity of fires, the species-composition and structure of the vegetation, and so on. It follows that, in the ideal, it is desirable to monitor $\alpha_h$, preferably expressed so that richness and equitability are not confounded. This would satisfy the need, discussed under intraspecific genetic diversity, to detect sustained directional change in the sizes of populations. In a wider sense, $\alpha_h$ might be regarded to, among other things, index genetic diversity since if either richness or equitability change then the genetic material represented in the community must almost inevitably change too.

3. Structural community diversity. Biotic diversity might be regarded to have a structural dimension in the sense of the growth forms, sizes, densities, layerings, etc of the organisms present. Since these characteristics are species-specific it might be expected that $\alpha_h$ would be diagnostic of structural diversity and uniquely define or index, say, mid-seral shrubs, or species typical of arid sites where the climate is unsuitable for large-growing forest trees. It remains a moot point however just how community structure might vary

(eg a protea savanna with mostly mature trees vs the 'same' savanna with mostly immature trees prevented by periodic fire and browsing from maturing) independently of $\alpha_h$.

4. <u>Beta diversity</u>. The rate of turnover of species along an environmental gradient is defined as beta- ($\beta$-) diversity. The concept is particularly appropriate to and best understood in terms of the model of the so-called continuum school. According to this viewpoint, biotic communities are coincidences of species whose abundances change gradually or abruptly in time and space in sympathy with gradual or sudden changes in environmental factors. Species are distributed along an environmental gradient in the form of scattered response-curves that are more or less bell-shaped (Gaussian) (Figure 2). One average species-turnover is defined as the average distance along the chosen environmental axis within which a species appears, rises to its peak abundance, declines and disappears. In these terms, then, the change in, say, the proportion of palatable and unpalatable grasses would involve less than one species-turnover and would represent a lower $\beta$-diversity than the change from grassland to forest where the two extreme ends of the gradient have no species in common. In this way $\beta$-diversity might be regarded as a measure of variety within communities.

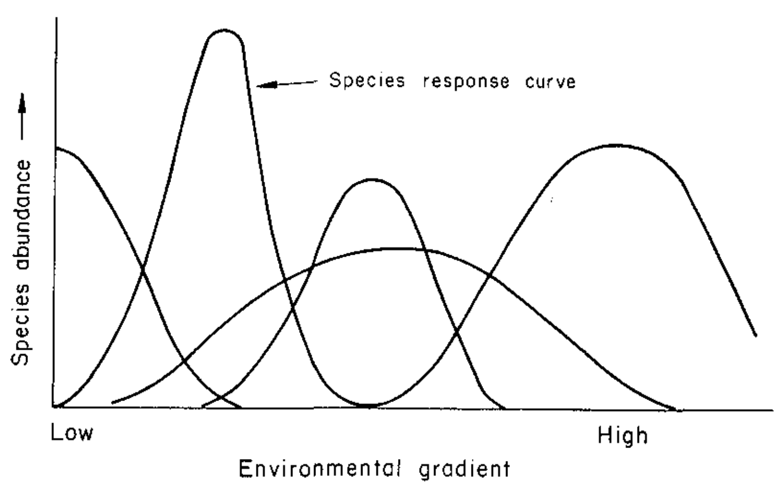


Figure 2. The continuum model of the organization of biotic communities with more or less bell-shaped species response curves scattered along environmental gradients.

5. <u>Gamma-diversity</u>. The composite $\alpha$- and $\beta$-diversity of an entire landscape or ecosystem is called gamma- ($\gamma$-) diversity.

While there is some stability to the cluster-concept of biotic diversity and its various components, any one of the types of diversity is of course amenable to a wide range of operational definitions. In other words, there is no single correct method by which to estimate, say, $\beta$-diversity, and there is no universal unit of diversity. The consequence - not an unfortunate one - is that the worker must choose and design his methods and units to suit his needs.

A third point arising from the aforegoing summary objective is that although the entire biota is explicitly of concern, it is not practicable to monitor more than a small fraction of it. This applies both in a geographic and a taxonomic sense. With respect to space, formal sampling designs are appropriate and these are considered below (section 4.1.2). In regard to the taxonomic issue, in the absence of an already identified group of special interest there are several merits to choosing vegetation. First, being at the base of the trophic pyramid the autotrophs (usually mostly angiosperms) might be thought to strongly affect (but not uniquely determine) the higher trophic levels. Second, higher plants are, compared with groups like insects, well known taxonomically. Third, obtaining representative samples of the vegetation is a realistic task for which there are relatively well-explored methods (Greig-Smith 1983).

Fourth, there are parts of the WCS-type objectives which are seemingly not incorporated in the aforegoing summary objective. For instance, there is no explicit mention of the so-called essential ecological processes. Such omission does not imply disregard for these important issues. But the plethora of such parameters and the scarcity of manpower demands resort to general techniques which provide moderate resolution over the gamut of issues rather than extreme resolution for just a few of them. Further, it is argued that monitoring biotic diversity offers just such a general approach. It seems that the particular circumstances under which soil loss is high, or primary production is low, or nutrients fail to recycle, or certain compounds accumulate would occur with characteristic community-composition. For example, under heavy grazing an area might be almost denuded, or otherwise be vegetated only by unpalatable plants or species tolerant of intense defoliation and trampling. The outcome of heavy grazing in any given area is likely to be broadly predictable in terms of community composition, erosion hazard, nutrient cycling, primary production, etc. Further, it is hardly conceivable that a shift in climate, an increase in the atmospheric $CO_2$ concentration, a decrease in the frequency of fire, or some such similar environmental change would not affect the relative competitiveness of individual species and hence be reflected in community-composition or $\alpha_h$. Indeed, resort to community-composition as an index of environmental quality is not novel (Whittaker 1978). There has long been regarded to exist a duality between species and environmental conditions such that specific positions along environmental gradients are characterized by the presence and relative abundance of particular species, and the presence and relative abundance of particular species are diagnostic of specific positions along environmental gradients. Naturally the conception of this has to be abstract (rather than be expressable in geometric terms like Figure 2) since there are potentially many species and an infinity of environmental gradients so that we are concerned with a space of multiple dimensions.

The multivariate approach implied by the above thus makes the tacit assumptions that if our world, country, national park, or whatever system does deteriorate in the sense of WCS this will be reflected by a change in $\alpha_h$, that if we keep $\alpha_h$ as it is now our system will not be any worse off, and that some changes to $\alpha_h$ are inevitable, might even be engineered and might be beneficial. It is argued that this approach, the interdependence of life and its environment, is the very essence of our ecology.

Fifth, there is some risk that <u>maintaining biotic diversity</u> might be construed as a wish to hold all parts of a system in the present state. But this is not necessarily so. Certainly a grazier, say, might well aim to keep $\alpha_h$ within fairly narrow limits, close to what maximizes what he wants out of the veld, and representing a small $\beta$-diversity. Having achieved the optimal $\alpha_h$ at any particular site, the grazier might be reluctant to see that state altered. In contrast, in a national park, the aim of management might well be to maintain present biotic diversity in the sense of the average for the system as a whole. On individual sites cyclical changes (eg in response to periodic fire, or as part of other senescence-regeneration cycles) or disturbances induced by random factors (eg flood, landslide, etc) are inevitable and part of the biotic diversity that it is wished to maintain.

Having established the general applicability of the species-by-samples matrix in monitoring in the context of pastoralism and nature conservation, it is appropriate at this stage to point out that our two-way matrices may take the form of environmental factors-by-sites:

$$\begin{array}{lccccc}
 & SM_1 & SM_2 & SM_3 \ldots & SM_j & \ldots SM_c \\
EF_1 & & & & \cdot & \\
EF_2 & & & & \cdot & \\
EF_3 & & & & \cdot & \\
\vdots & & & & \vdots & \\
EF_i & \cdots & \cdots & \cdots & b_{ij} & \\
\vdots & & & & & \\
EF_r & & & & &
\end{array}$$

where there are r environmental factors each measured at c sites, and $b_{ij}$ is the value obtained for environmental factor i in sample j.

There are of course instances where environmental variables other than species abundance values are of prime interest. For example, if monitoring is to give the grazier guidance on the day-to-day decisions of immediate consequence then it seems that additional environmental parameters of concern would be recent history of grazing, resting and burning, time of year, recent rainfall, the amount and quality of accumulated herbage and the vigour of the important plant species (palatable and/or unpalatable). As another example, and at a very gross level of community-changes concerning the extent of virgin-veld, cultivated land, afforested land, urban and industrial zones, etc.

#### 4.1.2 Field techniques

In our enthusiasm there is at the outset a temptation to simply employ our favourite or the traditional field apparatus, record our measurements, subject them to the standard analyses and tests of parametric or non-parametric statistics, accept the result and leave it at that. Yet if monitoring is to be the routine exercise that it is defined to be then we may be well rewarded in the long run to be thorough in determining what technique we are going to use, what sampling design to adopt, what the efficiency is (precision per unit of sampling time), how much sampling needs to be done, what confidence may be attached to our results, and other interrelated issues. Thus it is that the aim here is not to try to provide a ready-made recipe for immediate use in monitoring. Rather the purpose is to propose means of ascertaining answers to the above-listed kinds of issues so that the individual worker can determine for his own particular conditions what the appropriate sampling procedure is. The way in which this is done is to base discussion on a skeleton procedure - for which there was consensus at the workshop - and to consider how the worker might resolve the various details. This skeleton is provided in Table 1. The order in which the various points arising are discussed does not follow the enumeration in Table 1. Rather it is intended to indicate the chronological sequence that the worker might follow.

First is the problem of what apparatus to use. It will be recalled that species abundance values are required. Consideration of other kinds of data is postponed. Among point-based methods, quadrats and rating techniques, the first mentioned (and especially the wheel- and step-point) are relatively efficient (Everson pers comm).

Table 1. Field procedure for observing the proportional herb species composition of veld.

1. Locate sample sites judgmentally or randomly in study area.

2. At each site demarcate L x B m sample area.

3. On each sample area systematically locate N point-positions adopting the step-point or wheel-point method of survey.

4. At each point position identify and record the species of the nearest herb provided it is within M cm of the point.

A second issue concerns the spacing of the points. Strictly in sampling theory the points should be independent of one another. However, we are advised that it is satisfactory for the successive points to be positioned systematically provided the vegetation does not have a periodic pattern and provided the points are widely spaced. For example, 3 m was proposed sufficient in arid grassveld and karoo since this would provide relative independence of successive points with respect to other than a periodic pattern in the vegetation (Tidmarsh and Havenga 1955). In view of plants being rather sparsely distributed in this arid grassland/karoo it seems likely that in the more densely vegetated humid grassvelds a spacing of somewhat less than 3 m will be satisfactory. The Levy bridge (up to 2 m long with 10 pins) would seem to exhibit considerable dependence between successive points which often strike the same grass tuft even in humid grassveld. Longer bridges with more widely spaced pins are of course unwieldy.

The third dilemma relates to whether the original concept of basal cover should be adopted, or a point-centred method used. The weaknesses of the orginally proposed procedure of Tidmarsh and Havenga (1955) concern the biased and non-biased errors involved (Mentis 1982). The interpretation of a strike is subject to between and within worker variation, and unless these sources of error are catered for in the sampling design (and this would be expensive) the confidence that can be placed in the results must remain uncertain. Further, because of the usually low basal cover and the binomial distribution of the data a large number of point-observations is required for dependable data. It might seem that discarding the grass-lander's cherished parameter of basal cover is a particularly heinous and heretical omission, and a criticism might be that if the density of plants (indexed by basal cover) changes, then the procedure in Table 1 would not detect this. However, the use of a maximum radius in combination with the 'nearest plant method' is intended to obviate or at least minimize this apparent omission. It seems unlikely that merely the density of plants would change (in response to some environmental impact) without there being a simultaneous shift in proportional plant species composition. The possibility of such an impact affecting all species equally is hardly conceivable. Thus it is that community-composition is being argued to be diagnostic of environmental conditions, but an appropriately chosen maximum radius of M cm might improve sensitivity. Indeed such a maximum is necessary otherwise it could arise that on one sample area vegetated by only one plant, that plant would be the nearest for each of the N point-observations - hardly an informative circumstance. It is proposed that M might be to the order of 15 to 30 cm, but each worker might try a range of values and then select one that gives a positive record (a species present within M cm) for most (say 90 to 95%) of his point-observations for most of the vegetation with which he is dealing. If M is decreased to very small values there will be a tendency for increasing numbers of 'zero' records at each point-observation and the inefficiency of the original method of recording basal cover (very large number of points requiring to be observed) will be approached. If M is large then the point-centred method is insensitive to changes in the density of the vegetation. Thus some intermediate value of M is needed. Of course this approach to plant density is in the present context comparable to the phytosociologist's traditional measure 'frequency'. Here it is not only plant density which influences the value obtained. Plant size and pattern of distribution also contribute. The approach is therefore less accurate than direct estimates of plant density, but the latter are costly.

Problem number four to settle is the size and shape of the sample area. Grassland ecologists in South Africa have for several years now used a plot 30 x 30 m (approximately 0,1 ha). What would happen if the plot was a different shape, or was bigger or smaller? Let it be emphasized here that our purpose is to record the vegetation as an expression of the biotic and abiotic conditions of the site. Vegetation-environment relationships will be confused if the sample area is very heterogeneous. For example if a rectangular plot (eg narrow and very long) or a large plot were used much floral and environmental heterogeneity would be included, and the problems of distributing point-observations representatively increase (regardless of the intentions of systematic spacing or whatever, for the worker easily becomes disorientated). The smaller the plot the greater is the chance of including only part of the vegetation mosaic (eg the vicinity of a termiterium) when a representation of it at some grosser level is adequate. Having made these general points it has to be admitted that we have not defined criteria by which to strictly optimize plot-size, perhaps because mosaics and pattern in South African grassveld have been little studied. Perhaps studies of association among common species (eg Aristida junciformis, Diheteropogon filifolius, Eragrostis spp, Themeda triandra and Tristachya leucothrix) under a variety of treatments (eg burning, continuous and rotational grazing at various stocking rates and mowing) might show up the scale at which changes in the veld occur (eg simply individual tufts, or somewhat larger patches) and hence guide us in optimizing plot-size. In the absence of such guidance our choice of shape and size of plot might however be to facilitate the exact repetition of field procedures in baseline and follow-up surveys to ensure the comparability of successive sets of data.

The fifth point concerns optimizing the number of point-observations per sample area. Since we are dealing with multivariate data and since common means of analyzing these involve ordination and classification, the appropriate way of tackling the problem is to relate so-called replicate similarity to sampling intensity. Numerous measures of sample similarity are available (Goodall 1978), but in the case of proportional plant species abundance 'percentage similarity' or 'Euclidean distance' are among the most popular indices (Gauch 1982). A replicate in the present context is a set of N point-observations on a given sample area. If the similarity between two replicates (sets of N points from the same sample area) is calculated then only rarely will the similarity value of 1,00 (equivalent to exact indentity of samples) result. Usually a value of something less than one will be obtained, and this because of sampling error. As is to be expected, the greater N is, the less is the sampling error likely to be and the greater the similarity between replicate sets of observations. A means of determining this dependence of replicate similarity on sampling intensity is proposed in Table 2. It might be surmised that the results of a few such exercises executed in local grasslands will be of sufficient guidance for subsequent workers to adopt as a matter of routine.

Sixth, how many sample areas are required? A random, or stratified random, or some other distribution of sample areas involving a random element, is desirable to achieve a representative sampling of the study area. Judgmental sampling (Barnett 1974) is widely held to achieve this representativeness, if the observer is experienced and can locate sample sites on typical veld. It would be useful to formally test the capability of experienced and inexperienced persons in attaining representativeness. This is important because many graziers have never enjoyed the delights of sampling designs and we want to know to what extent we can depend on their judgmental sampling. It would seem that if paddocks in rotational grazing systems are homogeneous, as they are supposed to be, then one judgmentally located sample area per paddock is quite enough. Certainly in the absence

Table 2. Procedure for establishing the dependence of replicate similarity on sampling intensity.

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1. Locate 3 to 4 30 x 30 m plots so as to achieve representativeness of veld of concern with respect to species heterogeneity.

2. On plot 1 systematically locate, ca 3 m apart, 100 points using wheel-point apparatus. Apply 'nearest plant method' with maximum radius M cm as described for Table 1, numbering in sequence the observation at each successive point.

3. Repeat step 2 twenty times, maintaining the sequence of point-observations up to 2 000.

4. Enter data into computer.

5. Use random number generator to select 30 sets of N points. Repeat for N=10, 20, 30 ... 200. For each 30 sets of N points calculate the sample similarity for each set with every other set (to produce a 30 x 30 similarity matrix). For each such similarity matrix calculate mean (± standard error of mean) sample similarity.

6. Using the data calculated from all similarity matrices plot results as in Figure 3.

7. Repeat steps 2 to 6 on remaining plots (2, 3 and 4). From the four figures (cf Figure 3) choose the highest value for N (cf $N_o$ in Figure 3) beyond which replicate similarity is hardly improved.

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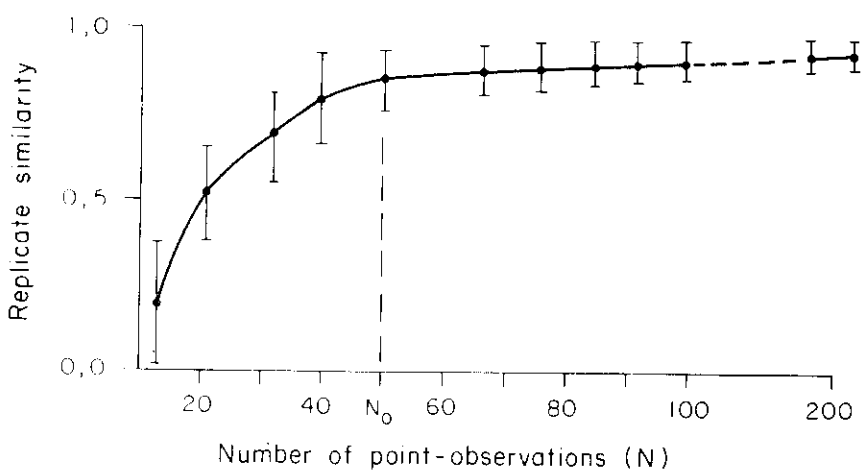


Figure 3. A plot of mean (± standard error of mean) replicate similarity on sampling intensity.

of such homegeneity and in the absence of tests of the representativeness attained by judgmental sampling, doubts exist and there is limited utility to data for which variance cannot be calculated. Formal sampling designs thus come to the fore and they are particularly appropriate in the case of nature conservation where very often at the outset no homogeneous areas (equivalent to the paddocks in rotationally grazed pastures) have been identified.

Our decision about the appropriate number of sample areas is tied up with how heterogeneous our study area is, and this the worker will probably have to determine for himself. Ideally this exercise should result in an objective stratification of the study area, and, depending on the variability within strata, how intensively each might be sampled to yield data of predetermined precision. A procedure for doing this is proposed in Table 3.

Table 3. Proposed procedure by which to stratify the vegetation of a study area as a preliminary to monitoring.

1. Identify main abiotic factors to which vegetation seems to respond (eg slope, aspect, geological substrate, elevation).

2. Use these identified factors to impose a simple subjective stratification of the study area.

3. Delineate the strata so identified on a map and estimate their extent.

4. Apply a stratified random sampling design (Barnett 1974) to allocate K sample sites in proportion to the extent of each stratum.

5. Observe $N_o$ (see Table 2) point-positions on each of the K sample sites.

6. Ordinate and classify (eg using DECORANA and TWINSPAN (Gauch 1982)) the stands. Stratify the vegetation of the study area hierarchically to give say three levels of class each comprising successively narrower ranges of $\beta$-diversity (say, $>3$ species turnovers, 3 to 1 species turnovers, $<1$ species turnover).

7. Pick one 'typical' class from each of the three levels in the hierarchy.

8. Take one such 'typical' unit and randomly locate say, 100 sample sites within that unit. At each site observe $N_o$ (see Table 2) point-positions.

9. Enter data into computer.

10. Use random number generator to select 30 sets of J sample sites. Repeat for J=10, 20, 30, 40 ... (perhaps to 50 will do).

11. For each 30 sets of J samples drawn ordinate (using DECORANA (Hill 1979)).

12. For the main axis extracted by each ordination (Figure 4) plot the frequency distribution of samples along the axis (Figure 5). Among the 30 sets of J samples compare, using $\chi^2$ goodness-of-fit, each frequency distribution with every other to give a 30 x 30 matrix of $\chi^2$ values.

13. J (equivalent to the number of sample areas to be examined in a stratum to yield a satisfactory representation of its condition) is sufficient when no more than, say, 5% (the normally chosen level of biological significance) of the $\chi^2$-values in the respective 30 x 30 matrix are signficant at the 5% level).

14. The analysis can be extended to secondary, tertiary, etc ordination axes if desired.

15. Repeating the analysis (steps 8 to 14) for each of typical categories picked in step 7 will provide a basis for deciding on how the optimal J changes with the β-diversity (variability within) of a stratum.

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Seventh, questions arise about the design and execution of baseline and follow-up surveys. How frequently should surveys be conducted? Should baseline plots be marked permanently and revisited every survey, or should fresh sample sites be drawn on each occasion?

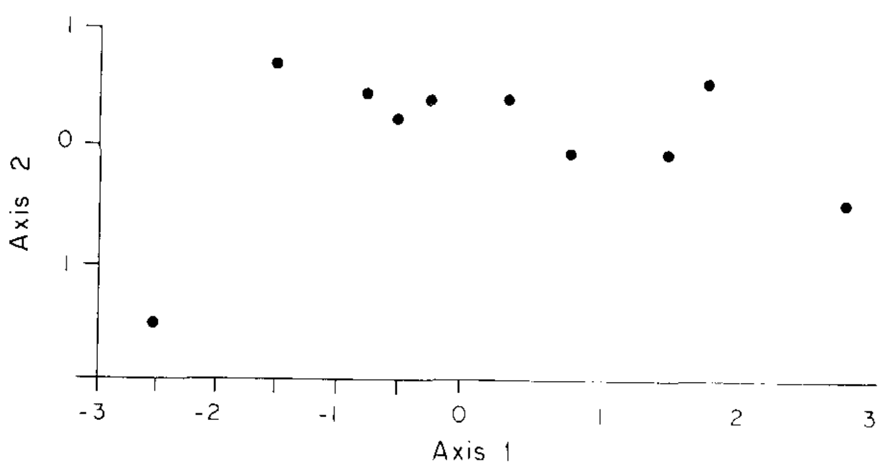


Figure 4. Hypothetical ordination diagram showing points (sample stands of vegetation) along first two axes graduated in standard deviations (4SD=1 species turnover (Gauch 1982)).

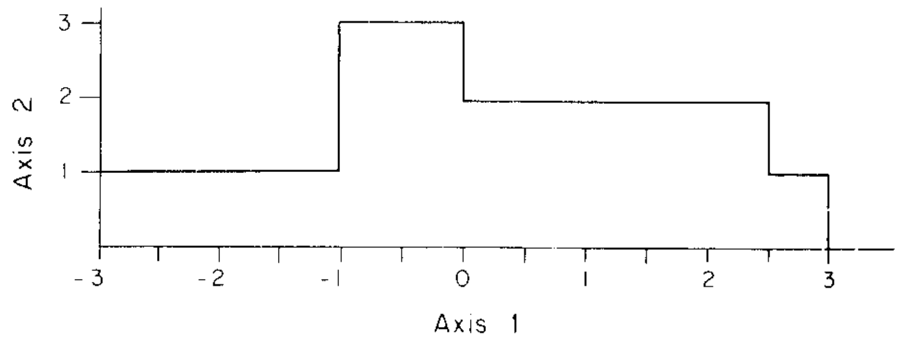


Figure 5. A frequency distribution of sample stands of vegetation along the first ordination axis of Figure 4.

The frequency of survey ought to be dictated on the basis of such considerations as the likelihood of floral change, and the degree of change considered significant to the manager. For the established system there is surely no need to survey more frequently than once in two to four years provided the system of management is not altered. When monitoring in grasslands with potentially a high proportion of annuals it might be useful for records at each point-observation to be made, kept and analyzed separately for annuals and perennials.

Where persons (eg graziers) untrained in sampling theory are monitoring veld they are likely in the first instance to locate sample sites judgmentally. Detecting floral change in time will be facilitated by marking permanently the initially surveyed sites. There might then be confidence about the reality of change on these marked sites. There must remain, however, uncertainty in how representative events on the sites are of the area in general. On the other hand, if sample sites are located in strict adherence to some random sampling design to obtain representativeness, then permanent marking of sites and return to them in follow-up surveys is unnecessary. In this case the only justification for permanent marking can be that it is less expensive than drawing a fresh set of samples - a dubious proposition. Even then, the necessary knowledge of sampling variation is here proposed (Table 3) to be constructed empirically on the basis of randomly selected plots. The use of permanently marked plots will provide an estimated population mean for follow-up surveys with confidence limits different to those arising by repeated random sampling. It is emphasized that all this is said in the context of monitoring as it is defined in this document. Obviously there remains a role for permanently marked plots to investigate community-responses to particular experimental treatments (Section 4.1.3.2, Austin 1981).

Eighth point, the aforegoing discussion is focused on herbs. Other groups (eg trees and shrubs) might also be considered using the same principles but perhaps other field techniques.

Monitoring change on a regional scale - as an agency concerned with commercial or subsistence pastoralism might wish to do - brings to the fore the need for efficient sampling design and possibly the impracticability of using permanently marked sites. Some form of cluster sampling is likely to be appropriate (Barnett 1974). And a freshly drawn set of samples for each follow-up survey obviates the entropic losses to which 'permanent' field markers, 'meticulous' records and 'unforgetful' memories are subject.

Having considered the main issues in collecting data for our species-by-samples matrices, attention might turn to other information on communities.

Regional surveys, conducted by a governmental agency, might employ remote sensing such as by standard aerial photography or satellite imagery. These approaches would seem most appropriate for detecting gross changes such as the loss of native grassland to planted pasture, crop cultivation, afforestation or urban or industrial area, or the conversion of grassland to karoo. While the local utility of these forms of remote sensing has not been investigated thoroughly it is unlikely that the techniques are sensitive to changes in the quality (abundance values of plant species) of the veld involving less than one species turnover. In other words, 25 or 50% of say, Themeda triandra in 'good' veld might be lost without the remote sensing detecting the change. Thus, should a governmental agency interest itself in shifts in the state of veld of this scale, then the aforementioned procedure for obtaining the species-by-samples matrix applies.

Photography has also been used at a detailed level, to record temporal change at marked sites periodically visited. This means of documentation has the merit of possibly illustrating to laymen changes in vegetation that have been detected by such procedures as those discussed above. However, unless the photography is preceded by a statement of null hypothesis, and careful statistical design, there is a risk that 'evidence' will be used in an unscientific manner. For example, the sites might be located judgmentally and not in accordance with any formal sampling design. How representative then are the photographs of the target population? Further, selection may occur among the store of photographs so as to inductively confirm that the target population is changing in the way proposed. Also, we have been cautioned about possibly misleading visual impacts when eye-balling vegetation (Greig-Smith 1983). This applies no less to photographs of vegetation than it does to real vegetation. At this stage it might seem unfair to single out 'phytophotography' for particular attack when almost every other monitoring procedure is as vulnerable to abuse. It is apparently necessary, however, to take justificationism to task for there are continued attempts to validate theses by citing supporting evidence. By these means it is of course possible to validate any argument. One must simply be selective enough with the evidence. It needs to be emphasized that no environmental study should be entertained without serious consideration of the points discussed by Green (1979: 1-64).

Turning lastly to the detailed issues which might guide the day-to-day decisions of the grazier (or national park or mountain catchment manager) (last paragraph section 4.1.1.2), some of the data (eg rainfall) may be collected readily. However, simple means of estimating parameters like the amount and quality of herbage have not been developed, and there are therefore no guides for routine day-to-day observations. For the researcher, who is prepared to expend considerable effort in sampling and analysis, there is of course extensive guidance (t'Mannetje 1978).

### 4.1.3 Analysis and interpretation

Returning briefly to our algorithm for management (Figure 1) and its accompanying explanation (section 1.1), our generalized null hypothesis ($H_O$) is that there is no departure from our goals, or no change in the system between baseline and follow-up surveys. The following discussion of analyzing data to test $H_O$ and interpret the result will be confined essentially to the community-data contained in the species-by-samples matrices.

It is worth emphasizing at this stage that the primary aim of monitoring is to detect a departure from goals or to detect change, all with respect to those properties of the system predetermined to be of special interest. It is by definition not a primary function of monitoring (= maintaining regular surveillance) to necessarily identify also the causes of those changes detected. If it is known in advance which areas are and which are not to be impacted by some factor, then an appropriate sampling design can be devised to provide the basis for deciding after impact whether the impacted and non-impacted areas differ to some predetermined degree with respect to predetermined variables (Green 1979). But in a general context it is simply not practicable to try to ascertain all things about all systems, and the limited resources of manpower and money ought to be directed at maintaining surveillance of the things that count most. Having picked up a change, the scarce resources might then be focused at the causes of that particular change without being dissipated on a host of other more or less remote changes and their conjectural causation.

#### 4.1.3.1 Data analysis

While multivariate analysis lacks the rigour and sensitivity of the univariate and bivariate statistics with which most biologists are familiar, this former type of approach is useful in identifying patterns or trends in large sets of data (Williams 1976, Gauch 1982). For example, it can serve as a basis for stratification of the study area (Table 3, section 4.1.2), it might aid in identifying the main gradient to which the vegetation responds and which are the main indicator species along these gradients, and it might help to identify what kinds of community change are being experienced in which strata. Among the three principal multivariate strategies of direct gradient analysis, ordination and classification, the last two are particularly appropriate because of their formality and the existence of computer algorithms for handling large matrices.

These three multivariate strategies are not normally used in conjunction with rigorous tests of null hypotheses, in contrast with the univariate and bivariate counterparts. This is not to say that tests cannot be devised.

Indeed, the principal aim of the procedure in Table 3 was to determine empirically the properties of methods and data so as to enable tests for which the outcome could be specified with known confidence. Whether such a method will be successful remains to be seen, but it has the potential to be more flexible and more powerful than any resort to cookbook non-parametric and other tests.

The essence of the method of data analysis being proposed to be developed and applied to test our $H_o$ is as proposed in Table 4. Supposing $H_o$ were rejected (a high $\chi^2$-value resulted from the test) we would be asserting that the chances are that the community-composition in the stratum under test has so changed that the primary (secondary, tertiary, ...) axes of ordinated samples differ. A few points warrant discussion.

First, that it is possible to reject or not to reject $H_o$ at some predetermined level of significance (say 5%) arises from the preliminary work explained in Table 3 - that is all sheer statistics. Whether such a scale of difference is significant in terms of the management goals can be answered only by the manager and the policy maker.

Second, in order to make comparisons between, say, baseline and follow-up ordination, common 'marker' samples included with both sets of data might be necessary to enable the centroids of the ordinations to be aligned.

Third, in few cases are ordination axes beyond the first and second interpretable, and especially if these first few account for large proportions of the variation in the data there may be little point in looking at the higher axes.

Table 4. Proposed procedure by which to test the null hypothesis that community-composition does not differ (1) from that prescribed by management goals, or (2) between baseline and follow-up surveys.

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1. The study area is stratified, and the appropriate number, J, of sample areas per stratum ascertained (Table 3).

2. For a baseline survey, J samples are randomly located per stratum (or whatever depending on choice of stratified, cluster, etc sampling design) and surveyed by the procedure of Table 1.

3. The results of the baseline survey are compared with the prescriptions in the goals, or a follow-up survey (ie repeat of step 2) is conducted and the results of follow-up and baseline surveys compared.

4. $H_o$ is that either goals and baseline or baseline and follow-up do not differ.

5. The comparison to effect the test of $H_o$ is for each stratum to use $\chi^2$ goodness-of-fit to evaluate the differences in frequency distributions of samples along the primary (and in turn secondary, tertiary, ...) ordination axes (using DECORANA and in Table 3), the paired comparisons now being goals with baseline, or baseline with follow-up.

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Obviously the aforegoing discussion applies in particular to monitoring programmes of formal sampling design. There might be little point in subjecting data that have been collected by judgmental location of sampling sites (and thus data of uncertain representativeness) to such thorough analysis. The grazier in any case usually does not have the necessary electronic computational aids. What might happen here however is that the biologist develops, using formal techniques, simple types of data analysis which the grazier might use to successfully detect change in perhaps the majority of cases. The application of the so-called quantitative climax method of assessing veld condition (Foran 1976, Foran, Tainton and Booysen 1978) has been the primary catalyst in South Africa in injecting measurement and objectivity in the management of local grasslands. Subsequent attempts have been to improve the generality of the method, to facilitate estimation of appropriate stocking rates and remedial management, to refine ordering of species and identify indicator species (Tainton, Edwards and Mentis 1980, Vorster 1982, Mentis 1982, 1983, 1984).

4.1.3.2 Data interpretation

Although it has already been stressed that the primary aim of monitoring is to identify change rather than necessarily identify the cause of it, it is nevertheless important that the whole exercise of data collection and analysis be executed with a view to how the detected change might be interpreted, and how such results might potentially influence management. Some general issues and some specific to the main procedures considered above are dealt with below.

The first issue is an old one and concerns the temporal and spatial heterogeneity of vegetation (Austin 1981). Vegetation composition might change in response to any of a variety of types of factors involving climatic fluctuations, succession, cycles, the persistent effects of episodic events or random variables. Taking these one at a time, climatic fluctuations over geologic time are of course commonly accepted to have been important sculptors of vegetation. On a shorter time-scale, it is almost inevitable that runs of wet and dry years will favour or disfavour species differentially. Even shifts in the seasonal distribution of rainfall might have effects, such as recognized in the karoo where summer-rain favours grass and winter-rain favours bush. Response to climatic fluctuations might be assumed to be ubiquitous, but demonstration of the importance of moisture separated from other variables requires some ingenuity (Snyman and Opperman 1983). Turning to succession, that there occur in cases predictable sequences of change in community composition is hardly questionable. However, that the term succession is explanatory except in a superficial sense, is doubtful. If succession is used embracingly to apply to all vegetation-change then it is a catch-all, and explains nothing. If change to a community is to be predicted the conditions have surely to be defined. (What was the starting state? What intensity and frequency of what kinds of disturbances occurred or were applied?) Having got this far succession is superfluous and we ought, in the interests of parsimony, to simply refer to the particular cyclical, episodic or random factors that apply. Indeed, it might be of great service to South African ecology if a 5-year moratorium on using the term succession was pronounced. Ecologists might then be encouraged to describe changes and their circumstances explicitly, and not put it all down to succession, whatever that means. Moving on to cyclical change, the recognition of this might be rejected as hardly possible on grounds similar to those argued by Markham (1980) about the cyclicity of rainfall in South Africa. However, a senescence-regeneration cycle might, for example, be superimposed on episodic recruitments of stands of evenly-aged individuals. Although little studied in South Africa, a constant rate of recruitment, or regular uniformly-sized pulses of recruitment are by no means universal, and it may be expected rather as the norm than the exception that the success of recruitment following sexual and vegetative propagation is of an episodic nature (Crawley 1983). Threshold events might also apply in relation to mortality, where, for example, the rare occurrence of frost might kill most or all individuals of a particular species.

The partitioning of the effects of the above kinds of factors is problematical (Austin 1981). First, it is tempting to assume that spatial sequences represent sequences of temporal or other change. Of course this may not be so. Second, aside from the uncertainty in representativeness of judgmentally located plots, temporal changes on such plots permanently marked and periodically assessed need not reflect a shift in the system as a whole. Such phenomena as senescence-regeneration cycles coupled with spatial heterogeneity at a scale much smaller than the study area might lead to oscillation on small fixed (permanently marked) plots being unrelated to the average state of the whole system. Third, this average state can be captured by a special sampling design, as described above, but this alone will not enable the partitioning of causes of change. Thus for confidence in interpreting changes detected by monitoring, formal experiments on permanently demarcated areas might be designed and run to complement the monitoring. Suggestions for design are given by Austin (1981).

A second main issue concerning the interpretation of measurements of veld is the impetus that such interpretation has been given by application of the quantitative climax method of Dyksterhuis (1949) (Foran 1976, Foran, Tainton and Booysen 1978, Tainton, Edwards and Mentis 1980, Vorster 1982, Mentis 1982, 1983, 1984). Several points have arisen. First, formal methods of ordination and classification should be used in documenting the response of plant species to environmental gradients. Resort to such techniques avoids the criticism that the method of assessing veld condition has transferred guesswork from stocking rate to species response, and has achieved no advance in objective procedure. Second, it should not be expected that there is any single universally applicable classification of plants into decreasers and increasers. For example, species of a group of plants which behave similarly in relation to one environmental gradient at one locality need not respond similarly at other localities or in relation to other gradients (Grunow, Pienaar and Breytenbach 1970, le Roux 1983). Third, local applications of the quantitative climax method have involved classifying (into decreasers and increasers) all herbs. For the rare species this is statistically questionable even using the most powerful objective techniques available. More cogently however is that it is unwieldy and probably unnecessary for graziers and nature conservation managers. The main gradients to which the vegetation is locally responding need to be identified, and the common species scattered along the lengths of those gradients to be recognized. For example in moist tall grassveld in Natal, species indicative of position along a gradient of grazing intensity are (in order of increasing tolerance of grazing) Diheteropogon amplectens, Tristachya leucothrix, Themeda triandra, Aristida junciformis and Eragrostis curvula (Mentis 1982, 1983). This is a small fraction of the 40 species or so which might typically occur on a farm or in nature reserves in humid grassveld. What deserves special emphasis too is the need to determine local gradients and species orderings. Local variation is inevitable. For example, ordination of species-by-samples data in the Natal Drakensberg yielded an ordering with Tristachya more (not less) tolerant than Themeda of grazing intensity (Brockett 1983). Evidently grazing and other forms of defoliation are major factors affecting grasslands, but they are composite factors interacting with numerous other factors (McNaughton 1983). Because of this somewhat paradoxical circumstance of ubiquitous uniqueness in things environmental, the emphasis lies on devising procedures the execution of which will guide as to how a local situation is to be managed. And it is such general algorithms (rather than cookbook recipes of how to manage a farm or national park directly) which are so poorly developed in South Africa. Fourth, the traditional usage of carrying capacity has itself become a hindrance to progress in range science. Classically carrying capacity is considered as a stocking rate yielding stated positive animal performance without causing degradation of the veld or soil. But using even a simple model of plant-animal interactions (Caughley 1979), any number of carrying capacities is possible. The so-called ecological carrying capacity is an extreme at which animal performance will be zero, since by definition this occurs upon equilibration of plants and animals. The stocking rate can be held (by managerial intervention) at any level less than ecological carrying capacity. Some positive animal performance will result. But the plant-animal system will be in disequilibrium and will thus have an inherent tendency to change. This change, which might be countered by managerial intervention, represents degradation since, if allowed to proceed, equilibrium will be approached, animal performance will be lowered, and the grazier will say the system has deteriorated. Caughley's (1979) model is of course simple (although helpful) when the likelihood of systems with multiple stable states is considered (May 1977). Thus any attempt to improve the realism of Caughley's model makes the case for carrying capacity even more hopeless (Mentis 1982, 1984). It would be better for the classical terminology to be dropped altogether and optimal stocking rate to be adopted (Mentis 1984). It is so that this alternative demands a qualification of optimal, but in any case that should be done in defining objectives and goals. This change in terminology might help to rationalize the ecopathological doctrine that the system is in the pink of health if it is at climax (climatic in pure grassveld, biotic in false grassveld) and diseased if not. Fifth, insufficient attention has been directed at developing strategic models of the dynamics of veld and herbivores which capture the essence of how various objective functions vary with the state of the plant-animal system. For methods of assessing veld to be effective they ought to be related rigorously to the objective functions. On this basis exact procedures might be developed which enable the grazier (or whoever) to combine his inputs of objectives and system-state, and emerge with explicit guidance on how to manage (Mentis 1984).

The third issue, not unrelated to the first two, concerns reigning models of vegetation dynamics. These of course represent the backdrop against which vegetation is interpreted. Some workers have remarked that scientists no longer take the classical ideas of Clements and Tansley on ecological succession seriously. Such statements presuppose a narrow definition of scientist that excludes most rangeland workers, for neo-Clementsian theory remains the soul of rangeland thinking, certainly in a local, if not world-wide context. The fall from grace of these superficially plausible doctrines is described in, among others, a readily accessible form by Colinvaux (1973). A recent review of vegetation dynamics is provided by Miles (1979). A welcome injection of Darwinism into the subject, led by Harper (1967), has been given by Crawley (1983), and his review is of particular relevance to grazing ecosystems. An earlier competitor to the Clementsian school was that of the continuum school (Figure 2 and section 4.1.1.2). This latter paradigm is much more deeply entrenched than classical succession in contemporary computer algorithms for handling community-data (Williams 1976, Gauch 1982). It is not without its critics and some precautions need to be observed. The problems lie not in executing the procedures of Tables 1 to 4 and testing $H_0$ - all that is essentially a mechanical operation. The tricky issue is to interpret the axes and thereby diagnose possible remedies to shifts in frequency distributions of samples along these axes (such shifts of course would lead to $H_0$ being rejected). An arbitrary example might help to illustrate.

Suppose baseline and follow-up surveys yield the ordinations and frequency distributions of samples along the first axis as indicated in Figures 6 and 7 respectively. Suppose further that the differences between the frequency distributions in Figure 7 were significant ($P < 0,05$) and that our $H_0$ of no difference was therefore refuted. We now have to accept the hypothesis that change has occurred and we must address the question of whether this matters in terms of our goals. One partial answer (in respect of nature conservation) might be that the difference is important, because $\beta$-diversity is less in the follow-up that the baseline data, and that in the follow-up there is a relative tendency for the vegetation to become uniform and take on whatever is the appearance between -2 and -1 SD (4SD = 1 species turnover) from the original (baseline) centroid (asterisk in Figure 6). For pastoralism the change might be different. For example it would be favourable if the objective function was increased, or unfavourable if it was decreased. Suppose that the detected shift in community-composition was considered unfavourable (for pastoralism and/or nature conservation) and it was decided to try and reverse it. How would we achieve this? We would want to know what environmental gradient axis 1 represented. This can be straightforward. For example we might suspect that it is a gradient of grazing intensity. We could test this hunch either by adaptive management (by changing the grazing intensity preferably on only a part of the system, and observe the results on such experimental and control areas) or by deferred action. In the latter instance we might set up some permanent plots of the kind suggested by Austin (1981). Otherwise we might collect numerous samples (using the procedure in Table 1) which are deliberately located on areas differing essentially in grazing intensity (and not in other factors such as catenal position and soil type). This special location might, for example, radiate outwards from waterpoints, or farm gates, or 'lê plekke' or other sites of animal concentration. For confidence in interpreting the outcome of such a test considerable redundancy is required (Gauch 1982). Alternatively, understanding what axis 1 represents may not be straightforward. Almost inevitably the axis extracted by ordination will often represent complex

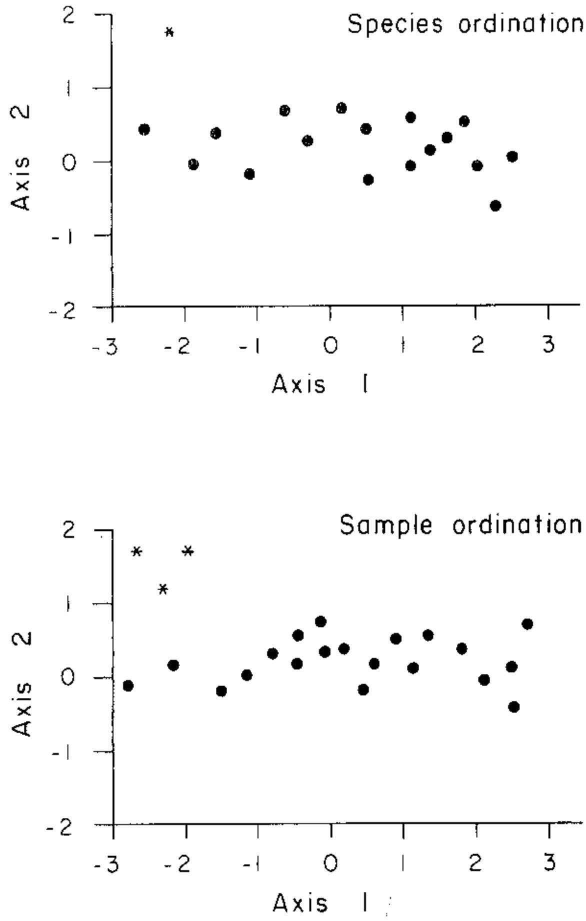


Figure 6. An arbitrary example of ordinations of samples from baseline and follow-up surveys.

gradients. Even in the case of the gradient of grazing intensity it is most unlikely that the ordering of plant species is simply a reflection of capacity to tolerate defoliation. Other factors like palatibility, erectness of plant and accessibility to herbivores, capacity to tolerate trampling, urine and dung, and much else might be involved. The prospect of separating all such individual effects is, at best, not in sight (McNaughton 1983), and we have to be content with a limited capacity that in most instances might indicate a general pattern or provide the basis for formulating testable hypotheses about gross cause and effect.

It might arise on occasions that with little managerial change to the system a sudden and dramatic change in community-composition occurs, or, alternatively in the face of considerable managerial change the community-composition does not alter. These circumstances might well reflect the existence of multiple stable states. In some instances it is conceivable for even a small change in the state of the system to lead to a threshold being crossed so that the behaviour of the system alters dramatically (Walker, Ludwig, Holling and Peterman 1981). In other cases, for example

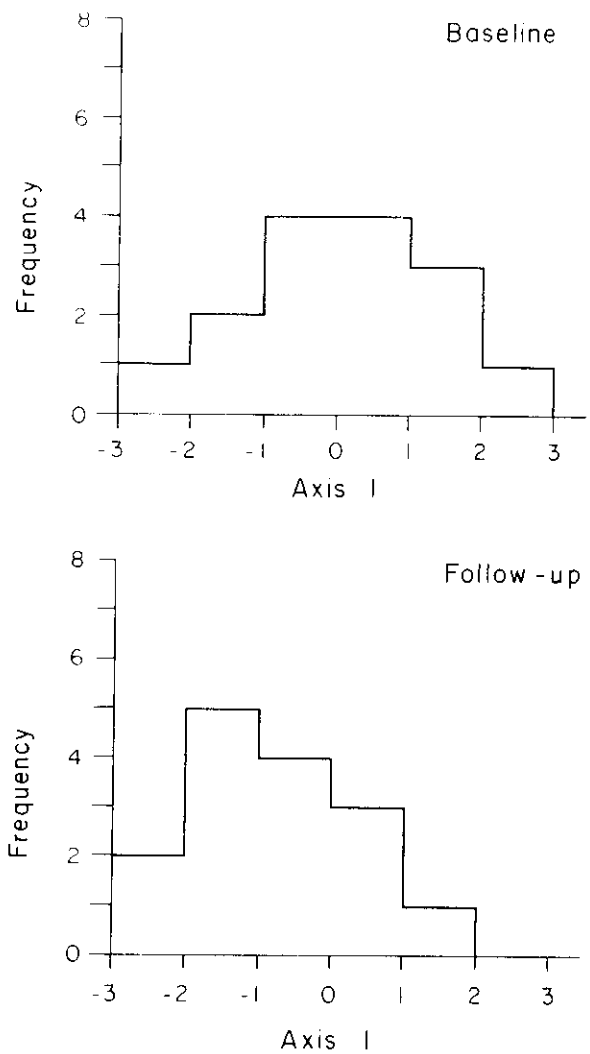


Figure 7. Frequency distributions of samples along axis 1 for ordinations of arbitrary baseline and follow-up surveys in Figure 6.

in veld dominated by Aristida junciformis, almost no form of management (other than ploughing or use of herbicide) will lead to displacement of this grass. These two extreme forms of response of community-composition to environmental factors emphasize the need for caution in using the paradigm of the continuum school, and are again grounds for the value of studies of the stability and dynamics of our grassland systems.

## 4.2 Selected Species

Individual species might be selected for monitoring on the basis of any of several main reasons. Of course all would remain in the context of our $H_0$ that no change in abundance (or relative abundance) has occurred (ie the population has not increased or decreased beyond certain predetermined limits). The main circumstances for selection might be described as follows.

1. Rare species. A species might be defined as rare if it has a small population, or a population of low density, or the organisms can tolerate only a narrow range of environmental conditions. Value judgement might well be involved. Some species are apparently especially appealing, or easily evoke sympathy or are readily perceived as of immediate utilitarian value. For instance compare elephants, rhinoceroses and spotted cats with rodents, frogs and butterflies. A rare species is thus one for which the individuals are scarcer than people want them to be. That curt definition is not intended to be in contempt of the WCS-type objectives. It merely emphasizes that the human mind and its associated value judgments strongly determine the state of the biosphere.

2. Invasive species. These might be identified as undesirable (again a value judgment), alien to the system of concern, and vigorous competitors. Invasives are often r-selected species, being fecund with propagules readily and widely dispersed and being adapted to occupying disturbed areas. Invasion may be from a single point source, or, as usually develops, from numerous sources.

3. Indicator species. A species may be described as an indicator if it has a limited range of tolerance to environmental conditions such that its presence and/or abundance may be used to indicate specific environmental conditions. These latter conditions might be edaphic (eg soil depth, geological substrate, degree of soil drainage or leaching, etc) or might concern more strictly biotic factors (eg the frequency and intensity of fire or grazing) which might be under the influence of management.

4. Keystone species. These are species whose presence (or absence) in the system is critical to the present (desired) mode of system-behaviour, or to the continued existence of other valued species or system-outputs.

### 4.2.1 Parameters and estimates

As already indicated, our $H_0$ in monitoring is that no change in abundance or relative abundance has occurred. Perhaps more often than not an index of abundance will be more efficient (ie precision per unit cost of sampling) than direct estimates of absolute abundance. But aiding in decisions on sampling design ought to be the already acquired knowledge that enabled identification of the species as rare, invasive, indicator or keystone.

The rare species might, for instance, have been found through ordination of the community-data (section 4) to occupy 'outlier' habitat types poorly represented in the area of concern and biotically and abiotically very different. The simultaneous ordination by correspondence analysis (eg DECORANA (Hill 1979)) of both species and samples facilitates recognition of these kinds of patterns (as illustrated in the arbitrarily chosen plots in Figure 8). Alternatively the ordinations might reveal that the rare species occur among average samples of the community, either scattered along the lengths of axes or localised on short portions of them. As a further contrast, being a rare species no record might have been made during collection of the rather gross community-data, and the worker might be relying on subsidiary observations.

In the general case a thorough stratification of the study area (Table 3) would facilitate what the ordinations do automatically - identify whether the rare species are patchily distributed and locally common, more or less evenly distributed but individuals at very low density, etc. This kind of background will aid substantially in designing specific sampling procedure. The same approach will be similarly helpful for the invasive, indicator and keystone species.

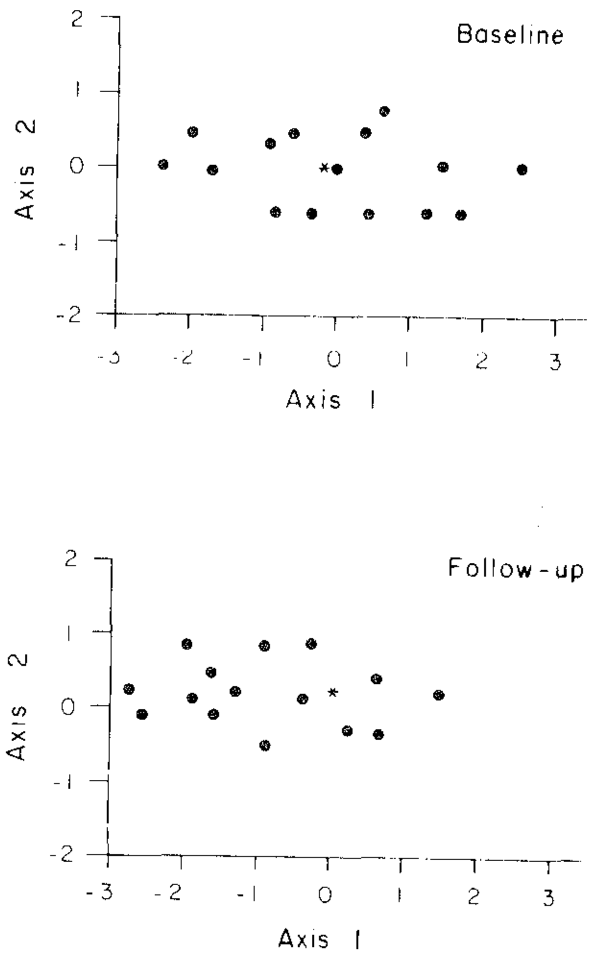


Figure 8. Arbitrarily constructed joint ordinations of species and samples to illustrate the correspondence of 'outlier' samples and the species occurring in them (see asterisks).

With this background, augmented by autecological data (local or from the literature), decisions must now be taken about using point-, line-, quadrat- or plotless-techniques, how sampling units are to be distributed in time and space, and what kinds of tests will be applied (see Green

1979). Whatever technique and apparatus are chosen it is important that the procedure be repeatable (by initiator of the monitoring and any successor). Rating-techniques, for example, thus hardly qualify. Further, an element of randomness must be involved in the distribution of sampling units if resort to formal statistical tests is not to be invalidated. Next, non-parametric tests might be used, but the worker is exhorted to weigh-up the seriousness of rejecting $H_0$ when he should not, and accepting it when it is invalid. For example, does the worker need to be very confident that when he rejects the $H_0$ at the 5% level that there is indeed a 1-in-20 chance that such rejection is erroneous? If the target species is, say, a poisonous plant which causes serious economic losses when it is above a certain threshold density, then the worker would want a high degree of confidence in his rejection or acceptance of $H_0$. In such case the weaknesses and uncertainties inherent in cookbook parametric and non-parametric tests may require the worker to resort to a rigorous and specific design. This will usually require a comparison of two or more likely techniques one with another, a determination of the type of data yielded (eg normally distributed, skewed, amenable to transformation, or intractable data), and the precision obtained per unit cost of sampling. As emphasized by Green (1979) it is recommended that the planning of the technique actually involve trial monitoring in the field and an analysis of at least mock data. Time 'saved' in not taking these precautions is usually time wasted when it is found later that the target parameter is not being sampled, the data are imprecise, insufficiently replicated, etc.

### 4.2.2 Analysis and interpretation

If the monitoring has been planned thoroughly with trial data collection and analysis there should be no problems in deciding whether $H_0$ is or is not refuted. However, if $H_0$ is refuted questions will arise as to whether anything should and can be done to arrest or reverse the change. Useful answers depend on either using results from previous relevant study, or hypothesizing and designing and executing tests of the hypotheses.

An example of dependence of previous knowledge is most likely in the case of indicator species. The very recognition of the organism as indicators presupposes that we know that their presence or abundance is diagnostic of specific environmental circumstances. Remedial measures, if desired, should therefore be obvious. For example, the invasion by *Acacia* spp into dambo grassland would suggest a change (drying-up) to the soil-moisture-regime. The remedy - supposing we want to retain the dambo grassland - would be to slow the rate of drainage of the dambo, perhaps by arresting gully erosion through construction of gabions in the dambos and improvement of vegetal cover on the adjoining toplands. Naturally the remedial measures, if applied, must be followed up by continued monitoring for although we say we 'know' what an indicator species indicates we can never be certain. We ought to test our remedial measures, and this of course constitutes part of our algorithm of scientific management (Figure 1).

The 'dependence on previously gathered knowledge' and 'hypothesizing' are really only two extremes in degree of confidence that might be asserted in explaining observed changes. In the case of 'hypothesizing' we are, in principle, designing and executing an experiment to test our views of cause and effect and/or whether we can reverse (or accelerate) some change to the system. Deriving the question which produces the appropriate $H_0$ requires inspiration and is not within the realm of exactly prescribable method. The step in framing $H_0$ and designing tests are discussed by Green (1979).

## 4.3 Selected Issues of Process and Structure

In sections 3.2 and 4 it was argued that certain aspects of the structure and functioning of ecosystems might deserve monitoring, and this might well be the responsibility of relevant governmental agencies where a country has committed itself to WCS-type objectives. Again the whole philosophy is that of testing the $H_0$ that no change has occurred - and generally under the circumstances of not knowing the 'what, where and when' of environmental impact. Should the type, place and time of impact be known then our sampling design can usually be made highly specific, and it changes from 'baseline vs follow-up' to 'impacted vs non-impacted'.

It is appropriate to mention here that, in retrospect, the workshop devoted insufficient attention to defining and distinguishing between monitoring, inventory and data collection. The first term has now been defined (Section 1.1). Inventory might be regarded as involving exercises to describe the main characteristics of the system under consideration. Recognising that such exercises are aimed at describing the unknown (who needs a description of the known?), specifying an infallible procedure is not possible. There exists no certain means of discovering without "wasted" effort. Data collection might be regarded as the practice of collecting input for predefined models. In this case the standards of precision required should of course be set in terms of the model. The collection might be to either test or calibrate a model. If data are not collected for these purposes then the worker should beware that he is not simply recording the chaos about us.

In the discussion which follows on issues of process and structure, there is some implicit confusion between monitoring, inventory and data collection (as defined above). This arises from a deficiency in workshop-organization (for which I take blame). Rather than try to resolve this confusion here, the topic is left for perhaps a future workshop.

### 4.3.1 Parameters and estimates

A number of parameters of likely relevance is listed and discussed briefly below. It is not being asserted that every parameter ought to be monitored everywhere. The interest and emphasis must clearly vary depending on governmental agency.

#### 4.3.1.1 Soil loss

Three general facets might be recognized.

First, there are point losses arising from the erosivity of rainfall and associated runoff, or otherwise caused by wind. Of course other agents of detachment and transport might be locally important (Morgan 1978). The Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978) and the

Soil Loss Estimator for Southern Africa (Anonymous 1976) model soil loss by sheet erosion. Neither model has been extensively corroborated on rangeland, but small runoff plots and rain-simulators now offer efficient means of gathering data and developing or testing predictive models. As far as is known, wind erosion models have not been applied in grasslands in South Africa, but are perhaps locally relevant (eg grasslands of southern Mozambique plain, mine dumps, strip-mined areas).

Second, sediment yield might be estimated for whole catchments, using stilling ponds as at Cathedral Peak.

Third, interest may focus on geomorphological features or processes such as nick-points, gullying, sub-surface erosion, differential removal and accretion of erosional debris, stream-bed incision, scarp-retreat, etc.

#### 4.3.1.2 Water yield and hydrological regime

Annual and seasonal flows might be measured at a limited but representative range of catchments in the grassland biome. Catchments vegetated essentially by grass are needed. The gauging of further catchments should be determined in relation to the adequacy of present study sites (viz Cathedral Peak, Lydenburg, Tzaneen, Bethlehem, Cedara, nTabamhlope and nTuze) to provide a picture across the variation of the grassland biome. The same catchments might be used to measure flow regime (viz peak floods, volume of flood flow as a proportion of total annual flow, etc).

In arid grasslands and on sandy coastal plains it is appropriate to measure water-tables rather than stream-flow. This might be done by recording water-levels weekly or monthly at a network of wells. The design of the network to gain representativeness would require special attention.

#### 4.3.1.3 Water quality

The parameters selected here might anticipate (if at all possible) the activities upstream and recognize the interests of downstream users. Some suggestions follow.

1. Physical: temperature, suspended sediments, turbidity.

2. Chemical: conductivity, pH.

3. Biological: biological oxygen demand and community-composition.

Existing stream gauging sites might be used, and augmented as necessary for, say, policing purposes. Procedures should be according to the standards of the Hydrological Research Institute which should be contacted in the event of plans to monitor water quality.

#### 4.3.1.4 Primary production

Estimates (or at least indices) of primary production might be considered as measures of process in ecosystems. Making the estimates is bedevilled with numerous complications (Grossman 1982), and even an approximate index (eg annual accumulation of herbage in the absence of large herbivores) is time-consuming to obtain if the results are to be reasonably precise (CV of 10%). And while having knowledge of the average and the likely variation in primary production at a particular site is of practical advantage, the utility of strictly monitoring (testing $H_o$ of no change) primary production is questionable (section 4.3.2).

4.3.1.5 Biogeochemical cycles

Long-term trends in pollution (eg acid rain) and short-term changes in vegetation might affect the biogeochemical cycles in grasslands. The potential significance of such disturbance might best be evaluated by measuring trends in streamflow chemistry at selected sites in wilderness areas (eg Cathedral Peak). Suggested parameters are $NO_3$ concentration, pH and conductivity. Atmospheric $CO_2$ might be monitored, but the possible effects of changed levels on communities defy simple study.

4.3.1.6 Biogeographic processes

Nature conservation areas have become increasingly isolated one from another as a result of the expansion and intensification of urban settlement and agriculture. Disruption of former movements between 'islands' of habitable area can lead to contraction of gene pools, increased chances of localised extinction, and lower probability of dispersal into depleted areas.

Inventories and censuses (conducted by standardized procedures) might yield the species-by-samples matrices considered in section 3. Movements or dispersal between areas might be monitored, for example, by examining the types and amounts of seed carried by birds.

4.3.1.7 Community structure

Communities have structure in both physical (eg height, density, growth form, pattern of distribution of organisms) and abstract (eg trophic structure) senses. Previously discussed measures of species heterogeneity (section 4.1.1.2) might be used or adapted as necessary to index the abstract attributes. Whether the physical attributes can change substantially without being reflected in species heterogeneity is uncertain.

4.3.1.8 Records

There is a variety of kinds of records which grassland managers might find useful to maintain. In terms of our strict definition of monitoring, where the $H_o$ of no change is being tested, this record-keeping does not comply (see Section 4.3). Nevertheless, information on weather and regimes of disturbance (types, frequencies and intensities of events like grazing, fire, cropping, 'pest' outbreaks, etc) may greatly aid in managing the system.

### 4.3.2 Analysis and interpretation

The previously mentioned maxims in relation to planning and executing environmental studies apply (section 4.2.1 and 4.2.2). Given the requisite thoroughness here (Green 1979), an unequivocal test of $H_0$ should be straightforward. In many instances hypotheses might easily be erected on the causes of change and their remedy, and tests might be designed involving control (non-impacted) and experimental (impacted) areas. In cases however the refutation of $H_0$ might be a very remote possibility or, with a differently designed test, highly probable but virtually impossible to interpret. Primary production is an example. It is notoriously variable, particularly in those regions receiving a generally low but erratic annual rainfall. A long run of data from many years might be argued to be necessary to show anything other than the dependence of primary production on precipitation. Such a regression is bound to have a large error attached to it so that substantial change in the dependence would be required before $H_0$ could be refuted. An alternative argument to the effect that one is interested only in possible real differences in primary production between years would lead to $H_0$ being refuted almost every year (if the sampling intensity was high so as to yield extreme precision). If management requires to test $H_0$ (retrospectively) every year, then so be it. The worker is however cautioned to temper some of the rather doctrinal views engendered by ecosystem-study (Miles 1979, Colinvaux 1981) with the practical issues of how things are to be tested and what earthly benefit might be enjoyed.

# 5. MONITORING BENCHMARKS

Questions now arise about how monitoring might be conducted on a national scale. Can individual university researchers and governmental agencies be left to institute monitoring and to further develop the theory? Or will local grassland monitoring benefit from certain coordinated activities? If so, what might the objectives be? With what methods and with whose participation might such objectives be achieved?

## 5.1 Objectives

It is proposed that a national network of grassland monitoring benchmarks might be developed as a baseline against which to interpret the results of routine monitoring exercises.

Some discussion of this and other possible objectives is warranted. It is convenient to examine the 'other' objectives first.

A long-term tracking of community-composition is demanded by WCS-type objectives. As explained in section 4.1, the aim of such investigations is to test the $H_o$ of no temporal change in average community-composition. This $H_o$ is best tested by using specifically developed sampling designs involving a random element in the spatial distribution of samples (ie some form of stratified random or cluster sampling is likely to be most efficient). Since individual grassland managers (be they graziers or governmental agencies) ought to practice their own monitoring - otherwise they are not managing scientifically - there is little room for national coordination in terms of the technical exercise of testing $H_o$. To be sure there will always be the benefits attached to exchanging ideas on how the tests might be conducted and interpreted, but the physical execution is up to the individual. Now there does seem to be one problem, so far not discussed, in relation to interpreting the refutation of $H_o$.

Suppose $H_o$ were rejected for some particular study area, and it had to be concluded that community-composition (or some other parameter) had changed over time. Would this necessarily reflect the impact of only management? Or could extrinsic factors like changed biospheric $CO_2$ content be implicated. To answer this a minimum requirement would be to test the $H_o$ of no change between control areas managed in a standard way with experimental areas anywhere outside these controls. The establishment of such permanently marked and consistently treated sites observed regularly indefinitely might provide careful points of reference by which to evaluate routine monitoring (cf Austin 1981).

Table 5. Definition of a veld ecotope as developed by the Department of Agriculture.

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A veld ecotope is a class of land which can be described in terms of the soil, landscape, climate and present optimal veld condition. The variation of resources within the ecotope are not sufficient to significantly influence the type of stock which should be kept, their potential production, and the required production techniques.

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## 5.2 Procedure

A network of sites might be selected consistent with the Soils and Irrigation Research Institute's ecotope, which is defined in Table 5. At each such selected site one or more plots might be delineated and managed in some defined consistent manner. This standard treatment might be a fixed system of grazing, resting and burning, or it might involve some artificial treatment like annual or bi-annual (or whatever) mowing. A variety of standard treatments on a single ecotope is desirable.

Each plot established in this manner might be surveyed periodically. The optimal procedure decided by resort to the procedures in Tables 1 and 2 might be applied to record community-composition .

Some caution ought however to be observed in interpreting and using the data collected. First, if the plots identified have not previously (or in the immediate past) been subjected to the standard treatment (whatever it be decided to be) then it is probable that the community-composition will shift in response to the new impact. If this impact is continuous (eg continuous heavy grazing as is often the case in subsistence pastoralism) then the community might settle at some equilibrium composition. But if the impact is periodic, as in rotational grazing, resting and burning, this sporadic disturbance might amount to repeated displacements of the system-state away from any inherent shift towards equilibrium. All this must be viewed against the variable background of fluctuating climate, possible senescence-regeneration cycles and various episodic and random factors. It seems then that the community on any given plot is likely to vary considerably in composition over time. But the extent of the variation remains to be seen.

Other types of record keeping might, for example, involve annually estimating primary production, and making exhaustive checklists of species present.

If primary production, or rather some approximate index of it, is to be estimated then ideally some standardized practicable procedure should be used. This might first involve protecting the plot from large herbivores (ie larger than a hare), second, a standard aftermath removal treatment (eg mowing or burning) applied immediately prior to each growing season, third, undisturbed growth through the growing season to some arbitrarily fixed date (like 1 June) when accumulated above ground plant material (ie herbage mass) is estimated, fourth, a formal sampling design whereby the distribution of the sampling units incorporates a random element, fifth, the herbage cut as close to ground level as possible (eg using manual or electric sheep-shears), sixth, drying and weighing cut herbage, and seventh, expressing the index of primary production as herbage mass in gDM $m^{-2}$. It is proposed that the precision of this estimate should be such that the coefficient of variation does not exceed 10%. Even if these indices of primary production are of limited value in detecting, say, possible effects of changed atmospheric $CO_2$ concentrations, they certainly will be valuable as an aid in fodder-banking (Jones 1983).

If exhaustive species lists are drawn up then it is imperative that the sampling procedure be defined, since unless every last individual organism is handled (this is usually quite impracticable and some sort of sampling has to be resorted to) the length of the list is sampling-dependent.

### 5.3 Participation

Participants in such a national network of benchmark sites might be

1. the Department of Agriculture using both its various research stations and privately owned farmland;
2. universities who might establish plots on their experimental farms; and
3. state and provincial agencies concerned with natural resource conservation.

### 5.4 Programme for the immediate future

It is proposed that GMW might now

1. examine the procedures proposed (especially in Tables 1, 2 and 3);
2. meet at a second workshop to consider the experience gained with these procedures which might be improved;
3. establish several benchmark sites and observe these for a trial period as a prelude to a more ambitious layout of permanent quadrats; and
4. plan and initiate appropriate monitoring programmes and use the experience gained to update the currently recommended procedures.

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