Estimating Green and Teal carbon stocks across the Gauteng Province of South Africa using a multi-source remote sensing approach

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GCRO | Gauteng City-Region Observatory

Carbon estimation across Gauteng

Introduction and Background

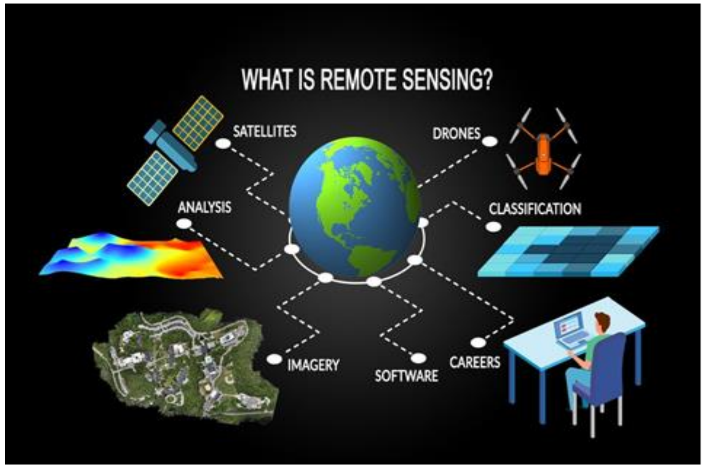
- Motivated by various metros' drive to be carbon neutral by 2050

- Cities exacerbate climate change because they emit more carbon (i.e. carbon sources) than they capture and store (i.e. carbon sinks)

- Track progress towards this goal by measuring the city-region's stored carbon and possible sources

- Colours of carbon helps differentiate carbon elements which need quantifying at the landscape scale using multisource Remote Sensing and Machine Learning (ML)

- ML is suited for big data applications and for not linear relationships between the response and predictor variables



Green Carbon across Gauteng

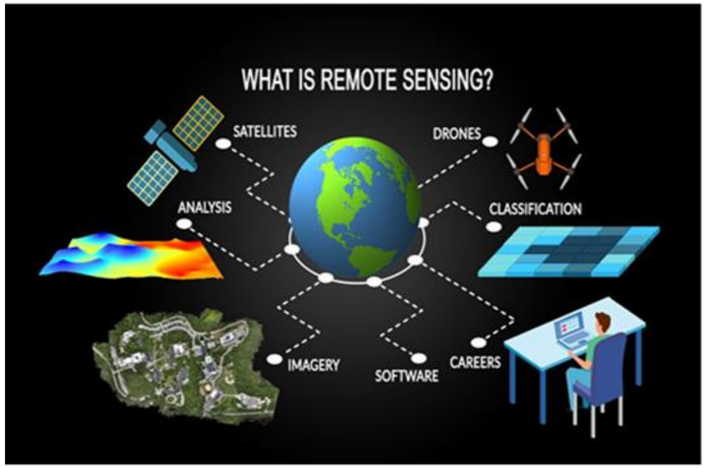
Research Objectives

- Green carbon, i.e. carbon stored within trees and grasses, occupies the biggest component of the terrestrial carbon budget and quantifying this type of carbon can play a big role in understanding and monitoring the natural and anthropogenic changes to the carbon balance

Research Objectives:

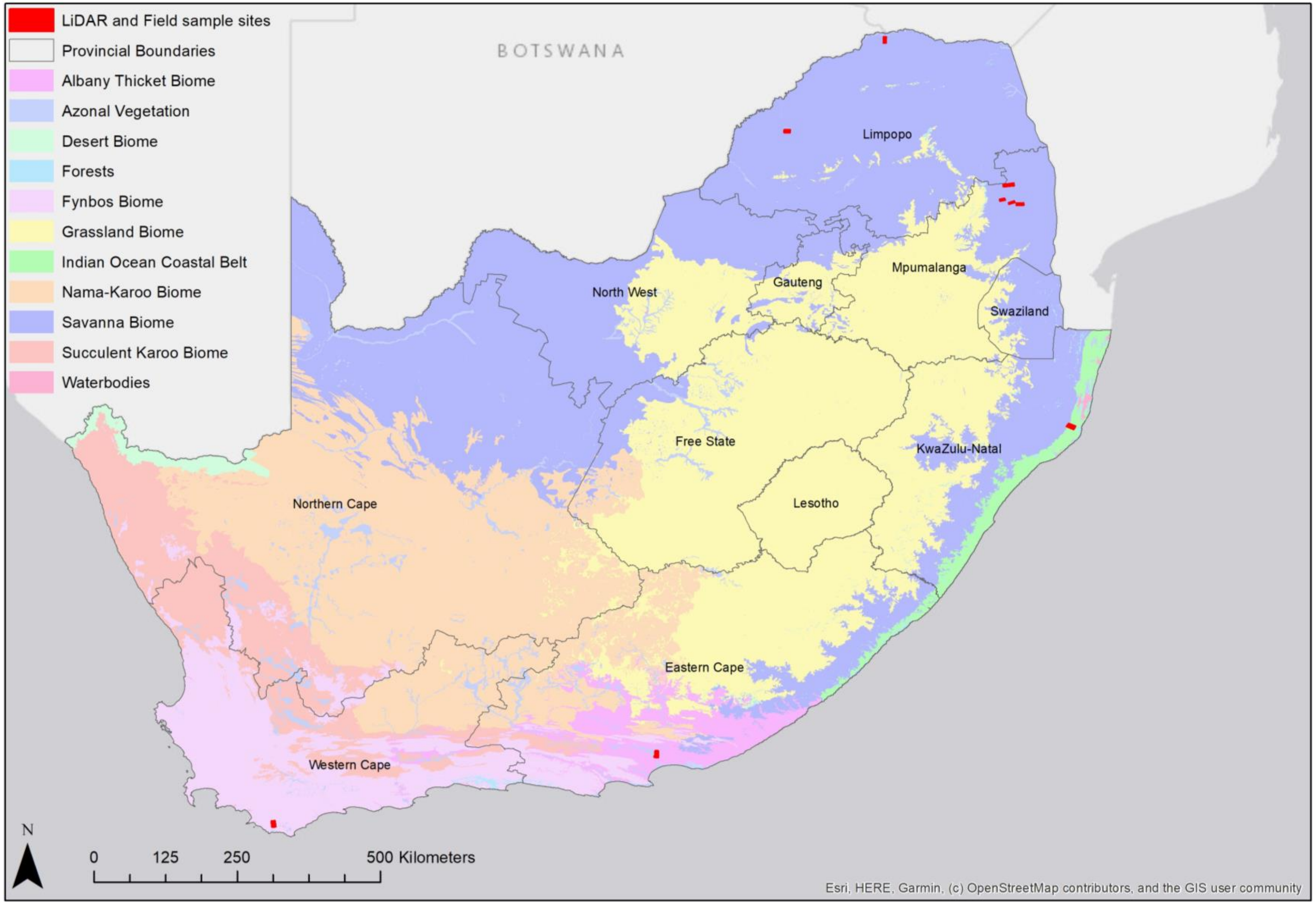
- To map the spatial distribution of green carbon, using a regional ground-LiDAR-SAR upscaling modelling approach, across Gauteng and to analyse the greatest share of green carbon and the highest concentration of green carbon per hectare

- To assess the distribution of green carbon across various above ground biomass structural classes, Critical Biodiversity Areas (CBA), and Ecological Support Areas (ESA) and across the proportional cover of the top 4 alien invasive tree species (NIAPS)



Green Carbon Study Areas

Collected Green Carbon (T C/ha) field samples (25X25m) plus LiDAR footprints



Savannah Green Carbon (2018)

# Sites	Mean	Min	Max
152	15.6	0	108.8

Natural Forest Green Carbon (2018)

# Sites	Mean	Min	Max
22	38.4	0	103

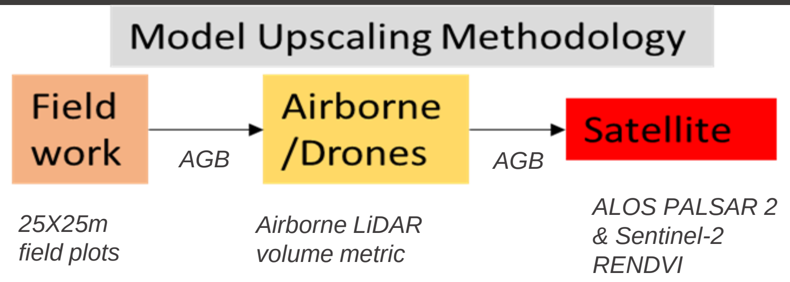
Fynbos Green Carbon (2018)

# Sites	Mean	Min	Max
23	54.1	6.8	212.5

Green Carbon across Gauteng

Methodology

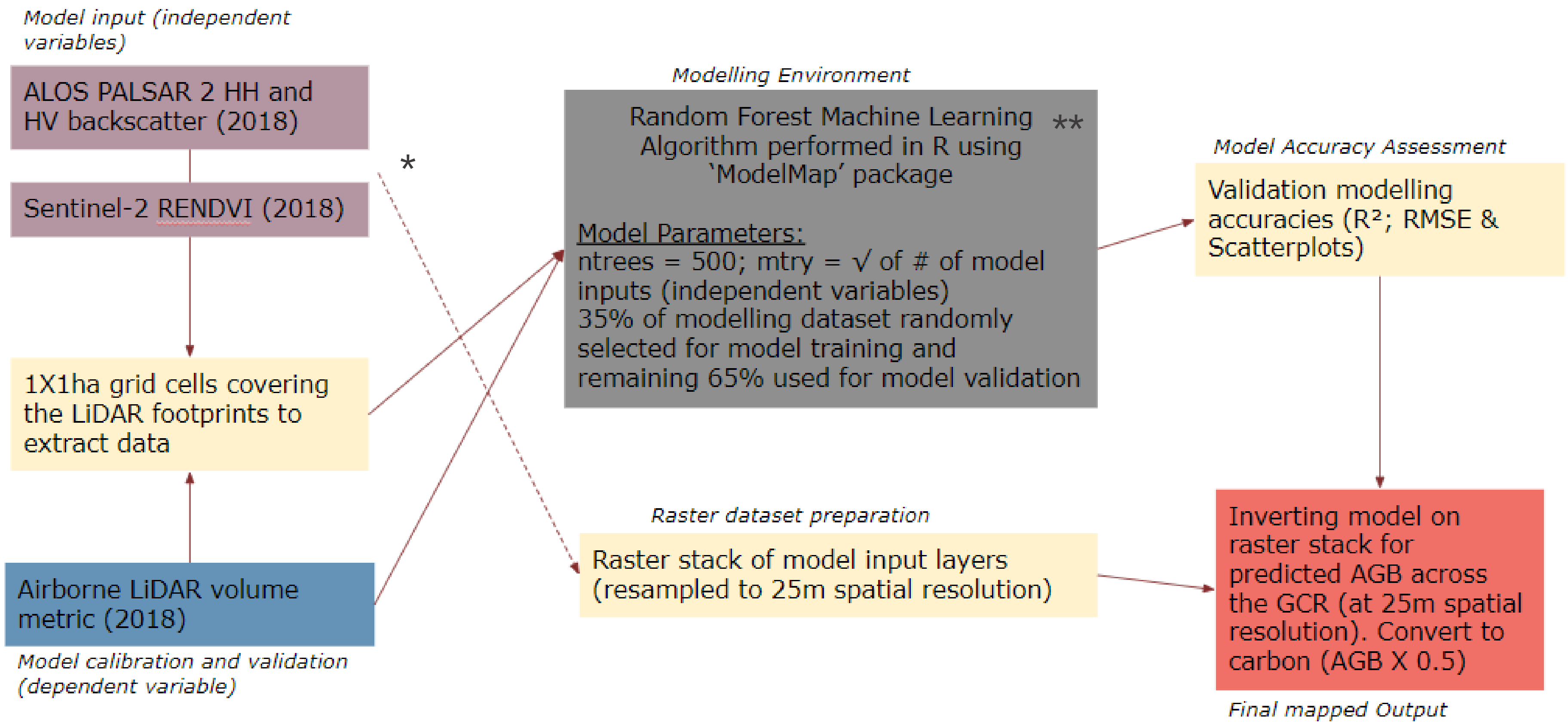
Species Groups	Allometric Equations
AcLo	(((LN(8.133)*DHB)+2.013)*0.4)*0.001
Ppin	(EXP((-10.928+2.07*(LN(DBH+2))+0.996*LN(HGT))))*1.06
AcMe	(EXP((-10.916+1.953*(LN(DBH+0))+1.232*LN(HGT))))*0.84
AcSel	(58.67*(DBH)^2.49)*0.000001
EuGr	(EXP((-10.398+1.977*(LN(DBH+0))+0.959*LN(HGT))))*1.28
Hakea	(100.76*(DBH)^2.3)*0.000001
Lepto	(((LN(8.133)*DBH)+2.013)*0.4)*0.001
Savannah	(0.109*DBH^(1.39+0.14*LN(DBH))*(Hgt^(0.73))*(0.9^(0.8)))



*Naidoo, L et al., 2015. Savannah woody structure modelling and mapping using multi-frequency (X-, C- and L-band) Synthetic Aperture Radar data, ISPRS Journal of Photogrammetry and Remote Sensing, Volume 105, Pages 234-250, ISSN 0924-2716

** Naidoo, L *et al*., 2014. "The assessment of data mining algorithms for modelling Savannah Woody cover using multi-frequency (X-, C- and L-band) synthetic aperture radar (SAR) datasets," *2014 IEEE Geoscience and Remote Sensing Symposium*, Quebec City, QC, Canada, 2014, pp. 1049-1052

AGB = Above Ground Biomass

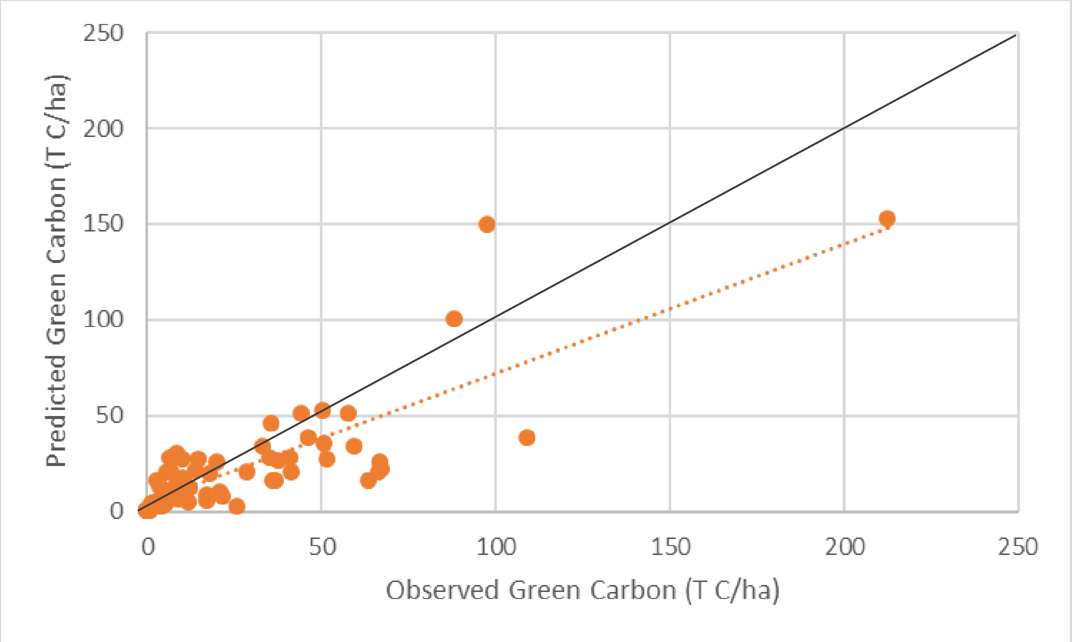


Green Carbon Upscaling Modelling Validation Results

Key Findings

Ground to LiDAR model

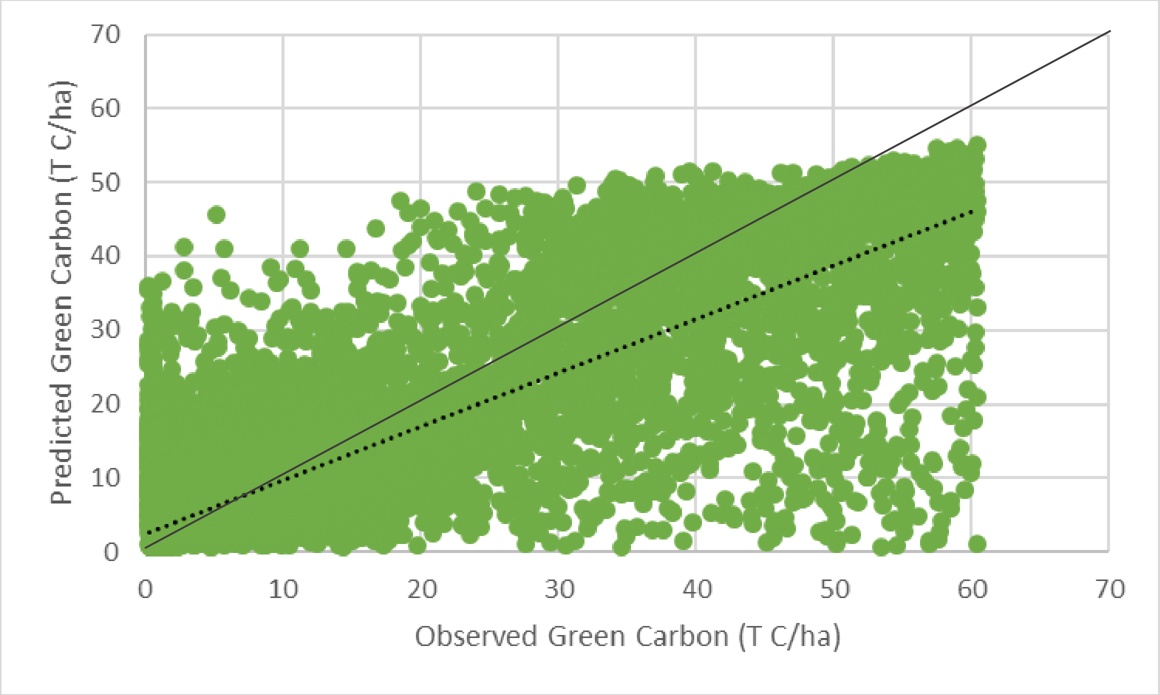
R^2	RMSE (t/ha)	SEP (%)	N
0.67	36.90	69.92	69



- Gradual under prediction of Green Carbon past the 25 T C/ha with a larger margin noted past the 70 T C/ha mark

LiDAR to SAR (+RENDVI) model

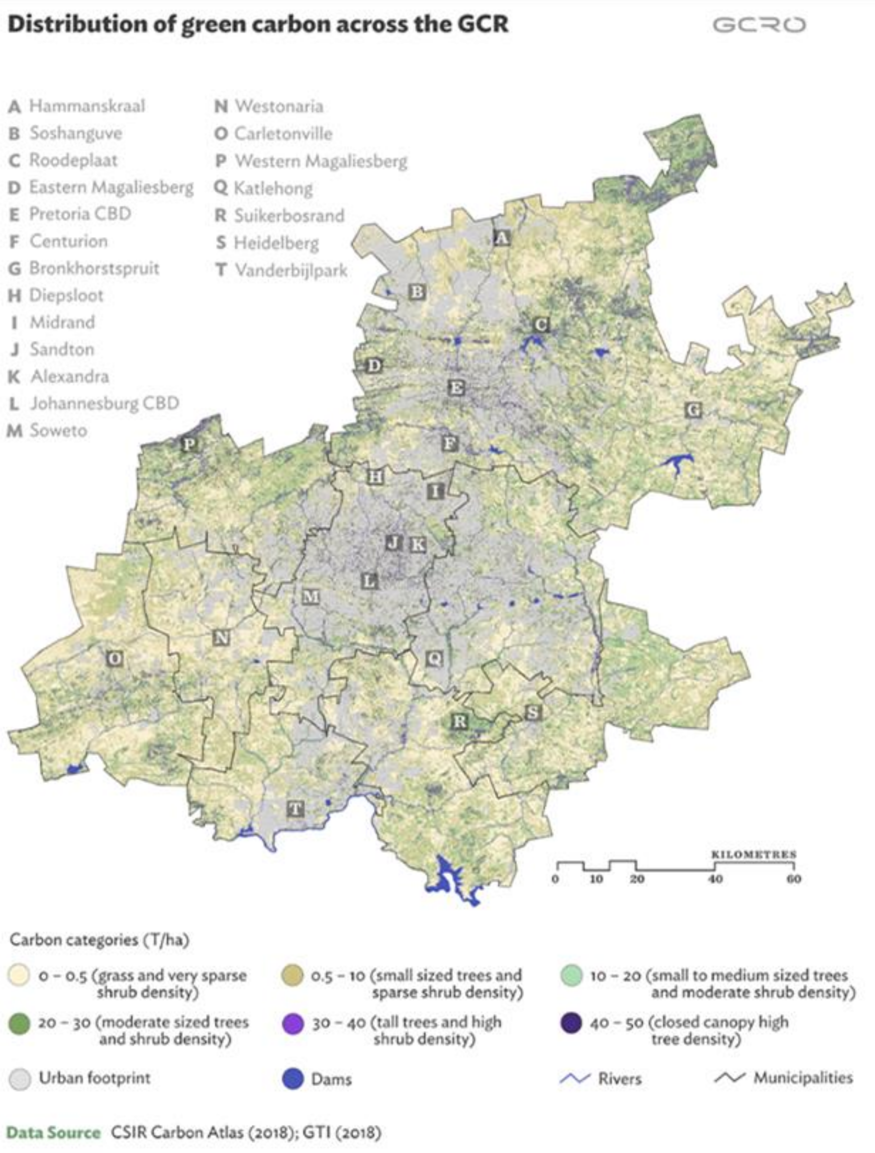
R^2	RMSE	SEP (%)	N
0.74	12.21	68.37	29105



- Similar pattern of under prediction of Green Carbon past the 15 T C/ha with a larger margin past 20 T C/ha
- Linked to potential saturation of the L-band

Green Carbon across Gauteng

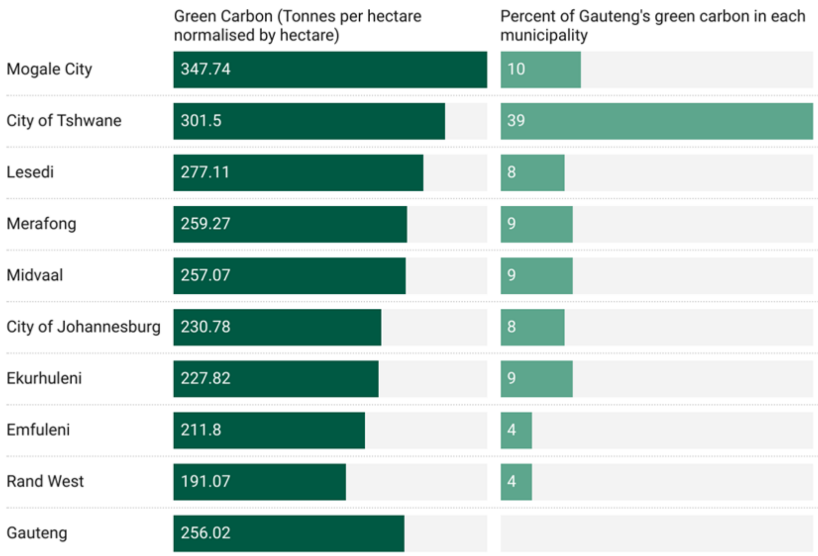
Results: Green Carbon distribution across the GCR



- Mogale City yielded the highest concentration of green carbon of 347.74 T/ha/ha than the City of Tshwane despite being 4 times smaller in area
- Emfuleni (the smallest municipality) yielded a higher concentration of green carbon than Rand West City which had the lowest overall (191.07 T/ha/ha)
- The City of Johannesburg yielded the highest percentages of both the closed canopy and tall trees/high shrub density classes which confirms the observation of the tall tree-lined streets of the northern suburbs

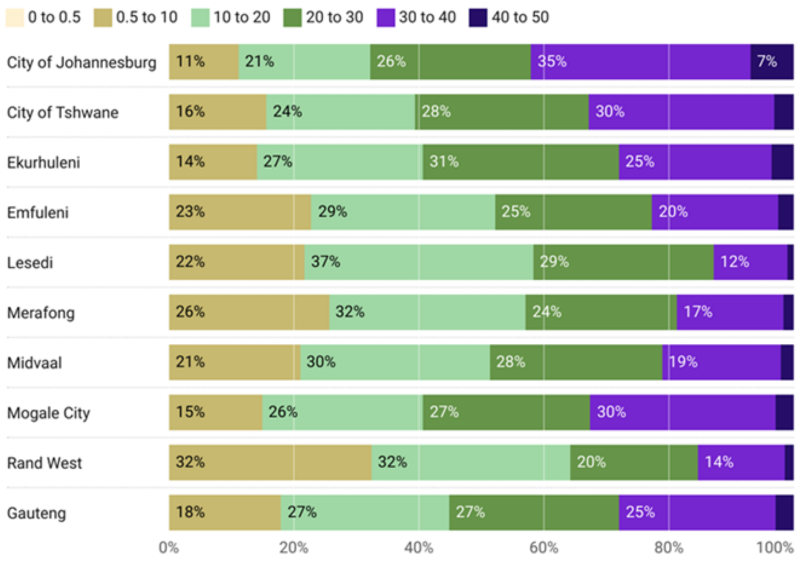
Total Green Carbon per Municipality normalised by area

Measure of the concentration of green carbon per municipality against the total proportion contribution to green carbon in Gauteng



Green Carbon categories per Municipality

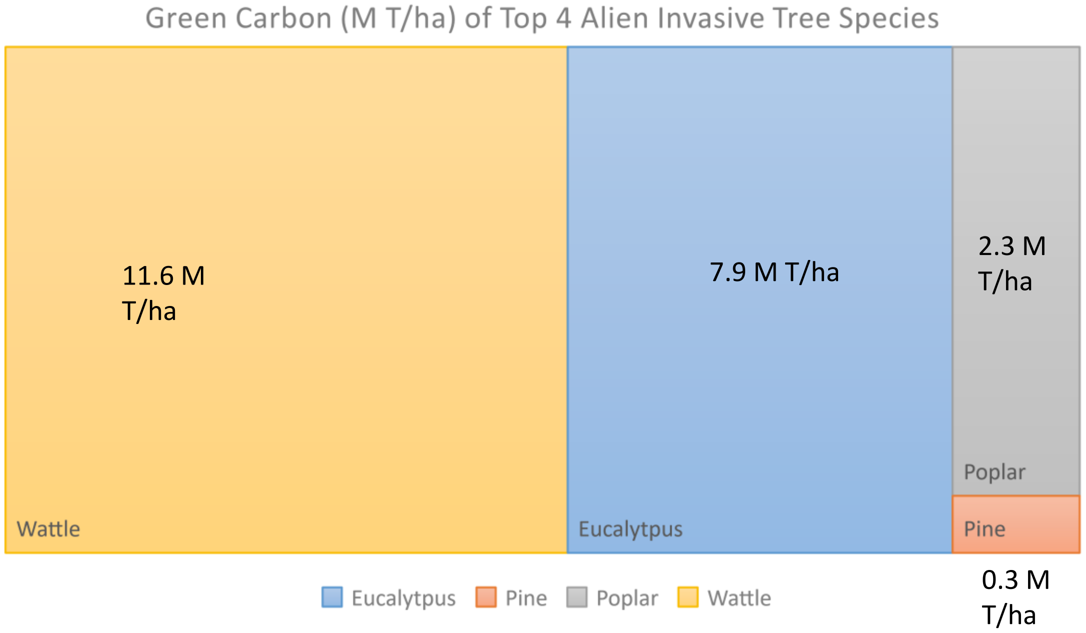
Proportional distribution of the type of green carbon at a municipal level

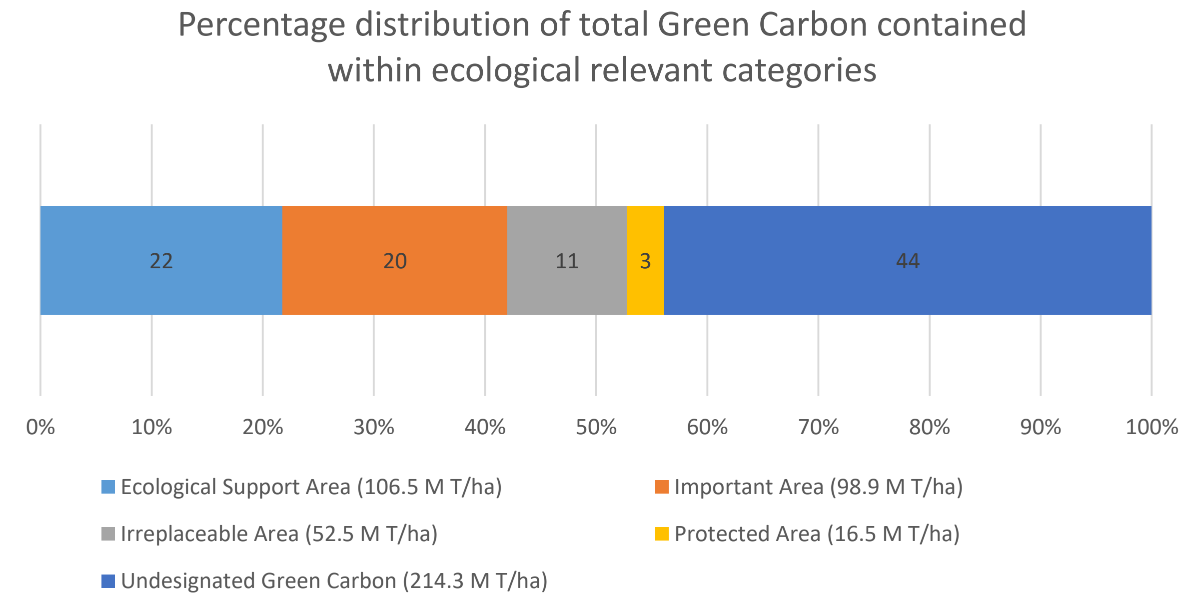


Units: Tonnes per hectare

Green Carbon across Gauteng

Results: Green Carbon distribution across Gauteng





- Wattle has the greatest store of green carbon (11.6 M t/ha) with Eucalyptus following second (7.9 M t/ha)
- Pine possesses the lowest amount (0.3 M t/ha)
- 5% of the total green carbon store consists of these top four mapped invasive species
- Debate of climate goals versus ecological threat

- A total of 56% of green carbon within the GCR was found in ecologically relevant areas though formal protection is minimal
- The significant remaining portion (44%) was found to be undesignated and undocumented which could lead to possible misappropriation.

Teal Carbon estimation across the GCR

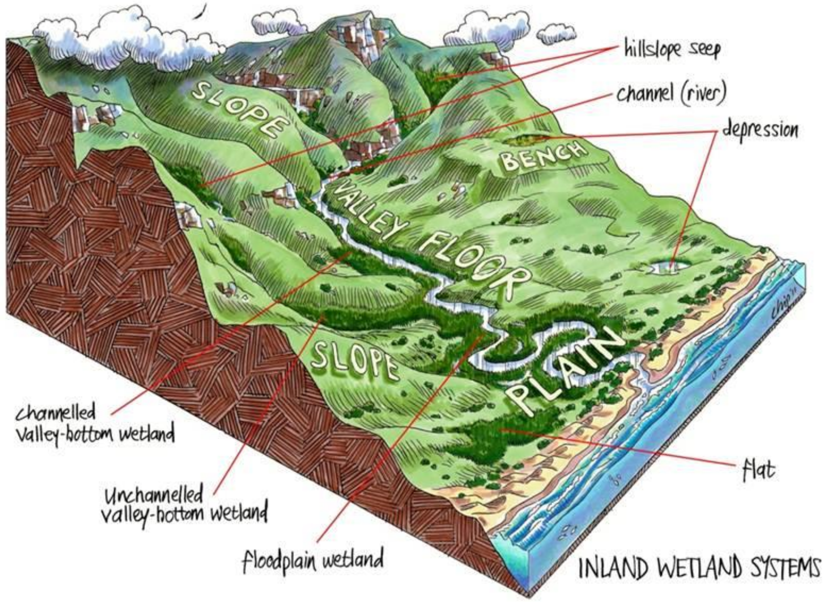
Research Objectives

- Teal carbon, i.e. carbon stored within wetland sedges, reed beds and grasses, occupies one of the smallest but most vital component of the terrestrial carbon budget.
- Teal carbon, despite occupying 5-8% of the global land surface holds up to 30% of the stored soil carbon (Mitsch & Gosselink, 2007) and are potential ‘super-sequesters’

Research Objectives:

- To map the spatial distribution of teal carbon (g C/m^2) across Gauteng using multi-seasonal and regional collected field data, Leaf Area Index (LAI) measurements and fused Sentinel-1 C-band SAR and Sentinel-2 optical imagery within a RF environment

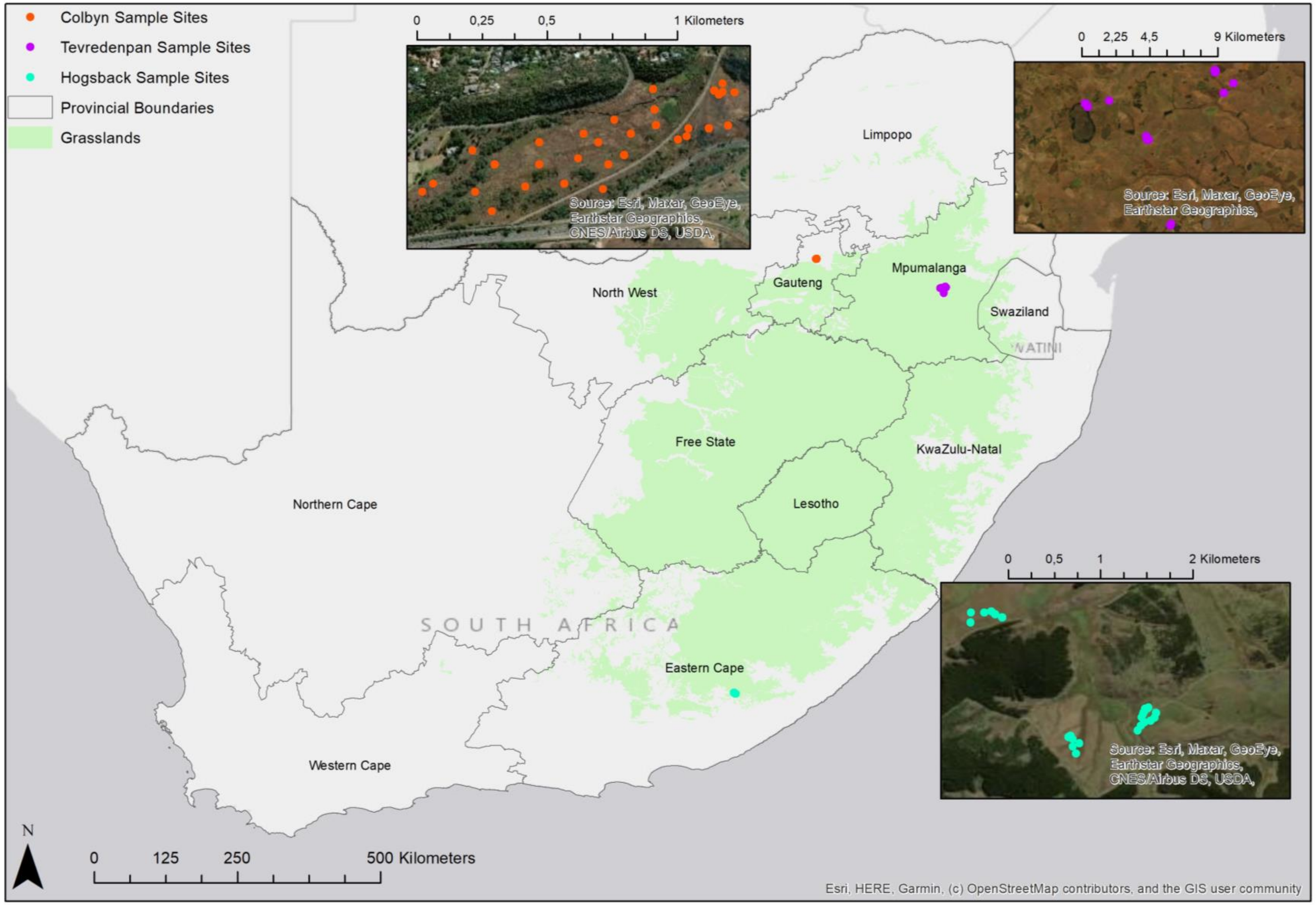
- To assess the distribution of teal carbon across various Hydrogeomorphic (HGM) unit types and ecological condition and threat level classes from the updated National Wetland Map 6



http://dx.doi.org/10.13140/2.1.3857.0248; Ollis et al., 2013

Study Areas

Collected Teal Carbon (g C/m^2) field samples (multi-seasonal where applicable) data statistics



*Colbyn Wetland – Gauteng (2022)

# Sites	Mean	Min	Max
36	421.7	110	1106

*Chrissiesmeer – Mpumalanga (2017)

# Sites	Mean	Min	Max
64	291.8	88.7	857.4

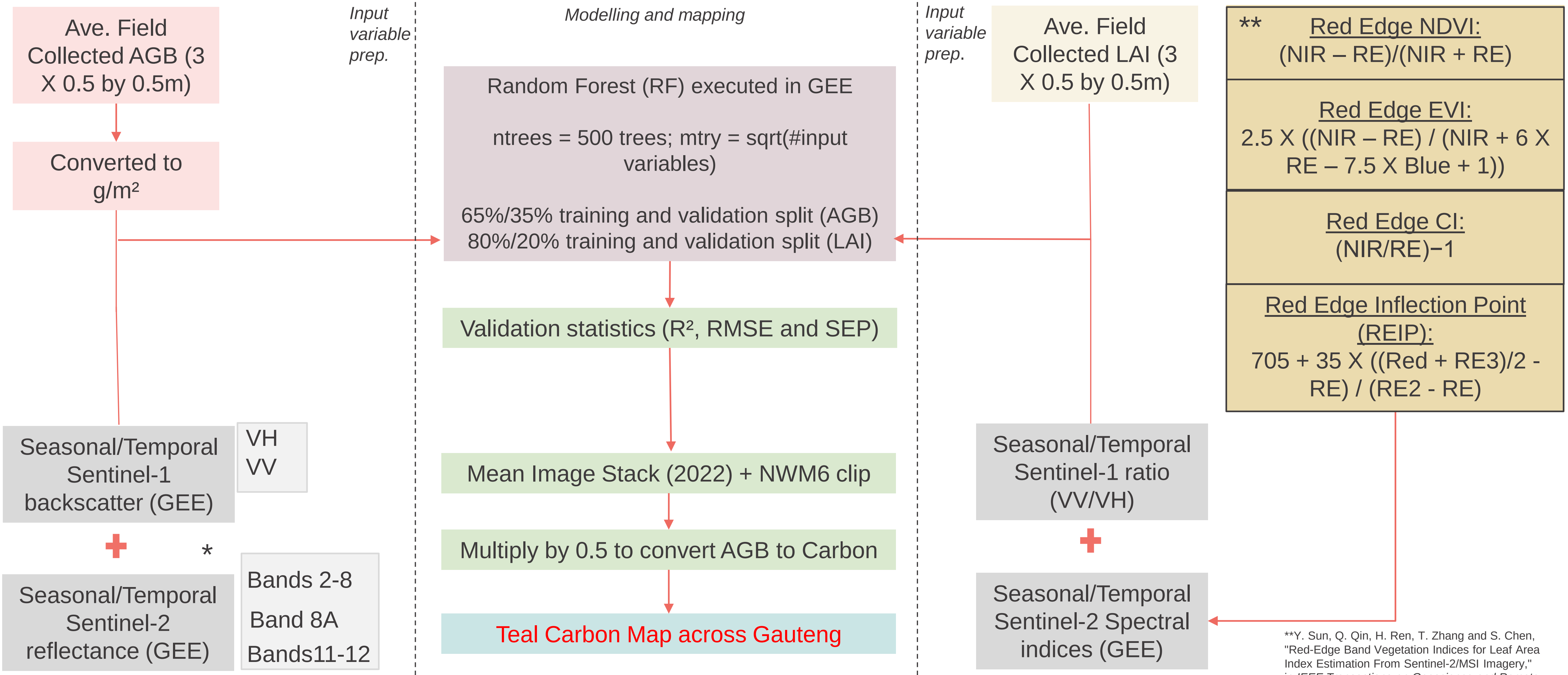
Hogsback – Eastern Cape (2017)

# Sites	Mean	Min	Max
30	196.6	26.8	452

*Summer and winter AGB samples collected

Teal Carbon estimation across Gauteng

Methodology Schema



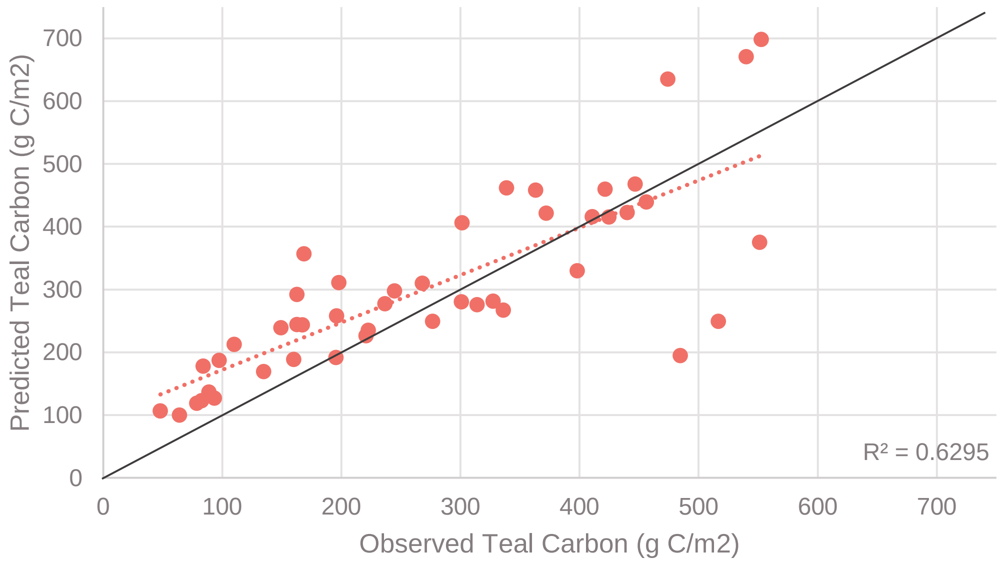
*Naidoo, L et al., 2019, Estimating above ground biomass as an indicator of carbon storage in vegetated wetlands of the grassland biome of South Africa, International Journal of Applied Earth Observation and Geoinformation, Volume 78, Pages 118-129

**Y. Sun, Q. Qin, H. Ren, T. Zhang and S. Chen, "Red-Edge Band Vegetation Indices for Leaf Area Index Estimation From Sentinel-2/MSI Imagery," in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 58, no. 2, pp. 826-840, Feb. 2020, doi: 10.1109/TGRS.2019.2940826.

Teal Carbon Modelling Validation Results

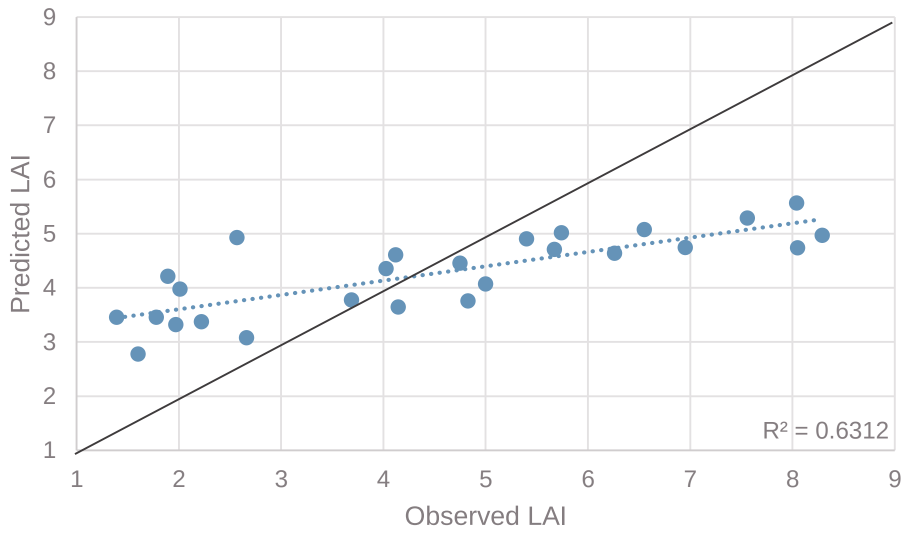
Key Findings

R^2	RMSE (g C/m²)	SEP (%)	N
0.63	98.07	35.58	46



- Marginal overestimation at low Teal carbon values (<400 g C/m²)
- More noticeable underestimation at high values (> 400 g C/m²)

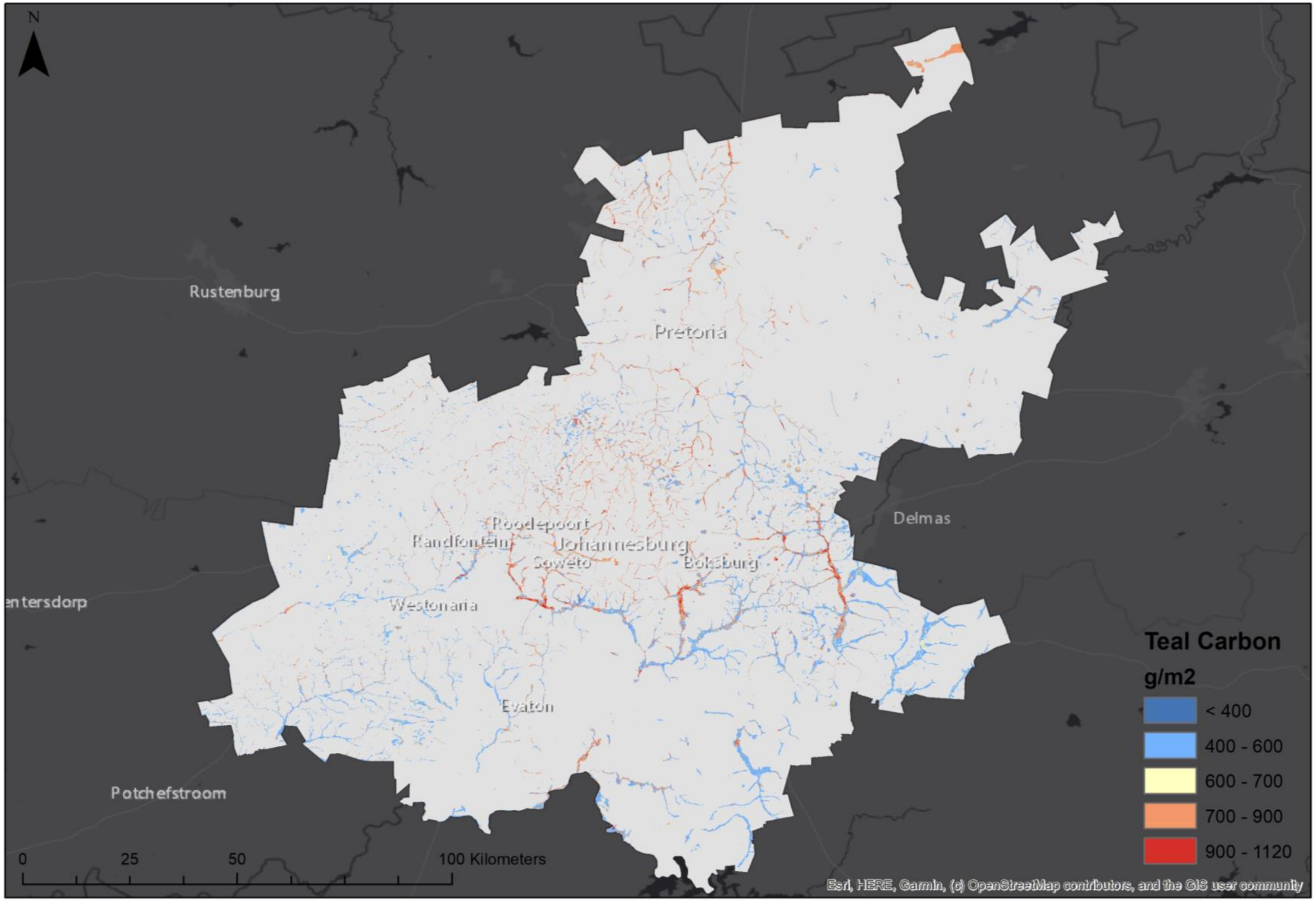
R^2	RMSE	SEP (%)	N
0.63	1.69	37.44	26



- Noticeable overestimation at lower LAI values (between 1 and 5)
- Noticeable underestimation at higher LAI values (> 5)
- Need to investigate alternative approaches (e.g. RTM/PROSAIL)

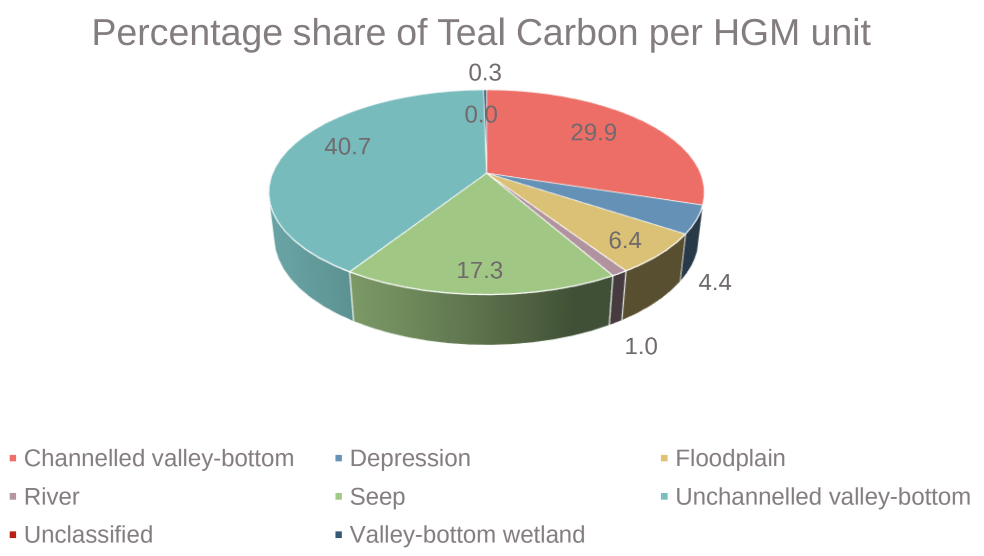
Teal Carbon distribution (g/m^2) across Gauteng

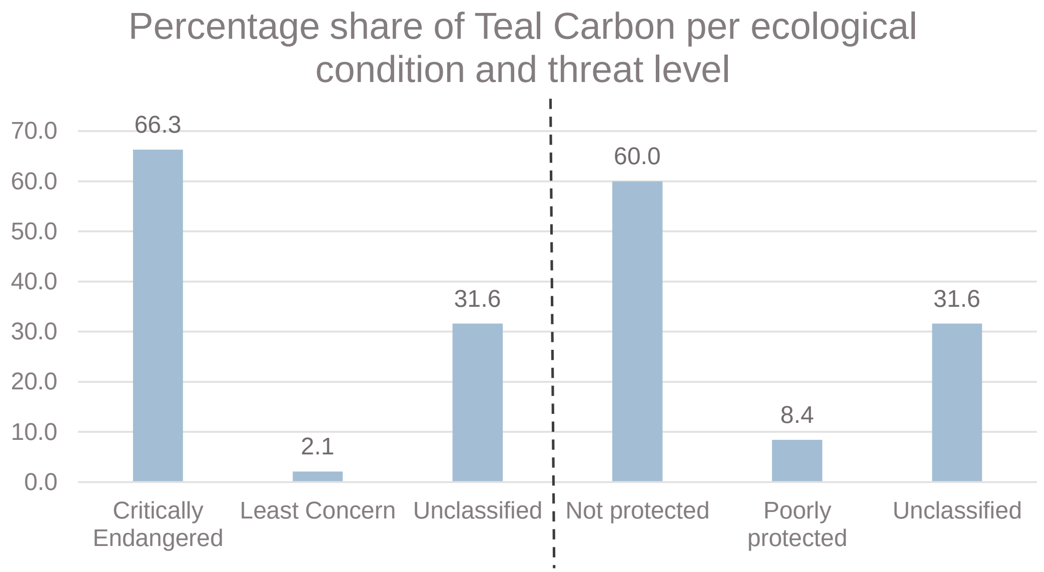
Map and Key Trends

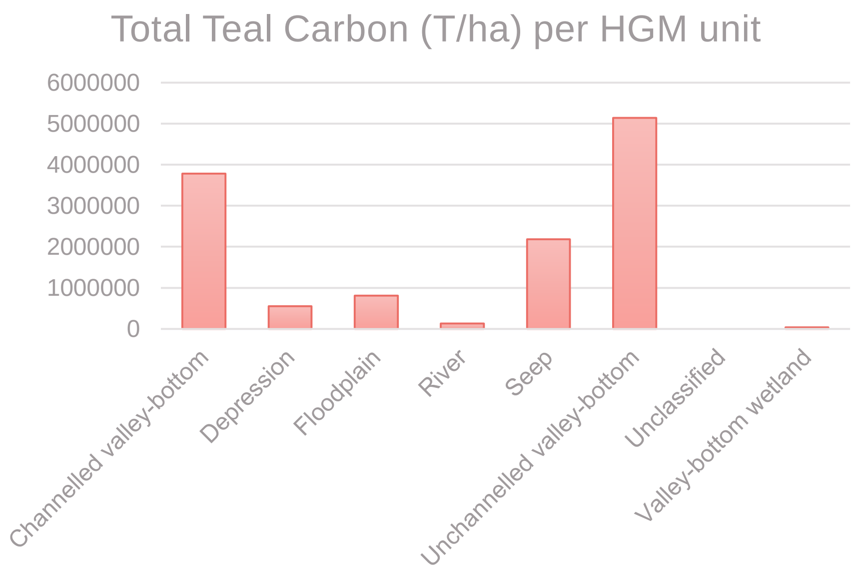


Hydrogeomorphic unit and Ecological Condition/Threat Analysis

Extracted teal carbon statistics







- Unchannelled and channelled valley-bottom occupy 41% (5.1 million t C/ha) and 30% (3.7 million t C/ha) of the total stored teal carbon pool across Gauteng (followed by Seeps with 17%)
- Between 60-66% of the stored carbon pool is not protected and critically endangered (average of 8 million t C/ha)

Conclusions

Key outcomes and ways forward

Conclusions:

- This study produced one of the first ever teal carbon map of Gauteng which, when combined with green carbon, accounts for a large amount of the terrestrial carbon store
- 44% of green carbon stores were found to be undesignated and undocumented which could lead to possible misappropriation
- Wattle occupies the most green carbon in terms of AIPs
- Approximately 8 million t C/ha out a total of 12.6 million t C/ha in teal carbon stores were not protected and are critically endangered

Ways forward for Teal carbon:

- Improvements of the LAI estimation using RTM approaches (e.g. PROSAIL)
- Experiment with model upscaling with airborne datasets (e.g. airborne SAR and optical drone imagery) to improve accuracies

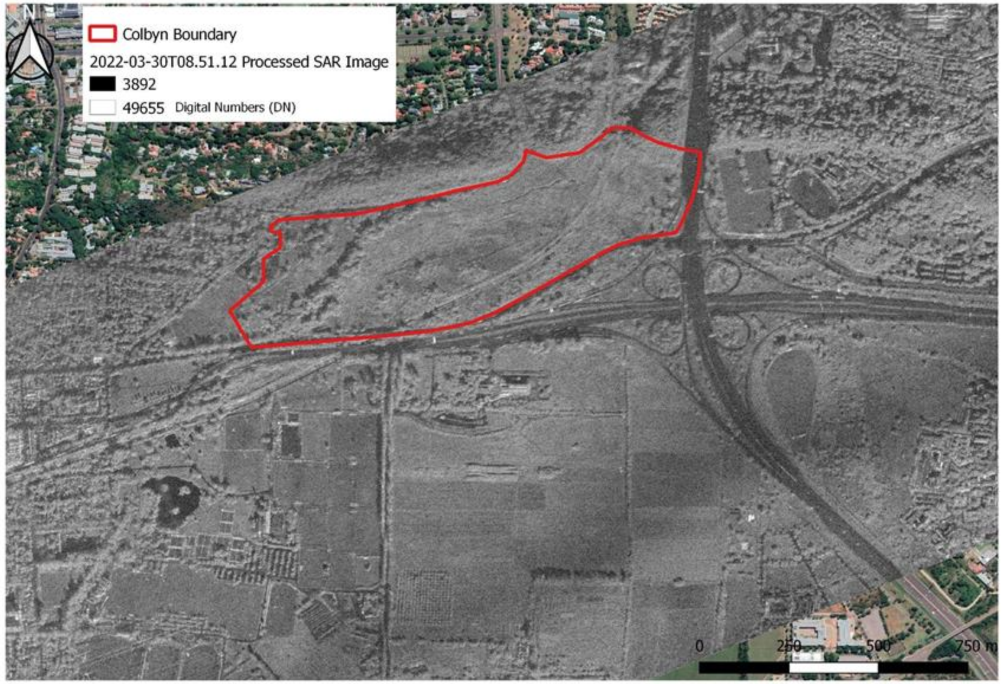
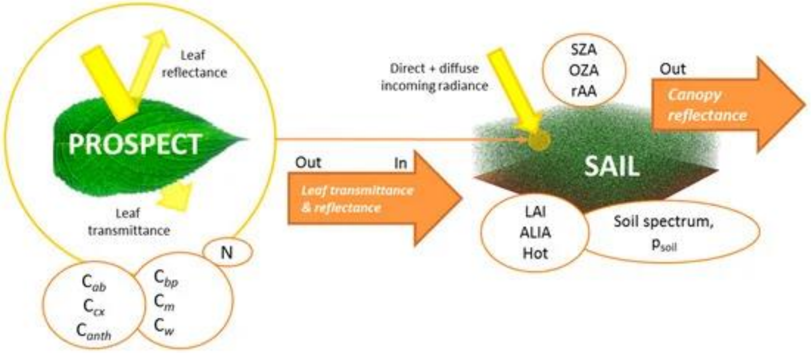


Image courtesy of the CSIR from the CSIR Airborne SAR campaign (2022)



https://www.mdpi.com/2072-4292/10/1/85; Berger et al., 2018

Thank you!

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