Quantifying the Extent and Rate of Changes in Wetland Types of the Maputaland Coastal Plain with Remote Sensing

Report to the
Water Research Commission

by

H Van Deventer[1,2], P Apleni[2] and K Nortje[1]

with contributions from

L Naidoo[1], P Tsele[2], I Aucamp[3], N Mhlongo[2], L Goso[2] and NB Ndlovu[2]
[1] Council for Scientific and Industrial Research (CSIR)
[2] University of Pretoria (UP)
[3] Equispectives Research and Consulting Services

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Water Research Commission
Bloukrans Building, Lynnwood Bridge Office Park
4 Daventry Street
Lynnwood Manor
PRETORIA

orders@wrc.org.za or download from www.wrc.org.za

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EXECUTIVE SUMMARY

RATIONALE

a) The importance of remote sensing to contribute to the monitoring and reporting of wetland ecosystem types

Globally, wetlands are considered the most threatened realm with rates of degradation considered faster than those of forests. In South Africa's last two National Biodiversity Assessments of 2011 and 2018, wetlands were found to be the most degraded and threatened realm, and poorly protected. To date, South Africa has an operational monitoring system for rivers, the River Eco-Status Monitoring Programme (REMP), yet lacks an operational monitoring system for wetlands. Earth Observation or remote sensing are considered Fourth Industrial Revolution (4IR) technologies that can contribute greatly to the monitoring of changes in wetlands and different types of wetlands. While open water (lacustrine) wetlands are currently well monitored with RS, the extent of different palustrine (vegetated) wetland types at a landscape scale is lacking. South Africa's previous reporting of the Sustainable Development Goal (SDG) indicator 6.6.1a in 2020 had high confidence in the extent of lacustrine wetlands, but changes in the extent of palustrine wetlands are deficient.

The results of several research projects, which tested remote sensing capabilities at local to landscape scales, showed promise for satellite images and derived products to contribute to temporal monitoring of wetlands at both these scales. These studies were, however, limited to only a few snapshots in time, and further work is required to assess the capabilities of remote sensing in quantifying the extent and rate of changes in freshwater ecosystems, especially different palustrine wetland types, at a landscape scale. While changes in the extent and rates of change have been done at a national scale for terrestrial ecosystems, the results were ineffective in quantifying changes in wetlands effectively.

The ability to detect and report changes in the extent of different palustrine wetland types would not only improve the reporting of SDG 6.6.1, but also facilitate reporting to targets 1, 2 and 3 of the new Global Biodiversity Framework (GBF), due in 2030 by member countries of the Convention on Biological Diversity (CBD). These targets are related to losses, restoration and protection of ecosystem types, respectively. Quantifying rates of change could also inform the Red Listing of Ecosystems (RLE) and contribute to improved management of these resources, facilitate the implementation of adaptation strategies, building resilience to climate change and anthropogenic impacts and prioritising interventions.

b) The value of using the Maputaland Coastal Plain as a case study area

The Maputaland Coastal Plain (MCP) presents a variety of forested, grass, sedge, and open water wetland cover types that have been surveyed by botanists and earth observation specialists at local scales. The wetlands transition from freshwater to estuarine systems in this sandy, coastal, aquifer-dependent ecosystem. Several pressures impact the MCP wetlands negatively, ranging from water abstraction, alien invasive tree species, exotic timber plantations, and slash-and-burn of forested wetlands to access peat for farming, while uncertainties prevail on the further impact of climate change within this region. Owing to the scale of the anthropogenic and climate change impacts across the landscape, and the limitations in accessing parts of the MCP, remote sensing can play a key role in quantifying and determining the extent and rate of change in wetlands and their catchments for the MCP, and potentially, the types of land covers resulting from anthropogenic impacts. This project therefore primarily aims to investigate the appropriate categories of wetland types to use for monitoring these systems with remote sensing at a landscape scale.
In addition, changes in the landscape occur within a social context, and to supplement the output from the remote sensing component, a social component was added to facilitate knowledge exchange between the

remote sensing outputs and the stakeholders. With the addition of the social component the project also contributes to the growing body of research that utilises the intersectionality of bringing narrative analysis together with earth observation and remote sensing to produce contextually relevant and locally embedded research, and research outputs. The social component of the research is focussed on understanding the perceptions, beliefs, and attitudes of different stakeholders of the biodiversity and conservation of wetlands.

AIM AND OBJECTIVES

The aim of this research project was to quantify the rate of change of different wetland types on the MCP using remote sensing. In addition, a subcomponent of the work also aimed to understand the social context of these changes, through enabling stakeholder engagement and communication through sharing the remote sensing product output with these stakeholders.

The objectives of the project were :

1. Compilation of an inventory of available *in situ* coordinates for wetland cover types;
2. Evaluation of the possible wetland classes that could be used in (optical) change detection for the MCP;
3. Learning exchange between earth observation products and local stakeholders for knowledge co-production;
4. Quantifying the areal extent, rate, and types of change observed for wetlands on the MCP; and
5. Strategic framework for the inclusion of earth observation products and community engagement in the National Wetland Monitoring Programme (NWMP).

The outputs showed that the Landsat and Sentinel-1 and -2 sensors were able to distinguish lacustrine and palustrine wetland Ecosystem Functional Groups (EFGs) with high accuracies across the seven years. In addition, for the first time, the types, geographic location, and rate of changes were also quantified in a consistent manner for the whole of the MCP. The outputs included a geodatabase with layers showing the extent of six wetland EFGs predicted with remote sensing for seven years that had above-average rainfall between 1981 and 2022. The wetland EFGs included two estuarine classes, Coastal saltmarshes and Intertidal forests and shrublands (mangroves), and four freshwater classes, Lacustrine wetlands, Large macrophytes, Permanent marshes, Seasonal marshes and Subtropical temperate forested wetlands (including swamp, riverine and floodplain forests). The extent of these classes was mapped for 1990, 2000, 2006, 2014, 2018, 2020 and 2022. A map was also generated comparing the outputs of 1990 and 2022, and showing three categories: (i) where the wetland EFGs remained the same type, (ii) where it changed from one wetland EFG type to another; and (iii) where it transformed from a wetland EFG to land uses associated with anthropogenic impacts.

METHODOLOGY

1. A literature survey was undertaken together with a data collection of spatial data related to the wetland types of the MCP. Our focus was on collating *in situ* data that would qualify as regions of interest (ROIs) to use in the remote sensing classification of the MCP's wetland types.
2. The literature review included consideration of the typology of the International Union for Conservation of Nature (IUCN) to inform the framework of wetland ecosystem functional groups (EFGs) to monitor, but to supplement these with the literature and studies done on the MCP to see the scale at which ecosystems are negatively influenced. The literature review also contributed to the types of transformation classes to use to map different types of degradation in the remote sensing, so we can test whether space-borne satellite images would suffice in the detection and monitoring of wetland ecosystem types and transformation classes.

3. The first step as part of the social component is to establish a trust relationship with the local community that the study will engage with. This was initiated with the team presenting the project to the local communities and asking for permission to work with the relevant Traditional Authorities and speak to people. The approach for stakeholder engagement is based on a qualitative methodology that enables the team to elicit information from different stakeholder groups through qualitative methods such as semi structured interviews and focus group discussions.
4. Changes in the extent and rate of wetland EFGs were assessed using freely available, space-borne sensors between 1990 and 2022. Images from the Landsat series of sensors between 1990 and 2014, as well as the Sentinel-1 radar and Sentinel-2 optical images, were used to assess the changes of the seven wetland EFGs. The outputs were generated for seven years that showed above-average rainfall, and where the maximum extent of all wetland EFGs would be visible. The Google Earth Engine (GEE) platform was used to facilitate the classification.
5. The Convention on Biological Diversity's (CBD's) monitoring framework for the Global Biodiversity Framework of 2030 and 2050 (CBD, 2022c) were investigated for use by South Africa for monitoring changes in wetland EFGs on the MCP. To date, the use of remote sensing and social studies has yet to be implemented in the National Wetland Monitoring Programme (NWMP) for reporting of changes in the extent of wetland EFGs.

RESULTS

The literature review indicated that multiple small-scale studies were done across the MCP, however, were incomplete in considering the full extent of comparable wetland EFGs across the whole, interconnected Aquifer Dependent Ecosystems (ADEs) landscape (Chapter 2). Historical studies contributed greatly to the understanding of natural growth in the landscape (e.g. forested wetlands), the types of transformations and pressures that exist, and current monitoring taking place by authorities. It was clear from the literature review that a full landscape study has not yet been undertaken to evaluate the changes in all seven wetland EFGs over a period of 32 years.

In-field validation and discussion with landowners also provided new information on the changes in the extent of the seven wetland EFGs (Chapter 3). Invasive plant species were not always extensive enough for detection and monitoring with the freely available, space-borne Landsat and Sentinel series of sensors. From our site visits, it was clear that for woody invasive plant species, airborne or drone images with a spatial resolution < 2 m would be critical to monitor changes in the extent of the woody invasive plant species. Invasive shrub and herbaceous species could benefit from drone images, however, infield identification and treatment by private and public landowners may just be the quickest and most effective way of monitoring and intervention. Aquatic invasive species were found to be very localised and already under intervention programmes. Sample points were collected from south to north on the MCP, with a key focus on the Indian Ocean Coastal Belt Biome, where a higher occurrence of all seven wetland EFGs were found.

The social interactions with community members from the Mbaso and Tembe TAs were undertaken in collaboration with the South African Environmental Observation Network (SAEON) team (Chapter 4). The engagements were held with groups of people from these TAs, while additional interviews were also held with a group of people farming in a wetland, and other individuals who are also dependent on food production from wetlands in their vicinity. It was clear that multiple users benefit from the wetlands in various ways, from direct, infield food production to a level of detached tourism where it forms a landscape setting that is attractive. Concerns around changes in the extent of wetlands varied: some community members, especially elders, were quite concerned, noting a drying trend and losses of wetlands. Others were not as concerned, but confident that there were four generations that have survived from cultivating wetlands, and the next three generations could continue with this way of farming. A group of cultivated wetland farmers physically showed the decline of the boundary of saturated soils and how this reduced in extent over time. Conflicts were observed from the interactions between different land users, but also within communities. Some spoke about forced removals by their leaders, saying that the leaders benefitted from selling the land for conservation, while they were simply chased away overnight. A few individuals from another location mentioned that their leaders still benefit hugely from conservation, while they struggle to find (wet peat) land to provide for themselves.

The remote sensing work was done by Mr Philani Apleni from the University of Pretoria as part of his MSc dissertation in Geoinformatics (Chapter 5). The results show that the total wetland extent of the MCP has declined from 1 420 (17% of the extent of the MCP) to 1 150 km² (14% of the extent of the MCP) between 1990 and 2022. In 2000, after cyclone Eline, a maximum extent of 1 625 (20% of the extent of the MCP) was recorded, which will imply that the decrease was 6% of the extent of the MCP in the past 22 years. The extent of wetlands varied for the other four of the seven years across the 32-year period (2006, 2014, 2018 and 2020). The overall accuracies of the GEE classifications were >78% for all years, whereas the user's accuracies for the seven wetland EFGs across all years were >74%. The six palustrine wetland EFGs showed a decrease in extent across the seven years. Between 1990 and 2022, 53% of the extent of the seven wetland EFGs remained the same, 39% changes to other natural cover type classes, and 8% changes to anthropogenic classes, such as cultivated wetlands. Four out of the six palustrine wetland types, namely, Intertidal forests and shrublands (mangroves), Permanent marshes, Seasonal marshes, and Subtropical-temperate forested wetlands, show that they will reach total collapse by the late 2040s if they continue at the current rate of change.

The Global Surface Water Product mapped 619 km² (7.6%) of wetlands for the extent of the MCP, predominantly as lacustrine wetlands, for reporting to the SDG 6.6.1a indicator. South Africa reported the extent of wetlands from National Wetland Map version 5, which mapped 12% of the MCP as freshwater wetlands, and another 12% as the Estuarine Functional Zone (EFZ), that included terrestrial and transformed land, in addition to estuarine and freshwater ecosystems within the EFZ. At the time of reporting in 2020, the correct extent of the lacustrine and palustrine wetland biomes, and changes in this over time, were not known for the extent of South Africa or the MCP. The outputs of the remote sensing work in this report, showed that most of the wetlands on the MCP were palustrine wetlands, totalling 907 km² (64% of the MCP's wetlands) in 1990, and declined to 513 km² (57% of the MCP wetlands) in 2022. The lacustrine wetland biome of the MCP totalled 513 km² (36% of the MCP wetlands) and declined to 498 km², which now constituted a larger percentage, or 43% of the MCP wetlands in 2022, owing to a loss in total extent of wetlands.

DISCUSSION

The Global Biodiversity Framework's (GBF's) monitoring framework (CBD, 2022c) is suitable to be adopted by South Africa for biodiversity reporting, and the indices should be explored for reporting at various scales over time (Chapter 6). Overall, the most important recommendation is that the mobilisation, centralisation and integration of available information for target reporting on wetland ecosystems extent, ecological condition, connectivity and changes in these, should be implemented to facilitate reporting to Goal A of the GBF. Multiple organisations are contributing to collection of physical variables and ecosystem extent that can be used for both the NBAs and GBF reporting. It is recommended that the Department of Forestry, Fisheries and the Environment (DFFE) coordinate and facilitate the collection and integration of ecosystem information for reporting. Remote sensing is a critical tool to consider in the monitoring of the MCP, at drone, airborne and space-borne levels. Because of the interconnectivity of the wetlands through the sandy ADE groundwater upwelling regions, it is critical to monitor the whole landscape to assess the impacts over time.

The outputs generated for the GBF target 1 which can be summarised to the wetland biome level for lacustrine and palustrine wetlands, respectively, and changes in the extent of these reported to the SDG indicator 6.6.1a by DWS through Statistics South Africa. Refinement of the first assessment of these biomes (Van Deventer, 2021) would be critical to overcome the coarse-scale limitations of the initial modelling. The Landsat and Sentinel spatial resolutions of 30 and 10 m, respectively, proved sufficient for quantifying changes in these two biomes for the MCP. Further work is required to assess the feasibility of these sensors for other non-ADE inland regions of South Africa, where some of the wetland EFGs may not be as extensive as on the MCP.

Remote sensing is an important tool that can contribute to monitoring, assessment, reporting and planning within the National Wetlands Monitoring Programme (NWMP). This study demonstrated the capabilities of two space-borne sensors in monitoring the extent of lacustrine and palustrine wetland EFGs over time. The required spatial resolution for other regions, and the temporal frequency of monitoring, remains to be assessed in different parts of the country. The use of aerial and drone images for validation, refinement of biodiversity types, transformations and degradation remains to be assessed for both the MCP and other wetlands of South Africa.

SHORT SUMMARY RESULTS

- **Remote sensing offers a valuable tool for monitoring and quantifying changes in the extent of different wetland EFGs, especially palustrine wetlands at a landscape scale for the MCP**. The use of the Sentinel-1 and -2 images were found to be suitable for future monitoring of the six wetland EFGs in the future, based on the current outputs generated in this study. Future work requires the assessment of finer spatial resolution images, to assess the potential improvements to the current work. Drone images can contribute to the validation of particular sites, classes, or improved quantification of the extent, characteristics and degradation of these six wetland EFGs.
- **The rate of change across the seven years showed a concerning decline in the extent of wetland EFGs on the MCP, and potential collapse by 2040 for most of the classes**. This trend concurs with the degradation previously reported by other studies on peatlands that has increasingly become degraded and desiccated on the MCP, and in some instances are continuously burning, even during wet years such as 2022. The results therefore indicate that the MCP has reached a tipping point and requires urgent intervention to change the trajectory of intervention(s) as soon as possible. The DWS and DFFE indicated that they intend to incorporate the results in their resource classification under the National Water Act (NWA), water use license applications (WULA) and Environmental Impact Assessments (EIAs) and Working for Wetlands priorities for the next cycle of 2024 onwards. SANBI would consider the rates of change and extent of change for RLE, following previous recommendations that the Forested wetlands qualify as a Red Listed Ecosystem.
- **Hotspots of change occurred within and outside protected areas**. The localities and types of these changes will be communicated to the relevant conservation authorities early in 2024 to prioritise areas of intervention. Further work is required to assess if interventions to remove illegal timber plantations can restore groundwater levels, and whether subsequent passive restoration would be adequate to restore certain wetland EFGs, or whether intervention(s) will be required. This finding also raised the fact that ecological condition and degradation were not considered and reported to target 3 of the GBF, and it is suggested that DFFE provide feedback and a strong recommendation on the indicator of protection levels, rather than using the Ecosystem Protection Level (EPL) assessment of South Africa's National Biodiversity Assessments (NBAs).

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

Overall, the most important recommendation is that the mobilisation, centralisation and integration of available information for target reporting on wetland ecosystem extent, ecological condition, connectivity and changes in these, should be implemented to facilitate reporting to Goal A of the GBF and SDG 6.6.1a. Multiple organisations are contributing to collection of physical variables and ecosystem extent that can be used for both the NBAs and GBF reporting. It is recommended that DWS, DFFE and SANBI coordinate and facilitate the collection and integration of ecosystem information for reporting.

Recommendations for future research:

- Validation with finer spatial resolution optical and radar images would inform the representivity and errors of the freely available Sentinel sensors in quantifying changes in the extent and ecological condition of the wetland EFGs.
- Floral species composition across the landscape should be investigated for the wetland EFGs. A great variation was observed across the latitudinal, longitudinal and elevation gradients. It may be that vegetation communities are more unique in some areas, and not part of a larger extensive wetland EFGs, as was represented in remote sensing. For example, the occurrence of some wetland tree species varied from south to north, and *B. viiimergent* formed denser stands towards the border with Mozambique, compared to systems near the Tugela River.
- The relationship between wetland EFG occurrence, species composition and fire regimes are also not well understood. Near the Tugela River, Forested wetlands showed expansion as a result of fire suppression in the landscape, and a general increase in canopy cover in the terrestrial parts of the Indian Ocean Coastal Belt that used to be predominantly grass cover. At the same time, the functional role of these systems to provide resilience against extreme climatic events should also be considered, rather than aiming for restoration calculated in reference to a 1750 extent that existed under different climatic conditions and anthropogenic pressures.
- The relationship between the trends in temperature and rainfall patterns, resulting from climate change, should be further investigated. In addition, the impact of transformation to other land uses, particularly the extent of timber plantations, should be assessed to improve environmental flow determination, and resource classification for a potentially drying ADE.
- The effectiveness of passive versus active restoration can be tested once groundwater levels are restored to a more resilient level.

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Collaborators:

Person	Affiliation	Respective projects (where relevant)
Dr Althea Grundling	Agricultural Research Council: Soil, Climate and Water (ARC:SCW)	WRC Project #: 2019/2020-00098 Determine peat loss and develop management and rehabilitation protocols for peatlands in South Africa
Dr Piet-Louis Grundling	Department of Forestry, Fisheries and the Environment (DFFE)	
Ms Susan Janse van Rensburg	South African Environmental Observation Network (SAEON)	WRC Project #: C2020/2021-00430 Advancing water and income security in the unique Maputaland Coastal Plain: A strategic decision-support tool to explore land use impacts under a changing climate

Steering Committee Members (alphabetic by surname):

Person	Affiliation
Mr Salomão Bandeira	Eduardo Mondlane University, Mozambique
Dr Kurt Barichievy	KwaZulu-Natal Agriculture & Rural Development (KZN DARD)
Mr Johan Bester	DFFE, Forestry Directorate
Mr Retief Grobler	Imperata Pty Ltd
Dr Debbie Jewitt	Ezemvelo KwaZulu-Natal Wildlife (EKZNW)
Ms Nancy Job	South African National Biodiversity Institute (SANBI)
Mr Elijah Mogakabe	Department of Water Affairs and Sanitation (DWS), Monitoring programmes
Mrs Esmeralda Ramburran	Department of Forestry, Fisheries and the Environment (DFFE), Operational Planning and Support Directorate
Dr Wietsche Roets	DWS
Dr Lulu van Rooyen	University of KwaZulu-Natal (UKZN)
Dr Carina van Zyl	University of Johannesburg (UJ)

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    - The Mbasa Traditional Council has granted permission on 7 June 2021 (Appendix A);
    - The Tembe Traditional Council has granted permission to work in their area on 8 June 2021; and
    - Ezemvelo KwaZulu-Natal Wildlife has approved the project application for a permit.
    - The iSimangaliso Wetland Park Authority has approved the project application for a permit.
- The United States Geological Survey (USGS) provides free access to the Landsat series of images since 1984 to the public for use. The European Space Agency's (ESA's) free, full and open data policy for the Copernicus programme, including Sentinel satellite sensors' data, has enabled the remote sensing component of this project.

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ACRONYMS & ABBREVIATIONS

4IR	Fourth Industrial Revolution
ADE	Aquifer-dependent ecosystems
AGB	Above Ground Biomass
ARC	Agricultural Research Council
BON	Biodiversity Observation Network
CS-TFW	Coastal subtropical-temperate forested wetlands
DFFE	Department of Forestry, Fisheries and the Environment
DGPS	Differential Global Positioning System
DWS	Department of Water and Sanitation
EBV	Essential Biodiversity Variables
EFG	Ecosystem Functional Group
EFTEON	Expanded Freshwater and Terrestrial Environmental Observation Network
EFZ	Ecosystem functional zone
EKZNW	Ezemvelo KwaZulu-Natal Wildlife
EO	Earth Observation
ESA	European Space Agency
FBIS	Freshwater Biodiversity Information System
FW BON	Freshwater Biodiversity Observation Network
GEOBON	Group on Earth Observations Biodiversity Observation Network
GIS	Geographic Information System
GMT	Greenwich Mean Time
GPS	Global Positioning System
GSWE	Global Surface Water Explorer
HGM	Hydrogeomorphic (wetland types)
HV	Horizontal-Vertical (polarised data of SAR)
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
LAI	Leaf Area Index
LiDAR	Light Detection And Ranging
LULC	Land Use and Land Cover
MAP	Mean Annual Precipitation
MCP	Maputaland Coastal Plain
NASA	National Aeronautics and Space Administration
NBA	National Biodiversity Assessment
NDVI	Normalised Difference Vegetation Index
NDWI	Normalised Difference Water Index
NEM:BA	National Environmental Management: Biodiversity Act
NEMP	National Eutrophication Monitoring Programme

NLC	National Land Cover
NRF	National Research Foundation
NWA	National Water Act
NWM	National Wetland Map
NWMP	National Wetland Monitoring Programme
OA	Overall Accuracy
PG	Parliamentary Grant
REMP	River Eco-Status Monitoring Programme
RLE	Red listing of ecosystems
RMSE	Root Mean Square Error
ROI	Region of Interest
RS	Remote Sensing
RSA	Republic of South Africa
SA BON	South Africa's Biodiversity Observation Network
SAEON	South African Environmental Observation Network
SANSA	South African National Space Agency
SAR	Synthetic Aperture Radar
SDG	Sustainable Development Goal
SMC	Soil Moisture Content
SPOT	*Satellites Pour l'Observation de la Terre*, French for 'Earth-observing Satellites'
SWSA	Strategic Water Source Areas
VI	Vegetation Indices
VV	Vertical-Vertical (polarised data of SAR)
WRC	Water Research Commission
WV	WorldView multispectral sensor

GLOSSARY

Climate change: A change in global or regional climate patterns, in particular a change apparent from the mid to late 20th century onwards and attributed largely to the increased levels of atmospheric carbon dioxide produced using fossil fuels.

Earth Observation: Is the gathering of information about the Earth's surface's physical, chemical and biological systems via remote sensing technologies supplemented by earth surveying techniques, encompassing the collection, analysis and presentation of data (European Union Science Hub, 2021).

Ecosystem Functional Group: the third division of the IUCN ecosystem typology for each realm under the biome level that refines the typology along environmental gradients (Keith *et al.*, 2020).

Field spectroscopy: The quantitative measurement of radiance, irradiance, reflectance, or transmission in the field / on the ground.

Global change: '… usually refers to the broad suite of biophysical and socioeconomic changes that are altering the functioning of the Earth System at the global scale. In essence, it refers to the remarkable change in the human-environment relationship that has occurred over the last few centuries. Global change encompasses change in a wide range of global scale phenomena: population; the economy, including magnitude and distribution; resource use, especially for production of energy; transport and communication; land use and land cover; urbanization; globalization; coastal ecosystems; atmospheric composition; riverine flow; the nitrogen cycle; the carbon cycle; the physical climate; marine food chains; and biological diversity … .' (Steffen *et al*., 2004:10).

Habitat: a place where plants or animals normally live, characterised primarily by its physical features (topography, plant or animal physiognomy, soil characteristics, climate, water quality, etc.) and secondarily by the species of plants and animals that live there (Bogaart *et al.*, 2019)

Hyperspectral (imaging): Data collected in a high number (> 100) of continuous narrow (1-2 nm) spectral bands across the electromagnetic spectrum.

Indicator: A measurable attribute used in monitoring (Noss, 1990).

Knowledge exchange: a process that brings together different stakeholders from diverse backgrounds to increase the relevance and impact of research. This process is characterised by participatory methods and events that facilitate the open sharing of ideas, experiences and data towards the ultimate benefit of all parties.

Lacustrine wetlands: 'The Lacustrine System … includes wetlands and deepwater habitats with all of the following characteristics: (1) situated in a topographic depression or a dammed river channel; (2) lacking trees, shrubs, persist emergents, emergent mosses or lichens with greater than 30% areal coverage; and (3) total area exceeds 8 ha (20 acres). Similar wetland and deepwater habitats totalling less than 8 ha are also included in the Lacustrine System if an active wave-formed or bedrock shoreline feature makes up all or part of the boundary, or if the water depth in the deepest part of the basin exceeds 2 m (6.6 feet) at low water. Lacustrine waters may be tidal or nontidal, but ocean-derived salinity is always less than 0.5 ‰' (Cowardin *et al.,* 1979:11).

Land conversion vs land degradation: Land conversion refers to the process of converting a natural ecosystem to another land use (Fisher *et al.* 2018) and land degradation, on the other hand, refers to the continuous, '… persistent changes in ecosystem services, function and biodiversity' (Fisher *et al.* 2018:19).

LiDAR: A type of 3-dimensional imaging technology. Usually mounted on an aircraft, the LiDAR sensor sends light pulses to the earth surface and measures the time until the reflected signal returns to the sensor. From the elapsed time, the distance between the airborne sensor and the earth surface, information on ground elevation and vegetation canopy structure are derived. A common product is a fine scale Digital Elevation (or Surface) Model which can be used for further geospatial analysis.

Local and indigenous knowledge systems (LINKS): Local and indigenous knowledge refers to the understandings, skills and philosophies developed by societies with long histories of interaction with their natural surroundings. For rural and indigenous peoples, local knowledge informs decision making about fundamental aspects of day-to-day life. (https://en.unesco.org/). Local knowledge can be understood as the unique knowledge that is held by a particular group of people over time in order to understand the world they live in. Local knowledge is also shaped by social and cultural traditions therefore the knowledge and skills and even ways of managing environments are linked to worldviews embedded within the social and cultural context in which the knowledge is held. (Naess, 2013; Sillitoe, 1998).

Marshland: 'Marshes are defined as wetlands frequently or continually inundated with water, characterized by emergent soft-stemmed vegetation adapted to saturated soil conditions. There are many different kinds of marshes, ranging from the prairie potholes to the Everglades, coastal to inland, freshwater to saltwater. All types receive most of their water from surface water, and many marshes are also fed by groundwater.' (United States Fish and Wildlife Service, 2021).

Monitoring: The collection of specific information for management purposes and the use of these monitoring results for implementation purposes (see Wilkinson *et al.*, 2016:7).

Multispectral (imaging): Data about the Earth's surface, collected in few (typically 3-8) relatively broad (> 50 nm) spectral bands.

Palustrine wetlands: '… includes all nontidal wetlands dominated by trees, shrubs, persist emergents, emergent mosses or lichens, and all such wetlands that occur in tidal areas where salinity due to ocean-derived salts is below 0.5%. It also includes wetlands lacking such vegetation, but with all of the following four characteristics: (1) area less than 8 ha (20 acres); (2) active wave-formed or bedrock shoreline features lacking; (3) water depth in the deepest part of basin less than 2 m at low water; and (4) salinity due to ocean-derived salts less than 0.5%' (Cowardin *et al.*, 1979:12).

Radar: A system for detecting the presence, direction, distance, and speed of aircraft, ships, and other objects, by sending out pulses of high-frequency radio waves that are reflected off the object back to the source.

Radiometry: A set of techniques for measuring electromagnetic radiation, including visible light. Radiometric techniques in optics characterise the distribution of the radiation's power in space, as opposed to photometric techniques, which characterise the light's interaction with the human eye.

Region of interest: 'Points or polygons drawn on a map prior to classification to show the classification algorithm areas where the pixel values will be obtained when performing the classification' (Mather & Tso, 2016:1).

Vegetation (or plant) community: is a group of recurring species that: share a characteristic habitat; collectively create a unique physiognomy; attain a typical range of species richness, annual productivity, and standing biomass; and through which nutrients and energy pass at predictable rates and with predictable efficiency (Pickett *et al.*, 1992).

Vegetation type: is composed of many communities that differ only in the identity of dominant or associated species, or both, but that otherwise share a similar physiognomy and environment (Pickett *et al.*, 1992).

Vegetation unit: the basic element of a vegetation map, defined as a complex of plant communities ecologically and historically occupying habitat complexes at the landscape scale (Mucina and Rutherford, 2006).

Watercourse: Means a river or spring, natural channel in which water flows regularly or intermittently, a wetland, lake or dam or a collection of water which can be gazetted (RSA, 1998).

Wetland: Land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil (RSA, 1998).

Wetland Biome: 'units reflecting functional and evolutionary processes' (Keith *et al.*, 2020:20).

Wetland Ecosystem Type: according to the South African National Biodiversity Assessment of 2018, refers to the division and spatial representation of inland wetlands according to (a) terrestrial bioregions at Level 2 and (b) hydrogeomorphic units at Level 4A (Van Deventer *et al.*, 2018a; 2020b) of the Classification Systems of Wetlands and other Aquatic Ecosystems of Ollis *et al.*, (2013; 2015).

CHAPTER 1: BACKGROUND AND INTRODUCTION

1.1 INTRODUCTION

Globally, wetlands are considered one of the most threatened ecosystems, with rates of transformation much higher than those of forests (IPBES, 2019). South African wetlands, both inland and estuarine, were found to be the most threatened ecosystems by the most recent National Biodiversity Assessment of 2018 (NBA 2018; Skowno *et al.*, 2019a). Wetlands in South Africa are defined as '… land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil' (RSA, 1998:9).

To date, South Africa has an operational monitoring system for rivers, the River Eco-Status Monitoring Programme (REMP), yet lacks an operational monitoring system for wetlands. At the moment, the REMP depends on *in situ* visitation of experts and subsequent laboratory analysis. For wetlands, *in situ* validation would be critical, however, the use of earth observation and remote sensing can greatly contribute to the monitoring of changes in the extent and some of the characteristics of wetlands. Earth observation and remote sensing are considered Fourth Industrial Revolution (4IR) technologies that can now particularly offer relatively instantaneous time-series information of, inter alia, ecosystem extent, structure and ecological conditions, compared to historical, static and delayed information.

The following subsections will detail the current state of using remote sensing to monitor lacustrine and palustrine wetlands, followed by the remaining challenges, the reporting unit, and quantifying changes.

1.1.1 Using remote sensing for mapping and monitoring lacustrine wetlands in South Africa

Changes in the extent of open water or lacustrine wetlands are monitored at a 30 m spatial resolution with remote sensing since 1984 at a global scale using the Landsat series of sensors (Pekel *et al.*, 2016). Outputs from the Global Surface Water Explorer (GSWE, https://global-surface-water.appspot.com/) were used to populate information related to the Sustainable Development Goal (SDG) sub indicator 6.6.1a in the Freshwater Ecosystems Explorer application (www.sdg661.app) and changes measured in relation to the reference period being the average extent of inundation between 2000 and 2004 (Van Deventer, 2021). In 2018, GeoTerraImage Pty Ltd (GTI) released the monthly extent of open water derived from images produced by the Sentinel-2 optical sensor at 20 m spatial resolution since January 2016 in the mzansiAmanzi Web Map Viewer (WMV) (https://www.water-southafrica.co.za/; Thompson *et al.*, 2018). The remote sensing monitoring of water quality of 102 open water bodies in South Africa also contributed to the National Eutrophication Monitoring Programme (NEMP) of the Department of Water and Sanitation (DWS), and included six freshwater and five estuarine wetlands (Kravits *et al.*, 2020; Matthews 2014; 2019; Matthews and Bernard, 2015). These products play a critical role in understanding changes in the extent of lacustrine wetlands over time. Changes in the extent can also be used to inform on the hydrological regime of wetlands, and whether any deviations occur as a result of anthropogenic or climate change influences, while hydroperiod classes can be derived to inform on the biodiversity of lacustrine wetlands (Mazvimavi, 2018; Van Deventer *et al.*, 2020a; 2022a).

1.1.2 Using remote sensing for mapping and monitoring palustrine wetlands in South Africa

It is estimated that < 11% of the extent of wetlands in South Africa are open water or lacustrine wetlands with permanent to seasonal inundation regimes (Van Deventer, 2021; Van Deventer *et al.*, 2020b), while 55% are very likely palustrine wetlands with vegetation cover. The remaining 34% are likely lacustrine, however, are rarely inundated with shallow and turbid water levels that are challenging to detect with open water remote sensing indices. These ephemeral wetlands would require a separate set of remote sensing indices for monitoring changes in these wetlands. The extent and characteristics of the palustrine wetlands are poorly understood and estimated to be largely underrepresented in our National Wetland Maps (NWMs; Van Deventer *et al.*, 2020b). Several studies at local to regional scales in South Africa have proven that remote sensing mapping and monitoring can contribute information on these wetlands in a number of ways. These studies have illustrated that hyperspectral and multispectral sensors can inform on the vegetation structure (e.g. above ground biomass or AGB), species and community composition, and soil moisture of palustrine wetlands, that can be used to inform on the nature and hydrological cycles of palustrine wetlands (Adam and Mutanga, 2009; Adam *et al.*, 2010; 2012; 2014; Gangat, 2019; Gangat *et al.*, 2020; Grundling, 2014; Grundling *et al.*, 2013; Lück-Vogel *et al.*, 2016; Slagter *et al.*, 2019; Van Deventer *et al.*, 2016; 2019a; 2020a; 2022b). These outputs inform the nature and biodiversity of these wetlands, but can also potentially be used to monitor these aspects of palustrine wetlands.

To date, however, the use of remote sensing in quantifying changes in palustrine wetlands in South Africa has been very limited. Mostly, quantified changes in South African wetlands were limited to the "wetlands" and "water body" standardised land cover categories (see, e.g. Dlamini *et al.*, 2021), with evident declines in the extent of these two classes observed (GTI, 2016; Nhamo *et al.*, 2017). These changes were, however, not well contextualised within the larger decadal hydrological cycles to indicate whether they are natural changes as part of a dry cycle, or unnatural, occurring within a wet cycle but as a result of anthropogenic or climate change impacts. The spatial resolution of land cover products in relation to the size of wetlands are also critical in this regard. For example, the 30 m spatial land cover data were unable to quantify the changes accurately for small and narrow wetlands that were situated within a single pixel or straddle more than one. Changes in inland wetland polygons from the National Wetland Map version 5 (NWM5) measured between 1990 and 2013/4 (GTI, 2015; 2016) detected that <2% of the extent of the wetlands transformed from natural to other land cover classes (Van Deventer *et al.*, 2019b). Even though the provincial land cover data can be of tremendous value in the red listing of our ecosystems (IUCN guidelines by Bland *et al.*, 2017), not all transformation types and extents can currently be detected accurately, resulting in an underestimation and underreporting of transformations in our wetland ecosystem types (e.g. Van Deventer *et al.*, 2021a). Most of the remote sensing studies on palustrine wetlands are also limited in geographic extent, which often result in a single biotype or ecosystem type not being detected, mapped or monitored in full. For example, to our knowledge, the study that included the typing of palustrine wetlands with remote sensing and had the largest geographic extent in South Africa, was that of Slagter *et al.* (2020), extending over 1 394 km^2, of which a large portion (1 352 km^2) overlaps with the Maputaland Coastal Plain (MCP) and totals 16.6% of the extent of the MCP. These challenges imply that a lot more work is required to address these gaps in being able to automate the quantification of changes in palustrine wetlands using time-series analysis.

1.1.3 Framework for monitoring and quantifying changes in wetlands ~ reporting unit and period for wetlands

The framework for the National Wetland Monitoring Programme (NWMP) that was previously funded by the Water Research Commission (WRC) and published (Wilkinson *et al.*, 2016), that reviewed the remote sensing products generated in South Africa at that time, however, did not provide a full review of the suite of tools and sensors that remote sensing offer for wetland monitoring. Hence, this project offers an opportunity to consider the components required for a framework where remote sensing will be used for monitoring wetlands. In this report, we contribute such technical component evaluation (in this subsection and synthesis Chapter 7), while also addressing the need to incorporate the social perception of remote sensing products for monitoring wetlands (Section 1.1.5).

Two components that are important for quantifying changes in wetlands in a monitoring framework include the reference date or epoch, and a reporting unit on which changes can be quantified. These two components are discussed in the following two subsections.

1.1.3.1 Choice of reference period

The guidelines for Red Listing of Ecosystems (RLE) as used by the International Union for Conservation of Nature (IUCN) recommend that changes across a 50-year period be used, whether this is along a historical and current timeline, and generally a reference date of 1750 is used (Bland *et al.*, 2017). Since we don't have extent information for 1750, this date is difficult to use for quantifying changes in wetlands. Historical imagery available in South Africa also does not offer a complete coverage for a single month or year for the period between 1940 and approximately 2000 (Van Deventer *et al.*, 2018b). In many instances, this implies that an epoch should be selected as a reference period, for example, images of the number of months within a year, or multiple seasons in a year, to map the extent of wetlands. Climatic periods and events are also crucial to consider in the selection of a reference epoch, as well as the natural growth of vegetation. The choice of a reference period for determining the original maximum extent of wetland types are regionally dependent. For example, in the RLE assessment of Coastal Subtropical-temperate forested wetlands (CS-TFW), the year 2000 was selected as the ideal epoch for these forested wetlands. Since the extent of the canopies of thirteen indicator tree species has been used as one of the significators of these forested wetlands, it was assumed that the maximum, intact extent could be captured where trees remained after the largest most recent cyclonic event on the MCP, Cyclone Eline – February 2000 (Van Deventer *et al.*, 2021a). Using georeferenced aerial photographs between 1942 and 2009 (Arndt, 2014), the extent of these forested wetlands on these photographs was much narrower compared to the extent mapped from the year 2000 onwards, and would not have served the quantification of the transformation observed after the early 1990s, when the first observation of transformation was documented (Wessels, 1991a-c; 1997). In a study by Wessels (1997), a natural growth rate in these forested wetland tree species was observed, which makes the measurement and quantification in forested wetlands challenging. Furthermore, a single month with complete and contiguous images across the MCP was not available to map the reference CS-TFW, and hence an epoch of 2000 with multiple images across different months were used as the reference period.

In other areas, the choice of a reference period for mapping the original and maximum extent of wetland types, we would use other criteria for selecting the reference epoch.

1.1.3.2 Unit of reporting

Changes in wetlands over time need to be reported to the maximum extent of an ecosystem type mapped for a reference period. South Africa's wetland ecosystem types straddle the freshwater and estuarine realms (Van Deventer *et al.*, 2019b; Van Niekerk *et al.*, 2019) with very different approaches in typing these wetlands for biodiversity assessments (Van Deventer *et al.*, 2020b). Inland wetlands are one of the subset categories of the inland aquatic or freshwater realm, and have been separately assessed from the river ecosystem types that are represented as line features. The combination of terrestrial bioregions and aggregated hydrogeomorphic units (HGM units, including at a course description level: depressions, floodplains, seeps, and valley bottoms) make up the inland wetland ecosystem types for the latest National Biodiversity

Assessment of 2018 (NBA 2018), irrespective of the vegetation structure and hydroperiod descriptors. The mapping of these ecosystem types requires heads-up digitising by trained personnel or experts, while changes in the extent or characteristics of these wetlands can be assessed through *in situ* visits (e.g. the WET-Health approach, MacFarlane *et al.*, 2009; 2018), through modelling where environmental data serves as surrogates of pressures and impacts (Collins, 2018; Melly *et al.*, 2016; Van Deventer *et al.*, 2019b), or indices derived from remote sensing data.

Estuarine wetlands, on the other hand, are typed according to the four biogeographical regions along the coastline of South Africa, with further typology depending on the size of the system, the degree of connectivity with the sea, its geomorphology, typical salinity and tidal regimes, mixing processes, sediment stability and mouth state (Van Niekerk *et al.*, 2019; 2020). Estuaries were grouped into Estuarine Lakes, Estuarine Bays, Estuarine Lagoons, Predominantly Open Large and Small Temporarily Closed Estuaries, Large and Small Fluvially Dominated, and Arid Predominantly Closed estuary types. Their ecological condition is derived from infield or modelled data of abiotic (hydrology, hydrodynamics, water quality, and physical processes) and biotic (microalgae, macrophytes, invertebrates, fish and birds) parameters. Monitoring of changes is currently undertaken by combining field visits, modelling of environmental flow and water quality, and heads-up digitising of changes in habitat extent over time (Adams *et al.*, 2019).

Both the estuarine and freshwater wetland ecosystem types, collectively referred to as wetlands under the ‘inland water’ category of the global ecosystem typology version 2 (Keith *et al*., 2022), are therefore depending on modelling and expert input for mapping their extent, and this cannot be determined through automated remote sensing methods. Remote sensing indices and datasets can be used to report changes that occur as percentage of the extent of each polygon, however, no changes in the extent of the polygons resulting from possible natural growth, for example. This presents a challenge in measuring changes over time that may be attributed to natural or anthropogenic climate changes. Another challenge is that wetlands have transformed over time, and an ideal reference epoch may not be easy to identify. For example, the original extent of Palmiet wetlands had to be modelled based on their extent derived from satellite images (Rebelo *et al.*, 2017). The reference epoch for forested wetlands may also be challenging, in that these would naturally grow over time, and the earliest historical extent could be less than what is currently observed, as was noted for forested wetlands on the MCP. Consequently, the choice of reference epoch for each habitat type and wetland ecosystem type may have to be carefully chosen.

An alternative typology that could accommodate remote sensing methods of the extent of wetland ecosystem types could be potentially that of the IUCN. The latest ecosystem typology framework of IUCN presents a six-tiered hierarchy of wetland typology (Keith *et al.*, 2020; 2022). At the top level, the wetland realm is distinguished from the terrestrial, marine, and other realms (Figure 1.1). At the second level under the wetland realm, the lacustrine and palustrine wetland biomes are distinguished, of which the extent of these two biomes is used for reporting to the United Nations Environment Programme (UNEP) for the SDG indicator 6.6.1a (e.g. DWS, 2020). At the third level, Ecosystem Functional Groups (EFGs) are further detailed, which for the lacustrine wetland biome, requires more information on the hydroperiod of the wetlands. Several remote sensing products are able to provide hydroperiod information for lacustrine wetlands, using indices such as the Normalised Difference Water Index (NDWI) of Gao (1996). For the palustrine EFGs, the climatic region, vegetation structure and hydroperiod classes are used to distinguish EFGs (Figure 1.1). Vegetation structure types, such as forest and grass/sedges, are also derived from optical and Synthetic Aperture Radar (SAR) remote sensing data.

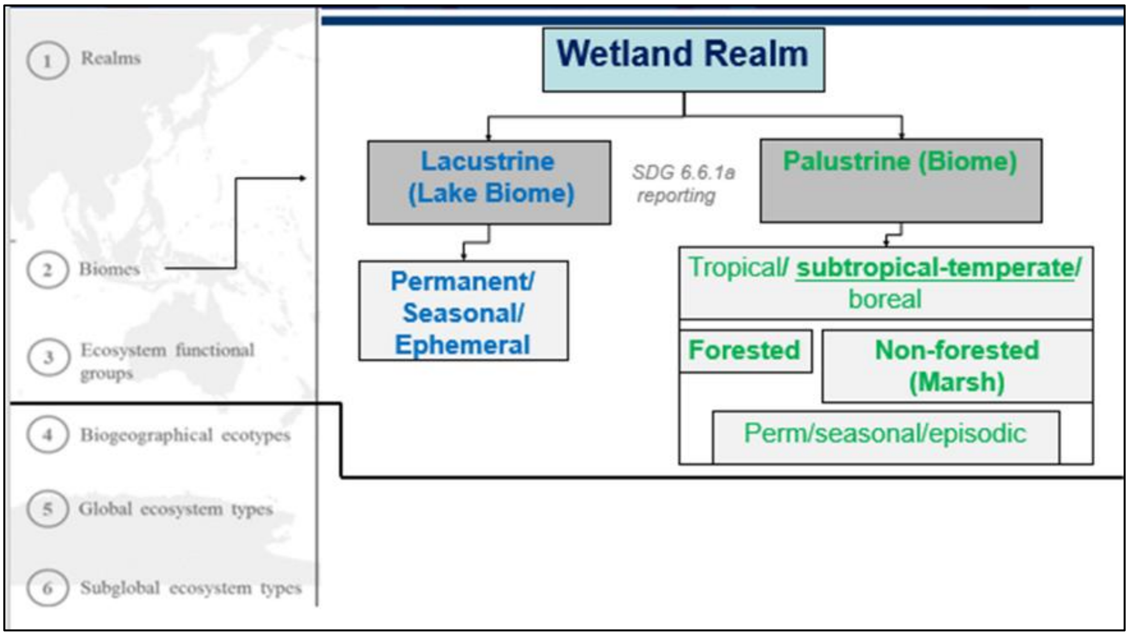


Figure 1.1. Schematic showing three of the six-tiered levels of the wetland realm according to the global ecosystem typology of the International Union for Conservation of Nature (Keith *et al.*, 2020). The reporting of the extent of wetlands for the Sustainable Development Goal (SDG) sub indicator 6.6.1a occurs at the Biome level for the Wetland Realm.

The IUCN typology for the wetland realm at the EFG level therefore offers a refinement of the South African HGM units for detecting and monitoring changes of wetland types with different vegetation structures. For example, forested wetlands can be distinguished from marsh wetlands in the EFG categories, whereas they co-occur in a single HGM unit such as floodplains and valley bottoms. Small transformations in the CS-TFWs, for example, will be reported as a fraction of the HGM unit, whereas if measured against the refined extent of an EFG, it could be detected and reported with greater emphasis and accuracy. It may also be possible that changes in the maximum extent of an EFG can be detected with RS, while the HGM unit, digitised by experts, will be a manual and time-consuming approach to update and monitor over time.

The next subsection details the motivation for choosing the MCP as a case study to inform the framework for wetland monitoring.

1.1.4 The importance of quantifying changes in wetlands on the Maputaland Coastal Plain (MCP)

The MCP is a unique region in South Africa that was chosen to serve as a case study for the quantification of changes in wetlands, for several reasons:

- The MCP forms part of the Maputaland Centre of Endemism and is considered a hotspot for biodiversity in South Africa (Van Wyk and Smith, 2001; Darbyshire *et al.*, 2019);
- A diverse number of wetland types are found on the MCP, ranging from forested wetlands (swamp, floodplain, and mangrove forests) to grass, sedge, and open water wetland types;

- The iSimangaliso World Heritage and Ramsar Site extends over 22.6% of the MCP, while other Provincial Parks contribute an additional 6.5% of the extent of the MCP, totalling 29.1% of the protection of the MCP;
- A total of 61% of the extent of the MCP forms part of South Africa's Strategic Water Source Areas (SWSAs; Le Maitre *et al.*, 2018). The subcategories of SWSAs as percentage of the full MCP makes up 33.9% for groundwater SWSA, 13.8% for surface SWSAs and 13.6% for a combination of the two;
- The largest freshwater lake of South Africa, Lake Sibaya, is found on the MCP (Van Deventer *et al*., 2019b);
- The MCP offers a unique transition between marine, estuarine, freshwater, and terrestrial ecosystems along the coastal zone of South Africa, where the extremely dynamic nature of aquatic ecosystems is challenging to monitor;
- Many of the wetlands of the MCP are aquifer-dependent ecosystems (ADEs), which during decadal dry cycles, become easily accessible and subsequently vulnerable to land transformation. In addition, natural changes in the aquifer, as well as lowering of the groundwater level resulting from anthropogenic influences, have a wide-spread impact on all aquatic ecosystems, from the inland wetlands to the estuaries and marine off-shore ecosystems;
- The MCP hosts the highest density of peatlands in South Africa, also hosting the oldest (Mfabeni) and the largest (the Mkuze floodplain) peatlands (Grundling *et al.*, 2017; 2021);
- Wetlands also provide essential ecosystem services on the MCP, in particular, recharging the aquifer, which sustains water provision during the dry season and particularly times of drought, base flow attenuation, water filtration and storage capability (Grundling *et al.*, 2000; Kotze *et al.*, 2020); and
- The northern part of the MCP, the quaternary catchment W70A, has recently been nominated as one of the six Expanded Freshwater and Terrestrial Environmental Observation Network (EFTEON) nodes (see https://efteon.saeon.ac.za/) selected for long-term research on ecosystems that will be coordinated by the South African Environment Observation Network (SAEON).

A number of issues and negative pressures on the wetlands on the MCP have been observed, including:

- It is estimated that 57% of the wetland extent in the iMfolozi/uMsunduze floodplain were lost by the 1980s because of land transformation (Begg, 1988);
- Some of the highest rates of vegetation loss and transformation have been observed in the Indian Ocean Coastal Belt Biome as a result of anthropogenic impacts, as part of the NBA 2018's terrestrial realm assessment (Skowno *et al.*, 2019b);
- Several pressures continue to influence wetlands on the MCP negatively, ranging from water abstraction, alien invasive tree species, exotic forest plantations, and slash-and-burn of swamp forests, while uncertainties prevail on the further impact of climate change within this region (Grundling and Grundling, 2019; Janse van Rensburg, 2019);
- The most recent provincial assessment showed that all riverine, swamp, and mangrove forests of KwaZulu-Natal are critically endangered, despite being moderately protected (Jewitt, 2018);
- The MCP overlaps with the Natal Coastal Plain peat ecoregion, which has shown the highest increase of peat fires over the past five years (Grundling *et al.*, 2021);
- Transformations of CS-TFW to other land cover types are not well detected or typed, and underreports observations and assessments done at a local scale (Van Deventer *et al.*, 2021a). Available land cover products, both at a national and provincial scale, are insufficient in detecting and reporting these transformations observed. A lack of quantifying such transformations results in no and insufficient responses to the intervention by relevant authorities to curb negative influences;
- Very few river ecosystems are found on the MCP, which renders the REMP insufficient to infer the ecological condition of associated wetlands (Van Deventer, 2022b). Hence, there is insufficient monitoring of the ecological condition and rates of changes occurring on the MCP's wetlands;
- The MCP hosts some of the poorest local communities in the country, who depend on the ecosystem services of the wetlands for food production and harvestable materials, such as amadumbes

(*Colocasia esculenta*), a high-energy and mineral food crop (Grundling *et al.*, 2000), and sugarcane (kwaSokhulu), and reeds and other building materials; and
- Transformation and degradation of these wetlands negatively affects the resilience of the landscape to climate change, impacts and influences, and present risks to the ability of the communities to continue with their livelihoods, to the ecosystems to serve as refugea to faunal species during current natural and predicted extreme drought periods, and provide essential regulation services under extreme flooding events associated with future climate change scenarios.

Owing to the scale of the influence of negative pressures across the landscape, and the limitations in accessing wetlands in parts of the MCP, remote sensing can play a key role in quantifying and determining the extent and rate of change on the MCP wetlands and their catchments.

In the RLE assessment of the MCP's CS-TFW, these forested wetlands were found likely critically endangered, although improvements in the mapping and transformation of these forested wetlands with improved remote sensing images and technologies were strongly recommended (Van Deventer *et al.*, 2021a). This assessment did not include changes in the estuarine functional zone (EFZs) legal boundaries, although previous work showed that some of the habitat types and mangroves can be monitored with remote sensing (Lück-Vogel *et al.*, 2016; Van Deventer *et al.*, 2013; 2015; 2017; 2019a). In addition, the automated remote sensing monitoring of marsh wetlands is critical to detect refined EFG types and the results of influences such as desiccation and peat fires. Several peatlands on the MCP have been burning infrequently since 1996, including Vasi Pan, Muzi, Mfabeni, Lake Sibaya and Siyadla (Grundling *et al.*, 2021). The degradation of these systems has been attributed to the lowering of the groundwater levels. Ground levels naturally decline during the 10-year dry hydrological regime, however, recently the extreme drought of 2015/6 (Malherbe *et al.*, 2016), combined with the impact of timber plantations, exacerbated the situation. The exotic timber plantations have much deeper root levels and higher evapotranspiration rates compared to the indigenous forests, resulting in a more severe drawdown of groundwater levels, especially near wetlands (Bate *et al.*, 2016).

1.1.5 Importance of stakeholder engagement with remote sensing output products

Within social scientific disciplines such as Anthropology and Sociology, it is well established and illustrated that space and place is socially constructed within the worlds of people. What this means is that space derives meaning through the interactions people have with it (Lefebvre, 1991). At the same time, a space is also created and allows for those social interactions and relationships to emerge and evolve; this includes the reinforcement of social hierarchies and deployment of power (Rucks-Ahidiana and Bierbaum, 2015). In other words, the study of a location, including the people and the lives lived in that location, captures a unique configuration of social relationships that reinforces and implements pre-existing social hierarchies.

If we delve a little deeper, Descola and Palsson (1996) and Brosius (1999) argue that the idea of a social construction of space is also applicable to nature (also described as the natural environment). They argue that nature is socially and culturally constructed by our 'meaning-giving' and discursive processes. How we talk about it, how we describe it, how our lives find meaning through it. In other words, we construct meaning and value of nature that makes sense to us as particular cultural or social beings. It is therefore essential that if one truly wants to get to a holistic understanding of a place, such as our case study site, it is important to uncover the different ways in which people ascribe meaning to that place, and in this study, also the natural resources available in that place.

Output products generated by remote sensing are valuable to inform decision making from local to national scale, yet access to these products is often limited at the community scale. There is a need to bridge information and knowledge across three domains: science, regulatory authorities, and local communities. People's knowledge and perception of coastal swamp forests remains to be understood and incorporated in the decision-making process. A learning exchange is required to facilitate improved understanding and knowledge co-production (Nel *et al.*, 2016). On the one hand, local communities have extensive knowledge (local and traditional ecological knowledge) of their land, the processes on their land and the value (ecosystem services and livelihoods) that wetlands can provide. In return, scientists can provide an overview of the regional landscape, quantify ecological degradation, types and rates, and access information published on climate change. Bringing together these different kinds of knowledge will produce a transdisciplinary exchange of information. The exchange of information from these two domains alone would enhance knowledge and understanding that will also provide a holistic picture and not only a one-sided view.

Engagements with local communities were therefore critical on two fronts. Firstly, it provided an opportunity for the local communities to provide a local context on the current state of the wetlands and surrounding areas. It included an emic understanding of the way in which locals engage with wetlands as well as the way in which these wetlands may be linked to cultural, social and economic processes. Secondly, these engagements between science and society create opportunities for scientists to share some of the outcomes from this research, understand how remote sensing products can supplement their current knowledge, and inform them on the processes taking place across the MCP. The maps and statistics therefore serve as a key discussion point for concerns on the status and ecological degradation of wetlands on the MCP.

1.2 PROJECT AIM AND OBJECTIVES

The aim of this research project was to quantify the rate of change of different wetland types on the MCP using remote sensing. In addition, a subcomponent of the work was also aimed at understanding the social context of these changes, through enabling stakeholder engagement and communication through sharing the remote sensing output with these stakeholders.

The objectives of the project were:

1. Compilation of an inventory of available *in situ* coordinates for wetland cover types;
2. Evaluation of the possible wetland classes that could be used in (optical) change detection for the MCP;
3. Learning exchange between earth observation products and local stakeholders for knowledge co-production;
4. Quantifying the areal extent, rate, and types of change observed for wetlands on the MCP; and
5. Strategic framework for the inclusion of earth observation products and community engagement in the NWMP.

1.2.1 Value of quantifying changes in wetlands with remote sensing

The use of remote sensing as a 4IR technology can inform policy and decision making on our most threatened ecosystem in South Africa: wetlands (NBA 2018 synthesis findings). The outputs to support various decision-making structures, including, but not limited to the following:

- Refinement and monitoring of the critically endangered CS-TFW and degraded peatlands (Grundling *et al.*, 2021) within the Ramsar Site, which could pose a risk to South Africa losing this Ramsar Site. The intention is for DFFE or provincial governments to have information to know where to intervene;
- The red listing of range-restricted and endangered ecosystems, such as swamp forests, which require statistics on the rate of degradation or decline, as per the IUCN guidelines (Bland *et al.*, 2017). If the swamp forests were found to be in serious decline, the statistical results will enable SANBI and DFFE

to write the nomination for gazetting swamp forests as a threatened wetland and/or forest type in South Africa;

- The NWMP that is managed by the Department of Water and Sanitation (DWS), to consider the use of remote sensing as a tool for monitoring changes in wetland types;
- The results of the research on optical and radar changes of swamp forest could contribute to the work done by the Forestry Directorate of DFFE for Forest Resource Assessments in South Africa;
- We have also supported student development in both the inland water, remote sensing and social science sectors, addressing gender and race transformation;
- The results can contribute to the long-term monitoring of the MCP and particularly the Maputaland EFTEON node; and
- The study has made a significant contribution to understanding the contribution of remote sensing to the South African and global Freshwater Biodiversity Observation Networks (SA BON; FW BON) for South African wetland types.

1.2.2 Outcomes and expected impacts in South Africa and elsewhere

The outcomes of this study provided information on:

i. Hotspot areas within the Ramsar Site for DFFE to continue or initiate intervention(s);
ii. Changes in areal extent and rates of decline for potential red listing of swamp forest and peat ecosystems according to the IUCN guidelines;
iii. Capabilities and sensitivities of satellite images to detect changes in palustrine and lacustrine wetlands on the MCP for use hereafter in the National Wetlands Monitoring Programme (NWMP), and long-term monitoring as an EFTEON site;
iv. Technical knowledge and findings to inform the FRA of South Africa;
v. Contribution to the South African Biodiversity Observation Network (SA BON) and the global Freshwater Biodiversity Networks (FW BON), which are voluntary organisations concerned about biodiversity monitoring at national and global scales, respectively;
vi. A social study documenting co-learning through bridging science, governance and local stakeholder information; and
vii. A strategic framework for guiding the use and incorporation of remote sensing in the NWMP, and knowledge co-production across the three domains (science, governance, and stakeholders).

1.3 STUDY AREA: THE MAPUTALAND COASTAL PLAIN

1.3.1 Overview and description of wetland types of the MCP

The MCP (Figure 1.2a&b) straddles and extent of 8 141 km² with an approximate total extent of 313 km of coastline and from north-south distance of approximately 64 km. In the north the climate is subtropical, however, gradually transitioning to a temperate climate towards the south. An integration of the NWM5 and terrestrial ecosystem types from the NBA 2018 (Skowno *et al.*, 2019a; Van Deventer *et al.*, 2020b), showed that inland wetlands made up 12% of the total surface area of the MCP, while estuarine systems were 12% and terrestrial systems 76% (Table 1.1).

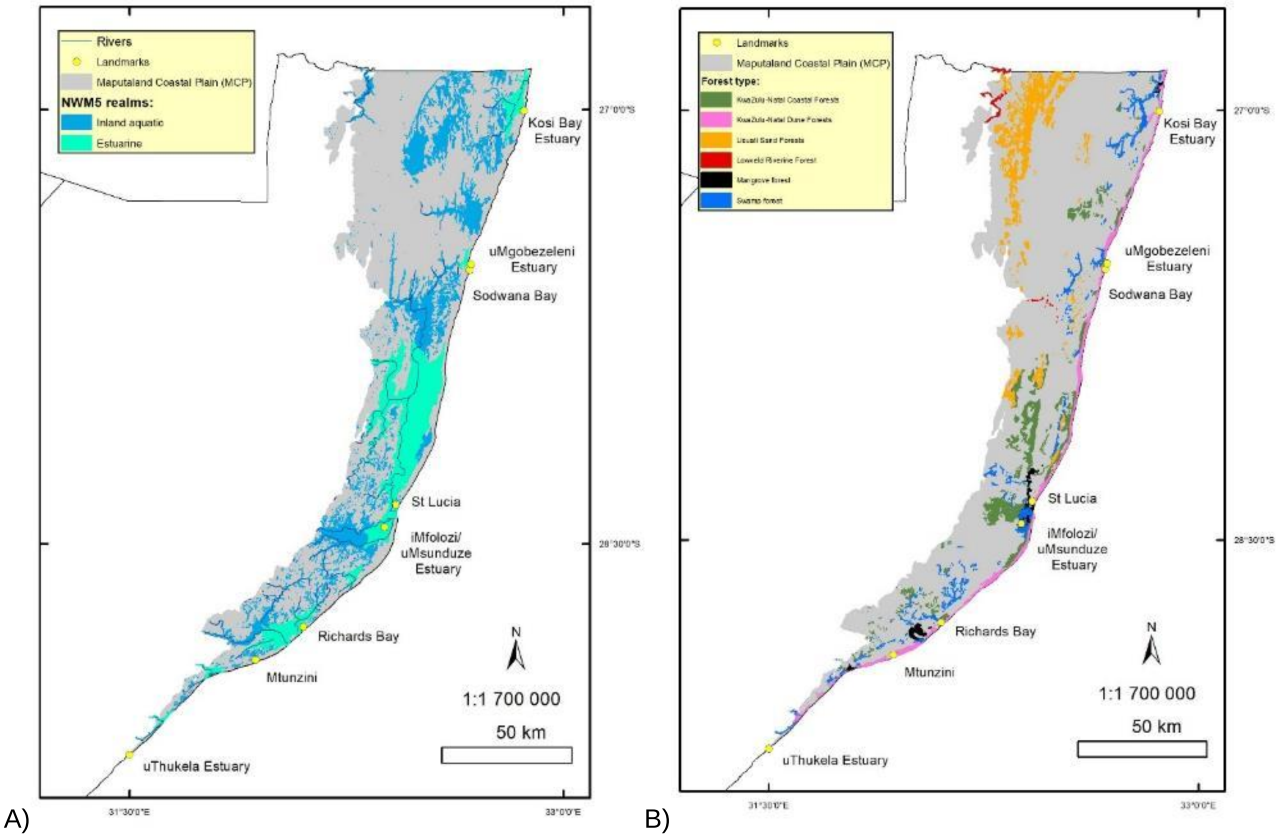


Figure 1.2. A) The location of freshwater and estuarine wetlands; and B) the location of different forest types on the Maputaland Coastal Plain.

Twelve river ecosystem types occur on the MCP with a total length of 764 km (Smith-Adao *et al.*, 2018), and river flow is predominantly permanent/seasonal (85% of the extent), with floodplain rivers making up 60% of the extent of the river extent. Three of the rivers are flagship rivers of the MCP, being the Mkuze, St Lucia and iMfolozi/uMsunduze (Nel *et al.*, 2011a&b).

Table 1.1. Extent of ecosystem realms on the Maputaland Coastal Plain based on the National Biodiversity Assessment of 2018 data (Van Deventer *et al.*, 2020b)

Realm	Number of ecosystem types	Extent (km²)	Percentage (%) of the Maputaland Coastal Plain (MCP)
Estuarine wetlands (polygons)	2	992.6	12.2%
Freshwater wetlands (polygons)	7	962.1	11.8%
Freshwater river (lines)	12	764.3	-
Terrestrial (polygons)	15	6185.9	76.0%

To date, the NWM5 mapped 2 698 polygons for the MCP (Van Deventer *et al.*, 2020b), however, includes many sliver polygons (small and narrow polygons) resulting from the combination/integration of a variety of datasets. In total, 921 km² of freshwater wetlands (inland wetlands and the extent of some rivers) and 941 km² across ten EFZs have been represented in NWM5 for the MCP, which totals 1 938 km² of aquatic ecosystems or 24% of the extent of the MCP (Table 1.2). The EFZs totalled 49% of the extent of aquatic ecosystems and include freshwater wetlands, mangroves, salt marsh, seagrass, sediments and open water (Adams *et al.*, 2016; 2019).

A recent integration of national and provincial datasets of forested wetlands (Van Deventer *et al.*, 2021a) added another 24.5 km² of wetlands to those mapped by NWM5. The output distinguished 116.5 km² of forested wetlands for the MCP and was the first refinement of inland wetland ecosystem types used in the NBA 2018 with EFGs used by the IUCN for South Africa. Further work was recommended to refine these digitised CS-TFW polygons, and remote sensing was recommended for the improvement of this heads-up digitising product. The integration of NWM5 and these forested wetlands showed that the latter totals 6% of all wetlands on the MCP and occurs across estuarine, river and freshwater ecosystems, but are found mostly within the EFZs and along valley-bottom HGM units (Table 1.2). The remaining freshwater wetlands in NWM5 that were not mapped as forested wetlands are either lacustrine wetlands or marsh wetlands, totalling 1 822 km² or 45% of the wetland extent.

A comparison of the extent of wetlands represented in NWM5 to other wetland maps (Van Deventer, 2021) showed that NWM5 mapped a significant larger number and extent of wetlands compared to the extents reported by the National Land Cover (NLC) data of 2013/4 (GTI, 2015), the mzansiAmanzi viewer (Thompson *et al.*, 2018) and the GSWE (Pekel *et al.*, 2016). This can be mainly attributed to these three remote sensing products primarily detecting and monitoring the extent of lacustrine (or open water) wetlands, while the NWM5 mapped more palustrine wetlands through expert mapping.

Table 1.2. Fraction of the National Wetland Map version 5 (NWM5; Van Deventer *et al.*, 2020b) wetland types that coincide with the Coastal subtropical-temperate forested wetlands of the Maputaland Coastal Plain (Van Deventer *et al.*, 2021a)

Wetland type	Forested wetlands		Other lacustrine and palustrine wetlands		Total of MCP wetlands	
	(km^2)	(% of all wetlands)	(km^2)	(% of all wetlands)	(km^2)	(% of wetlands or *freshwater ecosystems of NWM5*)
Estuarine functional zones (EFZs)	51.82	2.67	940.66	48.53	992.48	51.2
Rivers	0.18	0.01	6.18	0.32	6.36	0.3
Freshwater	40.00	2.06	874.87	45.14	914.87	47.2
Depressions	4.09	0.21	245.37	12.66	249.45	12.9
Floodplains	11.12	0.57	544.38	28.09	555.50	28.7
Seeps	0.85	0.04	36.55	1.89	37.39	1.9
Valley-bottom	23.95	1.24	48.58	2.51	72.52	3.7
Wetlands added by Van Deventer *et al.* (2021a) to polygons of NWM5	24.5	1.26	-	-	24.45	1.26
Total:	116.45	6.01	1 821.72	93.99	1 938.17	100.00

**These include the Estuarine Functional Zone extent, that includes multiple realms (terrestrial, freshwater and estuarine wetlands).*

1.3.2 Existing *in situ* monitoring of wetland types by the Department of Water and Sanitation (DWS) on the Maputaland Coastal Plain (MCP)

The MCP is situated across 23 quaternary catchments (Weepener *et al.*, 2012), of which the most northern one, W70A, extends to a third of the MCP (Figure 1.3A). A total of 28 flow monitoring points (Figure 1.3B), and 104 water quality points for aquatic ecosystems (Figure 1.3C, consisting of 52 estuarine, 15 lake, 34 river and three wetland categories) are managed by DWS. There is no flow monitoring done in W70A, whereas only nine water quality monitoring points (9% of the total of 104), are located within W70A.

The Cyanolakes remote sensing monitoring system (https://online.cyanolakes.com/) supplements the *in situ* REMP through the monitoring of 102 South African lacustrine artificial and natural wetlands (Figure 1.3D). A Chlorophyll-*a* index serves as surrogate to report on South Africa's largest freshwater lake (Lake Sibaya) and four other waterbodies within four EFZs, including Lake Cubhu (uMhlathuze EFZ), Lake Msingazi (Richard's Bay EFZ), Nhlabane (iNhlabane EFZ) and Kuhlange (Kosi EFZ).

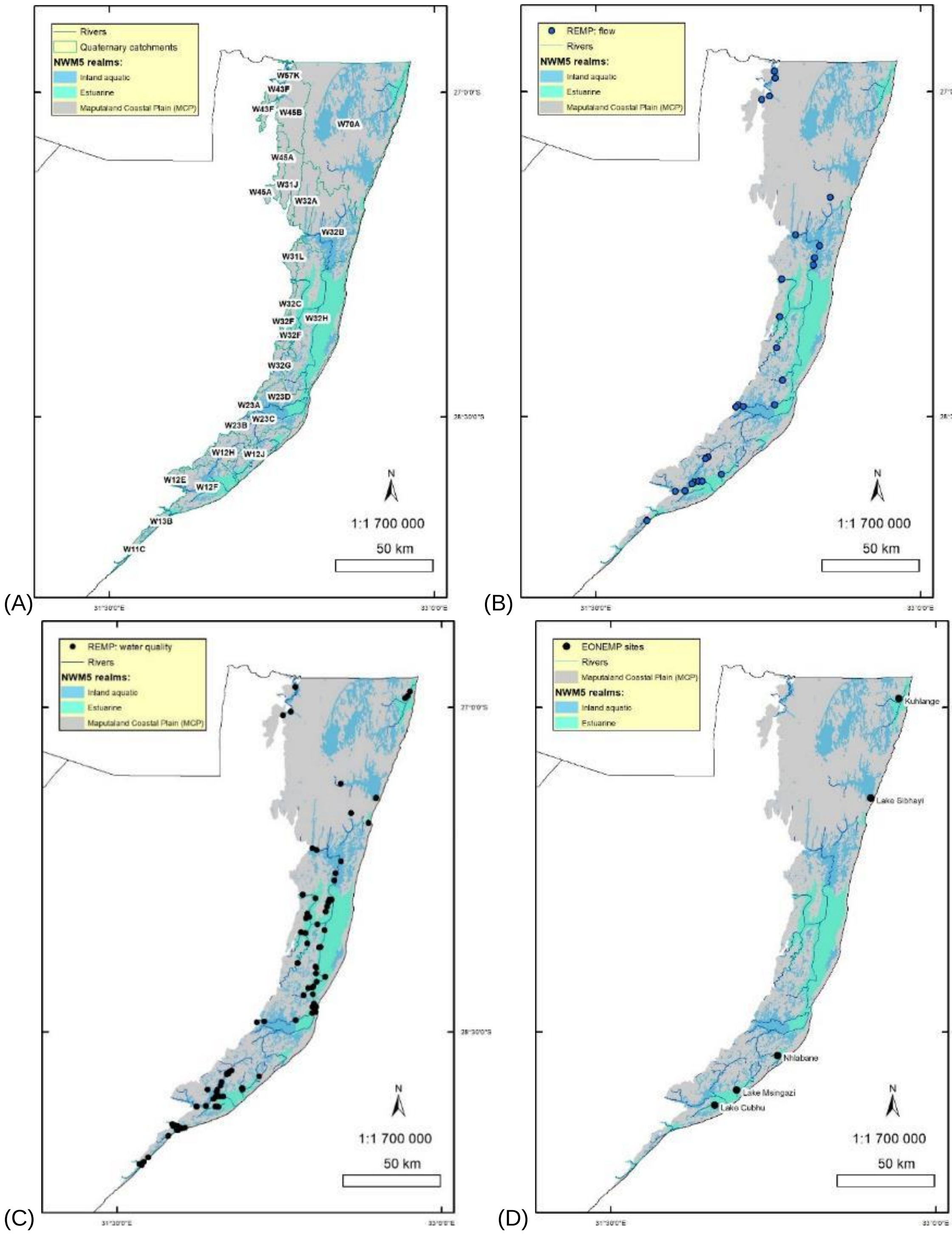
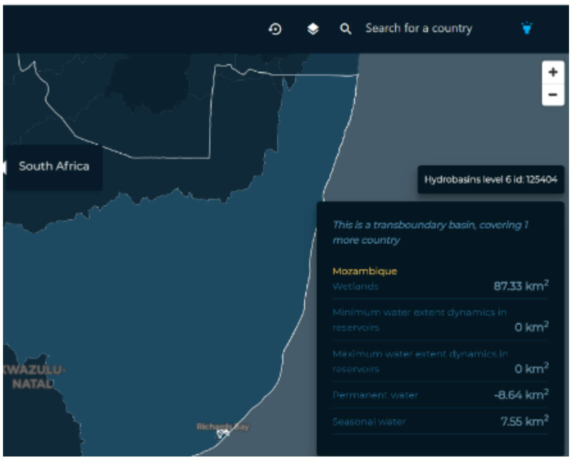


Figure 1.3. DWS catchments (A) and monitoring points of the River Eco-Status Monitoring Programme, including *in situ* (B) flow and (C) water quality; and (D) remote sensing monitoring of water quality.

1.3.3 Existing monitoring of wetland types on the Maputaland Coastal Plain (MCP) with remote sensing by other institutions

To our knowledge, there are three remote sensing monitoring systems of lacustrine wetlands occurring on the MCP. The first one is the GSWE that monitors the extent of lacustrine wetlands with a global monitoring system at 30 m spatial resolution, while the second one is the South African mzansiAmanzi reported inundation extent of open waterbodies or lacustrine wetlands at 20 m spatial resolution.

The GSWE reports the minimum and maximum inundation levels of lacustrine wetlands over a month or year, for a selected hydroshed or country. Figure 1.5A illustrates the hydroshed basins that are used to extract information, while Figure 1.5B shows the annual minimum and maximum inundation per year between 1984 and 2019. This graph showed that the drought of 2015/6 reduced the extent of surface water levels of the hydrological basin more severely compared to the 1992-1995 drought. The viewer does not offer the option to view the results of the extent of the MCP, and therefore the data would need to be downloaded and analysed for a better reflection of the hydrological regime.

A)


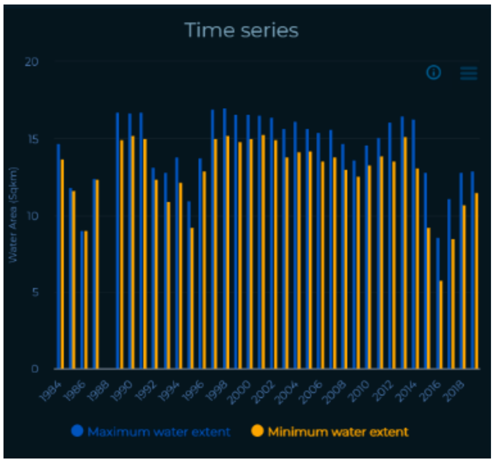
B)


Figure 1.4. Monitoring of lacustrine or open water wetlands with the Global Surface Water Explorer (Pekel *et al.*, 2016) with A) showing a hydroshed that overlaps to a large extent with the Maputaland Coastal Plain and B) the minimum and maximum extent of open water observed by the Landsat optical series of sensors between 1984 and 2016, and subsequently from 2016 to date with the Sentinel-2 optical sensors. Changes reported in A) were measured against the average measured across the reference period (of 2000 and 2004).

The GSWE's seasonality dataset (Pekel *et al.*, 2016) that was downloaded and clipped to the MCP showed that 2 577 lacustrine wetland polygons have been detected and monitored since 1984 (Table 1.3). These polygons extended over 461.5 km, totalling <6% of the MCP (Table 1.3). According to the GSWE online User Guide, three hydroperiod classes are mapped, including permanently inundated for 12 months over a 37-year period), seasonally (<12 months over the 37-year period), or ephemerally (outliers to the natural annual cycle across the 37-year period). The hydroperiod classes derived from this layer of the MCP showed that the majority of these are permanently inundated (89%). There are two limitations to this product. The palustrine wetlands are not being monitored with these open water indices, whereas the spatial resolution of 30 m limits the detection of wetlands smaller than 0.0081 km² (an area of 90 x 90 m, as a best practise guideline for pure centre cell detection).

Table 1.3. Hydroperiod information of wetlands on the Maputaland Coastal Plain (MCP) was obtained from the Global Surface Water seasonality data (Pekel *et al.*, 2016)

Hydroperiod	Number of polygons	Percentage (%) of number of polygons	Extent (km²) of polygons	Percentage (%) of MCP extent
Permanently inundated	2 305	89.4	436.8	5.4
Seasonally inundated	164	6.4	24.7	0.3
Intermittently inundated	108	4.2	29.9	0.4
Total	**2 577**	100	491.4	5.7

South Africa's mzansiAmanzi product initially reported the monthly extent of inundated lacustrine wetlands using the Sentinel-2 optical data at 20 m spatial resolution and was issued as a free viewer (e.g. Figure 1.6) but proprietary dataset (Thompson *et al.*, 2018). Subsequently, the South African National Space Agency (SANSA) purchased the rights of the dataset and are offering the dataset free of charge. The use of optical data limited the accurate reporting as a result of cloud cover. Since July 2021, both Sentinel-1 radar and Sentinel-2 optical data at 20 m spatial resolution informs the monthly extent of inundation in the country, and the omission errors resulting from cloud cover are minimised. The available monthly datasets range from January 2016 to date.

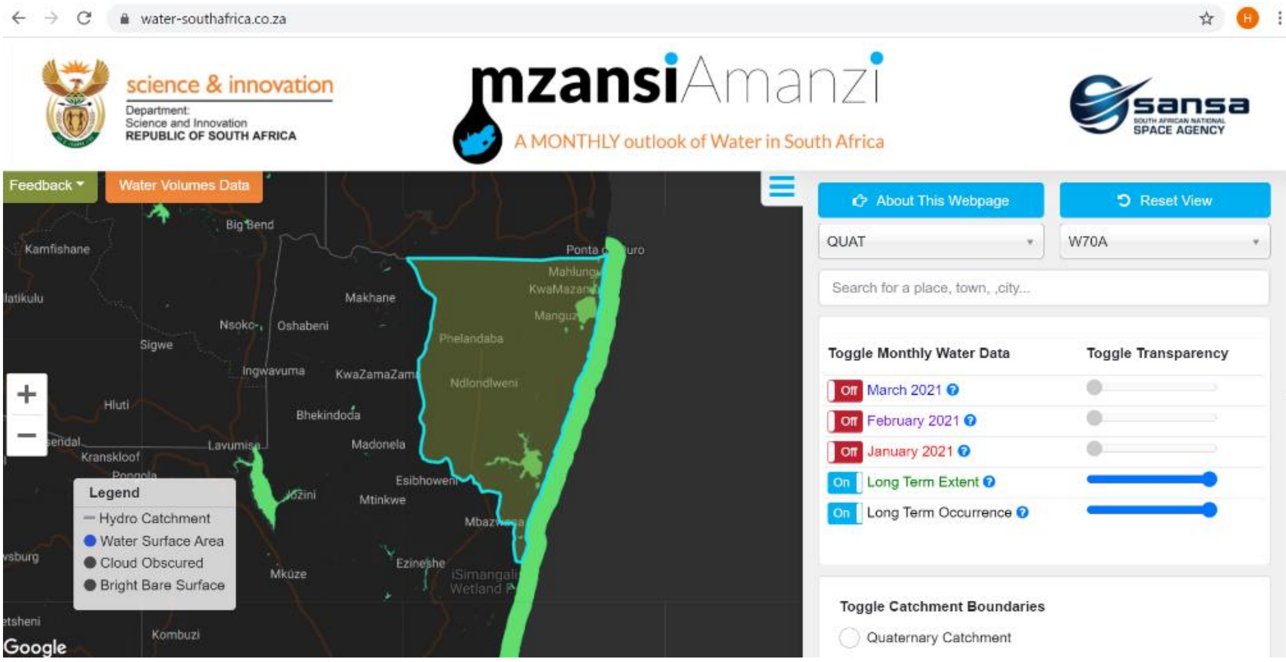


Figure 1.5. Monitoring of lacustrine or open water wetlands with the South African mzansiAmanzi product (Thompson *et al.*, 2018) since January 2016 (https://www.water-southafrica.co.za/).

The northern part of the MCP, which has been identified as one of the six EFTEON nodes by SAEON, covers about a quarter of the study area (2 635.6 km²) and less than a third of the coastline of the MCP (87 km). The results of this project's remote sensing of wetland types of the whole of the MCP are likely to contribute to the understanding of how different wetland ecosystem types have changed within this node.

1.3.4 Gaps in the monitoring and quantification of changes in wetland types of the MCP

From the above existing and available datasets monitoring the wetland extent of the MCP's wetlands, it is clear that only the extent of the lacustrine wetland biome is monitored, but not that of palustrine wetlands. To automate the monitoring of aquatic ecosystem extent with remote sensing will require a suitable typology for classification. Remote sensing cannot detect HGM units automatically, and there is a need to quantify changes in habitat types within the EFZs too. The EFGs of the IUCN topology offers refinement of some wetland types and can likely be monitored with remote sensing.

The following opportunities exist for improved mapping of the extent of EFGs:

- Lacustrine wetlands: Refining lacustrine wetlands to the IUCN EFGs will require their hydroperiod categories to be determined. Such a refinement will contribute to better biodiversity typing of these systems;
- Palustrine wetlands:
    - Refinement of climatic regions is not necessary;
    - The extent of palustrine CS-TFW could potentially be refined using remote sensing images to minimise commission and omission errors that may have resulted in the manual heads-up digitising process; and
    - A new structural class for macrophytes will be considered and depends on the capabilities of the space-borne sensors, both optical and SAR, in being able to separate this class.

Although habitats within the EFZs have also been previously manually mapped (Adams *et al.*, 2016; 2019), these habitat type categories and alignment with freshwater or estuarine EFGs should also be explored, to investigate the automation of remote sensing monitoring of estuarine habitats.

To enable the quantification of transformations to these EFGs, a reference extent should be explored for each one individually, and the remote sensing indices are used to type their transformation and degradation. Therefore, a number of opportunities exist on the MCP to see how remote sensing can contribute to improved mapping and monitoring of both lacustrine and palustrine wetlands. The learning will inform our framework for using remote sensing in the NWMP.

1.4 SCOPE AND LIMITATIONS

The project used the MCP as an example to illustrate the capabilities of remote sensing in mapping EFGs, their types of transformation or degradation that can be detected with the freely available, space-borne Sentinel-1 radar and Sentinel-2 optical images, and how these can be used to derive quantified trends over time. The results will inform a framework for decision making on how these freely available space-borne sensors can inform the NWMP. The types of EFGs, transformation and methods will not be transferable to other study areas as is. Each region requires their own investigation of the appropriate scale of images to detect the wetland EFGs, transformation types and extent, and suitable sensors for detecting and quantifying changes.

The social component of this study relies on collaboration and participation with stakeholders and therefore approval of ethics had to be obtained. Under normal (pre-COVID) circumstances, the project would be limited to the approval received by the TAs to engage with people in their territories. However, post-COVID-19 provides new and challenging limitations for engagement with stakeholders. The CSIR has in place a comprehensive risk mitigation plan which are reviewed before each trip and engagement. All necessary precautions were undertaken to ensure the health and safety of both the team as well as the stakeholders.

CHAPTER 2: INVENTORY OF AVAILABLE SPATIAL DATASETS RELATED TO WETLAND ECOSYSTEM TYPES OF THE MAPUTALAND COASTAL PLAIN (MCP)

Several studies have been undertaken on the Maputaland Coastal Plain (MCP) that are relevant to and useful in the remote sensing of wetland types. This chapter provides an overview of the available data and identifies how these studies can be used to inform the extent of Ecosystem Functional Groups (EFGs), or their transformation and degradation. Both science and citizen science data were considered, and an evaluation was done to see how these datasets could inform the image classification and sample points to visit in the field campaign.

2.1 INTRODUCTION: OVERVIEW OF SPATIAL DATA SETS RELATING TO WETLAND ECOSYSTEM TYPES ON THE MAPUTALAND COASTAL PLAIN (MCP)

We report here on two types of information that was collected, firstly the work done by scientists and secondly citizen scientists in the following two subsections.

2.1.1 Scientific studies with spatial data that can inform the remote sensing of the MCP's wetlands

A literature survey was done to compile a list of studies done on the MCP with spatial data that could be relevant to the remote sensing of wetland types. Primary spatial data where the coordinates of wetlands, such as floristic sampling, recording of peatlands, remote sensing studies, and other wetlands studies could provide valuable information to inform the capturing of Regions of Interest (ROIs) for image classification. These primary datasets, if suited for ROIs of the particular image sensor's spatial resolution, could provide some cost savings to a study. Other secondary datasets that are derived from remote sensing images may also be valuable to inform on the possible extent of EFGs and other Land Use and Land Cover (LULC) classes, although they should be used with caution, since they could be commission errors of a prediction model.

Table 2.1 shows the results of the literature survey undertaken. We have identified 27 studies with spatial data that were considered useful for this study. The extent of five of the datasets are at a country-wide scale, including the heads-up digitising and update of estuarine habitats (Adams *et al.*, 2016; 2019), the National Land Cover of 2018/9 (NLC2018/9) predicted from remote sensing images (Thompson, 2019), the National Peatlands Database (NPD) with point data of peatland localities (Grundling *et al.*, 2017) and the National Wetland Vegetation Database (NWVD) showing coordinates of floristic sampling done across the country (Sieben *et al.*, 2014). The first two datasets would be considered secondary datasets, whereas the last two would be considered primary.

A total of 22 studies have been done on a subnational scale, for various parts of the MCP. The primary and secondary data sources are discussed to consider the types of input to the image classification. Articles related to the same author(s) and area were grouped together as one record, for example, Adam and Mutanga (2009) and Adam *et al.* (2012; 2014) are three publications but form one record of work by Prof. Elhadi Adam associated with his PhD and related publications.

Six of the 22 subnational studies are primary resource types that collected the coordinates of wetland attributes. These include three floristic composition studies by Grobler (2009), Pretorius (2012), and Venter (2003). Although Neal (2001), Lubbe (1997), and Wessels (1991a-c; 1997) would also qualify as primary resources, it was not accounted for here in the reporting, because we could not track down the coordinates of these studies' relevés. If the coordinates were available, it would have added up to nine primary datasets of the 22 subnational studies available. Another two studies also collected coordinates of wetlands-related attributes, with Arndt (2014) investigating the degradation of wetlands across a transition from terrestrial areas to relic gardens, while Van Deventer (2016) collected coordinates of wetland tree species with a Differential Geographical Positioning System (DGPS) for remote sensing classification. A non-wetlands related primary dataset was also made available by Starke *et al*., (2020) related to timber and woodland localities that could be useful for image classification.

Twelve of the studies were remote sensing classification studies of parts of wetlands or other areas on the MCP. One of the studies focused on the classification of *Cyperus papyrus* at the St Lucia, Futululu and Lake Banagher nodes of the iSimanagaliso Wetland Park (Adam and Mutanga, 2009; Adam *et al.*, 2012; 2014). The data localities were plotted based on those reported in the publications, however, were not clear pure pixel representatives appropriate for the Sentinel-2 images and would only be used to inform potential localities of these macrophytes. Dlamini *et al.* (2021), Grundling *et al.*, (2013), and Lück-Vogel *et al.* (2016) studied the iMfolozi/uMsunduze floodplain, Muzi and part of Lake St Lucia in their image classifications respectively. The classes used by these studies were similar to some of our EFGs that we consider, however, new ROIs on Sentinel-2 must be created than using the secondary output datasets from these studies. Three studies were done on the DukuDuku Forest that could potentially be useful in identifying terrestrial parts of DukuDuku (Cho *et al.*, 2013), Malahlela *et al.* (2015) and Ndlovu (2013). Cho *et al.* (2013; 2015) provided coordinates of terrestrial tree species of which some of the species could transition to riparian forests, however, at a 10 m and 30 m spatial resolution, we had low confidence that these points do not include adjacent and contiguous terrestrial forests in the DukuDuku State Forest. Omer *et al*. (2015) used remote sensing to distinguish between a number of terrestrial and wetland tree species in St Lucia, however, did not provide these coordinates in the publication or on request. Ramjaewon *et al.* (2020) assessed the increase in timber plantations in the northern part of the MCP, mostly overlapping with the large quaternary catchment of W70A, and the tiff images provided, could be used for masking out LULCs such as timber, with the KZN land cover datasets also informing on these areas to mask out: cropland, timber and urban areas (EKZNW, 2011; 2013a&b; EKZNW and GTI, 2018). Riedel (2015) also used remote sensing to classify different wetland, terrestrial and LULC classes, however, the spatial data was not available for use. The remote sensing study with the largest geographic extent was that of Slagter *et al.* (2020), who used a number of secondary input datasets also listed in Table 2.2, in mapping broader vegetation categories (high, medium or low vegetation structure and various inundation categories) with a combination of Sentinel-1 and Sentinel-2 images. These classes are not compatible with the South African wetland types or the IUCN EFGs and will therefore not be considered. It was interesting to note, although, that this study proved that the combination of the SAR and optical images from Sentinel's sensors improved the overall accuracy of the classification.

Lastly, the heads-up digitising done by Scott-Shaw and Escott (2011) from a multitude of images were used in the mapping of the CS-TFW, but would also be useful to inform the location of sample points for some of the EFGs, however, since it is almost ten years outdated, if not more, it should not be used directly for ROIs. Where the EFG can still be recognised as being present for the reference or current date in the time-series classifications, the primary and selective source data will be used. Where it is not clear whether it is present, and it cannot be validated in the field, it would have to be discarded. In our data collection, we did not incur any copyright restrictions on these datasets and have given recognition due.

Table 2.1. Inventory of spatial studies and possible available spatial data for the mapping and typing of wetland types on the Maputaland Coastal Plain (MCP).

CS-TFW = Coastal Subtropical-Temperate Forested Wetlands; EFG = Ecosystem Functional Group; (D)GPS = (Differential) Global Positioning System; KZN = KwaZulu-Natal; LULC = Land Use Land Cover; ROIs = Region of Interest; SPOT = *Satellites Pour l'Observation de la Terre*

Province or South Africa (SA)	Citation	Study	Extent description	Primary (e.g. collected with a GPS) or secondary (derived) resource	Point or polygon dataset	Estimated scale	Type of sampling or mapping	Description of how data will be used in this study	Confidence in representing the areal extent of swamp and floodplain forests*	Ecosystem Functional Group or wetland class
SA*	Adams *et al*. (2016; 2019)	Estuarine habitats, updated also for the National Biodiversity Assessment of 2018	SA	Secondary	Polygons	1:2 500	Desktop, heads-up digitising from orthophotos or other space-borne satellite images	Polygons of estuarine habitats will be used to inform the regions of interest (ROIs) that will be captured for the CS-TFW, while the extent of *Avicennia marina* (white mangrove) and other mangrove habitat polygons will be used to inform the ROIs of mangrove habitats.	High	CS-TFW and mangrove habitats
SA	Thompson (2019)	National Land Cover of 2018/19	SA	Secondary	Raster	20 m spatial resolution	Desktop, from existing polygon datasets	This data can inform regions of interest for wetland classification. It will be used to mask out areas that could lead to spectral confusion, for example, timber plantations, urban or built-up areas, and cultivated land.	N.A.	(Mask out areas that should not be classified)
SA*	Grundling *et al*. (2017)	National Peatlands Database	SA	Primary	Points	1:50	Infield augering to measure peat layer	The peatland points will be used to inform both CS-TFW and marsh wetlands ROIs.	Medium	CS-TFW and marsh wetlands
SA*	Mucina & Rutherford (2006) and the Dayaram *et al.* (2019) update	Vegetation map of South Africa, Lesotho and Swaziland (Mucina & Rutherford, 2006) with updates from Dayaram *et al.* (2019)	SA	Secondary	Polygons	1:3 000-1:50 000	Desktop, heads-up digitising from orthophotos or other space-borne satellite images	Various polygons will be used to inform ROIs: • swamp forest to CS-TFW • mangrove habitats • terrestrial forests and grasslands	Medium	CS-TFW, mangroves, terrestrial forests and terrestrial grasses
SA*	Sieben *et al.* (2014)	National Wetland Vegetation Database (NWVD)	SA	Primary	Points	1:50	Collation of coordinates from infield surveys	Points will be used to inform CS-TFW and marsh ROIs of the MCP.	N.A.	CS-TFW and marsh wetlands

Province or South Africa (SA)	Citation	Study	Extent description	Primary (e.g. collected with a GPS) or secondary (derived) resource	Point or polygon dataset	Estimated scale	Type of sampling or mapping	Description of how data will be used in this study	Confidence in representing the areal extent of swamp and floodplain forests*	Ecosystem Functional Group or wetland class
KwaZulu-Natal (KZN) Province*	Adam and Mutanga (2009); Adam *et al.* (2012; 2014)	Remote sensing study of papyrus vegetation (*Cyperus papyrus L.*) on the MCP	MCP	Secondary	Points and raster datasets	1:50k	Infield coordinates of Paper reed, and sampling of some other wetland vegetation species	Points will be considered for ROIs where canopies can be clearly delineated and form pure pixels on the images for paper reed dominated wetlands.	N.A.	Macrophyte marsh wetlands
KZN Province	Arndt (2014)	Assessing historical changes in wetlands where small-scale farming occurred	Kosi Bay	Primary	Points	1:50k	GPS points of relic gardens	These points will be considered for the degradation part of the study.	N.A.	Degraded relic gardens
KZN Province	Cho *et al.* (2013; 2015)	Assessing subtropical forest fragmentation in the DukuDuku forest	Sub-catchment scale	Secondary	Sample locations and extent of canopies	Points, polygons and raster estimated at 1:50k	Segmentation of canopies and infield validation	The output map, if available, could be used to inform the location of terrestrial parts of the DukuDuku forest. If the fine-scale data of one of the tree species, *Bridelia micrantha*, could be obtained, it could be evaluated for use in the CS-TFW, as this is one of the indicator tree species.	N.A.	Terrestrial forests and maybe one for CS-TFW
KZN Province	Dlamini *et al.* (2021)	Remote sensing study of land use land cover changes on the iMfolozi floodplain, iMfolozi catchment	Sub-catchment scale	Secondary	Raster dataset predicted from Landsat	30 m spatial resolution	Validation and remote sensing classification of wetland types and other LULC classes.	Will be used as one of the benchmarks from which land cover changes will be evaluated.	N.A.	Changes in land cover
KZN Province	Ezemvelo KwaZulu-Natal Wildlife (EKZNW), 2011; 2013a; 2013b; EKZNW and Geoterra	KZN province	KZN Province	Secondary	Raster dataset	20 m spatial resolution	Classification of LULC classes for KZN using SPOT in the 2005, 2008, and 2011 classifications, and multiseasonal Sentinel-2 images for the 2017 classification.	Land cover categories to mask out urban, timber and cultivated land.	N.A.	Land cover categories to mask out urban, timber and cultivated land.

Province or South Africa (SA)	Citation	Study	Extent description	Primary (e.g. collected with a GPS) or secondary (derived) resource	Point or polygon dataset	Estimated scale	Type of sampling or mapping	Description of how data will be used in this study	Confidence in representing the areal extent of swamp and floodplain forests*	Ecosystem Functional Group or wetland class
	Image (GTI) 2018									
KZN Province	Grobler (2009)	Swamp forest at Kosi, KZN	Sub-catchment scale	Primary	Points: Coordinates of relevé points	1:50	Infield floristic-based sampling of vegetation.	Points will be used to inform CS-TFW and marsh ROIs of the MCP.	N.A.	CS-TFW and marsh wetlands
KZN Province	Grundling (2014); Grundling *et al.* (2013)	Mkuze floodplain	Sub-catchment scale	Secondary	Raster dataset	1:250k	Remote sensing classification of Landsat images.	The data cannot be used because the data seems to show an overestimation of swamp forest, which may be due to the lower resolution Landsat images (30m).	N.A.	N.A.
KZN Province	Lubbe (1997)	Between Lake Sibaya in the south and Kosi Bay in the north	Sub-catchment scale	Primary	Point and polygons	1:50k	Infield floristic-based sampling of coastal vegetation types from Kosi Bay in the North to Lake Sibaya in the South.	Although the original relevé coordinates are not provided, the maps drawn and provided in the MSc can be georeferenced and used to match to other sample locations to inform new sample points for this study.	N.A.	Some EFGs
KZN Province	Luck-Vogel *et al.* (2016)	St Lucia node	Sub-catchment scale	Secondary	Raster	6 m spatial resolution	Data was derived from existing GIS maps based on areal imagery.	This secondary map will not be obtained as input ROIs.	N.A.	N.A.
KZN Province	Malahlela *et al.* (2015)	DukuDuku forest	Sub-catchment scale	Secondary			Remote sensing of canopy gaps in DukuDuku using infield validation	Mapping forest gaps in the DukuDuku Forest. Not directly relevant and therefore will not be used.	N.A.	N.A.
KZN Province	Ndlovu (2013)	DukuDuku forest	Sub-catchment scale	Secondary	Raster	1:20 000-1:50 000	Classification and validation of SPOT satellite images, as well as the use of georeferenced aerial photographs and other data for change detection.	Images and data between 1960 and 2008 were divided into four classes, namely Indigenous Forests, Plantation Forests, Water Bodies, and Other (open areas, cultivated land, and all human disturbed and transformed land). Land cover changes were quantified. The data was not obtained and too coarse for informing on our EFGs.	N.A.	N.A.

Province or South Africa (SA)	Citation	Study	Extent description	Primary (e.g. collected with a GPS) or secondary (derived) resource	Point or polygon dataset	Estimated scale	Type of sampling or mapping	Description of how data will be used in this study	Confidence in representing the areal extent of swamp and floodplain forests*	Ecosystem Functional Group or wetland class
KZN Province	Neal (2001)	Mkuze	Sub-catchment scale	Primary	Points	1:50k	Infield floristic-based sampling in the Mkuze Floodplain	Data was not available.	N.A.	N.A.
KZN Province	Omer *et al.* (2015)	DukuDuku forest	Sub-catchment scale	Secondary	Raster	2 m spatial resolution	Infield validation of terrestrial and wetland tree species with DGPS	Data was not collected or used because it will include commission errors.	N.A.	N.A.
KZN Province	Pretorius (2012) Pretorius *et al.* (2014; 2016; 2020)	Kosi Bay, KZN	Sub-catchment scale	Primary	Points	1:50	Infield floristic-based sampling of vegetation.	Floristic sample points (relevés) will be used during the classification to inform ROIs for training, particularly the permanent and seasonal marshes.	NA	Sedge and grass marsh wetlands
KZN Province	Ramjaewon *et al.* (2020)	Part of the MCP	Sub-catchment scale	Secondary	Predicted raster maps	1:250k	Remote sensing prediction of timber plantation extent using Landsat images	Predicted extent of the timber plantations will be used in association with the provincial and land cover datasets in selecting regions of interest	N.A.	Timber plantations
KZN Province	Riedel (2015)	North-west of the Kosi Bay area	Sub-catchment scale	Secondary	Predicted raster maps	1:250k	Remote sensing prediction of wetland and terrestrial classes	Classes used are similar to our EFGs, being marsh and swamp forests (*Ficus* and *Raphia* spp.), and for terrestrial classes forests, thicket and shrub, grassland, water and bare sand. Transformed classes were built up, timber plantations and subsistence cropland. The data was however not obtained.	N.A.	Could inform EFGs and transformed classes.
KZN Province*	Scott-Shaw and Escott (2011)	KZN Province	Provincial	Secondary	Polygons	1:2 500-1:5 000	Desktop, heads-up digitised from orthophotos.	Polygons of swamp and floodplain forests were extracted and integrated with other datasets	Medium	CS-TFW
KZN Province	Slagter *et al.* (2020)	iSimangaliso Wetland Park	Sub-catchment	Secondary	Raster	1:250k	Remote sensing study predicting broad vegetation categories	The classification system used by Slagter *et al*. (2020) is not compatible with the International Union for Conservation of Nature (IUCN) Ecosystem Functional Groups (EFGs) and can therefore not be used.	N.A.	N.A.
KZN Province	Starke *et al.* (2020)	Manzengwenya Plantation, KZN	Sub-catchment scale	Primary	Points	1:50	Infield based floristic-based sampling of vegetation	The data will be used to inform regions of interest for classification. It will aid in distinguishing between timber plantations and natural woodland during training.	NA	Timber and terrestrial vegetation

Province or South Africa (SA)	Citation	Study	Extent description	Primary (e.g. collected with a GPS) or secondary (derived) resource	Point or polygon dataset	Estimated scale	Type of sampling or mapping	Description of how data will be used in this study	Confidence in representing the areal extent of swamp and floodplain forests*	Ecosystem Functional Group or wetland class
KZN Province*	Van Deventer *et al.* (2019a)	St Lucia	Local	Primary	Points	1:10	DGPS used to identify the location of swamp and mangrove tree species.	These points were used to correct the classification of polygons typed as other forested wetland classes.	High	CS-TFW
KZN Province*	Venter (2003)	Mfabeni Swamp	Wetland extent	Primary	Points (coordinates of relevés) and polygons of wetland vegetation communities.	1:50 (points) and 1:2 500 (polygons)	Infield Braun-Blanquet sampling of vegetation.	Polygons were used to distinguish between swamp and floodplain forests and non-forested wetlands.	High	CS-TFW
KZN Province	Wessels (1991a-c; 1997)	MCP	Floristic sampling of swamp forests	Primary	Data not available.	1:50	Infield Braun-Blanquet sampling of vegetation.	Spatial data is not available.	N.A.	N.A.

* *Adapted from Van Deventer et al. (2021a)*

The distribution of the 361 points of the NPD extends across the study area from north to south, but are mainly located within 40 km of the coastline (Figure 2.1A). Most of the wetlands have been sampled across the marsh and CS-TFW, and these localities would be valuable for the selection of ROIs for these two EFGs. The NWVD has 1 038 points on the MCP (Figure 2.1B), containing some of the relevés from Grobler (2009) and Venter (2003) as well as other studies. Further work is required by Dr Sieben to identify which of these relevés could be used as ROIs in the image classification study.

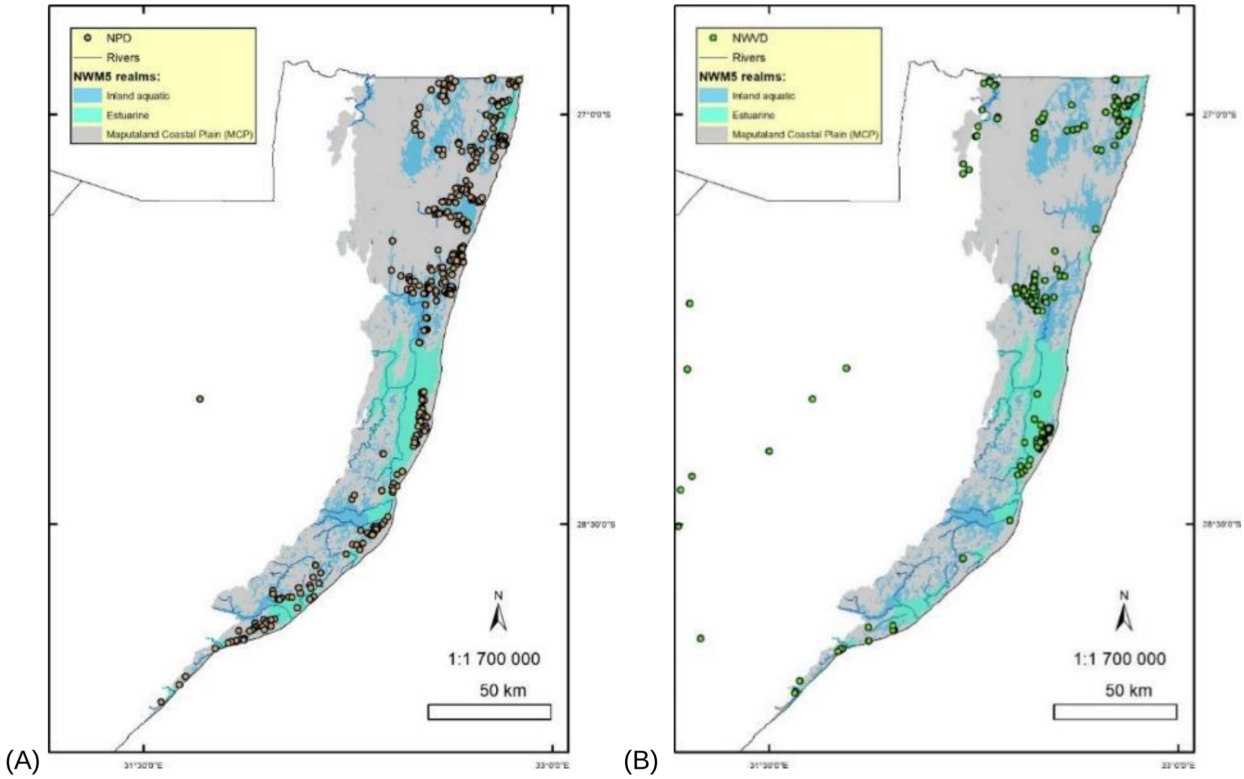


Figure 2.1. Location of point data from (A) the National Peat Database (Grundling *et al.*, 2017) and (B) the National Wetland Vegetation Database (Sieben *et al.*, 2014)

Primary studies that could assist in the typing of EFGs and their degradation are geographically distributed in the North around the Kosi Estuarine Functional Zone (EFZ), extending to the northern parts of Lake Sibaya and to the west in the Mkuze, including those of Arndt (2014), Grobler (2009) and Pretorius (2010) (Figure 2.2). Further South relevés are found in the Mfabeni Swamp (Venter, 2003), whereas the DGPS points of Van Deventer (2016) are East of the Narrows, extending South to the Maphelane Node and west along the iMfolozi River.

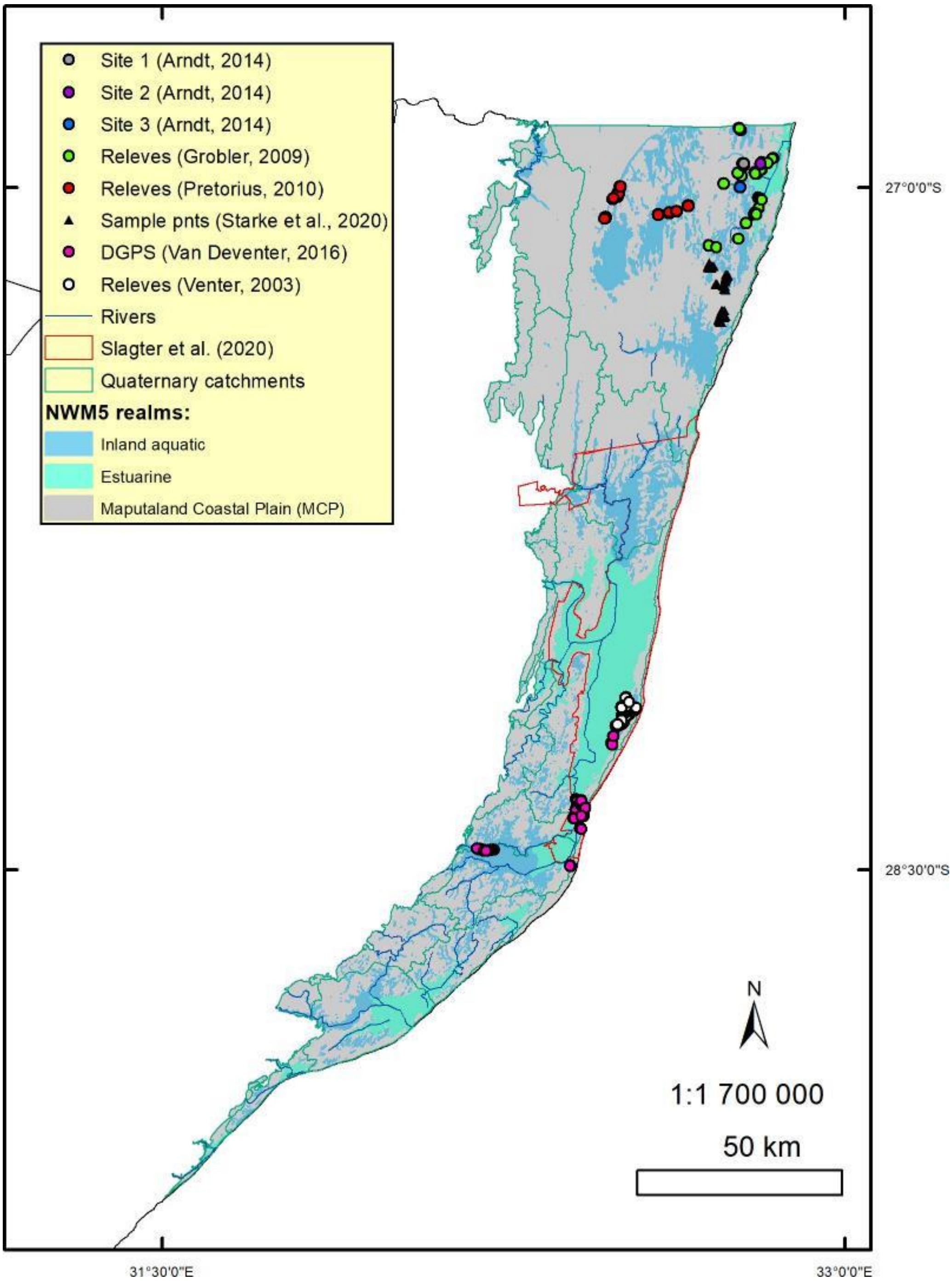


Figure 2.2. Location of point data from the National Peat Database (Grundling *et al.*, 2017) and the National Wetland Vegetation Database (Sieben *et al.*, 2014).

Figure 2.3 shows the growth forms that were mapped by Mrs. Ina Venter based on her relevés done in the Mfabeni Swamp (Venter, 2003). The majority of the extent is covered by sedges that could be classified as the marsh EFG, whereas CS-TFW occur along the Mfabeni stream to the south-west of the marsh vegetation.

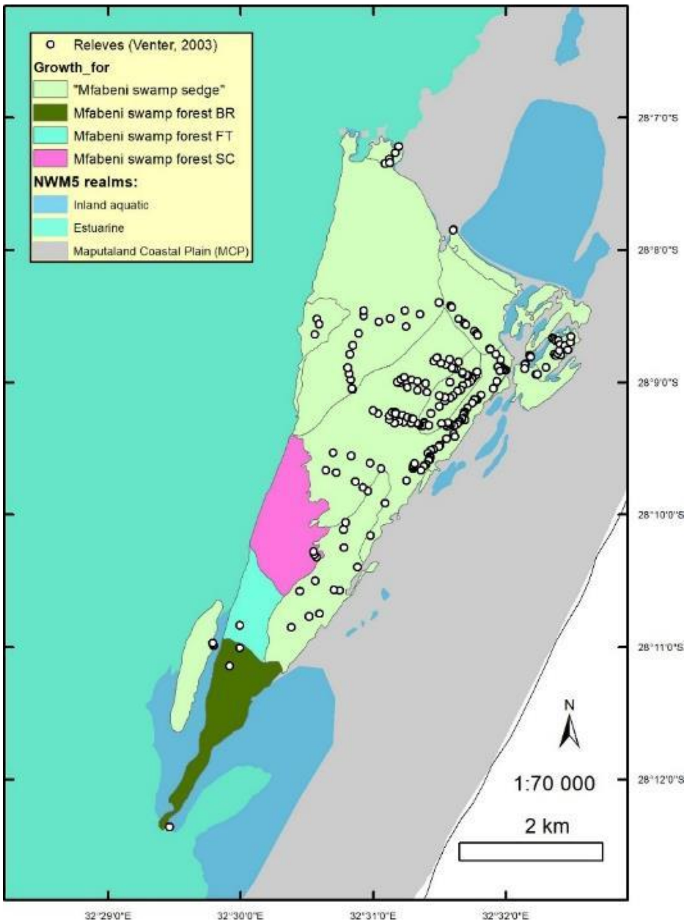


Figure 2.3. Growth forms mapped by Venter (2003) for the Mfabeni swamp.

2.1.2 Citizen science studies with spatial data that can inform the remote sensing of the MCP's wetlands

Citizen science observations of wetland-dependent plant species are valuable for informing the selection of ROIs and sample locations for the MCP. While these localities are not of high horizontal spatial accuracy for use in image classification, they can indicate possible areas where these species may be present and can influence sampling locations. If one considers, for example, the distance one would have to stand away from a tree to take a picture, it may be >5 m away, which for image classification, irrespective of the spatial resolution, may be in the next pixel (e.g. Sentinel-2 at 10 m spatial resolution). Citizens also use a variety of devices for recording coordinates, which may not always be horizontally as accurate compared to a DGPS.

In our consideration of species, we focused firstly on observations made for the thirteen key indicator tree species that are associated with Coastal Subtropical-Temperate Forested Wetlands (CS-TFW, or forested wetlands hereafter) in Van Deventer *et al.* (2021a). The CS-TFW are difficult to distinguish from adjacent contiguous terrestrial tree species, especially when using coarse-scale satellite images such as Sentinel-2. Ideally, one would want to use images at ≤1 m spatial resolution to segment the image into canopy objects and then classify each canopy according to the tree species (see for example Cho *et al.*, 2015). Validation of tree species would also require extensive validation procedures that exceed the available costing of this project. Therefore, working at a coarser scale of Sentinel-2 at 10 m spatial resolution, citizen science observations of these tree species can guide sample areas for validation in the fieldwork campaign.

The second group of plant species that we focussed on was a category ‘Large macrophytes’, that includes the Paper reed, Common and Lowveld reeds, and the Common Bulrush (Table 2.2). These species may present a large extent of dominant canopies that may be detectable on a Sentinel-2 pixel while also being a potentially unique EFG that we can separate from marsh EFGs. Theoretically, it could also be possible to identify obligate wetland plant species observations, however, we have limited our search here, since spectral reflectances of marsh wetlands may serve us better in distinguishing this EFG rather than citizen scientist observations. In our opinion, it may take a long time to compile a suitable list of such facultative species, only to find a small number of observations with low horizontal accuracy. Therefore, we did not pursue this category in our search.

To our knowledge, there are at least three citizen scientist observation platforms that may be of use:

- The Global Biodiversity Information System (GBIF);
- The South African National Biodiversity Institute’s (SANBI’s) herbarium records; and
- iNaturalist (http://www.inaturalist.org).

SANBI uploads their observations bi-annually or annually to GBIF, whereas a selective amount of iNaturalists’ records is uploaded to GBIF if tagged as research grade (Mrs Dewidine van der Colff, SANBI, personal communication on 2 July 2021 and 26 October 2021). The horizontal and species identification accuracies of records in all of these databases are not always correct either.

In addition to the citizen science databases, South Africa has a Freshwater Biodiversity Information System (FBIS) at https://freshwaterbiodiversity.org, which offers a range of freshwater information on typing, ecological condition, and species observations related to rivers. At the moment, FBIS does not contain wetland observations, however, this gap will be addressed in the future (Mrs Kate Snaddon, National Wetlands Indaba 2021 presentation).

Two of the authors, Dr Heidi van Deventer and Mr Philani Apleni, met with Mrs Dewidine van der Colff from SANBI on 2 July 2021 to learn how to extract the location of species on the MCP from iNaturalist. Subsequently, Mr Apleni extracted the coordinates of observations for the key indicator tree species of the CS-TFW from iNaturalist. A total of 402 observations was recorded (Table 2.2). For the Large macrophytes, a total of 57 observations were recorded (Table 2.2).

Table 2.2. Number of observations extracted from iNaturalist relating to the MCP's wetlands

Key indicator tree species for Coastal Subtropical-Temperate Forested Wetlands	Number of observations recorded in iNaturalist	Other species	Number of observations recorded in iNaturalist
Barringtonia racemosa (Powderpuff tree)	48	*Cyperus papyrus* (Paper reed)	28
Bridelia micrantha (Mitzeerie)	34	*Phragmites australis* (common reed)	12
Casearia gladiiformis (Sword-leaf)	7	*Phr. mauritianus* (Lowveld reed)	
Cassipourea gummiflua (Large-leaved Onionwood)	19	*Typha capensis* (Common bulrush)	17
Ficus sur (Broom-cluster fig)	5		
F. trichopoda (Swamp fig)	32		
Hibiscus tiliaceus (Lagoon hibiscus)	49		
Macaranga capensis (Wild poplar)	19		
Phoenix reclinata (Wild date palm)	67		
R. australis (Kosi palm)	27		
Rauvolfia caffra (Quinine tree)	7		
Syzygium cordatum (Water berry)	24		
Voacanga thouarsii (Wild frangipani)	16		
Total	402		57

Similar to the primary data collected, the iNaturalist observations of the key indicator tree species and four Large macrophyte wetland species showed a geographical distribution that are along the coast, concentrated on the eastern shores of the iSimangaliso Wetland Park, in the southern parts, and to a lesser degree, around the Kosi EFZ (Figure 2.4). The tree species associated with the CS-TFW would naturally occur within 20 km from the coast. No observations are reported for the Tembe Elephant Park to the west of the MCP and the Phongola River. There are also very few observations for Lake Sibaya and KwaNibela or the iMfolozi/uMsunduze floodplain.

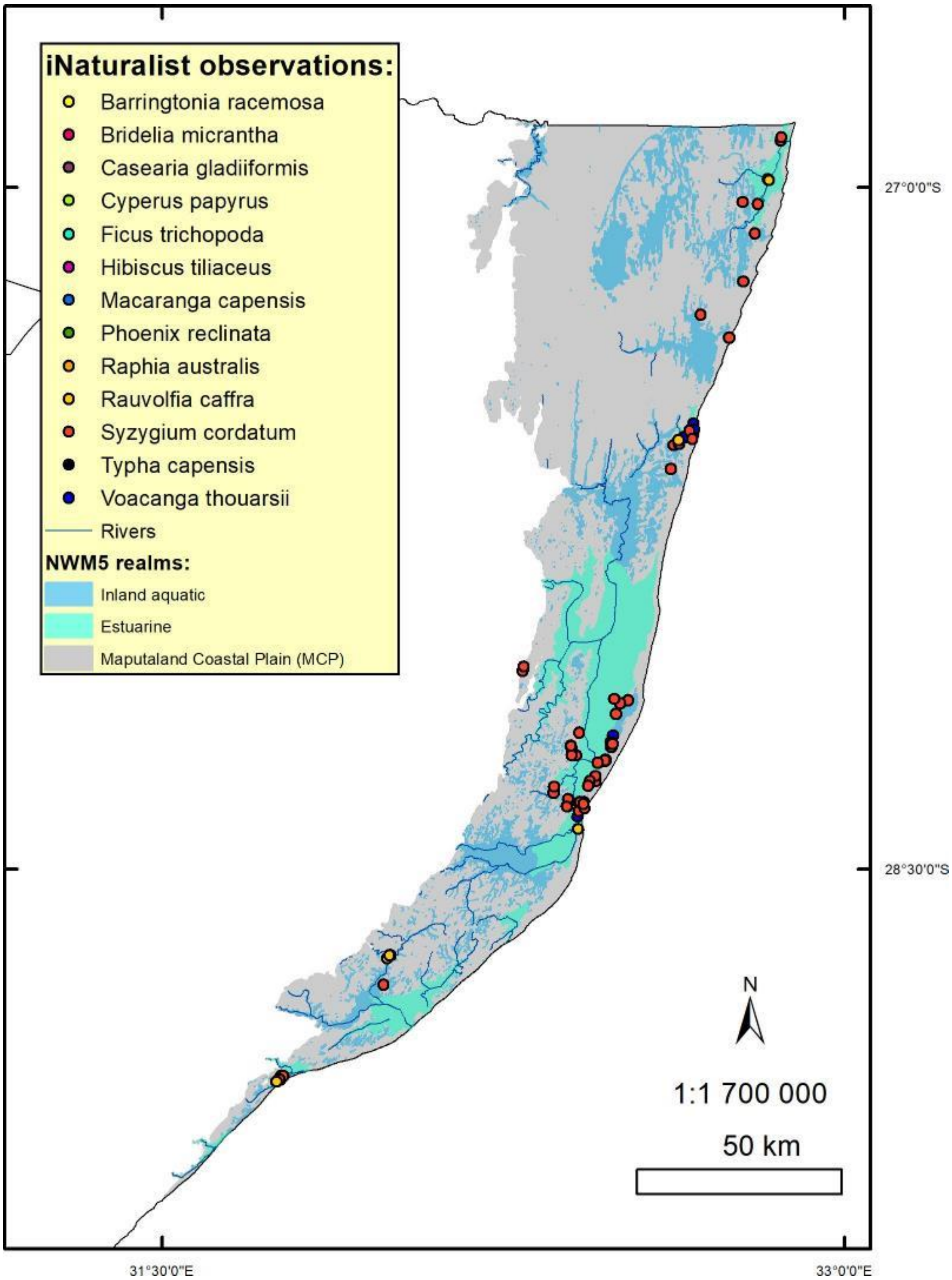


Figure 2.4. Location of citizen science observations recorded in the iNaturalist platform that relate to wetland plant species selected for use in this study.

2.2 STUDIES RELATED TO DEGRADATION AND TRANSFORMATION

A number of remote sensing studies demonstrated the capabilities of different airborne and space-borne sensors to quantify the changes in both ecosystem structure and ecosystem function (Pettorelli *et al.*, 2016). These include a wide range of Essential Biodiversity Variables (EBVs) for remote sensing, such as changes in ecosystem extent and geographic distribution, forest and fractional cover, land cover, and vegetation height for ecosystem structure (Pettorelli *et al.*, 2016). For ecosystem function, remote sensing is able to quantify changes in above-ground biomass (AGB), fire disturbances, inundation or soil moisture, Leaf Area Index (LAI), and vegetation phenology (Pettorelli *et al.*, 2016). We assessed the land transformation classes and degradation types reported in the available studies that are listed in Table 2.2 in the light of these EBV types.

2.2.1 Land transformation

The floristic sampling study of Grobler (2009) studied changes in floral species and vegetation structure in a part of Kosi Bay. In terms of land transformation, Grobler (2009) reported a succession from land clearing to subsistence farming of crops and then followed by commercial crops such as bananas (Figure 2.5). The current land cover categories of the provincial and national datasets do not report or detect these transformation categories (Van Deventer *et al.*, 2021a).

Figure 2.5. Transformation of coastal subtropical-temperate (swamp and floodplain) forested wetlands shown in the top photograph to banana plantations in the bottom photograph in the Siyadla River of the Maputaland Coastal Plain. Photographs by Mr Retief Grobler (Grobler, 2009).

Many remote sensing studies listed in Table 2.2 on the MCP used broad LULC classes for mapping changes in wetlands. Very often, waterbodies (lacustrine wetlands) and wetlands (palustrine wetlands) were used as broad classes, and the changes were not always related to the larger wet and dry cycles of the MCP. Land cover datasets derived from remote sensing remain important for quantifying land transformation, however, it is important that the extent and type of transformation are detectable and quantifiable in the land cover datasets. In addition, the reporting of such changes also now needs to be refined per wetland type, and just broad HGM units. In the red list assessment of CS-TFW (Van Deventer *et al.*, 2021a), the provincial land cover datasets showed an underrepresentation of the extent and type of land transformation from these forested wetlands to cleared land, subsistence and subsequently, commercial crops. Changes in the other wetland types of the MCP have not yet been assessed. There is an opportunity to assess whether the available Landsat archive in Google Earth Engine (GEE) would be able to detect changes in the different EFGs of the MCP.

2.2.2 Draining of peatlands and the subsequent risk of peat desiccation and peat fires

Various authors have also reported the draining of the CS-TFW which resulted in the drying out of peat and the subsequent risk of peat fires (e.g. Arndt, 2014; Grobler, 2009; 2012; Janse van Rensburg, 2019). These drains are not visible in the current space-borne satellite images, and would require infield validation or possible Light Detection and Radar (LiDAR) data to map and monitor. Therefore, these early signs of degradation may not be suited for a remote sensing (RS) monitoring system at a landscape scale.

Another study on peatlands (Grundling *et al.*, 2021) showed that an increase in the number of marsh wetlands on the MCP are becoming desiccated and show signs of degradation as a result of burning of the substrate. The Vasi Pan and Muzi wetlands are currently being monitored with infield equipment as part of another WRC project (Le Roux *et al.*, 2023), 2019/2020-00098, titled ‘Determine peat loss and develop management and rehabilitation protocols for peatlands in South Africa’ (Figure 2.6). The data recorded by the Grundling *et al.* (2021) study offers an opportunity to assess the possibility of tracking and monitoring these desiccated and degraded peatlands with remote sensing.

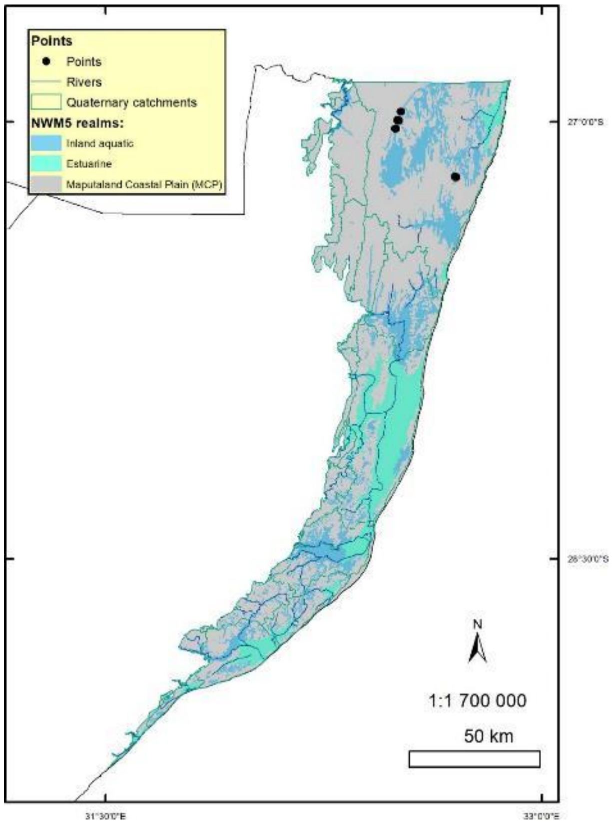


Figure 2.6. Location of the sample points for the Water Research Commission #: 2019/2020-00098, titled 'Determine peat loss and develop management and rehabilitation protocols for peatlands in South Africa' (Le Roux *et al*., 2023). These points are monitoring the changes and degradation of two peatlands on the Maputaland Coastal Plain.

2.2.3 Changes in vegetation structure

Grobler (2009) identified some interdune wetlands which had previously been CS-TFW but are now relic gardens. The floristic composition of these wetlands has changed to macrophytes, sedges, and grasses, although some of the key indicator tree species remain on the fringe of the wetland on the slope, that was not farmed (Arndt, 2014; Grobler, 2009; 2012). The soil structures were also found changed, with soils on the mounds are drier, and soils in the ditches between these mounds still show signs of higher organic and soil moisture content.

Arndt (2014) investigated the historical changes in the distribution and quality of interdune wetlands and recorded the changes in subsistence farming in the wetlands in the eMangusi area. He used 53 plots in five wetlands to describe changes in these wetlands between the years 1942 and 2009. He observed an increase in woodland density from 1942 to 1970, whereafter a decline was observed towards 2009. Tree cover outside the wetlands also increased gradually from 1942 to 2000, with a slight decrease in 2009.

A study on the impact of the suppression of fire in wetlands at KwaMbonambi, north of Richards Bay, across aerial photographs of 1937, 1970 and 2009, with the transition to timber plantations, showed a severe reduction in the extent of terrestrial and hydrophylic grasslands (69%) to 2% (Luvuno *et al*., 2016). The suppression of the fire regime has also increased the extent of swamp forests from 4% to 15%. Disturbed wetlands showed an increase in the dominance of *Macaranga capensis* and *Stenochlaena tenuifolia*.

Knowledge on the full extent of changes in wetlands across the MCP and structural or species changes has not been assessed to date. Remote sensing of changes in vegetation structure is possible with a range of space-borne SAR bands and the use of three indices, changes in AGB, Canopy Cover (CC), and height (HT) (Naidoo *et al.*, 2015). In a preliminary assessment (unpublished) at a desktop level, authors Dr Laven Naidoo and Dr Heidi van Deventer investigated whether changes in the AGB, CC and HT can be quantified to the extent of the CS-TFW, however, using the available datasets of 2010 and 2015 at a 25 m spatial resolution (Naidoo *et al*., 2015), the changes were not large enough to be detected. It may be that the bands used were not sensitive enough to detect changes in the structure owing to model errors propagated between the years, or that the spatial resolution was not suitable. The Sentinel-1 SAR is a C-band sensor that can penetrate only 5 m into the canopy and would therefore not be useful in mapping the vegetation structure in this study (L-band SAR is more suitable but no free high temporal satellite currently exists). We would recommend the use of LiDAR to quantify changes in the vegetation structure of the forested wetlands better, using the three indices AGB, CC, and HT.

2.2.4 Fragmentation

Changes in the extent of transformation and fragmentation of the CS-TFW were studied by Van Deventer *et al.* (2021a&b) using the four provincial land cover classes of KZN (Table 2.2). The first three land cover datasets derived from *Satellites Pour l'Observation de la Terre* (SPOT) images included the modelled extent of wetlands, and therefore underrepresents the different types of wetlands accurately. In addition, these three datasets were found to underrepresent the transformation and degradation of CS-TFW well, and therefore this project was proposed to determine whether this can be done more accurately. These land cover datasets have also been used in the assessment of fragmentation metrics for the CS-TFW, however, since the natural ranges of fragmentation of coastal forests are poorly understood, it is difficult to determine a threshold to distinguish natural fragmentation from those with increasing levels of degradation.

2.3 CONCLUSION ON IDENTIFICATION OF OPPORTUNITIES AND LIMITATIONS

Several opportunities for the improved remote sensing of EFG extent and their related transformation/degradation were identified and summarised here:

Mapping of wetland types:

- Monitoring changes of the original or reference extent;
- Refinement of categories to the IUCN EFGs;
- Validating citizen science observations where no current primary observations were made;
- Samples in geographically poorly represented areas; and
- The use of a selected reference period for different wetland types.

Mapping of transformation and degradation:

- Improvement of the detection, typing, and quantification of different transformation and degradation categories. Categories could include the following: cleared CS-TFW or cleared marsh; relic gardens; subsistence crops; commercial crops; desiccated peatlands; burnt peatlands (e.g. Vasi Pan); burning peatlands; and new forest regrowth in the case of transformed CS-TFW.
- Use of more frequent temporal intervals of reporting, depending on the rate of changes observed; and
- Changes need to be reported within selected time periods of the hydrological cycle.

Limitations:

- The extent of land transformation needs to be wider than a single Sentinel-2 pixel (10 m spatial resolution) before it could be detected. The varying shapes of wetlands, of both transformed and degraded areas, may be small and traverse a single pixel of Sentinel-2 at a 10 m spatial resolution. Some transformation and degradation classes may not be large enough to be detected early or entirely.

CHAPTER 3: WETLAND TYPES CLASSES TO USE FOR CHANGE DETECTION ON THE MCP

This chapter describes the wetland and degradation types that can be monitored for change on the Maputaland Coastal Plain (MCP). Wetlands typically contain a wide variety of plant communities and types of vegetation that are organised into easily discernible zones or patches (Van der Valk, 2012). These zones and patches are typically dominated by distinct types of growth and can be found at a number of different scales (Van der Valk, 2012). Because wetlands are dynamic, these growth forms can change over time as a result of natural or anthropogenic activities (Galatowitsch, 2018).

Remote sensing has been successfully used for mapping different wetland growth forms and detecting wetland changes over time. Classifying vegetation and detecting changes on a regional scale are possible using Sentinel-1 and -2 data, not only because of the advantages in spatial and temporal resolution, but also because the data is freely available. When performing change detection using remote sensing, a number of variables must be considered before deciding which classes to use because the classes used for change detection have a significant impact on the results. The classes are chosen for change detection based on their spectral and backscatter homogeneity. Classes are recognised when their spectral and backscatter properties are homogeneous but differ in other surrounding structures.

Furthermore, the sensor properties have a significant impact on the classes that are chosen. The spectral, temporal, and spatial resolutions of the sensor determine the classes, frequency of monitoring, and minimum size of detectable wetlands. The spatial resolution of Sentinel-2 is 10 x 10 m, and the wetland Ecosystem Functional Groups (EFG) that can be used should fit within this minimum size.

The International Union for Conservation of Nature (IUCN) provides a framework for the global ecosystem typology of ecosystems across the globe (Keith *et al.*, 2022). Wetlands are grouped with rivers under ‘inland water’, and the wetlands include both estuarine and freshwater realms. At the biome level, lacustrine (open water) and palustrine (vegetated) wetlands are distinguished, and these are reported in the Sustainable Development Goal (SDG) indicator 6.6.1a (DWS, 2020; Van Deventer, 2021a). At a finer level of the global ecosystem typology hierarchy, habitats are mapped as EFGs, of which the extent and EBVs can more easily be monitored with remote sensing, compared to the hydrogeomorphic (HGM) units of the National Wetland Map version 5 (NWM5) (Van Deventer *et al.,* 2020b; 2021a). Large macrophytes were chosen as a distinct group in addition to the IUCN EFGs due to their abundance and homogeneous spectral characteristics in the study area, as proposed by Van Deventer *et al.* (2022b). In addition to the wetland types, some degradation types were selected for change detention based on their abundance, extent and whether they were wide enough to be detected through the Sentinel-1 and -2 images.

Natural events such as tidal changes, river flooding, and changes in precipitation patterns can all cause wetlands to change over time. Natural changes can vary by wetland type, extent, and duration (Finlayson *et al*., 2018). Changes in wetland types result in natural shifts in plant communities and composition because wetland types have a varied tolerance to change (Galatowitsch, 2018).

In addition to the natural wetland changes, anthropogenic activities also influence wetland changes. Amongst the anthropogenic drivers of wetland change, land conversion, infrastructure development in wetlands, water withdrawal, pollution, overexploitation, and invasive species as the major contributors of wetland change (Galatowitsch, 2018). Indirect changes can occur as a result of timber plantations adjacent to wetlands, which can cause a drop in the water table and result in the burning of peatlands (Van Deventer *et al.,* 2021a&b).

This chapter will describe the wetland classes that will be used for change detection on the MCP, including natural and anthropogenic changes that were observed in other studies and during field work on the MCP.

3.1 WETLAND EFGs THAT CAN POSSIBLY BE DETECTED WITH SENTINEL-1 AND -2 ON THE MAPUTALAND COASTAL PLAIN

This subsection will be describing the wetland EFGs that will most likely be detectable using Sentinel-1 and -2 data. The subsection will give a description of vegetation structures including the dominant species that are found in each of the EFGs.

3.1.1 Subtropical-temperate forested wetlands

Subtropical-temperate forested wetlands consist of swamp, riverine and floodplain forests (Van Deventer *et al*., 2021a). These forests are different from other terrestrial species because of their association with wetlands, and in the majority of cases also peat, and they thrive in wet lowlands with moist soil near streams (Mucina *et al.*, 2006). These forests have an even height of about 12-15 m and contain the poorly developed understory layer that is usually ferns and lianas that have adapted to growing in inundated areas (Lubbe, 1997; Grobler *et al.*, 2004). The indicator species for these forested wetlands include *Barringtonia racemosa*, *Bridelia micrantha*, *Casearia glandiformis, Cassipourea gummiflua, Ficus sur, F. trichopoda, Hibiscus tiliaceus, Macaranga capensis, Phoenix reclinata, Raphia australis, Rauvolfia caffra, Syzygium cordatum and Voacanga thouarsii* (Van Deventer *et al.,* 2021a). Examples of these are provided in Figure 3.1.

(A)  (B) 

Figure 3.1. (A) flooded subtropical-temperate forested wetland dominated by *Barringtonia racemosa* and (B) shows the canopy of a forested wetland with a number of tree species.

3.1.2 Large macrophytes

The MCP contains a large number of large macrophytes, which are found along areas that are constantly inundated. Tall growing grasses, sedges, and reeds dominate the large macrophyte class. *Cladium mariscus, Cyperus papyrus, Phragmites australis,* and *Typha capensis*, with heights > 1.5 m (Figure 3.2).

(A)


(B)


Figure 3.2. A wetland dominated by (A) *Cyperus papyrus* and (B) *Phragmites australis.*

3.1.3 Permanently inundated marshes

Permanent marshes are those marshes that are flooded throughout most of the year (Gardner and Finlayson, 2018). These wetlands are found in areas where the water table is near the surface throughout the year (Kotze and O'Connor, 2000). Permanently wet marshes support submerged or floating aquatic plants (Cowardin *et al.*, 1979). An example of these is provided in Figure 3.3.

Figure 3.3. Permanent marshes dominated by short grasses and sedges.

3.1.4 Seasonal marshes

Seasonal marshes occur because of changes in the ground water table (Sieben *et al*., 2014). The groundwater table changes seasonally, it is high during the wet season and low during the dry season. They are dominated by short grasses, rushes, and sedges (Richardson, 2001). Seasonal wetlands have intermediate organic matter greater than 2% but less than 5% (Richardson, 2001). Seasonal floodplain marshes are inundated for 12.5% to 25% of the year (Rivers-Moore and Goodman, 2010). Examples of these are provided in Figure 3.4.

(A)  (B) 

Figure 3.4. Examples of seasonal marshes on the Maputaland Coastal Plain with (A) showing more extensive water inundation compared to (B).

3.1.5 Lacustrine wetlands

Lacustrine wetlands are found in deep water habitats and are associated with large lakes. Wetlands of this type lack emergent vegetation, trees, or shrubs, and their depth exceeds 2 m (Mitsch and Gosselink, 2015). Examples of these are provided in Figure 3.5.

Figure 3.5. Examples of lacustrine wetlands with no emergent vegetation.

3.1.6 Mangrove forests or IUCN MFT1.2 ‘Intertidal forests and shrubland’

Mangrove forests are salt tolerant trees, shrubs and other plants growing in brackish to saline tidal waters (Mitsch and Gosselink, 2015). *Avicennia marina*, *Bruguiera gymnorrhiza*, and *Rhizophora mucronata*, are the primary mangrove species and are fringed by *Hibiscus tiliaceus* (Rajkaran *et al.*, 2009; Lubbe, 1997). Examples of these are provided in Figure 3.6.

Figure 3.6. Examples of mangrove forests at Umlalazi Nature Reserve, KwaZulu-Natal.

3.1.7 Salt marshes or IUCN MFT1.3 ‘Coastal saltmarshes and reedbeds’

Salt marshes are dominated by rooted vegetation, primarily succulent chenopods found near river mouths, bays, coastal plains, and lagoons (Adams *et al.*, 2016; Keith *et al.*, 2020; 2022). Salt marshes are influenced by tides and have adaptations to flooding and salinity fluctuations. *Atriplex patula*, *Bassia diffusa*, *Juncus kraussii* and *Salicornia meyeriana* dominate these tidal systems (Adams *et al*., 2016; Raw *et al*., 2021). Examples of these are provided in Figure 3.7.

(A) 

(B) 

Figure 3.7. (A) *Bassia diffusa* dominated salt marsh and (B) *Juncus kraussii* dominated salt marsh.

3.2 NATURAL CHANGES OBSERVED ON THE MAPUTALAND COASTAL PLAIN

Natural changes, unlike anthropogenically induced changes, occur over long periods of time (Ellery *et al.*, 2012). Natural wetland changes are mainly driven by natural variations in weather patterns (Van Deventer *et al.*, 2019a). Processes like succession, in which one pioneer species is replaced by another, and canopy expansion occur over long periods of time. Wessels (1997), for example, estimated that the natural growth of floodplain and swamp forest is approximately 17.5 km² per year. Grundling *et al.* (1998) also used carbon 14 dating of pollen samples to determine the history of changes in wetland types across the MCP. The study showed that in the Majaji Mire, situated near Kosi Lake, wetland types changed from lacustrine, to sedge dominated and later coastal swamp and floodplain forests. Sedimentation has also been observed on the MCP (Ellery *et al*., 2012). Sedimentation can cause changes in the soil chemistry and wetland hydrological regime (Ellery *et al.*, 2012). According to Patrick and Ellery (2007), there is a rise in sediment buildup in the Lower Mkhuze River Floodplain, which is causing a decrease in the area of lacustrine wetlands and an increase in palustrine wetlands. There has also been a transformation from lacustrine wetlands to Large macrophytes in Lake Eteza Mr (Willaim Davidson, personal communication). Wright *et al.* (1997) also reported that there is an increase in the sedimentation and erosion in Lake Mpungwini near Kosi Bay. Changes in water levels due to drought and flooding events have also been linked to mangrove and saltmarsh dieback (Steinke and Ward, 1989). Adams and Tabot (2019), reported that between 2008 and 2013, there was a 57% decrease in saltmarsh and an increase in submerged macrophytes due to the dieback caused by drought.

3.3. ANTHROPOGENIC CHANGES OBSERVED ON THE MAPUTALAND COASTAL PLAIN

Table 3.1 lists several changes that have been observed for the EFGs, as listed in section 3.1.

Table 3.1. Anthropogenic changes in wetland Ecosystem Functional Groups observed on the Maputaland Coastal Plain

Wetland type	Types of degradation that were observed to date	Source or reference
Lacustrine wetlands	Invasive species	Observed by Dr Heidi van Deventer and Mr PhIani Apleni near Lake Nhlabane in February 2022 and also observed by Chetty *et al*. (2021).
Large macrophytes	Harvesting, burning	Observed by Mr Philani Apleni near Lake Sibaya in February 2022 as well as by other authors including Grundling *et al.* (1998), Grundling *et al.* (2021), and Le Roux *et al*. (2021).
Mangrove forests	Harvesting of mangroves for fish traps, branch harvesting	Observed in the Kosi Bay Lake system (Rajkaran and Adams, 2011).
Permanent marshes	Drainage, slash and burning, vegetable gardens	Observed by Dr Heidi van Deventer and Mr Philani Apleni in eManguzi (June 20221 and near Lake Sibaya (June 2021, February 2022) as well as by other studies including Grobler (2004a); Pretorius (2012).
Seasonal marshes	Burning, invasive species	Also observed by Dr Heidi van Deventer and Mr Philani Apleni in Vasi Pan in June 20221 and authors such as Grundling *et al.* (1998).
Subtropical-temperate forested wetlands	Cutting down, banana plantations, vegetable gardens, building of homes	Grobler *et al*., 2004b; Grobler, 2011; Grundling, 1998. Also observed by Dr Heidi van Deventer and Philani Apleni in Mgobezeleni in June 2021 and February 2022
Salt marshes	Affected by estuary manipulation, dieback in the St Lucia and iMfolozi floodplain	Rautenbach (2015)

3.3.1 Previous studies on degradation types

Several studies have been conducted to document the many different types of degradation that can occur in the wetlands of the MCP. The research conducted by Grundling *et al.* (1998) recorded the species composition of the plants as well as the types of degradation. There were reports of vigorous agricultural activity near the Kosi Bay Camp. The research also revealed that local communities in the Nhlangu peatland carry out annual fires on their peatlands. In Mgobezeleni, evidence of tree felling in the surrounding swamp forest was observed, and slash burning was also observed. Grundling *et al.* (1998), also reported on the burning of the edges of the Mfabeni swamp forest. In the vicinity of Vasi Pan, there was also a report of the encroachment of pine plantations in wetland areas (Grundling *et al.*, 1998). Finally, the study reported that cattle grazing was to blame for the degradation of the Majaji peatland. Grobler *et al*. (2004b) also reported the drainage of swamp forests for the cultivation of amadumbe (*Colocasia esculenta*), bananas (*Musa ssp.*), pumpkins (*Cucurbita* *spp.*), and tomatoes (*Solanum lycopersicum*), near Kosi Bay Lake. Grobler (2009) described the degradation occurring in the peat swamp forests of the northern MCP. The research also recorded the level of deterioration in peat swamp forests and also reported swamp forest clearance for farming. The study also reported wetlands being drained, cut and burned before the planting of amadumbe (*Colocasia esculenta*), banana (*Musa spp.*), and sweet potatoes (*Ipomoea batatas*). Pretorius (2012) also reported the draining, slash and burn of permanently wet peatlands near the Muzi swamp. The study observed the burning and draining of pans prior to their use for livestock grazing. Elshehawi *et al.* (2019) linked the burning of peatlands to the introduction of plantations near wetlands, the burning of peatlands is also documented by Grundling *et al.* (2021). The study reported that there had been 34 sites that have burnt on the MCP within the past five years. In addition to burning, and wetland cultivation, observations of alien invasive species have been reported on the MCP.

Singh *et al.* (2020) mapped the presence of invasive water hyacinth at a national scale using Sentinel-2 covering a part of the MCP. A study by Cho *et al*. (2015) reported an observation of *Chromoleana odorata* and *Lantana ssp.* in disturbed areas near power lines in the DukuDuku forest. Cho *et al*. (2015) mapped the distribution of *Chromolaena odorata* using Worldview-2 images for the Dukuduku Forest. The study successfully mapped the presence of *C. odorata* with an overall accuracy of 87%. Another study by Chetty *et al.* (2021) mapped the presence of the invasive *Parthenium hysterophorus* near Mtubatuba on the MCP with a user's accuracy of 58%. Grundling (2017) reported the presence of young commercial *Eucalyptus spp.* trees that have been planted near wetland edges near Manzengwenya, that should be removed.

Table 3.2 provides a summary of the invasive species listed by previous studies, and during the fieldwork of this project, to the NEMBA category (NEM:BA) (Act No. 10 of 2004).

Table 3.2. Invasive plant species documented on the Maputaland Coastal Plain

Species	Common name	NEM:BA category (SANBI, 2021)	Can it be detected using Sentinel-1 and -2 data at a 10-m spatial resolution?	Reference
Chromolaena odorata	Siam weed	1b	No	Cho *et al*. (2015a&b); Malahlela (2015)
Eichhornia crassipes /Pontederia crassipes	Water hyacinth	1b	Yes/ covers water bodies	Observed by Dr Heidi van Deventer and Mr Philani Apleni near lake Nhlabane on the 4th of February 2022 and mapped by Singh *et al.* (2020)
Eucalyptus ssp.	Gum tree	1b	Yes	Blackmore *et al.* (1996)
Lantana ssp.	Lantana	1b	No	Cho *et al.* (2015)
Parthenium hysterophorus	Famine weed	1b	No	Observed near Lake Eteza and by Dr Heidi van Deventer and Mr Philani Apleni on the 4th of February 2022; and mapped by Chetty *et al.* (2021)
Pinus ssp.	Pine	1b / 2 / 3	Yes	Blackmore *et al*. (1996)
Rubus fruticosus	European blackberry	2	No	Observed near St. Lucia western shore by Dr Heidi van Deventer and Mr Philani Apleni on 8 February 2022
Tradescantia zebrina	Wandering jew	1b	No	Observed in Twinstreams Environmental Education Centre in Mtunzini by Dr Heidi van Deventer and Mr Philani Apleni on 2 February 2022

3.4 DEGRADATION TYPES THAT WERE OBSERVED DURING FIELDWORK

- **Alien and invasive species:** Local villagers plant subsistence timber plantations to generate extra income. These *Eucalyptus* spp. did not dominate a Sentinel-2 pixel, and higher spatial resolution images would be required to map these accurately.
- **Cultivation:** The most noticeable change was the clearing of wetland areas for cultivation. Historical evidence of cultivated wetlands was observed near Lake Sibaya, which appears grassy and dried out now. Elsewhere, both graminoid and forested wetlands are drained and transformed to subsistence crop production (Figure 3.8A).
- **Development of houses:** We saw houses being built on wetland areas in some villages, and this is also visible on the iMfolozi/uMsunduze floodplain using Google Earth Pro images. One of the homesteads used a fence made of one of the swamp forest key indicator tree species, *Braringtonia racemosa*, that is also a protected tree species under the South African National Forests Act 84 of 1998, which indicated that the area is very likely a wetland.
- **Harvesting:** *Cyperus papyrus* and other reed cultivation and harvesting was observed near Lake Sibaya and reported by locals near Lake Futululu. Le Roux *et al.* (2021) also reported reed cultivation in the Muzi swamp. Reeds are primarily used to make "amacansi" (reed mats).
- **Plastic pollution:** There were very few instances of macro plastic pollution observed during the fieldwork, with the exception of a pile of used plastic bottles dumped near the lake by reed cutters.

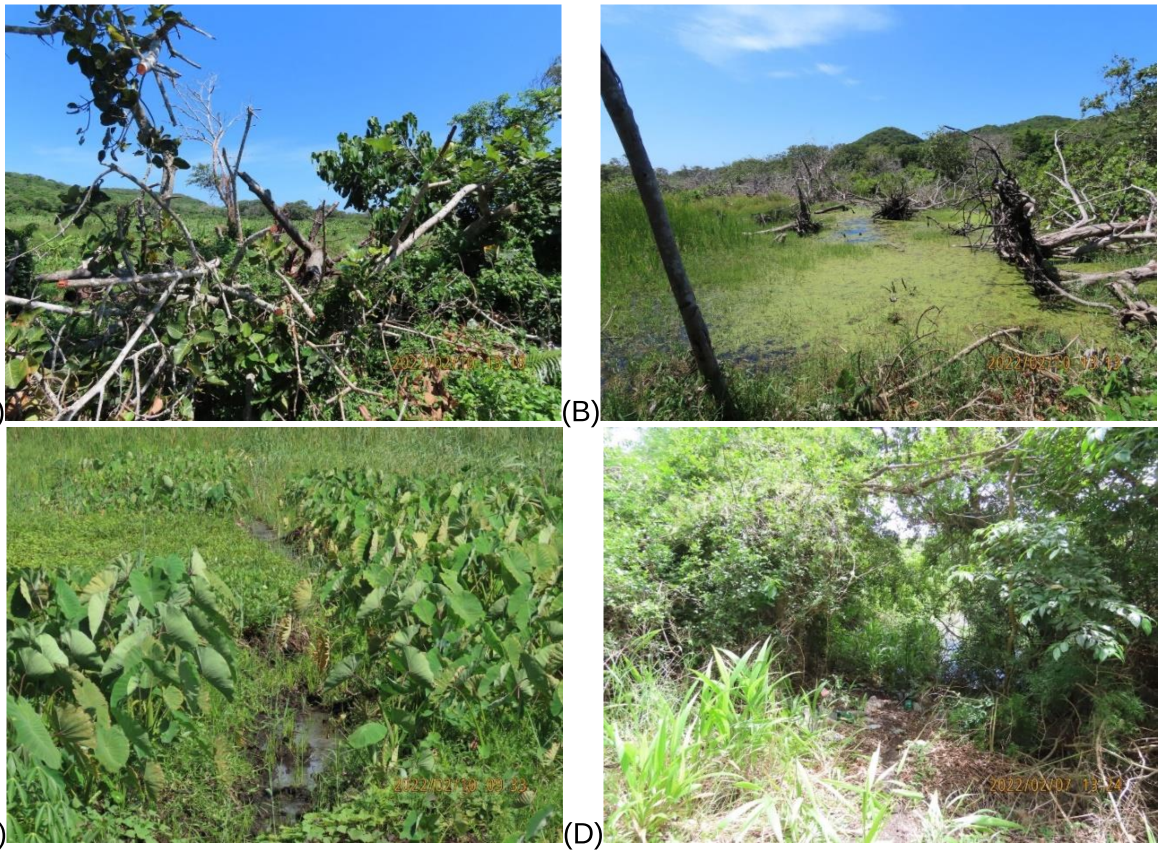
(A)  (B) (C) (D)

Figure 3.8. Examples of transformation observed in wetlands of the MCP, with (A) and (B) showing the forested wetlands that were cut down at Mgobezeleni in 2019, (C) Banana cultivation in a valley-bottom wetland, and (D) invasive tree species on the fringes of a forested wetland.

Figure 3.9A shows a *Eucalyptus* spp. plantation adjacent to a wetland area near Lake Nhlabane. Two studies (Blackmore *et al*., 1996; Elshehawi *et al*., 2019) reported that these plantations degrade forested wetlands by lowering the water table and can potentially lead to peat fires. Figure 3.9B shows *Tradescantia zebrina* in the understory of a forest in Twinstreams Environment Educational Centre near Mtunzini. Only small patches of this invasive species were observed in the field, and they were found under the forest canopy, and this obscures optical satellites from detecting them.

Figure 3.9. Invasive species observed on the MCP during February 2022.

As seen in Figure3.10 *Rubus fruticosus*; European blackberry, occur as isolated patches surrounded by other plant species, and they do not cover the 10 m by 10 m spatial resolution of the satellite data that is assessed in this project for monitoring of wetland EFGs. The European blueberry was observed on the Western shores of Lake St. Lucia. *Parthenium hysterophorus* was observed in a farm near Lake Eteza and it is considered as one of the most resistant and adaptable weeds in the world (Adkins and Shabbir, 2014). Chetty *et al.* (2021) had already detected *Parthenium hysterophorus* using SPOT and Sentinel-2 images near Mtubatuba on the MCP.

Figure 3.10. Invasive species observed next to Lake Eteza.

3.5 CONCLUSION

Considering the above natural wetland EFGs, transformed classes, and invasive species seen, Table 3.3 summarises the possible classes to use in the remote sensing classification of changes measured for the different wetland EFGs.

Table 3.3. Classes that could be used to determine the extent of changes in different wetland realms, biomes and Ecosystem Functional Groups (EFGs) using Sentinel-1 and -2 remote sensing data

Wetland IUCN type (down) // Type of change (across):			Natural		Anthropogenic					
Realm:	**Biome:**	**EFG:**	**Increase and decreases in extent as a result of the natural hydrological regime**	**Natural increase in (canopy) cover as a result of growth**	**Alien invasive spp.**	**Clearing**	**Crop production**	**Desiccation**	**Fire scarring**	**Housing development**
Freshwater-terrestrial	Palustrine wetlands	Forested wetlands		x	x	x	x			
		Large macrophytes	x	x						
		Permanently inundated marshes	x					x	x	
		Seasonally inundated marshes	x					x	x	x
Freshwater	F.1 Rivers		x		x					
	F.2 Natural waterbodies		x		x					
	F.3 Artificial waterbodies		x		x					

CHAPTER 4: PERCEPTIONS OF THE VALUE OF WETLANDS ON THE MAPUTALAND COASTAL PLAIN

This chapter documents the engagement that was conducted with a small selection of stakeholders and community members about the value of wetlands on the Maputaland Coastal Plain (MCP).

4.1 INTRODUCTION

Owing to the continuous conflict around the use of wetlands on the MCP, a social study was undertaken to assess different stakeholders' perceptions of the value of wetlands. To our knowledge, this has not previously been formally undertaken. It is evident from previous work that there are conflicting interests regarding the wetlands of the MCP. For example, for some poor communities, wetland vegetation provides an important resource of building materials for sangoma houses, called 'Guqasthandaze', and sleeping mattresses (Cunningham, 1985; Le Roux *et al.*, 2021; Liengme, 1983). Several wetland plant species, from across the estuarine and freshwater realms, and their uses have been summarised in Table 4.1. Many local people also fish in some of the rivers flowing through the MCP, such as the iMfolozi/uMsunduze rivers, particularly near the estuary mouth (Crook and Mann, 2002; Green *et al*., 2006). Tourists to the iSimangaliso Wetland Park also enjoy the wildlife and biodiversity of the park, and it is estimated that the park attracts about 522 954 visitors per annum (iSimangaliso Wetland Park Authority, 2019). The varieties of wetland ecosystems in and around the Park have compositional and structural characteristics that sustain unique species that depend on wetland environments, making them important hotspots for biodiversity (Van Wyk and Smith, 2001). Because they are nutrient-rich ecosystems that give people and animals access to food and clean water, they are essential for human livelihoods (Grobler, 2009). In addition, wetland habitats are the best setting for or long-term carbon dioxide storage because they have a high capacity to retain carbon dioxide (Doughty, 2016). These systems are crucial for processing nitrogen, phosphorus, and sulphur as well as storing carbon (Keddy, 2010). Wetlands also play an integral role in the hydrological cycle by attenuating flood peaks, augmenting dry season flows, controlling erosion, retaining nutrients, and reducing pollutants.

Despite these well-published ecosystem services and benefits of the various wetland types, the degradation of wetland ecosystem types persists across the whole of the MCP. Nine of the 12 inland aquatic ecosystem types on the MCP are critically endangered (Van Deventer *et al*., 2019b). The largest transformation of the iMfolozi/uMsunduze floodplain started in 1911 already, when settlers transformed the wetland to sugarcane farms (Taylor, 2011). Subsequently, a transformation to commercial and subsistence agriculture and timber plantations took place (Ramjeawon *et al*., 2020), resulting in the freshwater ecosystems becoming increasingly degraded. The increased intensification of anthropogenic and climate change pressures has resulted in easier access to, and an assumed a higher rate of transformation of wetland areas to other land uses. Some members of local communities transformed wetlands within the protected areas, both designated World Heritage and Ramsar sites, to subsistence farms for food production (visual observation during 2021-2 fieldwork campaigns). However, in some instances the fields are abandoned for unknown reasons. The disturbance gives invasive plant species the opportunity to settle, and drains are left to allow water to be channelled away from the wetland, resulting in unnecessary erosion, and potential desiccation of the peat substrate. During times of El Niño, peat is at risk of being ignited, and the burning peat converts the wetland sink to sources of carbon dioxide (CO_2). This greenhouse gas contributes further to the acceleration of a warming climate. The peatlands burning on the MCP increased at a faster rate and number compared to other regions of the country (Grundling *et al.*, 2021). In other instances, the rate of forested wetlands on the MCP has increased since the

1990s, to such a degree that these forests were recommended to be listed as critically endangered (Van Deventer *et al*., 2021a).

Table 4.1. Uses of wetland plant species on the Maputaland Coastal Plain. The threat status of the species is listed according to Raimondo *et al.* (2009) as LC – least concern or VU – vulnerable

Realm	Species name	Threat status	Use	Reference
Estuarine	*Juncus kraussii* (Matting rush)	LC	Craftwork, Sleeping mats	Cunningham (1985)
Estuarine	*Bruguiera gymnorrhiza** (black mangrove)	LC	Fences	Observations from the team during June 2021, February 2022 and August 2022 fieldwork trips
Freshwater	*Cladium mariscus* (Saw Grass)	LC	Hut building material	Cunningham (1985)
Freshwater	*Cyperus alternifolius* (Umbrella papyrus)	LC	LC (Raimondo *et al*., 2009)	Cunningham (1985)
Freshwater	*Cyperus fastigiatus* (Sedges)	LC	Hut building (thatch) material	Cunningham (1985)
Freshwater	*Cyperus latifolius*	LC	Craftwork, hut building material	Cunningham (1985)
Freshwater	*Cyperus natalensis*	LC	Craftwork, hut building material	Cunningham (1985)
Freshwater	*Cyperus papyrus* (Paper plant)	LC	Hut building material (door)	Cunningham (1985)
Freshwater	*Cyperus textilis* (Mat sedge)	LC	Craftwork, hut building material	Cunningham (1985)
Freshwater	*Eriochloa meyeriana*	LC	Hut building material (roof)	Cunningham (1985)
Freshwater	*Imperata cylindrica* (Cotton-wool Grass)	LC	Hut building material	Cunningham (1985)
Freshwater	*Ficus trichopoda* (Swamp fig)	LC	Hut building material (binding)	Cunningham (1985)
Freshwater	*Hemarthria altissima* (Red swamp grass)	LC	Hut building (thatch) material	Cunningham (1985)
Freshwater	*Hibiscus tiliaceus* (Lagoon Hibiscus)	LC	Hut building material (binding)	Cunningham (1985)
Freshwater	*Hyperthelia dissoluta* (Thatching Grass)	LC	Hut building material	Cunningham (1985)
Freshwater	*Melinis repens (synonym = Rhynchelytrum repens)*	LC	Hut building material	Cunningham (1985)
Freshwater	*Phoenix reclinata* (Cape Date Palm)	LC	Craftwork, Palm wine	Cunningham (1985)
Freshwater	*Phragmites australis* (Common reed) and *Phragmites mauritianus* (Lowveld reed)	LC	Hut building material	Cunningham (1985)
Freshwater	*Raphia australis* (Giant Palm; Kosi Palm)	VU	Hut building material	Cunningham (1985)
Freshwater	*Syzygium cordatum* (Water Berry)	LC	Food sources (insects, fruit and beer making), firewood	Cunningham (1985)

** Protected under the National Forest Act of South Africa*

The community and stakeholder perceptions about the value of different wetland biodiversity types on the MCP and how these vary across culturally and economically diverse stakeholders need further exploration. The aim of this chapter is to report on perceptions about the MCP's wetlands. In particular, we were interested to understand:

a) Whether communities and other stakeholders can identify different wetland ecosystem types;
b) Have different values and uses been associated with different types of wetlands;
c) Can they report the changes to the wetlands they have observed to date; and
d) Share their perceptions of future opportunities and concerns related to wetlands.

4.2 METHODS

This section provides information on the methods used for the social engagement study to address the objectives.

4.2.1 Ethic clearance and permissions to engage with two Traditional Authorities

Ethical clearance was approved for the team in 2021, after the application was submitted to the Council for Scientific and Industrial Research (CSIR).

It was recognised that the study area is quite extensive, and that the budget available through the Water Research Commission (WRC) funding of this project, which was supplemented by PG funding from the CSIR, would only be able to fund interactions with two TAs on the MCP. Through collaboration with Mrs Sue Janse van Rensburg from the South African Environmental Observation Network (SAEON), and her involvement in the Expanded Freshwater and Terrestrial Environmental Observation Network (EFTEON) work in tertiary catchment W70A in the north of the MCP, the Mbasa and Tembe TAs were selected as the two communities to engage with. During June 2021, our applications for engagement were presented at their council meetings, and approval for engagement was obtained (Appendix A).

During our fieldwork interactions with participants, we ensured that we follow the ethics guidelines as set out in our clearance. As a first step, participants were informed on the purpose of the study and were given an opportunity to ask questions about the work and the potential risks for them taking part in the research. The brief was done in a language of their choice. They were then asked whether they consent to taking part in the research, and whether photographs may be taken and used in the study. Everyone who were formally engaged as part of the research signed (written or verbally) an ethics form, and they were provided with an information sheet about the project, and that has the contact details of the project manager on in case they required any further information.

4.2.2 Drafting and updating of a stakeholder list for the MCP

A preliminary list of stakeholders was drafted based on the known contacts the team had of experts and community members on the MCP. The list was supplemented by recommendations from Mrs Janse van Rensburg's WRC project team, who also engaged with community members in the field. During our field visits of June 2021, February 2022 and August 2022, additional contacts and members were also added to the list.

From the current stakeholder list, we have identified at least seven different groupings of stakeholders (Table 4.2).

Table 4.2. Grouping of stakeholders and respective organisations

Stakeholder group	Example of organisations
Conservation agencies	Ezemvelo KwaZulu-Natal Wildlife (EKZNW) iSimangaliso Wetland Park Authority Private Nature Reserves (e.g. the Meycol PNR)
Commercial farmers	(Not specified)
Mining industry	For example, Richard's Bay Minerals (RBM)
Timber	SAPPI Siyaqhubeka Forests TMM Forestry company
Tourism industry	Lodge owners
Traditional Authorities	For example, the Mbaso and Tembe TAs in the northern part of the MCP
Urban-related industries	(Not specified)

With the WRC funding of this project, the focus of the work was set at the two TAs for the August 2022 engagement trip. Thereafter, the CSIR's Parliamentary Grant funding would have been used to engage with the remaining number of stakeholders of the MCP. However, owing to internal restructuring within the CSIR, this funding was no longer available for further engagement. We therefore report here only on the engagement with the TAs done in August 2022.

4.2.3 Stakeholder engagement in August 2022

Stakeholders were identified using the snowball method. Using contacts already established as part of the SAEON work being conducted in the area, our team contacted key stakeholders within the TAs (Mabaso and Tembe TAs), and other stakeholder groups such as tourism and urban related industries, and who then assisted with further contacts. Once we had a list of interviews and focus group participants, we asked those participants to help us identify further possible participants.

Between 14 and 20 August 2022, several engagements with stakeholders on the MCP were held. We engaged people via focus group discussions, group discussions and semi-structured interviews as listed in Table 4.3.

Table 4.3. Grouping of stakeholders and respective organisations

Stakeholder engagement method	Number of engagements	Details
Focus group discussions	4	No 1: Community members from the Mabaso TA (males, females, and people of all ages) No 2: Community members from the Tembe TA (males, females, and people of all ages) No 3: Female farmers farming within the Mabaso Area (all ages) No 4: Local business leaders (adult males and females).
Group discussions	1	Wetland farmers from the Mabaso TA (all ages).
Semi-structured interviews	7	Includes participants from the MCP; mostly farmers, and one person from the tourism industry.

In addition to the planned interactions (as documented above) the team also used observation, immersions, and in-the-moment discussion groups. As the team were moving around in the area and doing transect walks, we encountered several people with whom we had in-the-moment discussion groups. These methods contributed to our understanding of the local context.

4.2.3.1 Focus group discussions:

A0-sized posters showing the full extent of the MCP were presented to a group of participants to assist them with orientating themselves. Participants were allowed to indicate key landmarks on the posters, write on it, and also write notes and names of freshwater rivers and wetlands they recognised. Posters of the specific TA area that showed more detail than the overview poster were also presented, and participants were allowed to write and comment on these as well.

After this initial orientation discussion, questions related to the aim and objectives were asked (Appendix B). Once the discussion around these questions was completed, Mr Philani Apleni presented the outputs from his remote sensing work. The results showed the distribution of the different wetland types on the MCP. The discussion focused on simplifying the science behind the modelling of the different wetland types. After the presentation a questions-and-answers session was conducted, and the participants also indicated areas on the map that may have been omitted by the remote sensing. Upon completion of questions about the remote sensing products, Dr Heidi van Deventer showed participants the poster of the key tree species that are associated with forested wetlands. She explained that these trees are unique to the area, and mostly occur only on the MCP. She further explained that the scientists are concerned about the decline in these forested wetlands, saying that their work showed that it is being transformed much faster in the last ten years, and that losing these can result in poor flood regulation in the landscape.

4.2.3.2 Semi structured interviews

Two sets of interview questions were developed for the semi-structured interviews (Appendix B), one for interviews with businesspeople and the other for interviews with community members.

4.2.4 Analysis of results

The qualitative data gathered as part of the interviews and focus groups have been analysed using thematic coding. Thematic coding was implemented as follows:

1. Transcriptions of the discussions are compiled.
2. The transcriptions are read through without any notes made to get an overall sense of the data.
3. On second read through, the text is analysed for themes. In other words, the researcher reads through the texts and highlights (codes) the text according to the different themes as they are identified. Findings are written up.
4. The text is also analysed for any emerging themes – in other words themes that have not been identified before analysis started and that have emerged as significant from the text. Findings are written up.

The themes related to the project objectives are:

1) Perceptions and understandings of what a wetland is;
2) Values and uses associated with different types of wetlands;
3) Changes to wetlands observed by participants; and
4) Perceptions of future opportunities and concerns related to the wetlands.

4.3 RESULTS

This chapter reports the findings around the main questions for the engagement study, as four different subsections in the report.

4.3.1 Ability of participants to identify different wetland ecosystem types

Members of the community recognised more than half of the key indicator tree species associated with the forested wetlands as depicted on the poster (Appendix A). Some of the trees were commented on more, compared to others, especially the Raffia palm (*Raphia australis*) and the Waterberry (*Syzygium cordatum*), because the fruits were considered to be very nice. The participants also indicated that the Raffia palm can be used to create Raffia palm wine and mats.

The community provided constructive feedback on the remote sensing, pointing potential wetlands out on the map that may have been missed during the classification. A question emerging from the exercise was why the narrow mangrove forests that line the coast were absent from the photographs. Mr Philani Apleni explained the limitations related to the spatial resolution of remotely sensed imaging. The community also drew attention to places that were once wetlands but have since been transformed into other land cover types. Other questions about how remote sensing may help the community in the future, were also asked by the community members.

4.3.1.1 Perceptions and understandings about wetlands

From the interviews it is clear that most people have a basic understanding of what a wetland is, for example, typical definitions provided by our respondents are:

> *"A wetland in my opinion, is an area which has constant water, whether it's raining or not, it is always wet. It can be stagnant water or running water".*

> *"It's a small river, which forms the lake due to the plenty water. I think it's that."*

It is interesting to note that in many cases it was difficult for participants to verbalise the definition of a wetland. However, when speaking about wetlands, participants seemed to know what the team was talking about, and generally where one could find these places. It is therefore important for scientists to consider that people may not be able to verbalise definitions, but their knowledge and experience of their living environment include knowledge about wetlands and how it works.

Wetlands are also associated with farming and particular farming methods, for example:

> *"Wetlands are areas which have water, we plough and grow all sorts of vegetables such as sweet potatoes, sugarcane and banana. Also, in this area we dig trenches so that water can flow whenever we experience rain."*

> *"Wetlands are small wet places to plough to get vegetables, for example amaDumbe and sweet potato."*

> *"Wetlands are wet areas which are important because people can plough in wetlands and sell vegetables."*

The plants that are described as part of these definitions are mostly plants used for agricultural purposes, for example, vegetables. Very few participants noted other types of plants without prompting or being shown pictures. However, the focus group discussions revealed that as soon pictures of types of plants that typically grow in or near wetlands were shown, participants were able to identify them as occurring or being associated with wetlands. This links to our discussion earlier that people may not be able to verbalise definitions, and yet know where these plants are located. In the same way, plants associated specifically with wetlands are known to the local community, however, these may not be valued as highly as plants such as vegetables that provide food or livelihood security.

Some participants were able to define different types of wetlands (according to their own definitions), for example:

> *"There are two types: Wetlands which saturate water quickly and the other one has dark sand. When it rains, the water quickly gets absorbed while the other one, the water doesn't absorb quickly that's the one with the dark sand."*

> *"A wetland is a small stream that feeds into a bigger stream such as a lake…you find wetlands with a lot of water and dry wetlands. The ones with a lot of water have black residuals."*

There are some training and capacity-building initiatives in the area, specifically in the Mabaso TA, which may have helped these participants know that there are different types of wetlands, and how to describe the differences.

"Karen: in the community, do you think people understand the importance of wetland?"
"Nomvelo: yes, some do understand and some don't understand. We share our knowledge with them, but some still don't understand."

4.3.2 Values and uses associated with different types of wetlands

From many of the conversations, it was clear that the organic material in the peatlands sustains the livelihoods of many of the community members, and that they depended on the availability of good peat for growing crops. Some participants reported that they have been farming for up to four generations in the wetlands and consider it a sustainable resource to them over these years. Farming in the peatlands was present in both the TAs' areas, near Lake Sibaya and further north up to eManguzi and Kosi Bay.

Participants further to the north said that they never saw their wetlands changing or drying up. They said they were shocked to hear about the drought of 2015/6, or the recent flooding in 2022. Over a distance of 20-30 km south of eManguzi, the majority of participants said they had a consistent supply of groundwater to water their food gardens right through the year. This is in contrast to a participant that identified himself as a "wetland farmer", who experienced the groundwater level dropping significantly, to such a degree that he had to install a pump to extract water from his well and wet his crops (including, inter alia, pineapples). His property is surrounded by timber plantations, to which he has shareholding rights which supplements his income. The farmer and his daughter recalled how they used to have wetlands on the eastern section of their property, where they could swim, harvest reeds (such as *Juncus spp.*) and even fished for barbels. With the growth of the trees in the timber plantations, the wetlands have dried up and the groundwater levels subsided.

During the interviews, participants were asked what wetlands are used for, and why wetlands are valuable to them. The results are as follows:

- Making the soil firm which prevents soil erosion
- Free fruit (do not have to buy from a shop)
- Beauty of nature (tourism)
- Growing of crops, vegetables and maize (vegetables mentioned: potatoes, spinach, sweet potatoes, carrots, cabbage)
- Cost saving crop growing techniques (no irrigation or fertiliser needed)
- Less labour costs (not so much weeding required)
- Hunting on land (bucks, monkeys, snakes)
- Hunting in water (crocodiles and hippopotamuses)
- Fishing
- Make grass mats and reeds
- Cut trees to build houses
- Use vegetation for medicinal plants
- Water for domestic use
- Water for cattle and other animals
- Making palm wine
- Sacred rituals

The most valuable use (mentioned most often and in most detail) of the wetlands for the participants in the study was that wetlands provide fertile soil for growing vegetables. The growing of vegetables also signifies the ability of the family to secure water for themselves and their animals, to secure food and to secure their livelihoods. The ability to grow vegetables was identified as being the most valuable, mainly because successes of growing vegetables have secondary implications on their quality of life and livelihoods. Some participants noted that being able to make money also means that people are able to be healthier and are able to send their children to school. These are significant motivational elements to consider given the pervasive poverty in the area.

4.3.3 Changes to wetlands observed to date

Different types of changes in the wetland extent and cover have been reported by the participants (Table 4.4). Declines in the extent of wetlands were reported by participants of the Mbasa TA primarily, with participants who made this observation being of all genders and an estimated age above 40 years. Some of these participants expressed concerns about an increasing decline in water levels, with a decrease in the extent of open water bodies and vegetated wetlands. This was reported by three of the 31 participants interviewed.

One group of female participants worked together on a peatland where a variety of crops were produced and sold to the nearby Spar (local supermarket). There were between 10-20 women, between the ages of 20 and 80 years old, who work in the field every second to third day. The profit is shared amongst the women. Three of the women showed us how the wetland was shrinking about 2 m to the edge of the wetland every three years, and has continued to decline for the past decade. It was especially the older participant of nearly 80 years of age, who confidently reported these changes in their wetland near Lake Sibaya. The participants indicated that they have resorted to digging holes and watering their crops with buckets.

During our fieldwork trip in February 2022, we visited a macadamia nut farmer who farmed next to Lake Eteza, in the southern part of the MCP. He said that he previously farmed in sugarcane, however, during the 2015/6 drought, it became impossible to irrigate the sugarcane due to its high water demand. He therefore changed to macadamia nuts which requires less water. The farmer indicated that Lake Eteza has shown natural changes in the extent and geographic location of different wetland vegetation communities, and that this was being studied by a scientist. Further descriptions of changes in the hydrological variation of the Black and White iMfolozi rivers were also explained to Dr Heidi van Deventer and Mr Philani Apleni. The farmer perceived all these changes as natural.

During the interviews and focus group discussions, participants were asked about any changes they have experienced or observed in relation to the wetlands. While some participants could not recall any changes, others indicated that significant changes have occurred. It is acknowledged that individuals living in the same place might have different experiences and therefore may not agree in terms of changes having taken place. Qualitative research includes descriptive and unstructured data and in this study, we examine how people experience the value of wetlands in their lives. Because this research is interested in changes over time in terms of wetlands, and of the qualitative nature of the social study, all different answers are considered. Lastly, it should also be noted that the changes participants mentioned may not be strictly wetland related, but there may be a secondary connection that people are making that may be significant to our understanding of these changes.

Table 4.4. Changes in wetlands as observed by participants

Previously	Now
People could fish as much as they wanted	People are required to have permits (which costs money) to fish
Small number of people in the area	Population growth, also due to an influx of people from other areas (notably from Mozambique)
More trees than now	Fewer trees due to more people using trees and wood to build houses
People had enough to eat	People often go hungry
Sense of community – people helping each other	Dwindling sense of community – community no longer helps to raise children, parents are on their own now
Two-parent households	Growing number of female headed households
Lake Sibaya – high water levels	Lake Sibaya – declining water levels
Water levels in wetlands would rise up again after periods of drought	Water levels in wetlands no longer rise up again after periods of drought
Healthy crops (large in size)	Small crops
People stayed on ancestral land	People removed from ancestral land without adequate compensation
Relatively unchanged swamp forests	Timber plantations is cut down so that people can plant crops. Wood carvings are made for tourists
No tourism	Influx of tourism
Wetlands remained dry	Climate change is causing wetlands like uWoye and Mntimbolo to have dried out
Good rains = good harvests	Less rain and more unpredictable rain cause poor harvests
Change in livelihood patterns. Previously it was more simplistic “you will eat samp and drink sugar water and go to sleep”	More options are available for livelihoods, for example, you can generate money from the vegetable and therefore buy more food, provide education and health services, etc.
Medicinal plants are readily available	Medicinal plants disappearing
Sacred spaces and areas protected	Sacred spaces and areas are no longer protected
Dense forests	Due to ploughing and clearing of areas, the forest is no longer thick

4.3.4 Perceptions of future opportunities and concerns related to wetlands

Some of the participants were very concerned about the continuous decreasing water levels observed. They said they do not know whether this decrease will continue, and whether they will be able to farm in the peat in the long run.

One participant indicated that he is very positive about continuing farming in peat. The participant suggested that they can farm and sustain themselves another 40 years through subsistence farming in the peat, and that he is not concerned about a decline in water, changes in the climate, or a reduction in the quality of the peat.

When some participants were asked what they will do if there are droughts again, they explained that there have been plans to bring water from the Jozini Dam to parts of the MCP previously, and that this solution should be pursued to solve any water shortages.

The following points were gathered from participants about how they see the future of the area. The points are presented to indicate what participants living in these areas perceive as challenges and opportunities, and not to place value judgements. This information is important in the long run when the perceptions and expectations of the different stakeholders in the area will be mapped.

Major concerns participants mentioned when considering the future:

- People are no longer thinking of the community, but only of themselves. People are concerned that those planting crops in the wetlands are only doing so in a manner that benefits themselves, and not the rest of the community, and also not the natural environment.
- Less rain is falling than before, which may cause people to become more desperate.
- Rising antagonism between the local people who believe their ancestors were forcibly removed and conservation authorities who are the legal guardians of the land.
- Increase in invasive species.
- Significant presence of timber plantations in the area and the contracts they are providing to individuals to plant gumtrees. This presents challenges both for the environment, but also in terms of the validity of the contracts for locals (which could be construed as them being taken advantage of).
- Reduced grazing for cattle due to less water.
- Diminishing role of the local chiefs as people no longer recognise their leadership and rules.
- Young people are not interested in agriculture, and particularly not in wetland farming. They rather want to be employed in urban areas.

Opportunities participants mentioned when considering the future:

- Active TAs can effect change in the communities to raise awareness of wetlands having value beyond livelihoods. However, given high levels of poverty; it will require intrinsic balance.
- Growing population is creating informal markets where people can sell goods at a small scale. Thus, there is more opportunity for people to make a little bit of money.
- Development of the area will bring more job opportunities.
- With the upgrade of roads, people will be able to access shops more; this will help with the economic upliftment of the area.

4.4 CONCLUSIONS AND RECOMMENDATIONS

The team found that the water and the organic substrate in wetlands and peatlands were of critical importance to community members to sustain their livelihoods, however, wetland vegetation were of significantly less importance and value to them. Indigenous fruits of the Raffia palm (*R. australis*), for example, were recognised, but considered more incidental and opportunistic in their daily food requirements. It was seen as more of a nice to have, rather than an essential food source. Further work is required to explain all wetland vegetation species available on the MCP, and have more in-depth and detailed discussions with different age groups on the value of such plant species to them. It is possible that older generations would have needed and valued some plant species more, compared to the younger generations due to changes in society and the world in general. The diversity of intergenerational values needs to be better explored in a singly focused social study on the MCP.

The team observed an increasing disconnect with wetlands between lower and higher income groups. The higher the income, the less interaction a person would have with a wetland, unless they are a scientist. Participants in a higher income group potentially had one of two opinions about wetlands, with one group considering it a valuable resource for sustaining the poor, and the others considering it an important aesthetic or conservation value in the landscape. However, in a recent presentation at the National Wetlands Indaba 2022, it was shown that many people in Africa fear wetlands, because of the dangers it poses, such as crocodiles, hippos and snakes (Goldschagg, 2022). Due to several limitations, this research project could not explore the topic in depth and further research is needed to understand the range in perceptions about the value of wetlands, how they have changed, and future concerns.

Participatory engagements around maps need to be explored in more depth. At least five participants were identified who wished to provide a more detailed mapping of changes in the wetlands. Due to limitations in time and budget, this could not be done. The areas presented on the posters were too broad. Although it was sufficient for this first scoping exercise, further work is required where posters are generated of specific areas at a scale of 1:10 000, for improved discussions and participatory mapping.

CHAPTER 5: QUANTIFYING CHANGES IN WETLAND ECOSYSTEM FUNCTIONAL GROUPS OF THE MCP

This chapter provides the results of quantifying the changes in wetlands Ecosystem Functional Groups (EFGs) of the Maputaland Coastal Plain (MCP) using freely available space-borne sensors. These sections are part of Mr Philani Apleni's MSc at the University of Pretoria (UP), under supervision of Dr Heidi van Deventer (CSIR, UP), Dr Philemon Tsele (UP) and Dr Laven Naidoo (GCRO).

5.1 DESCRIPTION OF FIELD DATA COLLECTION PROCEDURES

5.1.1 Collection of reference data of wetland Ecosystem Functional Groups (EFGs)

Data collection for understanding wetland EFGs on the MCP was conducted in two stages. The first stage involved collecting and compiling all available mapped and published information, identifying knowledge gaps and underrepresented areas (Table 5.1). The second stage focused on field validation, particularly targeting underrepresented areas. Field data for the classification of wetland EFGs on the MCP wetlands were collected during three fieldwork trips: 6-11 June 2021, 6-11 February 2022, and 15-19 August 2022 (Figure 5.1). Data was collected using a handheld Garmin 62s Global Positioning System (GPS) with ≤4 m horizontal accuracy. At all sites, GPS coordinates were taken, and the area was described according to the dominant wetland EFGs and photographs taken. Various classes of wetland EFGs and other land cover types were identified for use in the remote sensing classification (Table 5.1). A total of 551 points were collected during the field campaign (Table 5.1), with 371 within South African Protected Areas Data (SAPD, 2022) and 180 found outside SAPDs (https://egis.environment.gov.za/data_egis/data_download).

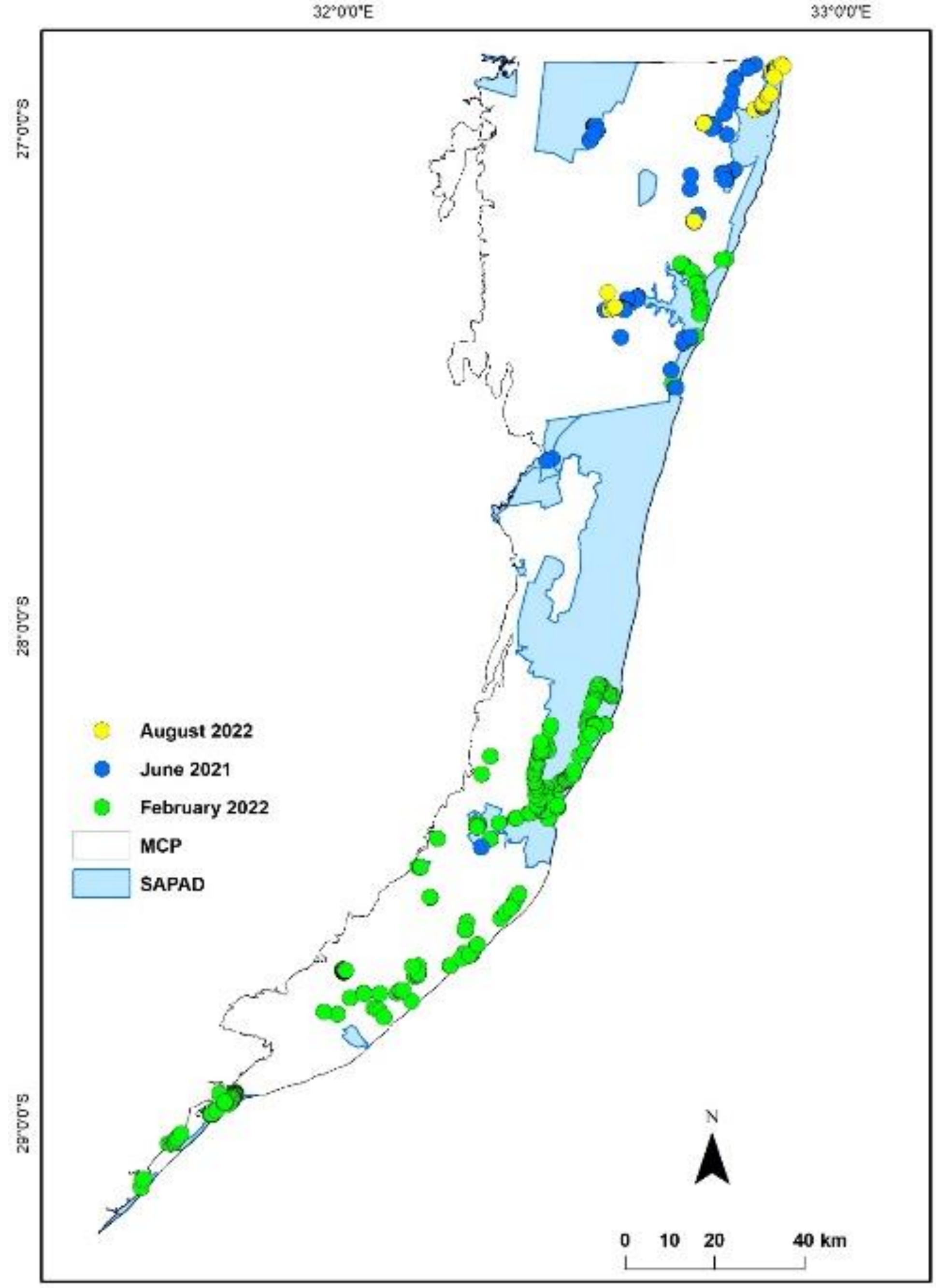


Figure 5.1. Distribution of point data collected during field work in June 2021, February 2022 and August 2022. The figure also shows the boundary of the South African Protected Areas (SAPD).

Table 5.1. Names and descriptions of wetland Ecosystem Functional Groups (EFGs) and the number of points collected in each field work campaign

Wetland EFGs and other wetland-related classes	Description	Number of points in June 2021	Number of points in February 2022	Number of points in August 2022
Burnt Wetland	Desiccated peatlands that have caught fire and burn in recent times, leaving a visible burn scar (Grundling *et al*., 2021).	11	6	2
Coastal salt marshes	Coastal salt marshes comprise rooted vegetation, mainly succulent chenopods found near river mouths, bays, coastal plains, and lagoons (Keith *et al.*, 2022).	0	27	3
Cultivated wetlands	A mosaic of subsistent vegetable gardens and fruit crops ranging from crops used for subsistence farming (amadumbes, cassava, maize, spinach, sugarcane, sweet potatoes, and pumpkins) to commercial farming (e.g. bananas; Grobler (2004) and Riedel (2015).	10	16	4
Intertidal forests and shrublands (or mangroves)	The intertidal forests and shrublands are salt-tolerant trees, shrubs, and other plants growing in brackish to saline tidal waters. These are mostly dominated by mangrove species (Keith *et al*., 2022).	0	32	1
Lacustrine wetlands	Wetlands that are predominantly permanently inundated, open water bodies (Keith *et al*., 2022).	0	7	4
Large macrophytes	All reeds and sedges taller than 1.5 m, including predominantly *Cyperus papyrus*, *Phragmites australis*, and *Typha capensis*. (Van Deventer *et al*., 2019a; 2022b).	22	83	4
Marshes	Permanent and seasonal marshes, dominated by emergent macrophytes, aerenchymatous stems and leaf tissues enable oxygen transport to roots and long rhizomes and into the substrate (Sieben *et al*., 2014; Keith *et al*., 2022).	15	62	0
Subtropical temperate forested wetlands	Forested wetland consists of swamp, riverine, and floodplain forests (Van Deventer *et al*., 2021a; Keith *et al*., 2022)	28	205	9
Total		**86**	**438**	**27**

Field data was pre-processed for the classification. This involved importing the data into ArcGIS Desktop version 10.8.1 (ESRI, 2020), and then cross-verifying GPS points in the respective Landsat and Sentinel-2 satellite images to select those for Regions of Interests (ROIs). Data from other relevant studies was also utilised, after careful review for quality, relevance, and compatibility (Table 5.2). This data was integrated with the primary field data and examined against the relevant Landsat and Sentinel-2 satellite images to ensure consistency with wetland or other types of ecosystem or land cover characteristics.

Table 5.2. Summary of key studies utilised in the research, providing an organised overview of the studies used for informing regions of interest and data preprocessing, listing the sources alphabetically, followed by the study title, and a brief description of the data available on the Maputaland Coastal Plain (MCP) study area

Source	Description of the study	Description of the data used	How the data was prepared for use in the remote sensing classification
Arndt (2014)	Distribution and long-term historic impact of small-scale subsistence farming on wetlands on the MCP, KwaZulu-Natal (South Africa) (Arndt, 2014).	A dataset containing the locations of historically degraded wetlands on the MCP (relic gardens).	Used to select cultivated wetland points.
Cho *et al*. (2013; 2015)	Assessing subtropical forest fragmentation for DukuDuku forest.	Point data set containing sample sites of terrestrial forest species with some related to freshwater ecosystems.	Some points were selected for classifying terrestrial forests (coastal forests). A few points of *Bridelia micrantha* could not be revisited during fieldwork to validate their extent relative to the Landsat and Sentinel-2 pixels.
GeoTerraImage (2019)	South African National Land Cover of 2018/19	A 20-m spatial resolution raster dataset containing most of the upland classes such as built-up areas, grasslands and shrublands.	To mask out the transformed land cover classes, such as commercial farms and mining.
Grobler (2004)	Subsistence farming and conservation constraints in coastal peat swamp forests of the Kosi Bay Lake system, MCP, South Africa.	In-field data of floristic sampling of forested wetlands containing a classification of swamp forests as pristine, recently disturbed, old, disturbed or active gardening in the Kosi Bay Forest Reserve.	Used as to inform Regions of Interest (ROIs) in the classification of subtropical/temperate forested wetlands and cultivated wetlands.
Grundling *et al.* (2021)	National Peatlands Database.	Ground sampled points of locations of peatlands around South Africa.	Data was corrected and some points were used to inform areas of forested wetlands, marshes and large macrophytes wetland EFGs.
Mucina and Rutherford (2006) and Dayaram *et al.* (2019) update	Vegetation map of South Africa, Lesotho and Swaziland.	Polygon dataset with estuarine, lacustrine and upland vegetation classes.	Used to inform regions of upland classes.
Pretorius (2012); Pretorius *et al*. (2014; 2016; 2020)	A vegetation classification and description of five wetland systems and their respective zones on the MCP.	Floristic sample points (relevés) with vegetation descriptions that include both seasonal and permanent marshes in the Muzi swamp system.	Used to inform points for marsh wetlands, large macrophytes and subtropical/temperate forested wetlands.
Ramjaewon *et al.* (2020)	Analysis of three decades of land cover changes on the MCP, South Africa.	The predicted extent of the timber plantations around the MCP.	Used to inform points for the selection of timber plantations.
Riedel (2015)	Satellite-imagery-based classification of near-natural and used wetlands in a subtropical region. A case study on the impact of subsistence farming on the MCP, South Africa	Polygon data containing marsh and swamp forests (*Ficus* and *Raphia* spp.), and for terrestrial classes, forests, thickets and shrubs, grassland, water, and bare sand. Transformed classes were built up, timber plantations and subsistence cropland.	Used to select points for cultivated wetlands, and upland classes.
Sieben *et al.* (2014)	National Wetland Vegetation Database (NWVD).	Point data set containing floristic sampling of vegetation clusters wetland points in South Africa.	Points that were identified with high confidence were used directly in the classification while other points were used to inform ROIs.
Starke *et al.* (2020)	Forest and woodland expansion in forestry plantations inform screening for native agroforestry species, MCP, South Africa	Dataset with points with descriptions of terrestrial forests/ woodland and timber plantations.	Used to select ROI points for timber plantations.
Venter (2003)	The Vegetation ecology of the Mfabeni Peat Swamp, St Lucia, KwaZulu-Natal.	Polygon data with descriptions of marsh and forested wetlands.	Used to select subtropical/temperate forested wetland classes, large macrophytes and marsh wetlands ROIs.
Van Deventer *et al*. (2021a)	Conservation conundrum – Red listing of subtropical-temperate coastal forested wetlands of South Africa.	Polygons containing digitised extent of forest types on the MCP.	Used to select ROIs of subtropical/temperate forested wetland and terrestrial forests.

Table 5.3. Description of wetland Ecosystem Functional Groups (EFGs) and other classes that were used in the remote sensing classification, and their respective Regions of Interest (ROIs) that were captured in relation to the images; * *derived from the Normalised Difference Water Index (NDWI; Gao, 1996)

Wetland EFGs and other classes	Description	No of ROIs 1990	No of ROIs 2000	No of ROIs 2006	No of ROIs 2014	No of ROIs 2018	No of ROIs 2020	No of ROIs 2022
Wetland EFGs								
Coastal salt marshes	Coastal salt marshes comprise rooted vegetation, mainly succulent chenopods found near river mouths, bays, coastal plains, and lagoons (Keith *et al.*, 2022).	366	421	349	366	358	366	367
Cultivated wetlands	A mosaic of subsistent vegetable gardens and fruit crops ranging from crops used for subsistence farming (amadumbes, cassava, maize, spinach, sugarcane, sweet potatoes, and pumpkins) to commercial farming (e.g. bananas; Grobler (2004) and Riedel (2015).	492	63	79	395	472	492	492
Intertidal forests and shrublands	The intertidal forests and shrublands are salt-tolerant trees, shrubs, and other plants growing in brackish to saline tidal waters. These are mostly dominated by mangrove species (Keith *et al.*, 2022).	938	890	879	938	938	938	939
Lacustrine wetlands	Open waterbodies including large lakes and river channels.	581	359	554	538	512	348	575
Large macrophytes	All reeds and sedges taller than 1.5 m, including predominantly *Cyperus papyrus*, *Phragmites australis*, and *Typha capensis*. (Van Deventer *et al*., 2019a; 2022b).	2 951	1 574	2 360	2 613	2 608	2 851	2 951
Mudbank	A submerged or partly submerged bank of mud along rivers and lakes with no vegetation cover.	142	23	153	158	159	159	159
Permanent and seasonal marshes	Inundated lacustrine wetlands > 20% of the time in a year (Slagter *et al*., 2020).	1 042	1 112	957	1 112	1 133	1 106	1 043

Wetland EFGs and other classes	Description	No of ROIs 1990	No of ROIs 2000	No of ROIs 2006	No of ROIs 2014	No of ROIs 2018	No of ROIs 2020	No of ROIs 2022
Subtropical – temperate forested wetlands	Forested wetland consists of swamp, riverine, and floodplain forests (Van Deventer *et al*., 2021a; Keith *et al*., 2022)	917	941	941	941	905	938	917
Terrestrial ecosystem classes								
Bare land	Dry land consisting of sand or soil with no vegetation cover.	922	201	543	676	526	1019	922
Beach	Coastal landform alongside sea water, which consists of loose particles, typically made from rock, such as sand, gravel, shingle, or pebbles.	785	777	758	798	784	796	784
Coastal forests	Dry lowland terrestrial forests along the KwaZulu Natal coastline.	1 967	1821	2 054	2156	1 841	2156	1 967
Dune forests	A rich ecosystem comprising a variety of trees, shrubs, and herbaceous plants, many of which have adapted to the sandy, nutrient-poor soils.	736	593	593	593	593	593	580
Sand forests	Subtropical forest regions with unique restrictions to ancient coastal dunes.	780	331	331	331	331	331	305
Shrubs	Small-to-medium-sized woody plants.	690	751	741	752	707	707	690
Terrestrial grasses	large open areas of dry grass.	963	812	963	974	974	955	963
Transformed land use and land cover classes								
Built-up	Areas dominated by human-made structures, such as buildings and roads.	870	1718	629	790	887	887	784
Burnt peatland	Peatland areas that have experienced fire events with visible burn scars.	142	0	0	82	82	106	142
Cleared land	Areas where vegetation and other obstacles have been removed, typically for construction or agricultural purposes, leaving the soil exposed.	736	262	316	344	599	706	736

Wetland EFGs and other classes	Description	No of ROIs 1990	No of ROIs 2000	No of ROIs 2006	No of ROIs 2014	No of ROIs 2018	No of ROIs 2020	No of ROIs 2022
Commercial farms	Large-scale farming operations focused on the production of crops, mainly maize and sugarcane.	780	676	738	761	780	780	780
Relic gardens	Historical wetland gardens that are often associated with indigenous cultivation practices.	256	256	245	257	256	256	257
Timber plantations	Large-scale plantations where trees are grown for timber production. This includes both commercial and subsistence timber plantations.	3 701	1 355	1 570	974	256	3 099	963

5.2 DESCRIPTION OF DATASETS USED AND PREPROCESSING

A multifaceted approach was designed to classify wetland EFGs and their dynamics (Figure 5.2). The research combines fieldwork, remote sensing, and data analysis techniques. Fieldwork involved the establishment of field sites to collect ground-level data as ground-truthing exercises to train and validate remote sensing data. Remote sensing leveraged Landsat, Sentinel-1, and Sentinel-2 satellite data for historical context and high-resolution information. Data obtained from both fieldwork and remote sensing were integrated and analysed to identify the geographic locations, types and rate of changes in wetland EFGs.

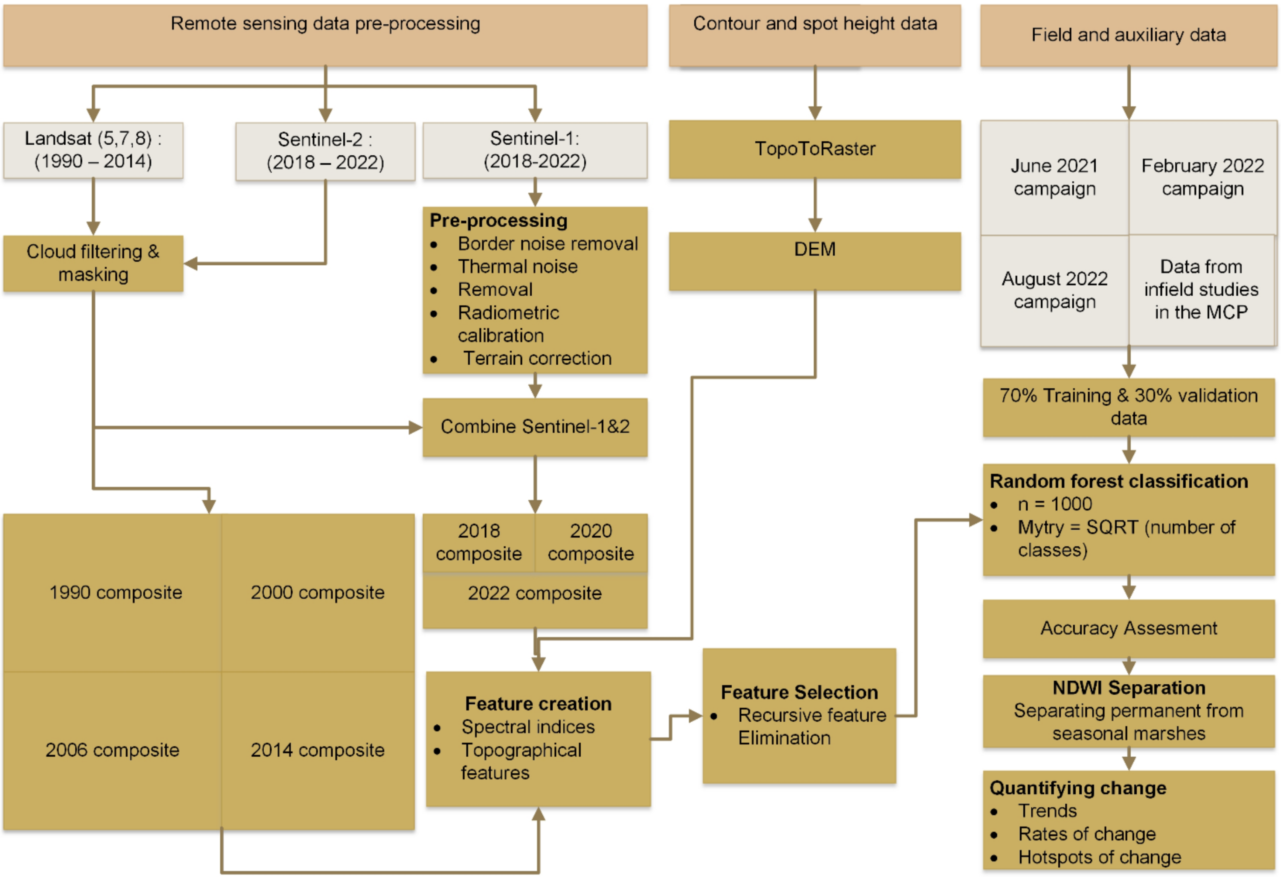


Figure 5.2. General workflow for the quantification of changes of wetland Ecosystem Functional Groups.

5.2.1 Selection of years for classification of wetland Ecosystem Functional Groups

To identify the peak rainfall periods over the past forty years, and identify the maximum extent of wetland EFGs during such wet years, rainfall data was obtained from the Climate Hazards group Infrared Precipitation with Stations (CHIRPS; Funk *et al*., 2015), which is a dataset available in Google Earth Engine (GEE). The dataset uses a combination of remotely sensed data and information from gauge observations incorporating daily, pentad and monthly precipitation estimates from 1981 to 2022 (Funk *et al*., 2015). This dataset is especially important for regions like the MCP that currently records rainfall in only 18 of the original 81 stations that was available between 2016 and 2022 (Ndlovu *et al.*, in prep). The rainfall pattern shows great variability across the 41 years (Figure 5.3A), with the five highest rainfall years notable as 1984, 1986, 1991, 2000 and 2006.

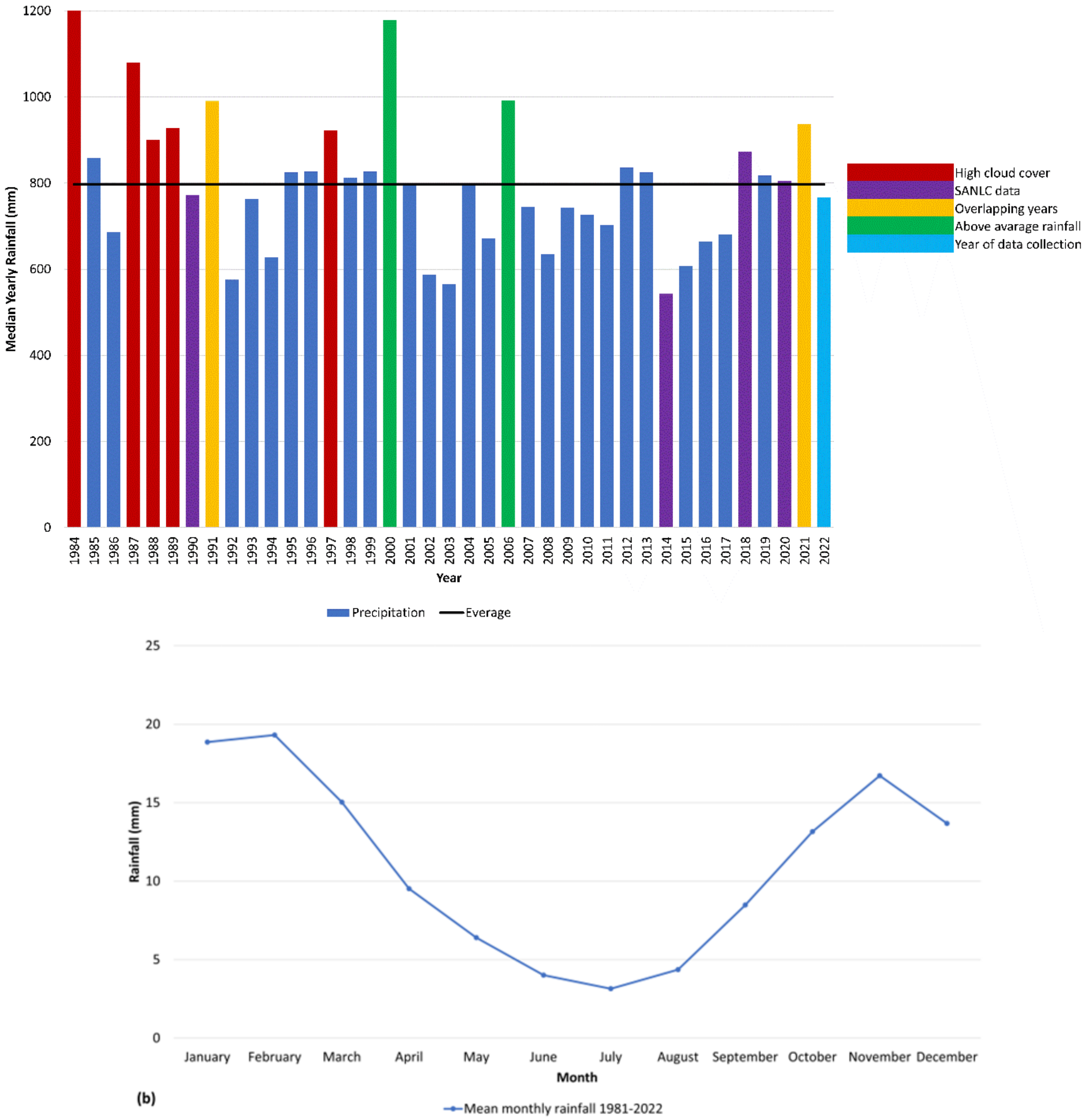


Figure 5.3. Variation in rainfall across the Maputaland Coastal Plain (MCP), with (A) Median Annual rainfall data from 1981 to 2022. The orange straight line represents the median annual rainfall (790.4 mm); (B) represents the median monthly rainfall for the MCP from January 1981 to December 2022.

The selection of years for the quantification of changes in wetland EFGs was guided by rainfall data. The selection of years with peak rainfall events on the MCP is based on the premise that wetlands are highly responsive to precipitation. During periods of high rainfall, both lacustrine and palustrine wetlands expand to their maximum extent, capturing more water and potentially supporting a greater diversity of species. Conversely, during droughts, these areas contract and only the minimum extent of the EFGs across their hydrological cycle would be mapped. Thus, mapping during peak rainfall events allows us to capture the maximum extent of these ecosystems across their hydrological cycles. The selection process involved identifying years with peak rainfall events on the MCP. This was achieved by analysing historical weather data (as shown in Figure 5.3A). The years that corresponded to these peak events were then selected for the remote sensing classification of the EFGs. Subsequently, the analysis of monthly rainfall was also conducted for each selected above-average rainfall year to identify the month(s) of peak rainfall. Satellite images were then chosen at least a month after a peak rainfall event. The rationale behind this is to avoid mapping flooding events, which are temporary and do not accurately represent the true extent of wetlands. Furthermore, the images were selected only from the wet season, which typically falls between September and February each year (Figure 5.3B). This is because wetlands are most likely to be at their maximum extent during this period due to higher rainfall and evergreen wetland tree species and other wetland types are highly separable during these months compared to the winter (Van Deventer *et al*., 2017; 2019a).

Although 1981, 1984, 1987 and 1989 showed above average rainfall (Figure 5.2a), they did not provide a suitable composite covering the entire study area due to cloud cover. The year 2000 was also an exception because the composite image was created spanning the period from 23 March to 30 April 2000. This was done in response to the floods that occurred from February 22-25, caused by tropical cyclone Eline, as documented by Dyson and Heerden (2001) and Reason and Keibel (2004). The composites that were generated from September 2000 to February 2001 were unfortunately of poor quality due to extensive cloud cover across the study area. As a result, the decision was made to use images from the autumn season instead. A similar exception was made for the 2006 composite, where the selection of dates for creating composite images was influenced by a La Niña event which occurred on 30 November of that year (Mpungose *et al.,* 2022). The selected dates ranged from 4 January 2006 to 30 April 2007. The rationale behind this selection was to increase the number of images in the composite. For the notably dry years of 1990, 2014, 2018, and 2020, composites were created spanning from September of each mentioned year to February of the following year. The inclusion of these years was to classify wetland EFGs in line with previous National Landcover Classifications of South Africa (1990, 2013-2014, 2018, and 2020). However, an exception was made in 2013 when the composite was extended until April. This strategy aimed at mitigating the effects of the scan line error observed in Landsat-7 images. For the year 2022, a composite was created for the months of March and April. This decision was made in response to two significant La Niña floods that occurred in February and November within the KwaZulu-Natal Province (Mpungose *et al*., 2022). The timing for the selection of the 2022 image was chosen to align with in-field data collection.

5.2.2 Satellite image selection and preprocessing

Landsat Surface Reflectance (SR) datasets from the tier 1 collection in GEE were utilised, the datasets included a fusion of images from Landsat 4, 5, 7, and 8 sensors which were combined to create an image collection. To ensure consistency, all dataset names were standardised to match Landsat-8 bands. Only bands common to all datasets were considered, and these were resampled to the spatial resolution of 30 m. The Landsat SR datasets in GEE provide calibrated surface reflectance values that have been corrected for atmospheric effects. This makes them particularly suitable for analysing changes in the extent of wetland EFGs. Prior to analysis, the Landsat SR datasets underwent a series of preprocessing steps in GEE. Initially, images with more than 10% cloud cover were excluded from the image collections. Cloudy pixels within the images were then masked using the cloud mask band. This was achieved by applying a threshold to the pixel quality assurance band, retaining only high-quality pixels based on bitmasks. Images with less than 10% cloud cover were selected from the Landsat collection of images available in GEE. To create composites of the remaining images, the median reflectance values of the Landsat SR collections for each period were used. This resulted in a multi-band image where each band represents a composite image for a specific year. Finally, all the bands were scaled to reflectance values. The specifications of the Landsat sensors are described in Table 5.4. Landsat images were used to create median composites for four years, 1990, 2000, 2006 and 2014, based on the selection criteria mentioned above.

Table 5.4. Names and wavelengths of Landsat bands including their descriptions

Name	Wavelengths for Landsat 5 & 7	Wavelength Landsat 8	Description
SR_B1	0.45-0.52 µm	0.435-0.451 µm	Band 1 (ultra blue, coastal aerosol)
SR_B2	0.45-0.52 µm	0.452-0.512 µm	Band 2 (blue)
SR_B3	0.52-0.60 µm	0.533-0.590 µm	Band 3 (green)
SR_B4	0.63-0.69 µm	0.636-0.673 µm	Band 4 (red)
SR_B5	0.77-0.90 µm	0.851-0.879 µm	Band 5 (near infrared)
SR_B6	1.55-1.75 µm	1.566-1.651 µm	Band 6 (shortwave infrared 1)
SR_B7	2.08-2.35 µm	2.107-2.294 µm	Band 7 (shortwave infrared 2)

Sentinel-1 is a constellation of two Synthetic Aperture Radar (SAR) satellites (Sentinel-1A and -1B) which operates in the C-band which has a wavelength of about 5.6 cm. The interferometric wide-swath mode (IW) and the wave mode (WV) are the two main operational modes of the satellite, and they provide an exact six-day repeat (Potin *et al*., 2016). The IW is the primary operational mode on land (Huang *et al*., 2018). In GEE, Sentinel-1 images in dual-polarimetric (VV/VH) mode were used in the analysis (Table 5.5). However, from the 23rd of December 2021 onwards, only Sentinel-1A was operational since Sentinel-1B experienced a power anomaly, rendering it unable to deliver radar data (ESA, 2022), giving Sentinel-1A data a temporal resolution of only 12 days. Sentinel-1A images at Ground Range Detected (GRD) scenes were selected for classification (Gorelick *et al*., 2017). The GRD products were pre-processed in GEE following the workflow by Mullisa *et al.* (2019) which includes data selection, additional border noise correction, speckle filtering and radiometric terrain normalisation. SAR is advantageous because it can provide weather-independent observation as it can penetrate cloud cover. Additionally, C-band SAR can moderately penetrate soil and vegetation cover (1-5 cm) depending on sensor configuration.

Table 5.5. Description of polarimetric modes of the Sentinel-1 sensor

Abbreviation	Units	Description
HH	dB	Single co-polarisation, horizontal transmit/horizontal receive
HV	dB	Dual-band cross-polarisation, horizontal transmit/vertical receive
VH	dB	Dual-band cross-polarisation, vertical transmit/horizontal receive
VV	dB	Single co-polarisation, vertical transmit/vertical receive

Sentinel-2 is a satellite constellation of two satellites, Sentinel-2A and Sentinel-2B images with a wide field (290 km) created by the European Space Agency (ESA; Drusch *et al*., 2012). The spatial resolution of Sentinel-2 ranges varies across the 12 bands from 10 m to 20 m and 60 m. Sentinel-2 was developed to improve on Landsat and SPOT capabilities while maintaining data continuity (Wang *et al*., 2016). Sentinel-2 SR data were obtained from the GEE data catalogue, which hosts Level-2A products generated by the ESA. Level-2A Sentinel-2 images are atmospherically corrected using the Sen2Cor algorithm and default values based on the geographic locations. The Sen2Cor algorithm uses the scene metadata and auxiliary data, such as atmospheric profiles and aerosol optical thickness, to correct for atmospheric effects and derive surface reflectance values (Main-Knorn *et al*., 2017). Additionally, pixels with cloud and cloud shadow were masked using the built-in quality assurance (QA) 60 band, which flags pixels that are affected by clouds or cloud shadows and images were filtered based on cloud cover percentage of ≤10%. In GEE, all the Sentinel-1 and -2 bands were resampled to 10 m for use in classification. B1 and B9 were not used since they are coarse spatial resolution and are used for atmospheric correction of the bands, but not classification (Table 5.6).

Table 5.6. Spectral bands of the Sentinel-2 sensors. NIR = Near Infrared; SWIR = Shortwave Infrared

Name	Pixel Size	Centre of wavelength for S2A/S2B	Description
B1	60 m	443.9 nm / 442.3 nm	Aerosols
B2	10 m	496.6 nm / 492.1 nm	Blue
B3	10 m	560 nm / 559 nm	Green
B4	10 m	664.5 nm / 665 nm	Red
B5	20 m	703.9 nm / 703.8 nm	Red Edge 1
B6	20 m	740.2 nm / 739.1 nm	Red Edge 2
B7	20 m	782.5 nm / 779.7 nm	Red Edge 3
B8	10 m	835.1 nm / 833 nm	NIR
B8A	20 m	864.8 nm / 864 nm	Red Edge 4
B9	60 m	945 nm / 943.2 nm	Water vapour
B11	20 m	1613.7 nm / 1610.4 nm	SWIR 1
B12	20 m	2202.4 nm / 2185.7 nm	SWIR 2

The Sentinel-1 and two images were then combined to create an image collection containing bands for the two images in GEE. The median composites for 2018, 2020 and 2022 were created from a combination of Sentinel-1 and -2 images. The availability and the number of images are represented in Table 5.7.

Table 5.7. The number of images from freely available Landsat and Sentinel-1 and -2 sensors between 1990 and 2022 used for mapping changes in the maximum extent of wetland Ecosystem Functional Groups (EFGs). The tick marks (✓) represent datasets that were used, while (X) represents images that were not available

Year	Landsat				Sentinel		Total number of images used per year
	4	5	7	8	1	2	
1990	*X*	✓	*X*	*X*	*X*	*X*	24
2000	*X*	*X*	✓	*X*	*X*	*X*	7
2006	*X*	✓	✓	*X*	*X*	*X*	61
2014	*X*	*X*	✓	✓	*X*	*X*	38
2018	*X*	*X*	✓	✓	✓	✓	181
2022	*X*	*X*	X	X	✓	✓	353

5.2.3 Inclusion of additional layers in the image stack for classification

A number of additional derivatives were generated to enhance the accuracy of the remote sensing classification. These included the addition of spectral indices, deriving topographical features (e.g. elevation) from the DEM and texture indices. The following subsections provide more information on each of these.

5.2.3.1 Spectral indices

Spectral indices are mathematical combinations of spectral bands derived from satellite or airborne remote sensing data that provide information on specific biophysical or biochemical properties of the Earth's surface. Previous studies showed that the inclusion of spectral water and vegetation indices improved the accuracies of wetland type classification in remote sensing (e.g. Van Deventer *et al.*, 2022b). This study therefore used spectral indices to optimise the classification of wetland EFGs, in addition to the use of elevation data (Table 5.8). These indices have been successfully employed to enhance the overall and user's accuracies of wetland classes across various study areas (Lang *et al*., 2011; O'Connell *et al*., 2018; Van Deventer *et al.,* 2022b). A total of eleven spectral indices were extracted from the optical sensors of Landsat and Sentinel satellites (Table 5.8). In addition to the ten optical indices, the Sentinel-1 ratio was calculated using the VV and VH backscatter data from this radar satellite.

Table 5.8. Spectral indices that were included in the classification of wetland Ecosystem Functional Groups (EFGs). NIR = near infrared; SWIR = Shortwave infrared

Spectral index	Equation	Wetland EFG property enhanced
Difference Vegetation Index (DVI) (Tucker, 1979)	$DVI = \text{NIR} - \text{Red}$	Soil Moisture
Enhanced Vegetation Index (EVI) (Huete *et al*., 2002)	$EVI = 2.5 \times \frac{(\text{NIR} - \text{Red})}{(\text{NIR} + (6 \times \text{Red} - 7.5 \times \text{Blue}) + 1}$	Chlorophyll
Green Difference Vegetation Index (GDVI) (Tucker *et al*., 1979)	$GDVI = \text{NIR} - \text{Green}$	Chlorophyll and nitrogen
Green Normalized Difference Vegetation Index (gNDVI) (Gitelson *et al*., 1996)	$gNDVI = \frac{(\text{NIR} - \text{Green})}{(\text{NIR} + \text{Green})}$	Chlorophyll
Green Soil Adjusted Vegetation Index (GSAVI) (Mahdianpari *et al*., 2020)	$gSAVI = \frac{(\text{NIR} - \text{Green})}{(\text{NIR} + \text{Green})} \times 1.5$	Chlorophyll
Modified Normalised Difference Water Index (MNDWI) (Xu, 2006)	$MNDWI = \frac{(Green - \text{SWIR})}{(Green + \text{SWIR})}$	Leaf water content
Modified Soil Adjusted Vegetation Index (MSAVI) (Qi *et al*., 1994)	$MSAVI = \frac{2\text{NIR} + 1 - \sqrt{(2\text{NIR} + 1)^2} - 8(NIR - RED)}{2}$	Chlorophyll
Normalized Difference Vegetation Index (NDVI); (Rouse *et al*., 1973; Tucker, 1979)	$NDVI = \frac{(\text{NIR} - \text{Red})}{(\text{NIR} + \text{Red})}$	Chlorophyll
Normalized Difference Water Index (NDWI) (Gao, 1996)	$NDWI = \frac{(R\text{NIR} - R\text{SWIR})}{(R\text{NIR} + R\text{SWIR})}$	Leaf water content
Optimized Soil Adjusted Vegetation Index (OSAVI) (Rondeaux *et al*., 1996)	$OSAVI = \frac{(\text{NIR} - \text{Green})}{(\text{NIR} + \text{Red}) + 0.16}$	Chlorophyll and leaf area Index
Red Edge Normalized Difference Vegetation Index (NDVIre); (Gitelson and Merzlyak, 1994)	$NDVIre = \frac{(\text{NIR} - \text{Red Edge})}{(\text{NIR} + \text{Red Edge})}$	Chlorophyll, leaf area/biomass and nitrogen
Sentinel-1 ratio	$Sratio = \frac{\text{VV}}{\text{VH}}$	Vegetation structure

5.2.3.2 Distinguishing between permanent and seasonal marshes using the Normalised Difference Water Index (NDVI)

The Normalized Difference Water Index (NDWI; Gao, 1996) is a widely used remote sensing technique for assessing wetland dynamics and identifying seasonal marshes. NDWI utilises the sensitivity of the Near-Infrared (NIR) and Shortwave Infrared (SWIR) reflectance spectrum to leaf water content and soil moisture

(Campos *et al*., 2012; Davranche *et al*., 2013; Nhamo *et al*., 2017), making it a valuable tool for vegetation and seasonal inundation studies. For the period from 1990 to 2014, NDWI calculations were based on Landsat imagery, while Sentinel-2 data was employed from 2018 to 2022. The NDWI *value was used* as proxy for wetland *hydroperiod, where* NDWI values are expected to be low *for predominantly dry wetlands*, <−0.3. Conversely, as moisture presence increases, NDWI values are expected to rise, with values >−0.2 indicating dampness (Nhamo *et al*., 2022). Consequently, fluctuations in NDWI values within a wetland area serve as indicators of water occurrence frequency. Based on the NDWI-derived water occurrence frequency, marshes were classified as follows:

- Permanent marshes: Inundated for > 80% of the time in a year.
- Seasonal marshes: Inundated between > 20% and < 80% of the time in a year (Slagter *et al*., 2020).

This classification scheme was used to distinguishes between permanently inundated wetlands and those that exhibit seasonal inundation patterns.

5.2.3.3 Deriving topographic features from the digital elevation model

Topographic indices and spectral indices play a pivotal role in understanding the spatial distribution of wetland EFGs. Topographic indices provide information about the physical features of the land, including aspects such as slope, aspect, and elevation. These features can influence water flow and accumulation, soil moisture content, and sunlight exposure, all of which are critical factors for wetland ecosystems. Indices derived from DEMs can enhance topographic traits and offer insight into the hydrological, geomorphological, and ecological processes shaping wetland ecosystems. Key topographic indices for wetland mapping include elevation, which impacts hydrological regime, soil properties, and vegetation; slope, affecting water flow, retention, and vegetation distribution; aspect, influencing solar radiation, temperature, and moisture gradients; and Topographic Wetness Index (TWI), measuring a location's propensity to accumulate water and helping identify areas prone to saturation and flooding (O'Callaghan and Mark, 1984; Sørensen and Seibert, 2007; Gumbricht *et al*., 2017; Zhang *et al*., 2019). Topographic indices were derived from the 10 m spatial resolution DEM. The slope, aspect terrain derivatives were computed using the ee.Terrain() function in GEE (Gorelick *et al*., 2017), while the TWI and terrain ruggedness index (TRI) algorithms were created in System for Automated Geoscientific Analyses (SAGA) geographic information system (GIS) (Conrad *et al*., 2015). The stochastic depression analysis (SDA) band was calculated using Whitebox tools (Lindsay, 2014). All these bands were imported into GEE for the final analysis.

While freely available elevation datasets such as the Shuttle Radar Topography Mission (SRTM; Farret *et al*. (2007) and the Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTER GDEM; Abrams *et al.,* 2020), offer valuable data, their coarse spatial resolution of between 30 and 90 metres, were deemed unsuitable for the purposes of this project. In addition, they record the top of canopy which is not suitable for wetland mapping and prediction. Instead, the project utilised the higher spatial resolution data ground-level elevation data provided by the South African Department of Agriculture, Land Reform and Rural Development (DALRRD), from their National Geo-Spatial Information (NGI) Directorate, which includes 5 m contour lines data and 1:10 000 spot heights (www.ngi.gov.za). This finer spatial resolution and ground elevation data allows for a more accurate representation of local variations in elevation, which is crucial for wetland classification. Wetlands are often characterised by subtle changes in elevation, and capturing these details can lead to a more accurate delineation of wetland boundaries and identification of wetland types (Rodhe and Seibert, 1999). A digital elevation model (DEM) was created from the NGI's contour and spot heights vector datasets using the Topo-to-Raster tool in ArcGIS version 10.8 at a 10 m spatial resolution.

5.2.3.4 Deriving textural information from image bands

Textural data can reveal structural patterns that characterise different types of wetlands (Solórzano *et al*., 2018; Zhang *et al*., 2020). The methodology for texture calculation involved the use of Landsat and Sentinel-1 and -2 images to calculate Gray-Level Co-Occurrence Matrix (GLCM) texture. The simulated grayscale panchromatic band for each sensor was computed by a linear combination of the NIR, red and green bands using the following formulas in Equations 5.1 and 5.2.

Equation 5. 1

$$PAN\_S2 = (0.3 \times NIR) + (0.5 \times RED) + (0.11 \times GREEN)$$

Equation 5. 2

$$PAN\_L = (0.52 \times NIR) + (0.23 \times RED) + (0.25 \times GREEN)$$

where *PAN_S2* represents the Sentinel-2-derived panchromatic image, while *PAN_L* represents the Landsat-derived panchromatic image, and the coefficients represent the contribution of each band (Chen *et al*., 2015; Zhan *et al*., 2019). The output image was standardised before a Principal Component Analysis (PCA) was performed for dimensionality reduction (Uddin *et al.*, 2020). The PCA was computed using the 36 GLCM textural features extracted from the panchromatic bands of the respective Landsat and Sentinel-2 optical sensors. Only the first three Principal Components (PCs) were extracted as they account for 90 to 95% of the variance, while the rest of the PCs contain mainly noise due to high correlation (Zhang *et al*., 2020).

5.2.4 Feature selection

Feature selection is a crucial step in image classification, because it eliminates subjectivity and contributes to higher classification accuracy and reduces overfitting (Zhou *et al*., 2021; Fu, 2022). For the Landsat images (years 1990, 2000, 2006 and 2014), the image bands, spectral indices, textural and the topographical information were combined into a single stack in GEE (Figure 5.3). The same was done for the combination of Sentinel-1 and -2 datasets. After the creation of the stacks, the images were exported and the feature selection was carried out in R-studio using the Recursive Feature Elimination (RFE) model. RFE is a method used to select the most important features in a dataset. It was first introduced by (Guyon *et al*., 2002). The basic idea of RFE is to repeatedly eliminate the least important features until all features have been evaluated. The RFE algorithm was used in the “caret” package (Kuhn, 2008) in the R statistical software using 10-fold cross validation.

5.3 ANALYTICAL METHODS

Two analyses were undertaken, firstly: the assessment of the extent of wetland biodiversity types for each year, and how well remote sensing was able to distinguish the types; and secondly: the assessment of types and rates of changes of the wetland EFGs between 1990 and 2022. The following sections provide the detail of these two assessments.

5.3.1 Assessing the extent of wetland EFGs

In this study, the random forest (RF) (Breiman, 2001) algorithm was used to classify wetland types. RF is an ensemble machine learning algorithm that combines multiple decision trees to improve the accuracy and robustness of image classification. It is known for its high accuracy, robustness to noise and outliers, and ability to handle large datasets with complex interactions between predictors. The RF classifier has been shown to be superior to other machine learning algorithms for wetland classification (e.g. Mahdianpari *et al*., 2022; Van Deventer *et al*., 2022b). The RF model was implemented using the ee.Classifier.smileRandomForest() function in GEE. This function contains a dictionary that can be used to specify and control the behaviour of the classifier. In RF, each tree is constructed using a randomly selected subset of features (variables) and data samples, thereby reducing the potential for overfitting and increasing the robustness of the model. The final prediction is the average or majority vote of all the individual tree predictions. RF is a non-parametric method, which is more appropriate for spectral reflectance data that often does not have a normal distribution. This is particularly advantageous for ecological mapping, where the relationships between environmental variables and wetland types can be complex and nonlinear.

The number of trees was set to *n*=1 000 and other parameters were left as default in the GEE RF classification algorithm. The training data was randomly split into 70% for training and 30% for testing. The raster result was generated at a 30 m spatial resolution for 1990, 2000, 2006 and 2014, and 10-m spatial resolution for 2018, 2022 and 2022. The highest possible spatial resolution was used to ensure the most accurate classification of the classes. For each year and class, the overall accuracy (OA%), producer's accuracy (PA%), and user's accuracy (UA%) were computed (Story and Congalton, 1986). An error matrix was also generated to report the spectral overlap between classes.

After the RF classification, each classified image was exported and projected to the Albers Equal Area (AEA) coordinate system of South Africa which has a Central Meridian of 25°, Standard Parallel 1 at 24° S, Standard Parallel 2 at 33° S, and Latitude of Origin at 0°. The extent of each wetland EFG was then calculated in km^2 and the percentage of each wetland EFG to the total area of the MCP was calculated.

5.3.2 Assessing the types and rates of change of wetland EFGs

The rate of change for each class was calculated using the following formula (Bland *et al*., 2017) as shown in equation 5.3.

Equation 5. 3

$$r = \left(\frac{1}{t2-t1}\right) * \ln\left(\frac{A2}{A1}\right)$$

Where A1 and A2 are the land cover at time t1 and t2 (per year or percentage per year. After calculating the rate of change, the amount of conversion was also calculated in order to know the classes that wetlands are lost to. This was done in ArcGIS Pro 3.0 software (ESRI, 2020) using the Compute Change Raster tool and using the categorical difference parameter. The changes were then categorised into three classes, anthropogenic, natural and remained the same. Anthropogenic changes are the transformation of wetlands from natural EFGs and cover types to human land cover or land use classes (description in Table 5.1). Natural changes, on the other hand, there are changes from one wetland EFGs to other wetland EFGs or terrestrial classes, whereas those wetland EFGs that remained consistent in class were distinguished from those with natural between-class changes. From these categories, hotspot maps were generated to show where most changes took place. Finally, the absolute rate of decline (ARD) was predicted for each wetland EFG to estimate the year of potential collapse (Kieth *et al*., 2009) as shown in Equation 5.4.

Equation 5. 4

$$\frac{Area(t2)-area(t1)}{Year(t2)-Year\ (t1}$$

where t represents time period 1 and 2.

5.4 RESULTS OF THE WETLAND ECOSYSTEM FUNCTIONAL GROUPS

The results are presented first for the different wetland EFGs per year, and thereafter the types and rates of change.

5.4.1 Variation in the extent, distribution, and location of wetland EFGs across the MCP

Between 1990 and 2022, the extent of wetland EFGs on the MCP showed variation (Figure 5.2), ranging from a minimum of 1 065 km² (13% of the full extent of the MCP) in 2006 to a maximum of 1 420 km² (17%) in 1990 (Table 5.9). Notably, when comparing the extent of wetland EFGs to one another, Lacustrine wetlands were consistently dominant throughout all years relative to the full MCP, with an average extent of 463 km² (6% of the extent of the MCP) compared to an average extent of 202 km² (2% of the extent of the MCP) for palustrine wetlands. Amongst the palustrine wetland EFGs, Large macrophytes emerged as the most dominant in extent, with an area that varied from a minimum of 305 km² (4% of the extent of all wetland EFGs) in 1990 to a maximum of 326 km² (4% of all wetland EFGs) in 2018. In terms of marsh wetlands, Seasonal marshes were more prevalent in the notably wet year of 2000, maximising at 512 km² (6% of the study area) in extent, compared to the minimum extent of 252 km (or 6% of the MCP) in 2022. In contrast, permanent marshes experienced a substantial decline in extent over the years, reaching their peak at 137 km² (2% of the MCP or all wetland EFGs) in 2000 but declining to 39 km² (0.47%) by 2022.

Table 5.9. Extent of wetland Ecosystem Functional Groups (EFG) on the Maputaland Coastal Plain (MCP) for seven years between 1990 and 2022

Wetland EFG	1990		2000		2006		2014		2018		2020		2022	
	km²	% of MCP	km²	% of MCP	km²	% of MCP	km²	% of MCP	km²	% of MCP	km²	% of MCP	km²	% of MCP
Coastal salt marsh	31	0	20	0	19	0	14	0	12	0	14	0	13	0
Intertidal forests and shrublands	14	0	31	0	26	0	17	0	16	0	15	0	14	0
Lacustrine wetlands	513	6	474	6	361	4	476	6	458	6	460	6	498	6
Large macrophytes	305	4	378	5	450	6	418	5	381	5	326	4	263	3
Permanent marshes	78	1	95	1	137	2	45	1	39	0	48	1	49	1
Seasonal marshes	370	5	512	6	14	14	284	3	193	2	243	3	252	3
Subtropical-temperate forested wetlands	109	1	115	1	72	1	99	1	69	1	62	1	61	1
Total Extent	**1 420**	**17**	**1 625**	**20**	**1 065**	**13**	**1 353**	**17**	**1 168**	**14**	**1 168**	**14**	**1 150**	**14**

The wetlands on the MCP exhibit distinct distribution patterns. The majority of these wetlands cluster around the central area of the study, particularly near St. Lucia (Figure 5.4). Notably, wetlands are more abundant towards the eastern part of the study area in comparison to the western region. Over the years, the northern distribution of wetland EFG's has undergone changes (Figure 5.5). In 1990 and 2000, the EFGs had a dispersed arrangement and presently they show a concentrated arrangement near the Kosi Lake estuarine wetlands transitioning from a scattered pattern to a more clustered presence around the Kosi Lake systems, with a noticeable gap in between. In contrast, the southern wetlands follow narrow distribution patterns along lake and river systems. It's worth mentioning that in 2000, there were a notable abundance of seasonal marshes in the northern region, which gradually decreased in extent between 1990 and 2018.

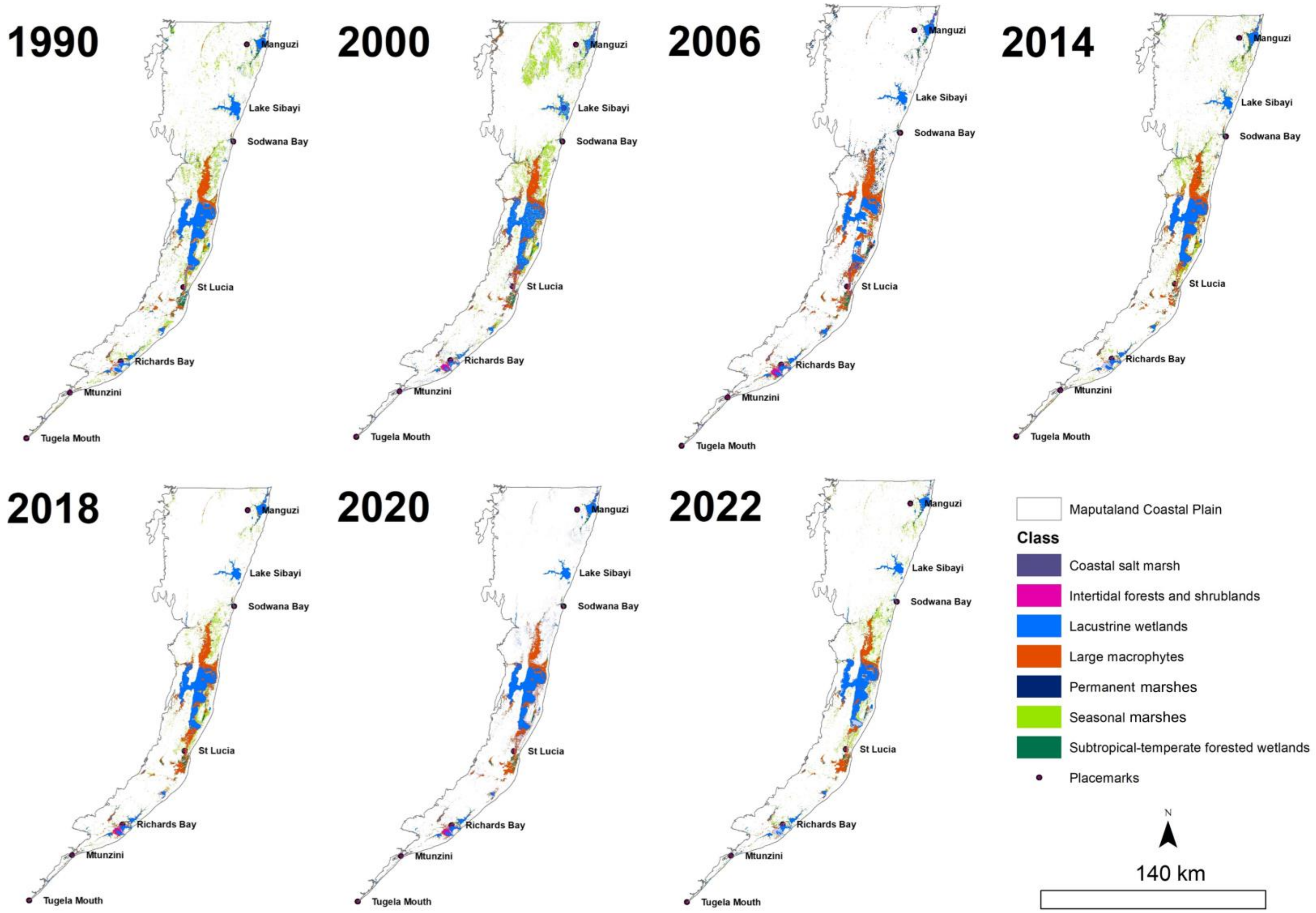


Figure 5.4. Distribution of wetland Ecosystem Functional Groups (EFGs) between 1990 and 2022 for the Maputaland Coastal Plain.

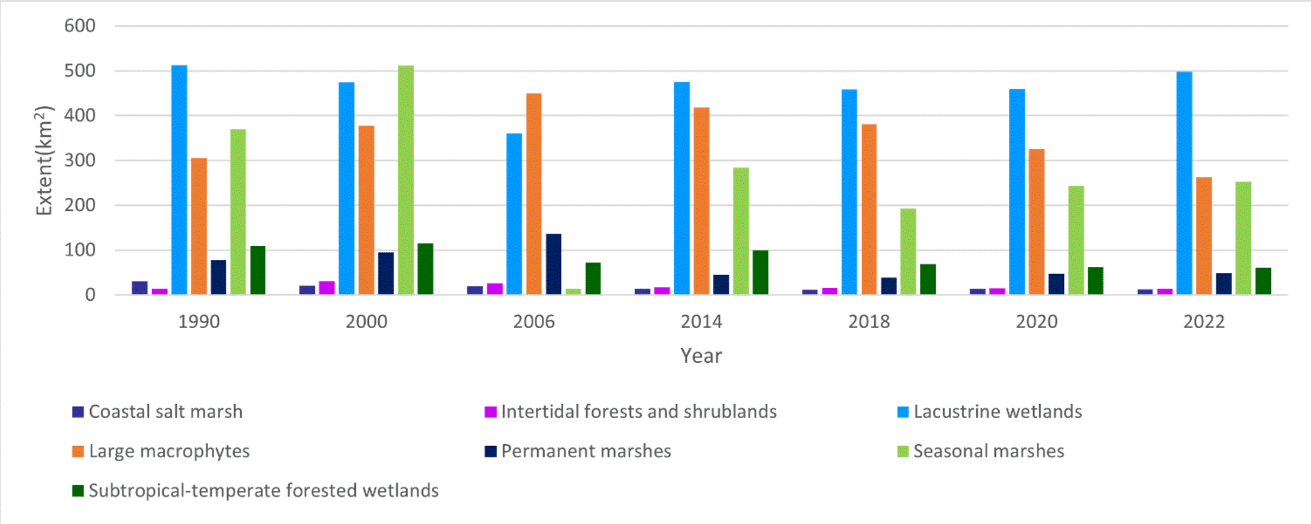


Figure 5.5. Changes in areal extents of wetland Ecosystem Functional Groups (EFGs) of the Maputaland Coastal Plain.

For the first four years (1990, 2000, 2006 and 2014), the overall accuracy (OA) of the classification ranged from 78.1% to 82%, with the average of these Landsat classifications being 81% (Table 5.2). In comparison, the three years that were classified using Sentinel-1 and -2 (2018, 2020 and 2022), achieved an OA of between 82% and 87% and showed an increase in average OA of 3%, averaging at 84.4%. Across all years, all four freshwater palustrine wetlands EFGs (Large macrophytes, Permanent and seasonal marshes, and Subtropical-temperate forested wetlands) attained user's accuracies ≥73%. Out of all the wetland EFGs across all seven years, the Intertidal forests and shrublands (mangrove forests) achieved the highest user’s and producer’s accuracies across all years of 98.9% in 2018. Conversely, Permanent and seasonal marshes, and Coastal saltmarshes exhibited a great variation in the producer’s and user’s accuracies, achieving between 28.1% and 100% for the seven classification years. While the classifier performed well overall, there were some instances of confusion when classifying wetland EFGs and terrestrial classes. Specifically, spectral confusion between Coastal salt marshes and Large macrophytes occurred, which can indicate natural habitat co-occurrence or a transition between hydrological cycles and estuarine mouth closure periods. Additionally, there were cases where Permanent wetlands were falsely identified as Large macrophytes, and *vice versa*. Spectral confusion was also high between terrestrial and wetland EFGs are noted between the Subtropical-temperate forested wetlands and coastal forests, which may be attributed to an overlap and grading of tree species that would occur in both forest types. Additionally, there were cases where Cultivated wetlands were classified as large macrophytes.

5.4.2 Changes in wetland EFGs

5.4.2.1 Changes in the extent of wetland EFGs

As depicted in Figure 5.6, the analysis of the changes in wetland EFGs between the seven selected years across a 22-year period (from 1990 to 2022) reveals distinct trends. Four of the seven wetland EFGs, namely, Coastal salt marsh, Intertidal forests and shrublands, Large macrophytes, and Subtropical/temperate forested wetlands, exhibited a decrease over the seven years assessed. The most extensive decrease was observed in the Large macrophytes category, which decreased from 305 km² in 1990 to 263 km² in 2022 (Table 5.10). In contrast, the Lacustrine and Seasonal marshes categories showed an increase over the years. The Permanent marshes category remained relatively stable with only minor fluctuations throughout the seven years. Extreme trends were observed in the Lacustrine and Seasonal marshes categories. For the Landsat years (1990-2014), most categories showed a decrease or remained relatively stable.

Table 5.10. Classification accuracies of wetland Ecosystem Functional Groups of the Maputaland Coastal Plain classified using remote sensing images for seven years between 1990 and 2022, summarised according to the percentage (%) of overall accuracy (OA), producer's accuracy (PA), and user's accuracy (UA)

Year	Accuracy	Coastal saltmarshes	Intertidal forests and shrublands	Lacustrine wetlands	Large macrophytes	Permanent/ seasonal marshes	Subtropical/ temperate forested wetlands
1990	OA			**78.1**			
	PA	68.5%	94.1%	80.4%	91.5%	80.9%	78.8%
	UA	82.1%	94.6%	87.4%	82.3%	73.8%	83.4%
2000	OA			**81.4**			
	PA	83.3%	95.3%	85.0%	92.1%	83.4%	78.1%
	UA	83.3%	94.7%	82.0%	80.9%	80.6%	75.9%
2006	OA			**81.9**			
	PA	80.5%	96.5%	86.8%	93.8%	79.4%	81.2%
	UA	89.6%	93.6%	88.4%	80.9%	78.0%	85.3%
2014	OA			**80.7**			
	PA	78.6%	94.7%	74.6%	92.2%	73.9%	79.9%
	UA	78.6%	92.0%	76.5%	81.0%	80.0%	86.0%
2018	OA			**82.2**			
	PA	73.3%	98.9%	82.4%	93.7%	77.3%	82.4%
	UA	85.1%	97.1%	88.6%	80.7%	84.8%	85.2%
2020	OA			**84.2**			
	PA	64.8%	98.0%	93.8%	92.8%	86.4%	82.2%
	UA	91.9%	94.9%	92.8%	79.9%	78.1%	81.9%
2022	OA			**87.0**			
	PA	69.9%	95.6%	95.0%	93.8%	86.4%	76.0%
	UA	84.0%	98.5%	90.4%	80.3%	83.0%	92.0%

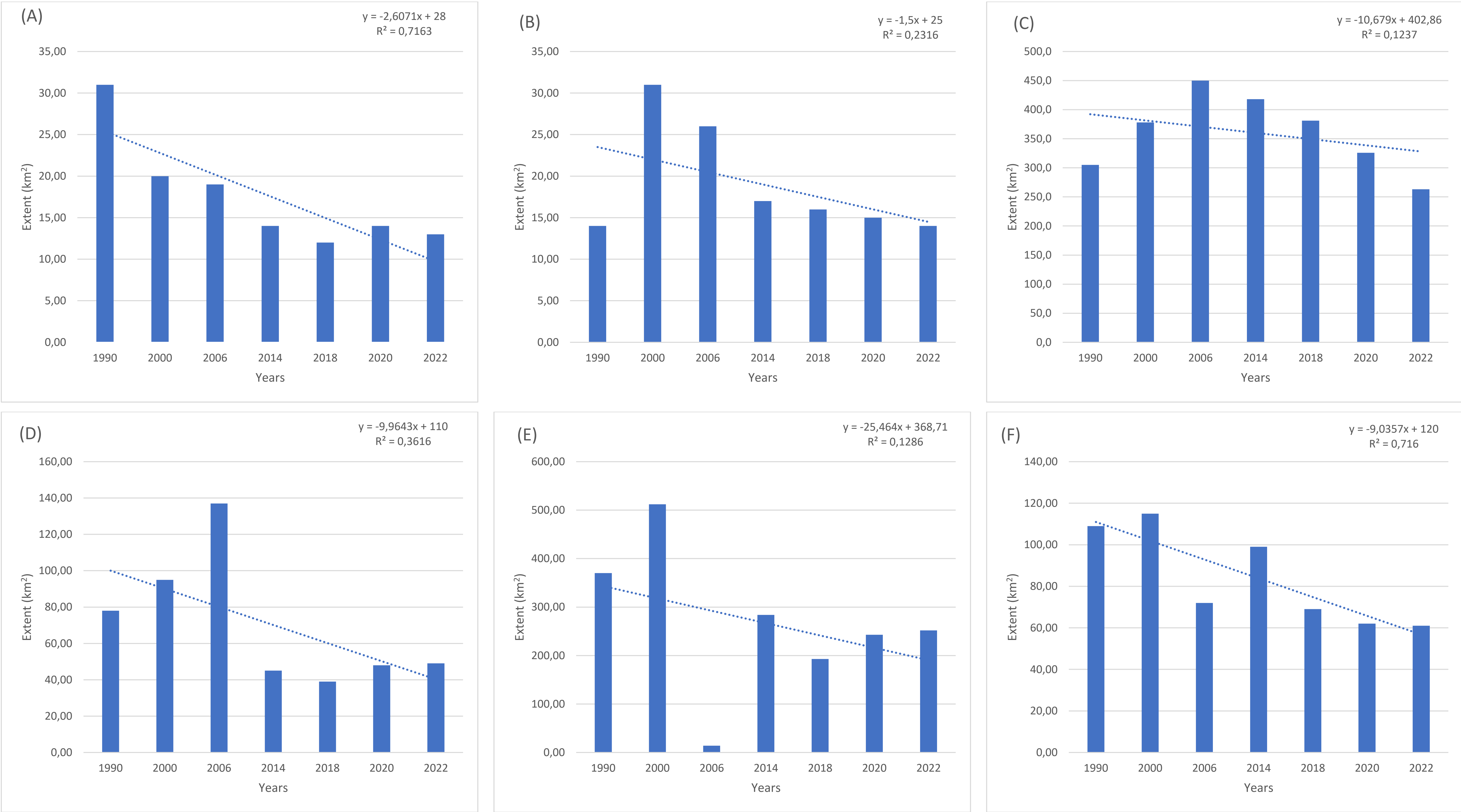


Figure 5.6. Trend graphs depicting rates of change in the extent of palustrine wetland EFGs over time for (A) coastal saltmarsh, (B) intertidal forests and shrublands or mangroves, (C) Large macrophytes, (D) permanent marshes, (E) seasonal marshes, and (F) subtropical-temperate forested wetlands.

Lacustrine wetlands also showed a decrease in extent over time, however they recovered in 2022 (Figure 5.7). There was a great decline in 2018.

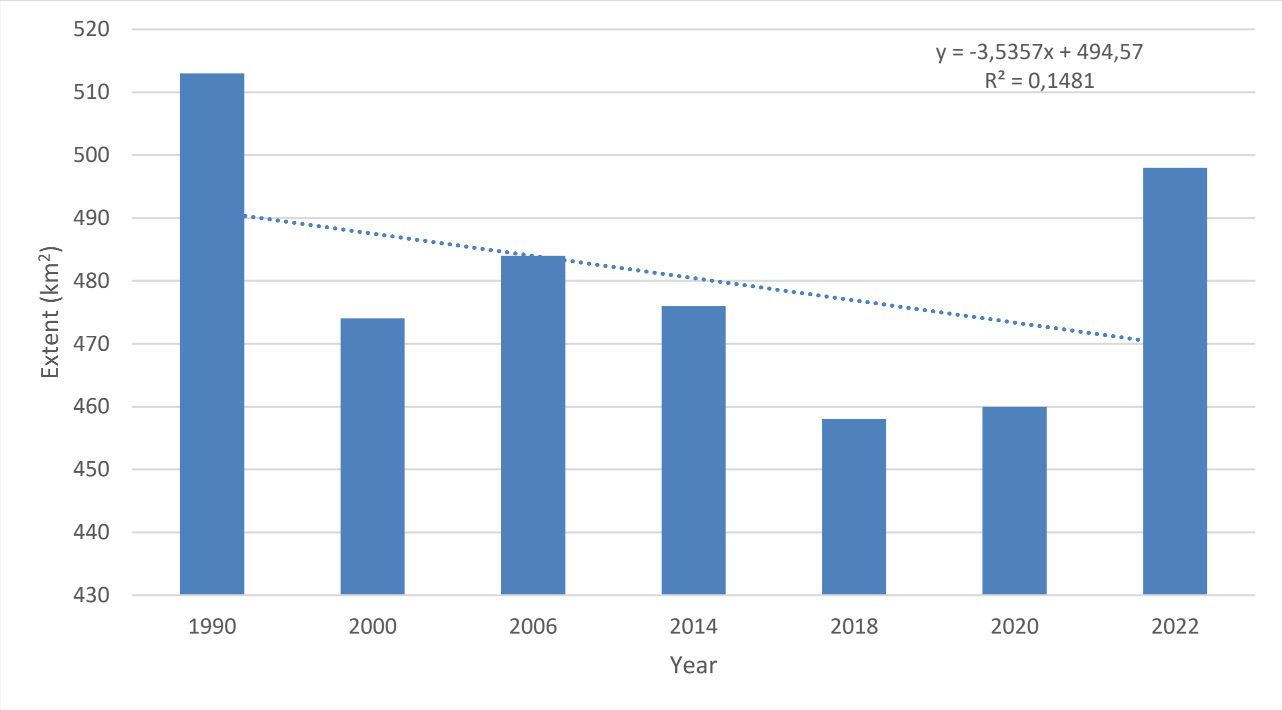


Figure 5.7. Rate of changes in the extent of lacustrine wetlands on the Maputaland Coastal Plain.

5.4.2.2 Rates of change of wetland Ecosystem Functional Groups

The results for the rates of change of wetland EFGs revealed a general downward trend in the rates for Coastal salt marsh, Intertidal forests and shrublands, Large macrophytes, and Subtropical-temperate forested wetlands (Table 5.11). Coastal salt marsh, despite an 8% increase per year from 2018 to 2020, have an overall average decline rate of -1% per year between 1990 and 2022, relative to the original extent of 1990. Intertidal forests and shrublands started with an 8% increase per year from 1990 to 2000, but later years show a decrease, bringing the average rate to -1% per year. Large macrophytes had a significant decrease of -11% per year between 2018 and 2020, contributing to an average rate of -3% per year. Subtropical-temperate forested wetlands mostly experienced decreases over the years, resulting in an average rate of -3% per year. In contrast, Lacustrine wetlands, Permanent marshes, and Seasonal marshes maintained a relatively stable rate on average per year across all seven years assessed. Lacustrine wetlands showed minor fluctuations with an average rate of 0% per year. Permanent marshes had a mix of increases and decreases, with a notable increase of 10% per year from 2014 to 2018, but the average rate remained at 0% per year. Seasonal marshes also had fluctuations with a significant increase of 12% per year from 2014 to 2018, yet the average rate was also 0% per year.

Table 5.11. Rates of change in wetland Ecosystem Functional Groups between 1990 and 2022 for the seven years assessed

Rate (%/year)	1990-2000	2000-2006	2006-2014	2014-2018	2018-2020	2020-2022	Average (%/ year)
Coastal salt marsh	-4	-1	-4	-4	8	-4	-1
Intertidal forests and shrublands	8	-3	-5	-2	-3	-3	-1
Lacustrine wetlands	-1	0	0	-1	0	4	0
Large macrophytes	2	3	-1	-2	-8	-11	-3
Permanent marshes	2	-8	-4	-4	10	1	0
Seasonal marshes	3	-9	-1	-10	12	2	0
Subtropical-temperate forested wetlands	1	-8	4	-9	-5	-1	-3

5.4.3 Types of changes in wetland Ecosystem Functional Groups

Overall, between 1990 and 2022, revealed transformations in wetland EFGs to other wetland EFGs or other land cover types (Figure 5.8). Coastal saltmarshes and Intertidal forests and shrublands primarily transitioned into Large macrophytes, respectively. On the other hand, Lacustrine wetlands largely remained the same with minor changes into Large macrophytes. Both seasonal and permanent marshes mostly transitioned into terrestrial grasslands while Subtropical forested wetlands mostly transitioned into Coastal Forest and Large macrophytes. 53% of the wetland types remained the same, while 39% changed to other natural classes and 8.1% transformed to anthropogenic classes between 1990 and 2022 (Figure 5.9). Most anthropogenic changes are concentrated around the floodplains of the iMfolozi and Mhlathuze floodplains. Most of the changes are due to the transformation from a natural category to wetland cultivation (Figures 5.10).

Legend
Aquatic to terrestrial
Estuarine to freshwater
Loss of forested wetlands to large macrophytes or marshes
Permanent to seasonal
Remained the same wetland EFG
Spectral confusion
Transformation to anthropogenic classes

		2022																			
		Estuarine EFGs		Freshwater EFGs					Other natural classes							Transformed classes					
	Change (%)	Coastal saltmarsh	Intertidal forest and shrublands	Lacustrine wetlands	Large macrophytes	Permanent marshes	Seasonal marshes	Subtropical-temperate forested wetlands	Beach	Coastal forest	Dune forest	Mudbanks	Sand forest	Shrubs	Terrestrial grasses	Burnt peatland	Cleared land	Commercial farm	Cultivated wetland	Relic gardens	Timber plantations
1990	Coastal saltmarshes	9	4	26	31	10	13	0	0	2	0	0	0	0	2	0	0	1	0	0	0
	Intertidal forests and shrublands	2	56	11	15	4	5	2	0	3	0	0	0	0	1	0	0	1	0	0	0
	Lacustrine wetlands	0	0	90	4	2	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0
	Large macrophytes	1	1	4	52	3	11	4	0	10	0	0	0	1	4	0	1	7	1	0	1
	Permanent marshes	0	0	2	5	4	29	0	0	10	0	0	0	6	32	0	2	2	0	2	5
	Seasonal marshes	0	0	1	4	4	20	1	0	15	0	0	1	12	25	0	4	4	0	1	8
	Subtropical-temperate forested wetlands	0	0	0	19	0	3	27	0	31	0	0	1	3	1	0	1	2	2	0	7

Figure 5.8. Transformations of wetland Ecosystem Functional Groups (EFGs) to other land cover type values highlighted in red show large transformations.

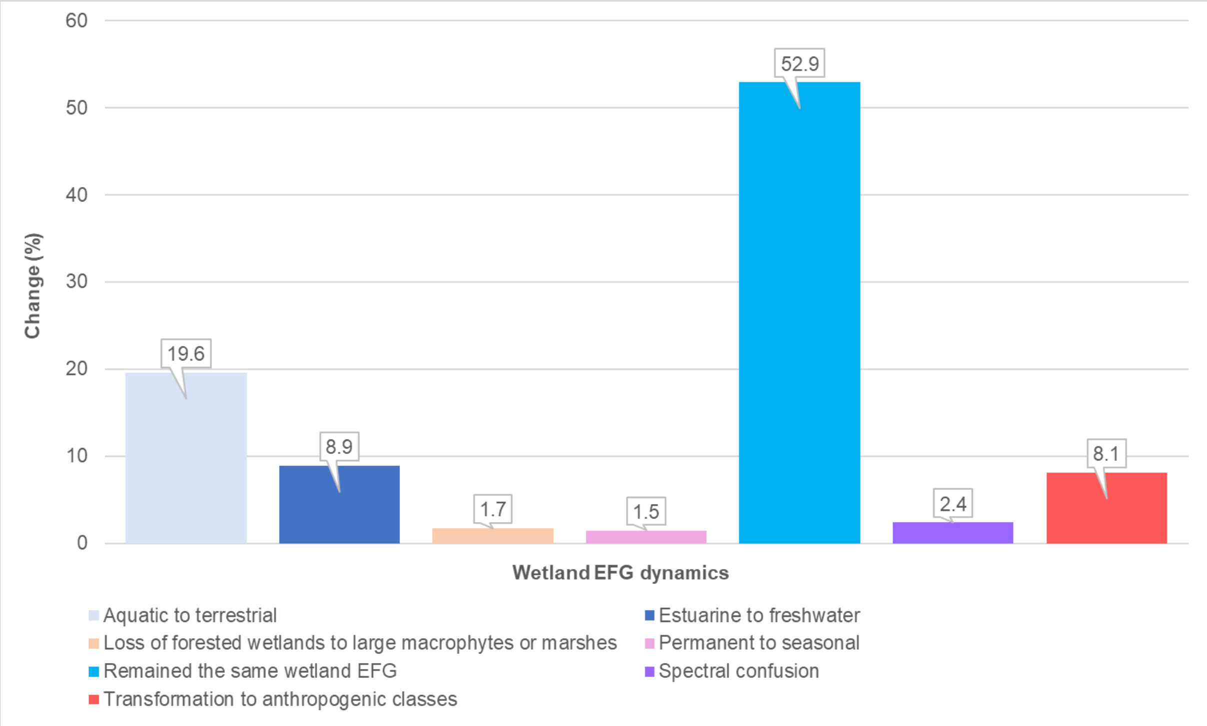


Figure 5.9. Percentage of the extent of wetland EFGs that remained the same, compared to those that were converted to anthropogenic or other wetland EFG, or terrestrial classes.

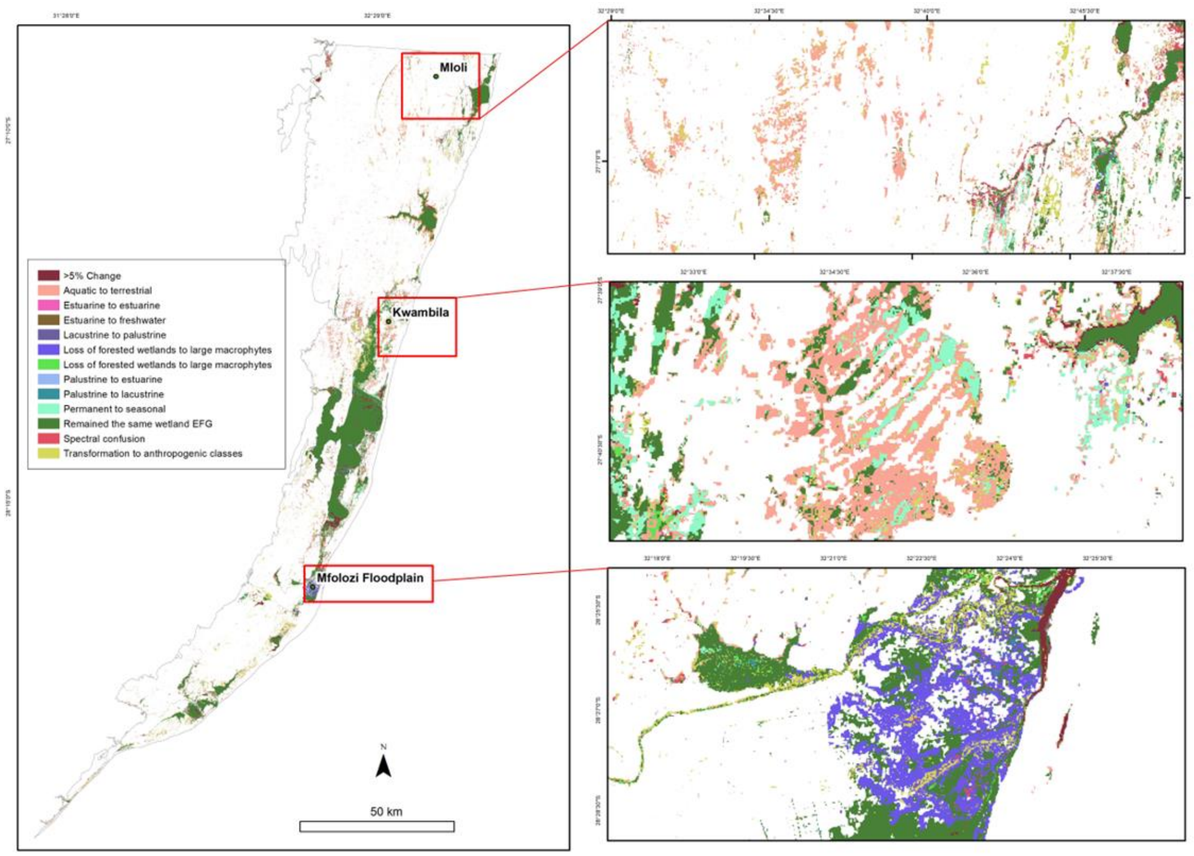


Figure 5.10. Geographic distribution of hotspots and types of changes in wetland EFGs between 1990 and 2022. MCP = Maputaland Coastal Plain.

5.4.4 Rates of change in wetland Ecosystem Functional Groups

Four out of the six palustrine wetland types, namely, Intertidal forests and shrublands, Permanent marshes, Seasonal marshes, and Subtropical-temperate forested wetlands, show that they will reach total collapse if they continue at the current rate of change (Figure 5.11). If these trends continue, these wetland ecosystems are expected to reach zero by the late 2040s.

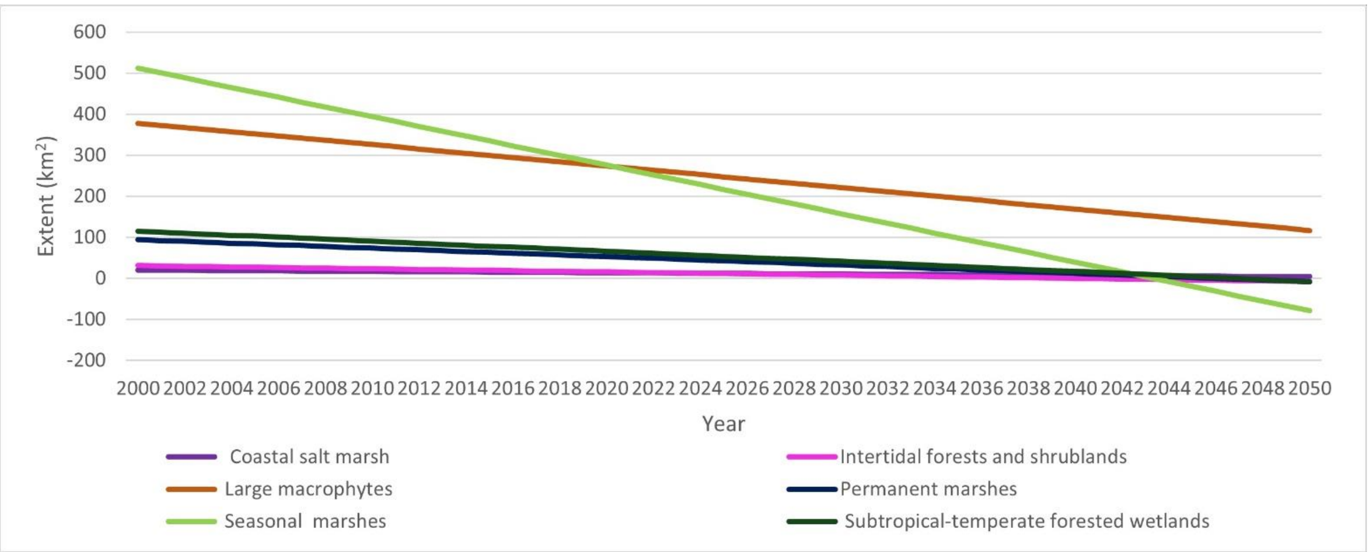


Figure 5.11. Absolute rate of decline (ARD) for wetland Ecosystem Functional Groups (EFGs) of the Maputaland Coastal Plain (MCP) between 2000 and 2050.

CHAPTER 6: STRATEGIC FRAMEWORK FOR THE INCLUSION OF EARTH OBSERVATION PRODUCTS AND COMMUNITY ENGAGEMENT IN THE NATIONAL WETLAND MONITORING PROGRAMME

6.1 INTRODUCTION

Monitoring changes in the extent of different wetland Ecosystem Functional Groups (EFGs) are not only important for reporting to national and global targets, but can potentially also facilitate early intervention where rates of decline are high. To date, remote sensing datasets have contributed to understanding the changes in the extent of lacustrine wetlands, or permanently inundated open waterbodies, with changes reported since 1984 through the Global Surface Water Products (GSWPs; Pekel *et al.,* 2016). However, changes in the extent of different types of palustrine (vegetated) wetlands are lacking globally. In South Africa, a comparison between the extent of the National Wetland Map version 5 (NWM5; Van Deventer *et al*., 2020b) and the open water body layer of the GWSP, showed an underrepresentation of 87% of wetland extent in the GWSP (Van Deventer, 2021). Further work is under way to improve on the underrepresentation of many wetlands in NWM5, and therefore, this percentage of underrepresentation of the GWSP may be even higher. These two datasets were used in combination for the reporting of the extent of the two (lacustrine and palustrine) wetland biomes to the Sustainable Development Goal (SDG) 6.6.1a of the United Nations' Environment Programme (UNEP) (DWS, 200; Van Deventer, 2021).

South Africa is also signatory to the Convention on Biological Diversity (CBD) and responsible for tracking changes in different ecosystem types and reporting these against global targets. Targets to halt the loss and attain percentages of extent targets were set for the Aichi targets, reporting on these by 2020. For target 11 that aimed at having 17% of the extent of wetlands in protected areas by 2020, South Africa achieved only 7% of the extent of wetlands (Van Deventer *et al*., 2019b). Changes in the ecological condition of wetland hydrogeomorphic (HGM) units were, however, difficult to assess in the most recent National Biodiversity Assessment of 2018 (NBA 2018), for a number of reasons. Changes in the extent of different wetland vegetation types are not always detectable using the historical, 30-m spatial resolution of the Landsat series of sensors, and complete coverage of the historical extent of aerial photographs remains limited in geographic extent and georeferenced or digitised vector format to inform such assessments. The Sentinel-1 and -2 radar and optical sensors of the European Space Agency (ESA) offered new improvements on both spatial and temporal resolution for monitoring purposes, compared to the Landsat series of sensors. These improvements can contribute to improved mapping of wetland biodiversity types at a regional scale, which several smaller scale studies have previously proven to be separable using space-borne sensors. The more recent global ecosystem typology of the International Union for Conservation of Nature (IUCN; Keith *et al*., 2022) further suggested the use of wetland EFGs as subcategories to the wetland biomes (palustrine and lacustrine). In Chapter 5, the capabilities of Landsat and Sentinel sensors showed that the extent, geographic location and rates of change of the six palustrine wetland EFGs can be quantified and monitored over time. The extent was illustrated for the Maputaland Coastal Plain (MCP), an interconnected, aquifer-dependent ecosystem (ADE), where pressures in the system can have far-reaching impacts in other parts of the region.

The GBF provides a good overview of the framework for monitoring by national members to report to the targets (CBD, 2022a; 2022b). The monitoring framework adopts headline, component and complementary indicators, possible at global to finer scales, and requires data and metadata for reporting purposes, with update lags less than five years if possible (CBD, 2022b). For wetlands, as an example, the headline indicator could be extent changes, or red list indices (also SDG indicator 15.5.1). Component indicators include connectivity or Ecosystem Integrity Index indicators, whereas the complementary indicators can include several listed indicators, with about 23 of the 54 indicators proposed in Appendix 1 of CBD (2022b) related to the wetland EFGs of the MCP:

- a.1. Forest area as a proportion of total land area (SDG indicator 15.1.1)
- a.2. Forest distribution
- a.3. Tree cover loss
- a.5. Mountain Green Cover Index
- a.6. Peatland extent and condition
- a.8. Red List of Ecosystems
- a.9. Continuous Global Mangrove Forest Cover
- a.10. Trends in mangrove forest fragmentation
  a.11. Change in the extent of water-related ecosystems over time (SDG indicator 6.6.1)
- a.12. Trends in mangrove extent
- a.22. Wetland Extent Trends Index
- a.23. Change in the extent of inland water ecosystems over time
- a.24. Change in the extent of water related ecosystems (SDG Indicator 6.6.1)
- a.25. Forest Fragmentation Index
- a.26. Forest Landscape Integrity Index
  a.27. Biomass of selected natural ecosystems (A.0.2)
- a.28. Biodiversity Habitat Index
- a.31. Relative Magnitude of Fragmentation (RMF)
- a.32. Ecosystem Intactness Index
- a.33. Biodiversity Intactness Index
- a.36. Wetland Extent Trends Index
- a.37. River Fragmentation Index
- a.38. Dendritic Connectivity Index
- a.39. Percentage of threatened species that are improving in status according to the Red List
- a.41. Number of threatened species by species group

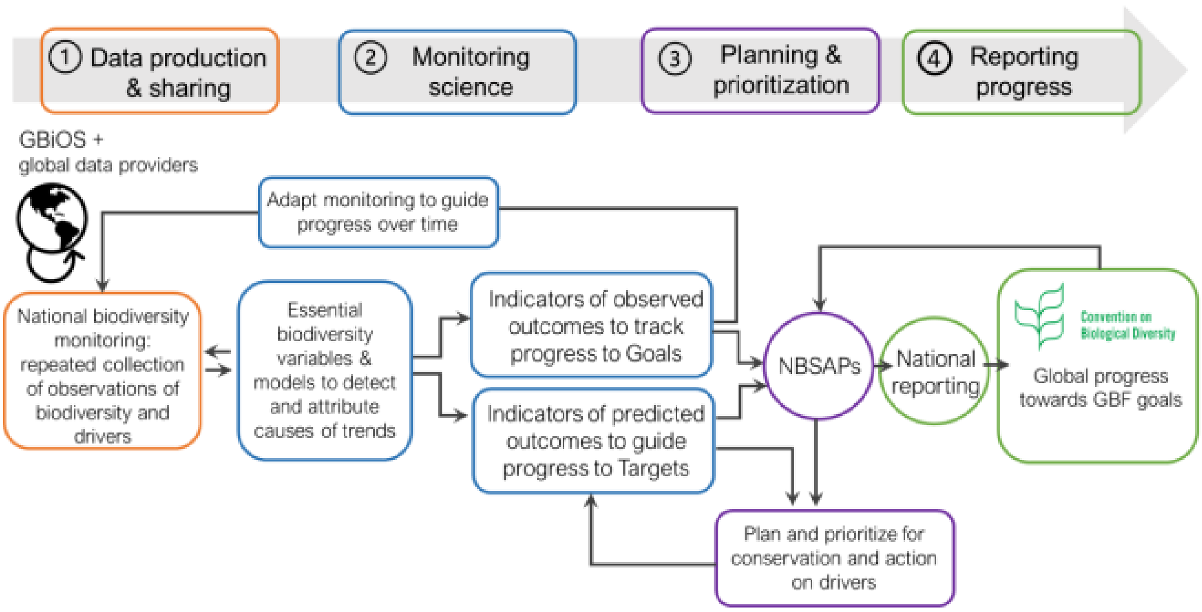


Figure 6.1. Overview of the Global Biodiversity Framework's overarching monitoring framework (CBD, 2022a), showing the various stages required for data production to monitoring, planning and national reporting. GBiOS = global biodiversity observation system; NBSAPs = national biodiversity strategies and action plans.

As a first step towards reporting to the GBF for the wetland EFGs of the MCP, and identifying the gaps which new monitoring points should address, this chapter first explores how the results of changes to wetland EFGs (Chapter 5), can be used to inform the three targets of the Global Biodiversity Framework's Goal A (CBD, 2022b), which includes:

(i) Target 1: halt the loss of ecosystems and facilitate effective management;
(ii) Target 2: ensure that 30% of the extent of degraded ecosystems are under restoration by 2030; and
(iii) Target 3: 30% of the extent of wetlands should be under restoration by 2030.

The outcomes of the target reporting will then be used to inform the proposed monitoring framework of wetland EFGs for the MCP in the second part of this chapter. Issues related to the suitability and **gaps** in existing reporting stations and methods; whether existing and known **interventions** are addressing the hotspots of change reported in Chapter 5 for wetland EFGs; and **knowledge gaps** that are important for improved reporting of changes in wetland EFGs on the MCP, will be discussed in section 6.2. Then, after considering the stakeholder inputs in section 6.3, the final three questions will be addressed in section 6.4 related to a monitoring framework for wetland EFGs of the MCP: (i) **who** are currently involved and responsible for the remaining extent of wetland EFGs on the MCP; (ii) what are the critical and complimentary **tools** for monitoring on the MCP; and (iii) what are the ideal temporal **intervals** of reporting.

6.2 SOUTH AFRICAN REPORTING TO THE 2030 GLOBAL BIODIVERSITY FRAMEWORK'S TARGETS FOR WETLAND ECOSYSTEM FUNCTIONAL GROUPS (TYPES)

6.2.1 The Global Biodiversity Framework's Goal A targets 1-3 for wetland ecosystems

South Africa is a member of the CBD and representatives from the Department of Forestry, Fisheries and the Environment (DFFE) participated in the Conference of the Parties number 15 (COP15), where the targets for ecosystems related to ecosystems (under Goal A) for the GBF were discussed in November 2023 (CBD, 2022b). The three targets, related to (1) reporting of losses, (2) interventions and (3) conservation, were finalised for first reporting by 2030, and then also by 2050 (CBD, 2022b; Figure 6.1). Losses of ecosystems were also recognised to include both loss of extent, connectivity and integrity (ecological condition). Global datasets, such as the GSWP and the Global Mangrove Watch (Pekel *et al*., 2016; Bunting *et al*., 2022) provide broad overviews of general trends of open waterbodies, however, insufficient for the reporting of losses in the extent, connectivity and integrity of South Africa's wetlands.

1. Reducing threats to biodiversity

TARGET 1

Ensure that all areas are under participatory, integrated and biodiversity inclusive spatial planning and/or effective management processes addressing land- and sea-use change, to bring the loss of areas of high biodiversity importance, including ecosystems of high ecological integrity, close to zero by 2030, while respecting the rights of indigenous peoples and local communities.

TARGET 2

Ensure that by 2030 at least 30 per cent of areas of degraded terrestrial, inland water, and marine and coastal ecosystems are under effective restoration, in order to enhance biodiversity and ecosystem functions and services, ecological integrity and connectivity.

TARGET 3

Ensure and enable that by 2030 at least 30 per cent of terrestrial and inland water areas, and of marine and coastal areas, especially areas of particular importance for biodiversity and ecosystem functions and services, are effectively conserved and managed through ecologically representative, well-connected and equitably governed systems of protected areas and other effective area-based conservation measures, recognizing indigenous and traditional territories, where applicable, and integrated into wider landscapes, seascapes and the ocean, while ensuring that any sustainable use, where appropriate in such areas, is fully consistent with conservation outcomes, recognizing and respecting the rights of indigenous peoples and local communities, including over their traditional territories.

Figure 6.2. Targets 1-3 of Goal A of the Global Biodiversity Framework (CBD, 2022b:9). Inland water includes both estuarine and freshwater wetlands and rivers.

6.2.2 The South African Monitoring Programme (NWMP) and National Wetland Map (NWM) updates

Remote sensing of lacustrine and palustrine wetland biomes and changes in their extents over time, offer a valuable contribution to the tools that can be used in the Gibo's South African NWMP that is coordinated by DWS. The outputs of Chapter 5 show that the extent of palustrine wetlands can be mapped and monitored with remote sensing tools, which can improve the reporting of the extent of these by DWS through Statistics South Africa, to SDG 6.6.1a. In addition, the outputs can improve on the biodiversity representation in the updates of the NWM. Underrepresentation of the extent and errors in the HGM units of NWM5 polygons is under way under the leadership of the South African National Biodiversity Institute (SANBI). The project includes the improvement of the initial modelling of the ecological condition of wetlands, using a combination of land cover and ancillary datasets (Van Deventer *et al*., 2019b). Changes in the extent of the wetland EFGs can contribute to the assessment or modelling of the NWM6 at HGM unit level.

Further work is required to assess the feasibility of remote sensing indices and products that can inform on changes in ecological condition and types, and would require in-field validation assessments. The current South African National Monitoring Programme (NWMP) has yet to be operationalised, identifying sites and tools for consistent monitoring and reporting of all wetland EFGs. To date, the Department of Water and Sanitation (DWS) is measuring water quality and flow at a number of stations in the country and on the MCP (Section 1.3.2., Chapter 1). In addition, a 102 large open waterbodies of South Africa, mostly artificial, with six freshwater and five estuarine systems, are monitored for chlorophyll-*a* using remote sensing data (Matthews and Bernard, 2015). The extent and ecological condition of palustrine wetlands are yet to be established and implemented in the NWMP. Therefore, none of the existing products available report the extent and type of changes in wetland EFGs adequately for the reporting to the GBF targets by 2030.

The following three sections therefore explore the way in which the outputs generated from this report (Chapter 5), can be used to report on the targets 1-3 of the GBF. The intention is for the MCP to serve as an example for other regions in South Africa, for reporting to the same targets of the GBF by 2030.

6.2.3 GBF target 1 of Maputaland's wetland EFGs

A total of 19% of the original extent of wetlands mapped for 1990 were transformed by 2022 (Table 6.1, as calculated based on Table 5.9 in Chapter 5). Coastal salt marsh showed the highest extent of transformation at 58%, whereas mangroves appeared to have remained the same in extent. Forested wetlands showed the second highest extent of transformation, with 44% of the 1990 extent transformed. Permanent and Seasonal marshes also showed changes of more than a third of their original extent, whereas Large macrophytes were 14% transformed, and Lacustrine wetlands were only 3%.

Table 6.1. Total extent (km²) of loss in wetland Ecosystem Functional Groups (EFGs) between 1990 and 2022

Wetland EFG	Extent 1990 (km²)	Extent 2022 (km²)	Extent transformed (km²)	Percentage (%) transformed from 1990 to 2022	Percentage of 1990 extent transformed to other natural classes	Percentage of 1990 extent transformed to anthropogenic classes
Coastal salt marsh	31	13	18	58.1	2.1	0.1
Intertidal forests and shrublands	14	14	0	0.0	0.4	0.0
Lacustrine wetlands	513	498	15	2.9	3.7	0.5
Large macrophytes	305	263	42	13.8	8.1	2.4
Permanent marshes	78	49	29	37.2	4.6	0.8
Seasonal marshes	370	252	118	31.9	15.8	5.4
Subtropical-temperate forested wetlands	109	61	48	44.0	4.5	1.0
Total Extent	**1 420**	**1 150**	**270**	**19.0**	**39.1**	**10.2**

According to Figure 5.4 that shows the rate of change in wetland EFGs, the Seasonal marshes showed the highest rate of loss compared to the other five wetland EFGs. This could potentially be attributed to a decline in the extent of open water over time, possibly as a result of a decrease in precipitation on the MCP, which should be explored for confirmation. This work is currently underway by MSc student Ms Nkosingizwile Ndlovu. Other studies have suggested that the increase in timber plantation extent, both commercial and subsistence, is contributing to a reduction in water availability on the MCP (Ramjaewon *et al*., 2020). The increase in desiccated and burning peatlands across the study area, south at the Mfabeni peatland, central at Vasi Pan, and in the north at the Muzi (Grundling *et al*., 2021; Le Roux *et al*., 2023), supports the notion of a drying trend in water availability for ecological systems. This would require the review of the legal extent of timber plantations and modelling of water availability in the landscape for resource determination. The RQO work for the Usutu to Mhlathuze catchment, is currently underway (DWS, 2022).

Another four wetland EFGs, Subtropical forested wetlands, Permanent marshes, mangroves (Intertidal forests and shrublands) and Coastal salt marshes, all show possible complete loss by 2044 at the current rate of loss. These types show narrower extent compared to the seasonal marshes, and may show a higher level of resilience, however, having narrower extents. Concerns about the rate of loss and change in the extent of forested wetlands have been raised before (Van Deventer *et al.*, 2021a). Increases and decreases in the extent of mangroves are documented for Maputaland (Adams and Rajkaran, 2020). A decline in the extent of salt marshes in Maputaland has also been observed by Raw *et al*. (2021).

Of all the wetland EFG classes, the Large macrophytes showed the lowest rate of loss. Monitoring changes in the extent of this class, and reporting its losses, is complicated. Changes in water availability and mouth state could result in the increase of Large macrophytes in estuarine open water systems, whereas nitrification and pollution can make *Phragmites australis* and *Typha capensis* dominate in other wetlands. Aerial or drone images should be used to distinguish *Cyperus papyrus* wetlands from the other species in the Large macrophytes class (*C. mariscus, Phr. australis* and *T. capensis*), and studies are done to assess changes in their extent, connectivity and ecological condition over time.

This project illustrated the feasibility of refining the current global data that is used for reporting of SDG indicator 6.6.1 at wetland biome level (the Global Surface Water Product of Pekel *et al*., 2016), to improve on the extent of palustrine wetlands reported, as well as their changes over time. Biodiversity types at the EFG level can be reported via target 1 to the GBF, but summarised for reporting to SDG indicator 6.6.1a. The rate of change is, however, a critical indicator that should be considered in reporting to target 1. If the Absolute Rate of Decline (ARD), as proposed in the red listing of ecosystems (Bland *et al*., 2017), can be useful in prioritising intervention in the larger landscape. In other catchments of South Africa, finer scale assessments can be useful and indicative of trends, however, in this large, extensive and interconnected sandy aquifer, and where access to wetlands will be limited and risky, remote sensing provides an important tool to contribute to mapping the extent and rate of change for reporting to target 1.

6.2.4 GBF target 2 of Maputaland's wetlands

To assess the feasibility of reporting to target 2 of the MCP's wetland EFGs, the existing intervention programmes managed by the DFFE were evaluated, data collected and overlaid to see how the percentages would add to the target of 30% of the extent of degraded ecosystems. The following two subsections address the data available from DFFE intervention programmes and their performance indicators, and the results of the statistics.

6.2.4.1 South African intervention programmes and performance indicators

Six of the intervention programmes of the DFFE can be linked to restoration efforts in wetlands (Table 6.2). Some of these programmes, such as the Working for Water programme, have been in existence since 1997, with the extent of intervention programmes captured as polygon spatial data layers (DFFE, 2023b). The Working for Wetlands Programme commenced in 2002, however, not all the data is available as a spatial data layer (DFFE, 2023c). Several point shapefiles showing the location of an attribute field related to the extent of interventions done between 2018 and 2023, were available for use. The Working for Coast data dates from 2013 and 2016, listing the extent of illegal timber plantation clearing done per estuary (DFFE, 2023a). Interventions done by Working for Ecosystems, Working on Fire and Working on Waste were not yet available at the time of reporting of this chapter.

Table 6.2. Summary of the intervention programmes managed by the Department of Forestry, Fisheries and the Environment (DFFE) that will impact wetlands, as documented on their website*

DFFE programme	A) Focus areas or objectives B) Monitoring/ Performance indicators	Available data	Years available electronically
Working for ecosystems 	A) Improve flows, minimise sediments, achieve optimal water quality B) Areas treated, employment, training; and extent regenerated, recovery, carbon sequestration, improved biodiversity, compositional and structural regeneration, recovery and ecosystem functionality, water retention and landscape stability	N.A.	N.A.
Working for the Coast coastcare our coast for life	A) Continuous sedimentation, environmental pollution, destruction of coastal habitats, urbanisation and influx of tourists; improvement of access to and along the coast, cleaning of the coast, removal of illegal and abandoned structures, removal of invasive alien vegetation, rehabilitation of degraded areas, monitoring & compliance; B) • Kilometres of accessible coastline cleaned • Number of hectares of dunes rehabilitated • Number of estuaries cleaned • Number of coastal community parks created • Number of waste bins installed • Kilometres of hiking trails established and rehabilitated • Number of kilometres of boardwalks constructed • Number of beaches cleaned	Excel summary of the extent of timber plantations removed	2013; 2016
Working on Fire WORKING ON FIRE	A) Reduce the cost of clearing the invasive plants, Prevention and control of wild fires, To implement integrated fire management, To contribute to the reduction of densely invaded areas, To reduce the risk of high biomass loads after clearing; https://workingonfire.org/	N.A.	N.A.
Working for Water WORKING FOR WATER	A) Preventing new and emerging invasive alien plant problems, Reducing the impact of existing priority invasive alien plants; Enhancing capacity and commitment to solve invasive alien plant problems; 'The projects include national priority wetlands (including existing and proposed Ramsar Wetlands of International Importance).'	Polygon shapefiles	1997-2023
Working for Wetlands	A) Wetland Protection, Wise Use & Rehabilitation, Skills and Capacity Development, Co-operative Governance & Partnerships, Knowledge Sharing Communication, Education & Public Awareness; B) • Number of person days • Number of jobs created • Number of training days	Point shapefiles	2018-2023

DFFE programme	A) Focus areas or objectives B) Monitoring/ Performance indicators	Available data	Years available electronically
	• Number of wetlands rehabilitated • Number gabion structures • Number of concrete structures • Number earthen structures • Number of earth works • Number of re-vegetation • Number of hectares of cleared invasive plants		
Working on Waste	A) Create and support mechanisms for the protection of environmental quality; Create sustainable livelihoods through recycling of waste (waste collection & minimisation), Support the use of environmentally friendly waste disposal technology, Promote environmental education and awareness to the communities especially as they are the main waste generators; B) • Number of licensed landfill sites established • Number of buy-back centres established • Number of households benefiting from waste collection • Number of Integrated Waste Management Plans developed • Number of waste bins provided/installed • Kilometres of streets cleaned • Area of illegal dumps cleared	N.A.	N.A.

* https://www.dffe.gov.za/environmental-programmes-projects-and-programmes

6.2.4.2 Quantifying the extent of intervention per degradation type

Using the available polygon and point data layer layers of Working for Water and Wetlands, respectively, the extent of the interventions was quantified in relation to the whole of the MCP (8 140 km²), in relation to all wetlands remaining on the MCP, using the 2022 prediction of Chapter 5, and in relation to the extent of each wetland EFGs. The total extent of wetlands on the MCP was assessed as 1 151.3 km² (14% of the MCP extent) in 2022. The interventions per wetland EFG was also assessed with respect to their location inside or outside protected areas (Statistics South Africa, 2021).

The Working for Wetlands Programme had interventions that covered 4.2% of the extent of all wetlands of which half were located within protected areas (Table 6.3; Figure 6.3). Between 1997 and 2023, the Working for Water Programme contributed another 12% of intervention programmes relative to the extent of all wetlands remaining in 2022 on the MCP, of which 11% of these interventions were within protected areas (Table 6.3). The calculations were done relative to the total extent of wetlands, while Target 2 requires that 30% of the extent of ***degraded*** wetlands be targeted for intervention by 2030.

Table 6.3. Extent of intervention programmes by the Department of Forestry, Fisheries and the Environment (DFFE) on the Maputaland Coastal Plain (MCP), assessed inside and outside existing protected areas

DFFE programme	Item assessed	Inside protected areas	Outside protected areas	Total
Working for Wetlands	Extent (km²)	22.5 km²	24.8 km²	47.2 km²
	Percentage of all working for wetlands interventions between 2018 and 2023)	47%	53%	100%
	Percentage extent of the MCP	0.3%	0.3%	0.6%
	Percentage extent of all wetlands	2%	2.2%	4.2%
Working for Water	Extent (km²)	127.4 km²	13.0 km²	140.4 km²
	Percentage of all working for water interventions between 1997 and 2023)	91%	9%	100%
	Percentage extent of the MCP	1.6%	0.2%	1.7%
	Percentage extent of all wetlands	11%	1%	12%

When comparing the interventions done by Working for Wetlands relative to the prediction of wetland extent for 2022 (Chapter 5, Figure 5.4B), it was evident that the remote sensing predictions did not have pixels at some of the points of intervention. Further work is therefore required to capture the full extent of historic Working for Wetlands interventions, to quantify the possible underrepresentation of the Landsat and Sentinel-1 and -2 sensors in monitoring wetlands on the MCP. A more complete dataset of historic interventions prior to 2018, will enable estimation of overlap between the intervention programmes and assist in more complete reporting. An overlay analysis to determine the interventions of Working for Wetlands with different types of wetland EFGs was not possible at this stage, because the intervention layer was points and not polygons.

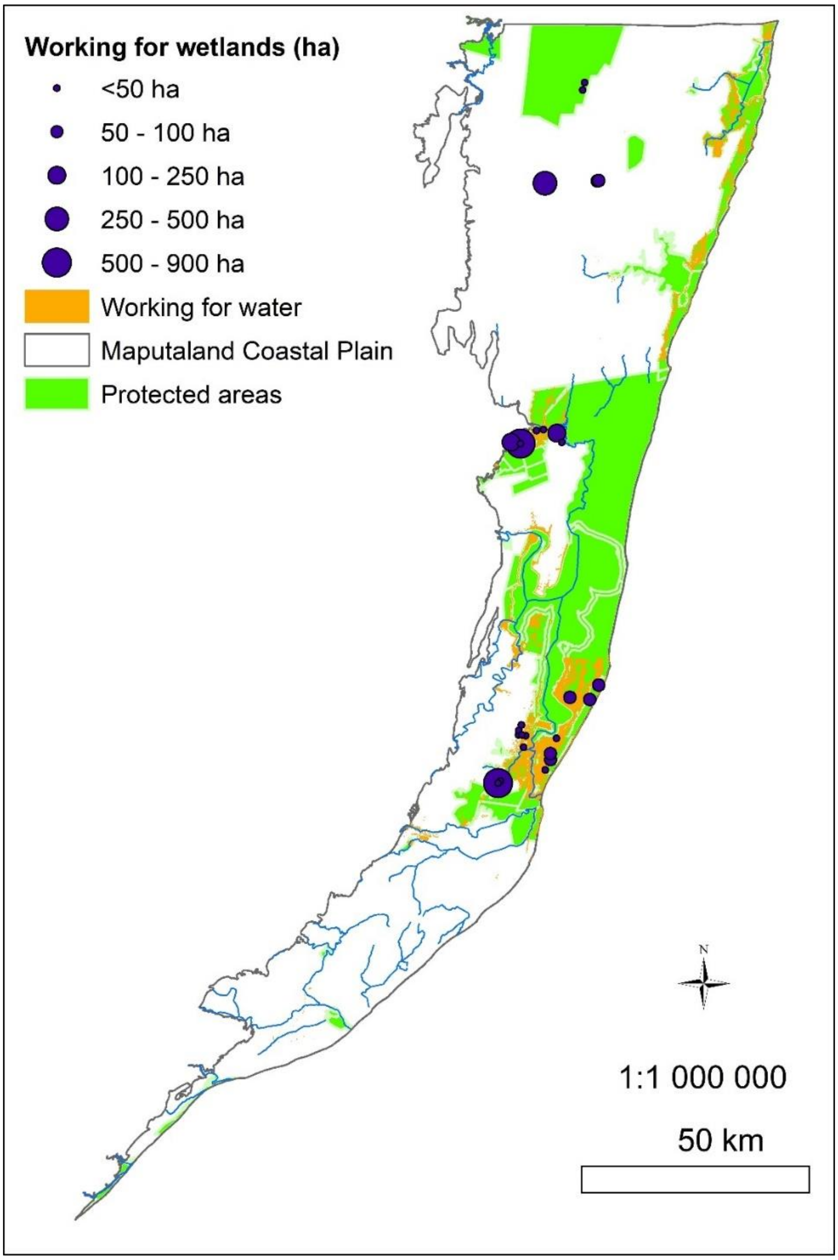


Figure 6.3. Location of intervention programmes from the Department of Forestry, Fisheries and the Environment on the Maputaland Coastal Plain.

The Working for the Coast Water programme provided an excel spreadsheet (DFFE, 2023a) that reported the extent of commercial timber plantations that were removed at the Kosi, St Lucia and uMgobezeleni estuaries by 2013 and 2016 (Table 6.4). The spatial extent of these interventions and their overlap with the wetland EFGs were difficult to assess, and therefore not reported here. For the iMfolozi estuary, a future plan was listed as 'Requires EMP and Removal of reservoir barrage separating upper estuary and southern lake basin to restore estuarine hydrodynamics, estuarine lake function, and connectivity for estuary fauna movement'. The impact of this intervention on the connectivity and changes in the extent of the wetland types will be critical for monitoring and reporting to targets 1 and 2 of the GBF.

Table 6.4. Reporting of interventions done on the Maputaland Coastal Plain by the Working for the Coast intervention programme of the Department of Forestry, Fisheries and the Environment (DFFE)

Name of Estuary	Initiative/Areas Restored	Year	Funded/Done by or Source of Information
Kosi	Land Care and Rehabilitation Programmes have removed 12,000 ha of commercial timber, which has improved ecosystem functioning; rehabilitated 45,000 ha through an alien plant control programme; created new habitats and provided employment for thousands of Park neighbours. This initiative was done at the Isimangaliso wetland park and not only at Kosi Bay Estuary.	2013	South African Government
St Lucia	Removal of the dredge spoil blockage from the path of the uMfolozi River towards the Lake St Lucia estuary. To ensure the link between the uMfolozi and the St Lucia Estuary was restored	2016	iSimangaliso' s own funds and the Global Environmental Facility (GEF) project.
	Land Care and Rehabilitation Programmes have removed 12,000 ha of commercial timber, which has improved ecosystem functioning; rehabilitated 45,000 ha through an alien plant control programme; created new habitats and provided employment for thousands of Park neighbours. This initiative was done at the Isimangaliso wetland park and not only at St. Lucia Estuary.	2013	South African Government
uMgobezeleni	Land Care and Rehabilitation Programmes have removed 12,000 ha of commercial timber, which has improved ecosystem functioning; rehabilitated 45,000 ha through an alien plant control programme; created new habitats and provided employment for thousands of Park neighbours. This initiative was done at the Isimangaliso wetland park and not only at uMgobozeleni Estuary.	2013	South African Government

The polygon data layers from the Working for Water programme were unioned in ArcGIS 10.7 (ESRI, 1999-2018) and the topology was checked to ensure no duplicate polygons existed. The layer was then unioned with the 2022 predicted wetland EFG extent, and the various attributes were combined to report for the extent within wetlands cleared in km², and as a percentage (%) relative to the full extent of the interventions, and the full extent of the wetland EFGs. The results showed that 140 km² of interventions was done for the MCP, of which 12.2% overlapped with wetlands (Table 6.5). Of the wetland EFGs, most of the interventions occurred in Seasonal marshes, whereas <2% were in the other wetland EFGs. However, to measure the interventions against the type of pressure – invasive species – further work would be required to determine the extent of invasive plant species, both woody and herbaceous, for the whole MCP. As discussed in Chapter 2 of this report, it may be extremely challenging to get a thorough assessment of the extent of invasion at the landscape level, although several remote sensing and infield botany studies could support an estimate of the extent of degradation resulting from invasive plant species, and whether the current interventions would be closer to the 30% extent target of degraded ecosystems. The total extent and subtypes of invasion (woody, herbaceous or aquatic), can also improve the reporting of intervention. To our knowledge, water hyacinth was present in small sections of rivers of the MCP, such as the Nseleni River, and intervention is under way at this location. Therefore, the target of 30% would likely be exceeded, if reported per subtype. It may be that expert knowledge would be required for such refinement and reporting by 2030, whereas several projects can be activated to improve on reporting per intervention subtype and wetland EFGs by 2050.

Table 6.5. Extent (km²) and percentage (%) of area cleared from invasive woody species by the Working for Water programme between 1997 to 2023

Wetland EFG	Extent (km²) of interventions in wetlands			Total extent (km²) of intervention (wetland and non-wetlands)	% of extent of interventions in wetlands relative to full intervention extent	% of total MCP wetland extent
	Invasive Alien Plant (IAP) Clearing	2019	2020			
Coastal saltmarsh	0.0	0.0	0.0	3.3	0.0	0.3
Forested wetland	0.0	0.0	0.0	17.0	0.1	1.5
Intertidal forest and shrublands	0.0	0.0	0.0	0.6	0.0	0.1
Lacustrine	0.0	0.0	0.0	11.0	0.0	1.0
Large macrophytes	0.0	0.0	0.0	20.2	0.1	1.8
Permanent marshland	0.0	0.0	0.0	14.2	0.0	1.2
Seasonal marshland	0.1	0.1	0.0	73.9	0.2	6.4
Total	**0.2**	**0.1**	**0.0**	**140.4**	**0.1**	**12.2**

Changes in the extent of wetland EFGs appears to be a feasible way in which monitoring and reporting to target 2 can be done by DFFE for the MCP, and likely also the rest of the country. Ten of the 23 component indicators listed in section 6.2.1, that can be used for reporting to target 2 of the GBF, all list changes in extent. Others consider fragmentation and continuous cover, or ecological condition (integrity) indicators, which at this stage would be more challenging to undertake consistently for the MCP. A major challenge is the estimation of the extent of degradation of wetlands. While a large extent of the MCP's wetlands appeared transformed and degraded, some pristine patches were also observed, and therefore a project to assess degradation across the types, with randomly selected points geographically distributed and representative of the extent of each type, should be undertaken.

6.2.5 GBF target 3 of Maputaland's wetland Ecosystem Functional Groups (EFGs)

The MCP constitutes a collection of national, provincial and private nature reserves, of which an overlap with the World Heritage and Ramsar Site boundaries exist. The overlap of the protected area boundaries with the 2022 wetland extent of the MCP showed that 77% are located in some type of protected area (Table 6.6). All the individual wetland EFGs exceed the 30% extent of the GBF target. Yet despite these extensive protection levels, they all show rates of decline. Hotspots of transformations were also identified within the protected areas (Chapter 5 outputs). The ARDs of these wetland EFGs suggest that flow management on the MCP are insufficient to sustain these wetlands and that current management practices and interventions are inadequate.

On the other hand, the extent of protected areas of 1990 for the historical extent of these wetland EFGs, is unknown and could not be assessed. An assessment of the percentage extent of the wetland EFGs can be done using the 1990 prediction and the most recent park boundaries.

Table 6.6. Relative areas of wetland Ecosystem Functional Groups (EFGs) within protected area types on the Maputaland Coastal Plain; with (A) the extent in km² and (b) the percentage of total extent of each EFG

(A) Wetland EFG	Forest Nature Reserve	Marine Protected Area	Nature Reserve	World Heritage Site	Outside Protected Area	Total
Coastal saltmarsh	0.0	-	8.0	-	3.3	11.3
Forested wetland	0.9	-	41.9	-	27.3	70.1
Intertidal forest and shrublands	0.0	-	6.9	-	7.1	14.0
Lacustrine	-	-	440.0	-	44.5	484.4
Large macrophytes	1.3	-	191.4	-	86.0	278.7
Permanent marshland	0.0	-	38.4	-	12.8	51.1
Seasonal marshland	0.0	-	174.1	0.1	89.8	264.1
Wetlands total	**2.3**	**-**	**900.6**	**0.1**	**270.7**	**1 173.7**
(B) Wetland EFG	**Forest Nature Reserve**	**Marine Protected Area**	**Nature Reserve**	**World Heritage Site**	**Outside PA**	**Total**
Coastal saltmarsh	0.0	0.0	70.7	0.0	29.3	100.0
Forested wetland	1.3	0.0	59.7	0.0	38.9	100.0
Intertidal forest and shrublands	0.0	0.0	49.5	0.0	50.5	100.0
Lacustrine	0.0	0.0	90.8	0.0	9.2	100.0
Large macrophytes	0.5	0.0	68.7	0.0	30.8	100.0
Permanent marshland	0.0	0.0	75.0	0.0	25.0	100.0
Seasonal marshland	0.0	0.0	65.9	0.0	34.0	100.0
Wetlands total	**0.2**	**0.0**	**76.7**	**0.0**	**23.1**	**100.0**

6.3 KNOWLEDGE CO-PRODUCTION FOR THE MONITORING AND REPORTING OF WETLANDS IN MAPUTALAND

The results of changes in the extent and type of wetland EFGs of the MCP, as described in Chapter 5, and the implications for GBF reporting by 2030 were workshopped with a number of stakeholders between 20 and 21 September 2021. It was expected that through knowledge co-production, a more comprehensive overview of information related to target 1-3 reporting can be generated through a conversation café around maps of the MCP. This section documents the results of this workshop and discussion points raised towards the required monitoring of wetland EFGs of the MCP.

6.3.1 Stakeholder engagement workshop and information generated

A stakeholder workshop was held between 20-21 September 2023 on the MCP, to discuss the reporting of outputs from this project towards the GBF, primarily Goal A’s targets 1 (halt loss of ecosystems and facilitate sustainable development), 2 (have 30% of the extent of degraded ecosystems under restoration) and 3 (30% of the extent of types should be protected by 2030). The team worked closely with Ms Esmeralda Ramburran, DFFE Deputy Director: Operational Support and Planning, provided input to the workshop planning, agenda and invitee list. The outputs of the conversation café discussions of the two days are briefly summarised in the following subsections.

Upon arrival, all participants were briefed about the purpose and potential diverse outputs of the workshop and given a two-page document relating to the use of the information as required by the Public Access to Information Act (PAIA). In addition to these two pages, four pages related to the Ethical Clearance of the CSIR were also attached to the hardcopy Agenda shared with participants. Participants were requested to consider these documentations and then sign the relevant columns in the attendance register. Despite the positive response of 30 people to the invite, several national government officials were not able to attend, owing to a cost containment measure announced by the government the week before the workshop. These names are listed on the attendance register, but no signatures next to them.

In the conversation café roundtables, five tables were set up to facilitate the conversation cafe:

- **Peatlands** by Dr Heidi van Deventer on behalf of Mr Jason le Roux, Dr Althea Grundling and Dr Piet-Louis Grundling's work;
- **SAEON's** table for work the done by SAEON, including Ms Susan Janse van Rensburg and Mr Paul Gordijn;
- **Northern Maputaland** was facilitated by Ms Lukho Goso. Lukho was an MSc student at the University of Pretoria (UP) funded for her studies by the WRC and WaterRDI;
- **Central Maputaland** was facilitated by Mr Philani Apleni. Philani was the MSc student on this WRC project who produced the remote sensing change detection results; and
- **Southern Maputaland** was facilitated by Ms Nkosingizwile Ndlovu. Nkosingizwile was a South African National Space Agency (SANSA) funded student working on her MSc on the remote sensing of changes in the hydrological regime of lacustrine wetlands of Maputaland, and also associated with this WRC project.

Each table had at least one A0-sized poster, or a set of A0-sized posters, or A3-sized printouts of the results of the various projects and/or zoomed in historical aerial photographs where available. Participants were encouraged to draw and make notes on the posters, as part of a participatory spatial mapping exercise of issues. Each one of the facilitators documents a brief summary of the two conversation café sessions held at the workshop, which are presented in the following subsections.

The following key observations were made from the engagements:

- **Peatlands:** Very few people knew what peatlands were, or were aware of the degradation of the peatlands and the severity of the overall trend since the previous decadal drought of 1992-1995, compared to after the 2015-6 one;
- **Degradation and transformation impacting wetlands:** Multiple stakeholders agreed that the water table is decreasing, especially in the southern and central parts of the MCP. An increase in the extent of timber plantations has been noted by some and linked to the declining water tables. Declining water tables around Lake Sibaya has resulted in a decrease in vegetation and aquatic animals such as hippopotami and crocodiles, while sand mining has increased. Settlement development and road construction has affected the natural flow of wetlands negatively. Wetlands are considered degraded inside and outside the protected area boundaries. Invasive plant species were noted in the Nseleni River (water hyacinth); and
- **Monitoring of wetlands:** are not done consistent by various conservation agencies. A few researchers in the Lake Sibayi have installed equipment to collect data for monitoring of aphysical variables, but not changes in ecosystem types for reporting consistent reporting across wetlands of the MCP, especially palustrine wetlands. Collaboration between a diverse number of organisations is considered crucial to effect diverse aspects of monitoring degradation and changes in wetlands of the MCP.

6.3.2 Workshop engagement at the National Wetlands Indaba 2023

A 1.5 hour workshop was held at the National Wetlands Indaba 2023 on 25 October 2023, where stakeholders could interact with the data generated for the MCP. Sixteen people attended the workshop and the following feedback has been summarised:

- The extent of the MCP is too wide in the north, and the part west of Tembe is likely not part of the aquifer dependent ecosystem. The soil data should be considered to reduce the boundary to a smaller management unit extent (communication with Prof. Wynand Malherbe, University of the North West Province).
- Peatlands are not as extensive as shown on the Grundling *et al.* (2021) related banner, and the extent below the water body of Lake Sibaya and the iMfolozi should be recorded and cut back (communication with Prof. Chris Curtis, University of Johannesburg).
- The depths of some of the systems were indicated on the banners by Prof. Chris Curtis to indicate limnetic vs littoral systems on the MCP.
- The Muze system has too many polygons labelled as “Muze” and should be corrected in the next National Wetland Map.
- A discussion was held about the term “lake” as used by the IUCN in the global ecosystem typology to indicate it as a realm, compared to the hydrogeomorphic unit classification used in the national wetland map.
- Several people questioned the extent of Lake Sibaya as only a depression, and suggested that a boundary can be used to distinguish the edges of the valley bottom and seep HGM units on the edges of the system.
- Species assessments were done to the west of the narrows, but the data has not yet been mobilised to the Freshwater Biodiversity Information System (FBIS).
- Ms Joelene Govender indicated on the maps where she found microplastics at relevant estuaries and positions (Govender *et al*., 2020).
- A few positions where alien clearing was done as part of restoration projects done by the Wildlife Trust outside Tembe Nature Reserve on private land by Darren. Mr Andrew Whitley should be asked to acquire more of this information for reporting to the GBF.

Information relevant to the national wetland and peatlands maps has been shared with SANBI and the ARC for future updates.

6.3.3 Knowledge co-production with DFFE and DWS

Two stakeholder engagement meetings were undertaken on 14 and 15 November 2023 in collaboration with Ms Esmeralda Ramburran from the Working for Wetlands Programme. In these two workshops, we gave overall presentations of the WRC project and the GBF, while the results of the remote sensing classification and social engagements were also done.

The first was a virtual meeting on 14 November 2023 with attendance from SAPPI, wetlands consultants undertaking the RQO for the Usuthu to Mhlathuze catchments, GroundTruth and a number of DFFE officials. Ms Marlanie Moodley from DFFE was also able to show a live demonstration of the District Development Model, that is under development. Key observations were from Mr James McKenzie, who noted that the decline in the extent of ecosystems (Figure 5.6) has correspondence with the declining water levels observed in Lake Sibaya. Other stakeholders mentioned the value of updating the extents of wetlands from specialist reports submitted to the DFFE Environmental Impact Assessment and DWS Water Use License Applications.

The in-person stakeholder engagement meeting on 15 November 2023 were attended by DFFE, DWS and ARC staff. The following key agreements and suggestions were listed at this meeting:

- The MCP has reached a tipping point with peatlands and wetland ecosystem types showing increasing negative impacts and declines in ecological condition and extent (Grundling et al., 2021; this study);
- Hydrological modelling of water use and trends in groundwater levels, should be fully assessed by DWS and the license allocations revisited;
- Areas identified as hotspots in this report that are located within and adjacent to iSimangaliso Wetland Park Authority and EKZNW, should be extracted and shared with the DFFE officials, to evaluate these as priority areas for restoration in the next Working for Wetlands cycle;
- Alternative livelihoods, as investigated by Ms Sue van Rensburg from SAEON in the collaborative WRC project, would also be important to inform on alternative options for local communities; and
- Once Mr Philani Apleni's journal paper is published, it needs to be shared with DFFE to submit to the Ramsar committee.

6.4 STRATEGIC FRAMEWORK FOR MONITORING CHANGES IN WETLAND ECOSYSTEM FUNCTIONAL GROUPS

6.4.1 Who should monitor the MCP's wetland EFGs?

Monitoring and reporting require a concerted effort by all stakeholders on the MCP. While many organisations are actively involved in monitoring and reporting, a collation of the available data for reporting is not accessible. Section 6.2 illustrates the challenges of the government to report spatially on the extent of interventions, whereas section 6.3 indicated that other public and private interventions are also under way, but not concertedly reported to a single database.

A diversity of information is collected by various organisations on the MCP, which could very well be complementary to reporting to the GBF's Goal A indicators on changes in ecosystems. These include physical variables of ecosystems, assessment of their health and remote sensing reporting. While remote sensing makes a clear contribution in the monitoring of changes at a landscape scale for this ADE, finer-scale validation and assessment are critical to understand the functioning, adaptability, resilience or ecological degradation of wetlands inside and outside protected areas.

In a monitoring framework, DFFE, SANBI and DWS have clear roles in reporting to the GBF and SDGs and the channels for reporting changes, interventions and protection levels through these organisations are in place. The key challenge is ensuring that all the information collected is mobilised, accessible, and comply to the FAIR (Findability, Accessibility, Interoperability, and Reuse) principles (CBD, 2022c). The design of a central repository to collect and integrate the ecosystem information needs to be facilitated.

Even though the majority of the remaining extent of wetland EFGs were within protected areas, this ADE landscape is highly connected via the groundwater compartments, which implies that management of flow would be extremely important, to manage and limit access to wetland areas. It was evident that during the drier years and as a result of the illegal branching of the St Lucia estuary mouth by commercial farmers, the iMfolozi/uMsunduze floodplain were accessible by people who then cut down and transformed the forested wetlands to cultivation inside the protected areas (Van Deventer *et al*., 2021a). This means that reporting should not be limited to the remaining extent of 2022, of which 77% lies within the protected areas. Ensuring well-functioning wetlands outside protected areas are critical to sustain their ecosystem services too.

Therefore, restoration efforts outside protected areas will be paramount. This means that the DFFE 'Working for' programmes need to reach out to private landowners to train people on the identification and wise use of wetlands outside protected areas.

6.4.2 Critical and complementary tools for monitoring of wetland EFGs on the MCP

In this report, we have demonstrated the capabilities of freely available, space-borne remote sensing data from the Landsat and Sentinel-1 and -2 sensors for monitoring seven wetland EFGs (six being palustrine) on the MCP. Remote sensing can provide a consistent means of assessing changes in extent and ecological condition over time, especially considering the consistent temporal resolutions of the Landsat and Sentinel series of sensors. The coarse spatial resolution of 30 m and 10 m, respectively, however, limits the details of the extent and condition of finer scale information. For example, sensors can potentially map broad forest types and changes in their extent, structure and nutrients, but not map individual tree species, an accurate representation of canopy height or above-ground biomass (AGB) or changes in species composition and structure underneath the canopy. Such detailed assessments would require infield validation. While drones would be able to support finer-scale assessments, they are limited in geographic extent to cover and monitor the whole of the MCP at regular temporal intervals. The benefits of using drones as part of the suite of tools for monitoring, is that they can be flown in highly inaccessible or dangerous wetland areas, and support the quantification of changes in the extent, and to some degree the ecological condition, of different wetland types. To facilitate monitoring of vegetation composition and structure in palustrine wetland EFGs, costly hyperspectral and Light Detection and Radar (LiDAR) sensors on drone platforms would be required for individual projects along selected case study areas.

Infield validation of changes in species composition and structure are therefore critical in the NWMP for proper *in situ* assessment of changes. These should include botanical surveys (e.g. Grobler *et al.,* 2009), where changes in the latitudinal variation of species composition can be assessed, as well as changes in vegetation composition and structure. Most challengingly, these should also be understood within the greater landscape's impacts resulting from changes in precipitation, increase of temperature associated with climate change, changes in fire regimes, water use/abstraction, and transformation in land cover types. Mr Gareth Robertson of the Meycol Private Nature Reserve (personal communication), on the southern boundary of the MCP, mentioned that the forested wetland on their property increased in extent as a result of the suppression of the fire interval. This is echoed in the work of Luvuno *et al.* (2016), who showed that *Macaranga capensis* started to dominate forested wetland canopies subsequent to the suppression of the fire regime near a timber plantation. The study team also observed great variation latitudinally in the composition of the forested wetlands, with some in the south as a result of deliberate planting of the Raffia palm (*R. australis*), that did not previously occur as far south. This was also confirmed by Mr Retief Grobler in personal communication at the onset of the project in 2021. Other changes in the landscape could also be supported through the newly developed miniWethealth citizen scientist tool (presented by Mrs Charlene Russell on 21 September 2023 in the afternoon at Mtunzini, http://www.groundtruth.co.za/; developed by Kotze [2016]; Ground Truth, 2023), that could compliment expert-driven infield assessments.

Many methods and tools are otherwise used in monitoring and reporting related to wetland ecosystems on the MCP and elsewhere in South Africa. This section would not cover a full review of these, nor how they would be able to be used for reporting to the Goal A targets of the GBF. Our focus was on the capabilities of remote sensing to contribute to the quantification of changes in the wetland biodiversity types of the MCP for reporting. The use of the Landsat and Sentinel-1 and -2 images proved valuable for mapping the different wetland EFGs as biodiversity types, especially those for the palustrine wetland biome, for the MCP. In addition, the types and rates of change could also be quantified and used in the reporting of the targets of Goal A of the GBF. Outputs to target 1 of the GBF, that requires the quantification of changes in the extent of these wetland EFGs, can also be summarised into changes to the two wetland biomes (lacustrine and palustrine), for reporting to SDG 6.6.1a by DWS through Statistics South Africa, to UNEP.

6.4.3 Temporal interval for monitoring

The CBD (2022c) recommends a five-year interval for reporting overall for Goal A. Temporal monitoring intervals may very likely not be set, given that continuous climate change and anthropogenic pressures may result in unpredictable degradation in the landscape. The remote sensing of woody invasive tree species and changes in the extent of the wetland EFGs of the MCP would be ideal for 5-year interval monitoring at the landscape level. However, refinement to finer spatial resolution remote sensing data should be investigated to understand the underrepresentation of extent and fragmentation in these systems, with priority given to areas that have been identified as recent hotspots of change.

Temporal monitoring intervals should be consistent with environmental variables at monthly or annual intervals, as determined by the parameters, to inform on the impacts of climate and anthropogenic pressures on the landscape.

Citizen scientists' contribution to monitoring would always be irregular and cannot be preset at a given temporal interval, unless formalized as part of national monitoring.

6.5 RECOMMENDATIONS FOR CONSIDERING IN REPORTING TO TARGETS 1-3 OF GOAL A TO THE GLOBAL BIODIVERSITY FRAMEWORK BY 2030

Overall, the most important recommendation is that the mobilisation, centralisation and integration of available information for target reporting on wetland ecosystems extent, ecological condition, connectivity and changes in these, should be implemented to facilitate reporting to Goal A of the GBF.

CHAPTER 7: SYNTHESIS AND CONCLUSION

This study assessed the capabilities of freely available Landsat and Sentinel-1 (radar) and -2 (optical) sensors to track changes in the extent of seven wetland Ecosystem Functional Groups (EFGs), for biodiversity reporting and monitoring. Six of these are palustrine wetland EFGs, that have not yet been reported for the full extent of the MCP, nor included in the SDG indicator 6.6.1a reporting from South Africa. The results showed that all seven wetland EFGs were highly separable for biodiversity mapping in each of the seven years assessed. In addition, the types and rates of change showed that nearly half of the extent of these seven wetland EFGs have changed to either another wetland EFG (39%) or anthropogenic transformation classes (8%). To our knowledge, this is the first study in South Africa that assessed changes of biodiversity types over seven years. The outputs prove the value of remote sensing for reporting to both the Global Biodiversity Framework (GBF) targets 1-3 and the Sustainable Development Goals (SDG) indicator 6.6.1a. Furthermore, the study contributed to several learnings on how South Africa can potentially improve the monitoring of changes in wetland EFGs at a landscape level, and would potentially contribute to finer-scale typing of wetlands for reporting in the National Biodiversity Assessments (NBAs) at country-wide scale.

In summary, we provide an overview of the contribution to three of the Goal A targets of the GBF:

- GBF Target 1: The report's outputs are the first comprehensive landscape assessment of changes in the extent of wetland EFGs for the MCP. To date, most changes were reported only for smaller regions of the MCP, not related to habitat extent, and previous studies did not assess changes across 22 years. Furthermore, a more comprehensive view is offered on the absolute rate of decline of these six EFGs, one of the criteria that is used by the International Union for Conservation of Nature (IUCN) in the red listing of ecosystems (Bland *et al*., 2017). Previous work has only assessed the rate of decline for the forested wetlands of the MCP (Van Deventer *et al*., 2021a), but not all wetland EFGs.
- GBF Target 2: Currently, there is no understanding of the full extent of each wetland EFG that is considered degraded, which is important for calculating the 30% of the degraded extent of wetlands that should be under restoration by 2030. Currently available data from DFFE (DFFE, 2023a-c) estimates that at least 16% of the extent of all wetlands on the MCP had some level of intervention to date. Working for Water contributed 12% of which 11% were located in protected areas. Working for Wetlands contributed 4% of which half were located in protected areas. These historical efforts do not overlap with the hotspots of transformation observed in this report, as well as those of Van Deventer *et al*. (2021a), where transformation to anthropogenic cultivated wetlands and structures occurred inside and outside the protected area boundaries. This project's outputs can contribute to informing new intervention hotspots to the DFFE.
- GBF Target 3: A total of 77% of the extent of the wetlands are located within the protected area boundaries. This means that for the MCP, the 30% extent target of protected areas for the GBF's target 3 is met. However, no consideration of the ecological condition is required for GBF reporting. The concern was raised that transformations to other land uses are also occurring inside the protected areas, and that these wetland EFGs may already be degraded too, not functioning optimally, considering that peatlands such as Vasi Pan, even outside the protected areas, had been burning during an extremely wet year. Possible structural changes and species composition resulting from drawdown of the water table. The presence of alien invasive species is not always easily detectable in size and extent, and their impact in this groundwater Strategic Water Source area would be difficult to map in two-dimensional reporting. Contaminants of environmental concern that are not regularly tested, their impacts understood on wetlands, nor the standards listed for them. A thorough assessment of the ecological condition and changes in structure would

be key to understanding the extent of degradation, to inform the interventions of target 2, both inside and outside the protected area boundaries.

Consideration of the monitoring framework of wetland EFGs on the MCP:

- Overall, the most important recommendation is that the mobilisation, centralisation and integration of available information for target reporting on the extent of different wetland ecosystems, ecological condition, connectivity and changes in these should be implemented to facilitate reporting to Goal A of the GBF. Multiple organisations are contributing to the collection of physical variables and ecosystem extent that can be used for both the NBAs and GBF reporting. It is recommended that DFFE coordinate and facilitate the collection and integration of ecosystem information for reporting.
- The GBF's monitoring framework (CBD, 2022c) is suitable to be adopted by South Africa for biodiversity reporting, and the indices should be explored for reporting at various scales over time.
- Remote sensing is a critical tool to consider in the monitoring of the MCP, at drone, airborne and space-borne levels. Because of the interconnectivity of wetlands through the sandy aquifer-dependent groundwater compartments, it is critical to monitor the whole landscape to assess impacts over time. The use of Landsat and the two Sentinel sensors provided a good overview of changes between 1990 and 2022, however, further refinement in the spatial resolution of the sensors would be critical for tracking changes as a result of fragmentation and ecological condition. Ideally, changes should be mapped at a consistent airborne scale every 3-5 years, whereas drone images could contribute detailed information for unique or hotspot areas. The Department of Science and Innovation, of the South African National Space Agency (SANSA) is working towards the launching of SumbandilaSat 2, with a finer spatial resolution and eight bands that would be ideal for monitoring of wetland EFGs on the MCP. Ad hoc, small extent drone analysis would complement the overarching landscape-scale monitoring.
- Monitoring changes in the extent of wetland EFGs with remote sensing at a landscape scale, provide valuable information on the response and resilience of the landscape to the impacts of anthropogenic and climate change impacts. The relationship between the trends in temperature and rainfall patterns resulting from climate change, should be further investigated. In addition, the impact of transformation to other land uses, particularly the extent of timber plantations, should be assessed to improve environmental flow determination and resource classification for a potentially drying ADE.

Summary observations of the social study on wetland EFGs:

- From our initial social study work on the MCP, it was clear that multiple users benefit from wetlands in various ways, from direct, infield food production to a level of detached tourism where it forms the landscape setting that is attractive.
- Concerns around changes in the extent of wetlands varied: some community members, especially elders, were quite concerned, noting a drying trend, degradation and loss of wetlands. Others were not concerned, confident that four generations survived by cultivating wetlands, and the next three generations could continue with this practice. A group of cultivated wetland farmers physically showed the decline of the boundary of saturated soils and how this reduced in extent over time.
- Conflicts were observed from the interactions between different land users, but also within communities. Some spoke about forced removals by their leaders, saying that the leaders benefitted from selling the land for conservation, while they were merely chased away overnight. A few individuals from another location, mentioned that their leaders still benefit hugely from conservation, while they struggle to find land to provide for themselves.

REFERENCES

ABD ELBASIT MAM, ABUTALEB K, GRUNDLING AT and CHAUKE M (2020) *Multi-platform remote-sensing tools for peat fire detection and monitoring,* Water Research Commission (WRC) Report No. 2836/1/20, WRC, Pretoria, South Africa. http://www.wrc.org.za/wp-content/uploads/mdocs/2836_Final_Report.pdf

ABRAMS M, CRIPPEN R and FUJISADA H (2020) *ASTER global digital elevation model (GDEM) and ASTER global water body dataset (ASTWBD)*. Remote Sensing **12 (7)** 1156.

ADAM E and MUTANGA O (2009) Spectral discrimination of papyrus vegetation (*Cyperus papyrus L*.) in swamp wetlands using field spectrometry. ISPRS Journal of Photogrammetry and Remote Sensing **64 (6)** 612-620.

ADAM E, MUTANGA O, ABDEL-RAHMAN EM and ISMAIL R (2014) Estimating standing biomass in papyrus (*Cyperus papyrus L*.) swamp: exploratory of *in situ* hyperspectral indices and random forest regression. International Journal of Remote Sensing **35 (2)** 693-714.

ADAM E, MUTANGA O and RUGEGE D (2010) Multispectral and hyperspectral remote sensing for identification and mapping of wetland vegetation: a review. Wetlands, Ecology & Management **18** 281-296.

ADAM E, MUTANGA O, ABDEL-RAHMAN EM and ISMAIL R (2012) Discriminating the papyrus vegetation (*Cyperus papyrus L*.) and its co-existent species using random forest and hyperspectral data resampled to HYMAP. International Journal of Remote Sensing **33 (2)** 552-569.

ADAMS JB, FERNANDES M and RIDDIN T (2019) *Chapter 5: Estuarine Habitat Extent and Trend,* VAN NIEKERK L, ADAMS JB, LAMBERTH SJ, MACKAY F, TALJAARD S, TURPIE JK, WEERTS S and RAIMONDO DC (eds.) (2019) South African National Biodiversity Assessment 2018: Technical Report, Volume 3: Estuarine Realm, Council for Scientific and Industrial Research (CSIR) report number CSIR/SPLA/EM/EXP/2019/0062/A, Pp. 52-75, Report Number: SANBI/NAT/NBA2018/2019/Vol3/A, South African National Biodiversity Institute (SANBI), Pretoria, South Africa.

ADAMS JB and RAJKARAN (2020) Changes in the mangroves at their southernmost African distribution limit. Estuarine, Coastal and Shelf Science **247** 106862. https://doi.org/10.1016/j.ecss.2020.106862.

ADAMS JB, VAN DEVENTER H, WHITFIELD E, MACHITE A, RIDDIN T, VAN NIEKERK L, APLENI A, MADASA A (in press). *Prioritisation of blue carbon ecosystems for implementation of restoration measures*. GIZ and DFFE draft report.

ADAMS JB, VELDKORNET D and TABOT P (2016) Distribution of macrophyte species and habitats in South African estuaries. South African Journal of Botany **107** 5-11. https://doi.org/10.1016/j.sajb.2016.08.001.

ADKINS S and SHABBIR A (2014) Biology, ecology and management of the invasive parthenium weed (*Parthenium hysterophorus L*.). Pest Management Science **70 (7)** 1023-1029.

ARNDT J (2014) *Distribution and long-term historic impact of the small-scale subsistence farming on wetlands in the Maputaland, KwaZulu-Natal (South Africa).* MSc thesis, Technische Universitat Munchen, Berlin, Germany.

BAILEY AK and PITMAN WV (2016) *Water Resources of South Africa, 2012 Study (WR2012)*. *Volume 3: Book of Maps*. Water Research Commission (WRC) Report No. TT 685/16, WRC, Pretoria, South Africa.

BANDEIRA S, SENKORO A, BARBOSA F, MUALASSACE D and FIGUEIREDO E (2014) *The terrestrial environment adjacent to Maputo Bay.* In: BANDEIRA S and PAULA J (eds.) The Maputo Bay Ecosystem, West Indian Ocean Marine Science Association (WIOMSA), Zanzibar Town, 239-274, 427 pp.

BATE G, KELBE BE and TAYLOR R (2016) *Mgobezeleni: The linkages between hydrological and ecological drivers.* Water Research Commission (WRC) Report No. 2259/1/16, WRC, Pretoria, South Africa.

BATE GC, MKHWANAZI M and SIMONIS J (2020) Blackwater in South African estuaries with emphasis on the Mgobezeleni Estuary in northern KwaZulu-Natal. Transactions of the Royal Society of South Africa **73 (2)** 133-142. https://doi.org/10.1080/0035919X.2017.1393471.

BEGG GW (1988) *The wetlands of Natal (Part 2): The distribution, extent and status of wetlands in the Mfolozi catchment*. Natal Town and Regional Planning Commission Report 71, Pietermaritzburg, South Africa.

BERKES F (1993) Traditional Ecological Knowledge in perspective. In *Traditional Ecological Knowledge: Concepts and cases.* INGLIS JT (Ed.). International Program on Traditional Ecological Knowledge and International Development Research Centre, Ottawa, Canada.

BERLINER D (2005) *Systematic conservation planning for the forest biome of South Africa.* Department of Water Affairs and Forestry, Pretoria, South Africa.

BERLINER DD (2009) *Systematic Conservation Planning for South Africa*. Doctor of Philosophy, Department of Botany, University of Cape Town, Cape Town, South Africa.

BEYER F, JURASINSKI F, COUWENBERG J and GRENZDÖRFFER G (2019) Multisensor data to derive peatland vegetation communities using a fixed-wing unmanned aerial vehicle. International Journal of Remote Sensing **40 (24)** 9103-9125.

BLACKMORE A, MULQUEENY C and MARAIS B (1996) Towards developing a model for the integration of afforestation and wetland conservation within the Zululand Coastal Plain. In: *Natal Board Annual Research Symposium: Programme & Abstracts* **2 82-82**.

BLAND LM, KEITH DA, MILLER RM, MURRAY NJ and RODRIGUEZ JP (EDS) (2017) *Guidelines for the application of IUCN Red List of Ecosystems Categories and Criteria. Version 1.1*.: International Union for Conservation of Nature (IUCN), Gland, Switzerland, 110 pp.

BOGAART P, CHAN JY, HORLINGS H, KEITH D, LARSON T, SAYRE R, SCHENAU S and SOULARD F (2019) Discussion paper 1.1: An ecosystem type classification for the SEEA EEA. Paper submitted to the SEEA EEA Technical Committee as input to the revision of the technical recommendations in support of the System on Environmental-Economic Accounting. Version 29 April 2019.

BREIMAN L (2001) Random Forests. Machine Learning **45** 5-32.

BROSIUS JP (1999) Analyses and Interventions: Anthropological engagements with environmentalism. Current Anthropology **40 (3)** 277-309.

BRUTON MN (1980) An outline of the ecology of the Mgobezeleni Lake system at Sodwana, with emphasis on the mangrove community. In: *Studies on the Ecology of Maputaland*. BRUTON MN and COOPER KH (Eds.) Natal Branch of the Wildlife Society of Southern Africa; 1st Edition, Pietermaritzburg, South Africa, 408-426.

BRUTON MN and COOPER KH (Eds) (1980) *Studies on the ecology of Maputaland.* Natal Branch of the Wildlife Society of Southern Africa; 1st Edition, Pietermaritzburg, South Africa, 560 pp.

BUNTING P, ROSENQVIST A, HILARIDES L, LUCAS RM, THOMAS N, TADONO T, WORTHINGTON TA, SPALDING M, MURRAY NJ, REBELO LM (2022) Global Mangrove Extent Change 1996-2020: Global Mangrove Watch Version 3.0. Remote Sensing **14** 3657. https://doi.org/10.3390/rs14153657.

CAMPOS JC, SILLERO N and BRITO JC (2012) Normalized difference water indexes have dissimilar performances in detecting seasonal and permanent water in the Sahara-Sahel transition zone. Journal of Hydrology **464** 438-446.

CHETTY S, MUTANGA O and LOTTERING R (2021) Detecting and mapping invasive *Parthenium hysterophorus L*. along the northern coastal belt of KwaZulu-Natal, South Africa using image texture. Scientific African **13** p.e00966.

CHO MA, MALAHLELA O and RAMOELO A (2015) Assessing the utility WorldView-2 imagery for tree species mapping in South African subtropical humid forest and the conservation implications: Dukuduku forest patch as case study. International Journal of Applied Earth Observation and Geoinformation **38** 349-357.

CHO MA, RAMOELO A, DEBBA P, MUTANGA O, MATHIEU R, VAN DEVENTER H and NDLOVU N (2013) Assessing the effects of subtropical forest fragmentation on leaf nitrogen distribution using remote sensing data. Landscape Ecology **28 (8)** 1479-1491.

CLULOW AD, EVERSON CS, PRICE JS, JEWITT GPW and SCOTT-SHAW BC (2013) Water-use dynamics of a peat swamp forest and a dune forest in Maputaland, South Africa. Hydrology and Earth System Sciences **17** 2053-2067.

COLLINS NB (2018) *Chapter 5: Modelling of probable wetland extent.* FS DESTEA internal report. In: South African National Biodiversity Assessment 2018: Technical Report. Volume 2a: South African Inventory of Inland Aquatic Ecosystems (SAIIAE), Version 3, final released on 3 October 2019. VAN DEVENTER *et al*. (Eds.) Council for Scientific and Industrial Research (CSIR) and South African National Biodiversity Institute (SANBI): Pretoria, South Africa. Report Number: CSIR report number CSIR/NRE/ECOS/IR/2018/0001/A; SANBI report number http://hdl.handle.net/20.500.12143/5847.

CONRAD, O, BECHTEL, B, BOCK, M, DIETRICH, H, FISCHER, E, GERLITZ, L, WEHBERG, J, WICHMANN, V. AND BÖHNER, J, (2015) System for automated geoscientific analyses (SAGA) v. 2.1. 4. Geoscientific Model Development **8 (7)** 1991-2007.

CONVENTION ON BIOLOGICAL DIVERSITY (CBD) (2011-2020) *Strategic Plan for Biodiversity 2011-2020 and the Aichi Targets.* Available online at: https://www.cbd.int/doc/strategic-plan/2011-2020/Aichi-Targets-EN.pdf. Last date accessed 11 March 2019.

CBD (2022a). *Briefing note on scientific and technical issues related to the global monitoring of biodiversity*. CBD/ID/OM/2022/1/INF/2. https://www.cbd.int/doc/c/0aef/09cb/0f9654d627222534df6c7a98/id-om-2022-01-inf-02-en.pdf.

CBD (2022b). *Decision adopted by the conference of the parties to the convention on biological diversity: 15/4 Kunming-Montreal Global Biodiversity Framework*. https://www.cbd.int/doc/decisions/cop-15/cop-15-dec-04-en.pdf.

CBD (2022c). *Proposed monitoring framework for the post-2020 global biodiversity framework*. https://www.cbd.int/doc/recommendations/sbstta-24/sbstta-24-rec-02-en.pdf. .

COWARDIN LM, CARTER V, GOLET FC and LAROE ET (1979) *Classification of wetlands and deepwater habitats of the United States*. United States Department of the Interior, Fish and Wildlife Service, Washington District Capital, United States of America, Jamestown, ND: Northern Prairie Wildlife Research Center Online. https://semspub.epa.gov/work/01/463450.pdf.

COWDEN C, KOTZE DC, ELLERY WN and SIEBEN EJJ (2014) Assessment of the long-term response to rehabilitation of two wetlands in KwaZulu-Natal, South Africa. African Journal of Aquatic Science **39 (3)** 237-247.

CROOK BJS and MANN BQ (2002) A critique of and recommendations for a subsistence fishery, Lake St Lucia, South Africa. Biodiversity and Conservation **11** 1223-1235.

CUNNINGHAM AB (1985) *The resource value of indigenous plants to rural people in a low agricultural potential area*. Doctor of Philosophy, University of Cape Town, South Africa.

DARBYSHIRE I, TIMBERLAKE J, OSBORNE J, ROKNI S, MATIMELE H, LANGA C, DATIZUG C, DE SOUSA C, ALVES T, MASSINGUE A, HADJ-HAMMOU J, DHANDA S, SHAH T and WURSTEN B (2019) The endemic plants of Mozambique: diversity and conservation status. PhytoKeys **136** 45-96. https://doi.org/10.3897/phytokeys.136.39020.

DAVRANCHE A, POULIN B and LEFEBVRE G (2013) Mapping flooding regimes in Camargue wetlands using seasonal multispectral data. Remote Sensing of Environment **138** 165-171.

DAYARAM A, HARRIS LR, GROBLER BA, VAN DER MERWE S, REBELO AG, POWRIE LW, VLOK JHJ, DESMET PG, QABAQABA M, HLAHANE KM and SKOWNO AL (2019) Vegetation Map of South Africa, Lesotho and Swaziland 2018: A description of changes since 2006, Bothalia **49 (1)** a2452. https://doi.org/10.4102/abc.v49i1.2452.

DEPARTMENT OF FORESTRY FISHERIES AND THE ENVIRONMENT (DFFE) (2023a) *Working for the Coast Programme*. 14 Loop Street, Cape Town, 8000, South Africa.

DESCOLA P and PALSSON G (1996) Introduction. In: *Nature and Society: Anthropological Perspectives. DESCOLA P and* PALSSON G (Eds.). Routledge, London, United Kingdom.

DEPARTMENT OF RURAL DEVELOPMENT AND LAND REFORM: NATIONAL GEOINFORMATION (DRDLR:NGI) (2012) *Colour orthophotography dated to 2012/3 available online via ArcGIS 10.6 Web Map Services.* DRDLR:NGI, Pretoria, South Africa.

DEPARTMENT OF WATER AND SANITATION (DWS) (2019) Water quality monitoring points and weirs at the time of the National Biodiversity Assessment of 2018). DWS, Pretoria, South Africa.

DESCOLA P and PALSSON G (1996) Introduction. In: *Nature and Society: Anthropological Perspectives*. DESCOLAR P and PALSSON G (Eds.) Routledge, London, United Kingdom.

DFFE (2023b) *Working for Water Programme*. 473 Steve Biko, Arcadia, Pretoria, 0083, South Africa.

DFFE (2023c) *Working for Wetlands Programme*. 473 Steve Biko, Arcadia, Pretoria, 0083, South Africa.

DLAMINI M, ADAM E, CHIRIMA G and HAMANDAWANA H (2021) A Remote Sensing-Based Approach to Investigate Changes in Land use and Land Cover in the Lower uMfolozi Floodplain System, South Africa. Transactions of the Royal Society of South Africa **76** 13-25.

DOUGHTY J (1979) The dangers of reducing the range of food choices in developing countries. Ecology of Food and Nutrition **8 (4)** 275-283.

DRUSCH M, DEL BELLO U, CARLIER S, COLIN O, FERNANDEZ V, GASCON F, HOERSCH B, ISOLA C, LABERINTI P, MARTIMORT P and MEYGRET A (2012) Sentinel-2: ESA's optical high-resolution mission for GMES operational services. Remote Sensing of Environment **120** 25-36.

DU B, MAO D, WANG Z, QIU Z, YAN H, FENG K and ZHANG Z. (2021) Mapping wetland plant communities using unmanned aerial vehicle hyperspectral imagery by comparing object/pixel-based classifications combining multiple machine-learning algorithms. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing **14** 8249-8258.

DWS (2020) *Sustainable Development Goal 6: 2020 Data Drive.* South African Response to the United Nations Environment Programme. Pretoria, South Africa. https://www.dws.gov.za/projects/sdg/Water%20related%20Indicator%20Reports.aspx.

DWS (2022) Classification of significant water resources and determination of resource quality objectives for water resources in the Usutu to Mhlathuze catchments. Project steering committee (PSC) meeting no. 2. Background Information Document (BID) of 4 November 2022.

DYSON LL and VAN HEERDEN J (2001) The heavy rainfall and floods over the northeastern interior of South Africa during February 2000. South African Journal of Science **97 (3)** 80-86.

ELLERY WN, GRENFELL SE, GRENFELL MC, HUMPHRIES MS, BARNES K, DAHLBERG A and KINDNESS A (2012) Peat formation in the context of the development of the Mkuze floodplain on the coastal plain of Maputaland, South Africa. Geomorphology **141-142** 11-20.

ELSHEHAWI, S, GABRIEL, M, PRETORIUS, L, BUKHOSINI, S, BUTLER, M, PLICHT, J, GRUNDLING, P and GROOTJANS AP (2019) Ecohydrology and causes of peat degradation at the Vasi peatland, South Africa. International Mire Conservation Group and International Peatland Society **24 (33)** 1-21.

ENVIRONMENTAL SYSTEMS RESEARCH INSTITUTE (ESRI) (1999-2018) *ArcGIS desktop 10.7*. Redlands, CA, ESRI, United States of America.

EUROPEAN UNION SCIENCE HUB (2021) *Earth Observation.* https://ec.europa.eu/jrc/en/research-topic/earth-observation. Accessed 25 October 2021.

EVERSON CS, SCOTT-SHAW BC, KELBE BE, STARKE A, PEARTON T, GELDENHUYS G, VATHER T and MAGUIRE M (2019) *Quantifying the water-use of dominant land uses in the Maputaland Coastal Plain.* Water Research Commission (WRC) Report TT/19, WRC, Pretoria, South Africa.

EZEMVELO KWAZULU-NATAL WILDLIFE (EKZNW) (2011) *KwaZulu-Natal Land Cover 2005 V3.1.* GIS Coverage [Clp_KZN_2005_LC_V3_1_grid_w31.zip], Biodiversity Conservation Planning Division, Ezemvelo KZN Wildlife, P. O. Box 13053, Cascades, Pietermaritzburg, 3202 South Africa.

EZEMVELO KWAZULU-NATAL WILDLIFE (EKZNW) (2013a) KwaZulu-Natal Land Cover 2008 V2 GIS Coverage [Clp_KZN_2008_LC_V2_grid_w31.zip], Biodiversity Research and Assessment, Ezemvelo KZN Wildlife, P. O. Box 13053, Cascades, Pietermaritzburg, 3202, South Africa.

EZEMVELO KWAZULU-NATAL WILDLIFE (EKZNW) (2013b) KwaZulu-Natal Land Cover 2011 V1 GIS Coverage [Clp_KZN_2011_V1_grid_w31.zip], Biodiversity Research and Assessment, Ezemvelo KZN Wildlife, P. O. Box 13053, Cascades, Pietermaritzburg, 3202, South Africa.

EZEMVELO KWAZULU-NATAL WILDLIFE (EKZNW) and Geoterra Image (GTI) Pty Ltd. (2018) KwaZulu-Natal Land-Cover 2017 V1 (Comparable) GIS Coverage [KZN_2017_Comparable_Landcover_V1_grid_w31.zip], Biodiversity Research and Assessment, Ezemvelo KZN Wildlife, P. O. Box 13053, Cascades, Pietermaritzburg, 3202, South Africa.

FARR TG, ROSEN PA, CARO E, CRIPPEN R, DUREN R, HENSLEY S, KOBRICK M, PALLER M, RODRIGUEZ E, ROTH L, SEAL D, SHAFFER S, SHIMADA J, UMLAND J, WERNER M, OSKIN M, BURBANK D and ALSDORF DE (2007) The Shuttle Radar Topography Mission. Reviews of Geophysics **45 (2)** RG2004.

FINLAYSON C, MILTON GR, PRENTICE RC and DAVIDSON N (2018) *The Wetland Book II: Distribution, Description and Conservation*. Springer, The Netherlands. https://doi.org/10.1007/978-94-007-4001-3.

FISHER J, MONTANARELLA L and SCHOLES R (2018) Chapter 1: Benefits to people from avoiding land degradation and restoring degraded land. In: *Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). The IPBES assessment report on land degradation and restoration.* MONTANARELLA L, SCHOLES R and BRAINICH A (Eds.) Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem services, Bonn, Germany.

FU J, YI X, WANG G, MO L, WU P and KAPULA KE (2022) Research on Ground Object Classification Method of High Resolution Remote-Sensing Images Based on Improved DeeplabV3+. Sensors **22 (19)** 7477.

FUNK C, PETERSON P, LANDSFELD M, PEDREROS D, VERDIN J, SHUKLA S, HUSAK G, ROWLAND J, HARRISON L, HOELL A and MICHAELSEN J (2015) The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes. Scientific Data **2** 150066. https://doi.org/10.1038/sdata.2015.66

GALATOWITSCH SM (2018) Natural and anthropogenic drivers of wetland change. In: *The wetland book II: Distribution, description, and conservation* (pp. 359-367). FINLAYSON C, MILTON GR, PRENTICE RC, DAVIDSON N (Eds.). Wildlife Resources, Kentville, Canada Nature Management Services. Springer Nature. The Netherlands. Pp. 359-367. https://doi.org/10.1007/978-94-007-4001-3_217

GANGAT R (2019) *Assessing whether Soil Moisture Content (SMC) can be estimated for wetlands in the grassland biome of South Africa using freely available space-borne sensors*. MSc thesis, Faculty of Science, University of the Witwatersrand (WITS), Johannesburg, South Africa.

GANGAT R, VAN DEVENTER H, NAIDOO L and ADAM E (2020) Estimating soil moisture using Sentinel-1 and Sentinel-2 sensors for dryland and palustrine wetland areas. South African Journal of Science **116 (7/8)** Art. #6535, 9 pages. https://doi.org/10.17159/sajs.2020/6535.

GAO B-C (1996) NDWI – A normalized difference water index for remote sensing of vegetation liquid water from space. Remote Sensing of Environment **58** 257-266.

GARDEN S (2008) *Wetland geomorphology and floodplain dynamics on the hydrologically variable Mfolozi River, KwaZulu-Natal, South Africa*. Ph.D. thesis. School of Environmental Science, Howard College Campus, Durban. University of KwaZulu-Natal: Durban, South Africa.

GARDNER RC and FINLAYSON C (2018) October. Global wetland outlook: state of the World's wetlands and their services to people. In: *Ramsar Convention Secretariat, 2018, Stetson University College of Law Research Paper No. 2020-5.* Available at SSRN: https://ssrn.com/abstract=3261606.

GEOTERRAIMAGE PTY LTD (GTI) (2015) *The 2013-2014 South African National Land-Cover Dataset*. 2013-14 South Africa Landcover report – Contents vs 05 Department of Environmental Affairs (DEA) open access. Data User Report and Metadata. GTI, Pretoria, South Africa. http://www.geoterraimage.com/downloads.php Accessed 17 September 2018.

GEOTERRAIMAGE PTY LTD (GTI) (2016) *South Africa Land Cover Water Feature Splits (1990-2013/14). Data Users Report and Meta Data (Version 2).* GTI, Pretoria, South Africa.

GITELSON A, AND MERZLYAK MN (1994) Spectral reflectance changes associated with autumn senescence of Aesculus hippocastanum L. and *Acer platanoides L*. leaves. Spectral features and relation to chlorophyll estimation. Journal of plant physiology ***143*** **(3)** 286-292.

GOLDSCHAGG P (2022) *Exploring the role of a teacher-initiated professional learning community to improve environmental and sustainability education of wetlands*. Presentation given at the National Wetlands Indaba 2022, 24-27 October 2022, Golden Gate National Park, South Africa.

GOOGLE LIMITED LIABILITY COMPANY (LLC) (2020) *Google Earth Pro version 7.3.3.7786*. Available from the server kh.google.com and online http://www.earth.google.com.

GORELICK N, HANCHER M, DIXON M, ILYUSHCHENKO S, THAU D and MOORE R (2017) Google Earth Engine: Planetary-scale geospatial analysis for everyone. Remote sensing of Environment **202** 18-27.

GOVENDER J, NAIDOO T, RAJKARAN A, CEBEKHULU S, BHUGELOO A and SERSHEN (2020) Towards characterising microplastic abundance, typology and retention in mangrove-dominated estuaries. Water **12 (10)** 2802. https://doi.org/10.3390/w12102802.

GREEN AN, GARLAND GG and UKEN (2006) Geomorphological and managerial implications of fish trapping in the Kosi bay estuary, KwaZulu-Natal, South Africa. African Journal of Marine Science **28 (3-4)** 617-624. https://www.tandfonline.com/doi/abs/10.2989/18142320609504211.

GROBLER LER (2009) *A phytosociological study of peat swamp forests in the Kosi Bay lake system, Maputaland, South Africa*. MSc thesis University of Pretoria, Pretoria, South Africa, 155 pp.

GROBLER R, MONING C, SLIVA J, BREDENKAMP G and GRUNDLING PL (2004) Subsistence farming and conservation constraints in coastal peat swamp forests of the Kosi Bay Lake system, Maputaland, South Africa. Géocarrefour **79 (4)** 317-324.

GROUND TRUTH (2023) Water Research Commission (WRC) project C2022-2023-00841: Remote citizen science learning support system and adapted toolbox for online community training. WRC, Pretoria, South Africa.

GROUP ON EARTH OBSERVATIONS (GEOBON) (2017) *Essential Biodiversity Variables: ENV classes and candidates*. http://geobon.org/essential-biodiversity-variables/ebv-classes-2/.

GRUNDLING AT (2014) *Remote sensing and biophysical monitoring of vegetation, terrain attributes and hydrology to map, characterise and classify wetlands of the Maputaland Coastal Plain, KwaZulu-Natal, South Africa*. PhD Thesis, University of Waterloo, Canada.

GRUNDLING P-L (2015) *Genesis and Hydrological Function of an African Mire: Understanding the Role of Peatlands in Providing Ecosystem Services in Semi-Arid Climates*. PhD thesis, University of Waterloo, Ontario, Canada. http://hdl.handle.net/10012/9037.

GRUNDLING PL, BAARTMAN L, MAZUS H and BLACKMORE A (2000) *Peat Resources of KwaZulu-Natal Wetlands: Southern Maputaland and the North and South Coast. Council for Geoscience (CGS) Report No. 2000-0132.* CGS, Pretoria, South Africa, 30 pp.

GRUNDLING P-L and GRUNDLING A (2019) Appendix C: Peat Pressures. South African National Biodiversity Assessment 2018: Technical Report. Volume 2b: Inland Aquatic Realm. VAN DEVENTER *et al.* (Eds.). Council for Scientific and Industrial Research (CSIR) and South African National Biodiversity Institute (SANBI), Pretoria, South Africa. CSIR report number CSIR/NRE/ECOS/IR/2019/0004/A and SANBI handle report no. http://hdl.handle.net/20.500.12143/6230.

GRUNDLING P-L, GRUNDLING AT, PRETORIUS L, MULDERS J and MITCHELL S (2017) *South African peatlands: ecohydrological characteristics and socio-economic value*. Water Research Commission (WRC) Report No. 2346/1, WRC, Pretoria, South Africa.

GRUNDLING P-L, GRUNDLING AT, VAN DEVENTER H and LE ROUX (2021) Current state, pressures and protection of South African peatlands. Mires & Peat **27 26** https://doi.org/10.19189/MaP.2020.OMB.StA.2125.

GRUNDLING P-L, MAZUS H and BLACKMORE A (1998) *Peat Resources in Northern KwaZulu-Natal Wetlands: Maputaland. Department of Environmental Affairs and Tourism (DEAT) Report no. A25/13/2/7.102.* DEAT, Pretoria, South Africa, 102 pp.

GRUNDLING AT, VAN DEN BERG EC and PRICE JS (2013) Assessing the Distribution of Wetlands Over Wet and Dry Periods and Land-use Change on the Maputaland Coastal Plain, North-Eastern KwaZulu-Natal, South Africa. South African Journal of Geomatics **2** 120-138.

GUMBRICHT T, ROMAN-CUESTA RM, VERCHOT L, HEROLD M, WITTMANN F, HOUSEHOLDER E, HEROLD N and MURDIYARSO D (2017) An expert system model for mapping tropical wetlands and peatlands reveals South America as the largest contributor. Global Change Biology **23 (9)** 3581-3599.

GUYON I, WESTON J, BARNHILL S and VAPNIK V (2002) Gene selection for cancer classification using support vector machines. Machine Learning **46** 389-422.

HUANG X, ZINITI B, TORBICK N and DUCEY MJ (2018) Assessment of forest above-ground biomass estimation using multi-temporal C-band Sentinel-1 and polarimetric L-band PALSAR-2 data. Remote Sensing **10 (9)** 1424.

INTERGOVERNMENTAL SCIENCE-POLICY PLATFORM ON BIODIVERSITY AND ECOSYSTEM SERVICES (IPBES) (2019) Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. DÍAZ S, SETTELE J, BRONDÍZIO ES, NGO HT, GUÈZE M, AGARD J, ARNETH A, BALVANERA P, BRAUMAN KA, BUTCHART SHM, CHAN KMA, GARIBALDI LA, ICHII K, LIU J, SUBRAMANIAN SM, MIDGLEY GF, MILOSLAVICH P, MOLNÁR Z, OBURA D, PFAFF A, POLASKY S, PURVIS A, RAZZAQUE J, REYERS B, CHOWDHURY RR, SHIN YJ, VISSEREN-HAMAKERS IJ, WILLIS KJ and ZAYAS CN (eds.) IPBES secretariat, Bonn, Germany, 56 pp. https://doi.org/10.5281/zenodo.3553579.

ISIMANGALISO WETLAND PARK AUTHORITY (2019) *Annual report 2018/2019.* https://static.pmg.org.za/iSimangaliso_Annual_Report_2018-19.pdf

JANSE VAN RENSBURG S (2019) *Appendix D: Pressures on the Maputaland Coastal Plain.* VAN DEVENTER *et al.* (Eds). South African National Biodiversity Assessment 2018: Technical Report. Volume 2b: Inland Aquatic (Freshwater) Realm. Council for Scientific and Industrial Research (CSIR) report number CSIR/NRE/ECOS/IR/2019/0004/A. South African National Biodiversity Institute (SANBI), Pretoria, South Africa. http://hdl.handle.net/20.500.12143/6230.

JEWITT D (2018) Vegetation type conservation targets, status and level of protection in KwaZulu-Natal in 2016. Bothalia, African Biodiversity & Conservation **48 (1)** a2294. https://doi.org/10.4102/abc.v48i1.2294.

KEDDY PA (2010) *Wetland ecology: principles and conservation*. Cambridge, Cambridge University Press, United Kingdom.

KEITH DA, FERRER JR, NICHOLSON E, BISHOP MJ, POLIDORO BA, RAMIREZ-LLODRA E, TOZER MG, NEL JL, NALLY RM, GREGR EJ, WATERMEEYR KE, ESSL F, FABER-LANGENDOEN D, FRANKLIK J, LEHMANN CER, ETTER A, ROUX DJ, STARK JS, ROWLAND JA, BRUMMIT NA, FERNANDEZ-ARCAYA UC, SUTHERS IM, WISER SK, DONOHUE I, JACKSON LJ, PENNINGTON RT, PETTORELLI N, ANDRADE A, KONTULA T, LINDGAARD A, TAHVANAINAN T, TERRAUDS A, VENTER O, WATSON JEM, CHADWICK MA, MURRAY NJ, MOAT J, PLISCOFF P, ZAGER I and KINGSFORD RT (2020) *The IUCN Global Ecosystem Typology V1.01: Descriptive Profiles for Biomes and Ecosystem Functional Groups*. IUCN. https://seea.un.org/content/iucn-global-ecosystem-typology-v101-descriptive-profiles-biomes-and-ecosystem-functional.

KOTZE D (2016) A simple Citizen Science tool to assess the ecological condition of a wetland. Water Research Commission: Water Research Commission (WRC) Project No. K5/2350. WRC, Pretoria, South Africa.

KOTZE DC and O'CONNOR TG (2000). Vegetation variation within and among palustrine wetlands along an altitudinal gradient in KwaZulu-Natal, South Africa. Plant Ecology **146** 77-96.

KOTZE DC, MACFARLANE DM, EDWARDS RJ and MADIKIZELA B (2020) WET-EcoServices Version 2: A revised ecosystem services assessment technique, and its application to selected wetland and riparian areas. Water SA **46 (6)** 679-688. https://doi.org/10.17159/wsa/2020.v46.i4.9084.

KRAVITZ J, MATTHEWS M, BERNARD S and GRIFFITH D (2020) Application of Sentinel 3 OLCI for Chl-*a* Retrieval Over Small Inland Water Targets: Successes and Challenges. Remote sensing of environment **237** 111562.

KUHN M (2008) Building predictive models in R using the caret package. Journal of Statistical Software **28** 1-26.

LEFEBVRE H (1991) *The production of space*. Blackwell, Oxford, England.

LE MAITRE DC, SEYLER H, HOLLAND M, SMITH-ADAO L, NEL JL, MAHERRY A and WITTHŰSER K (2018) Identification, Delineation and Importance of the Strategic Water Source Areas of South Africa, Lesotho and Swaziland for Surface Water and Groundwater. Final Integrated Report on the Water Research Commission (WRC) Project K5/2431, WRC, Pretoria, South Africa.

LE ROUX JP, GANGATHELE AM, REBELO AJ, GIBSON L, STEPHENSON RJ, KOTZE D and GRUNDLING AT (2023) Development of management and rehabilitation protocols for peatlands in South Africa: Case studies of peat fires. WRC Project No. 2019/2020-00098. Agricultural Research Council-Natural Resources and Engineering Report No. GW/A/2023/, 93 pages.

LIENGME CA (1983) A study of wood use for fuel and building in an area of Gazankulu. Bothalia **13** 501-518.

LINDSAY JB (2014) The Whitebox Geospatial Analysis Tools Project and Open-Access GIS. In: *Proceedings of the GIS Research UK 22nd Annual Conference*, Glasgow, The University of Glasgow, April., 16-18.

LUBBE RA (1997) Vegetation and flora of the Kosi Bay Coastal Forest Reserve in Maputaland, northern KwaZulu-Natal, South Africa. MSc dissertation, University of Pretoria, Pretoria, South Africa.

LÜCK-VOGEL M, MBOLAMBI C, RAUTENBACH K, ADAMS J and VAN NIEKERK L (2016) Vegetation mapping in the St Lucia estuary using very high-resolution multispectral imagery and LiDAR. South African Journal of Botany **107** 188-199.

LUVUNO LB, KOTZE D and KIRKMAN KP (2016) Long-term landscape changes in vegetation structure: fire management in the wetlands of KwaMbonambi, South Africa, African Journal of Aquatic Science **41** (**3)** 279-288. https://doi.org/10.2989/16085914.2016.1177482.

MACFARLANE D, KOTZE D, ELLERY W, WALTERS D, KOOPMAN V, GOODMAN P and GOGE M (2009) *Wetland Management Series: WET-Health. A technique for rapidly assessing wetland health.* Water Research Commission (WRC) Report No. TT340/09, WRC, Pretoria, South Africa. http://www.wrc.org.za/wp-content/uploads/mdocs/TT%20340-09.pdf.

MACFARLANE DM, OLLIS DJ and KOTZE, DC (2020) *Wet-Health (version 2.0): A refined suite of tools for assessing the present ecological state of wetland ecosystems.* Water Research Commission (WRC) Report No. TT820/20, WRC, Pretoria, South Africa. http://wrcwebsite.azurewebsites.net/mdocs-posts/wet-health-version-2-0-a-refined-suite-of-tools-for-assessing-the-present-ecological-state-of-wetland-ecosystems-technical-guide/.

MAHDIANPARI M, JAFARZADEH H, GRANGER JE, MOHAMADIMANESH F, BRISCO B, SALEHI B, HOMAYOUNI S and WENG Q (2020) A large-scale change monitoring of wetlands using time series Landsat imagery on Google Earth Engine: a case study in Newfoundland. GIScience & Remote Sensing **57 (8)** 1102-1124.

MAIN-KNORN M, PFLUG B, LOUIS J, DEBAECKER V, MÜLLER-WILM U and GASCON F (2017) Sen2Cor for Sentinel-2. Image and Signal Processing for Remote Sensing **10427** 37-48.

MALAHLELA OE, CHO MA and MUTANGA O (2015) Mapping the occurrence of *Chromolaena odorata* (L.) in subtropical forest gaps using environmental and remote sensing data. Biological Invasions **17 (7)** 2027-2042.

MALHERBE J, DIEPPOIS B, MALULEKE P, VAN STADEN M and PILLAY DL (2016) South African droughts and decadal variability. Natural Hazards **80 (1)** 657-681. https://dx.doi.org/10.1007/s11069-015-1989-y.

MARTIN-SMITH KM (2004) Aquatic habitats in forest ecosystems. In: *Encyclopaedia of Forest Sciences*. BURLEY J (Ed.) Elsevier, Oxford, United Kingdom.

MATHER P and TSO B (2016) *Classification methods for remotely sensed data.* CRC press, London, United Kingdom. https://doi.org/10.1201/9781420090741

MATTHEWS MW (2014) Eutrophication and Cyanobacterial Blooms in South African Inland Waters: 10 years of MERIS Observations. Remote Sensing of Environment **155** 161-177.

MATTHEWS MW (2019) *The Integration of Earth Observation into the National Eutrophication Monitoring Programme.* Water Research Commission Report no. TT770/18, WRC, Pretoria, South Africa.

MATTHEWS MW and BERNARD S (2015) Eutrophication and cyanobacteria in South Africa's standing water bodies: a view from space. South African Journal of Science **11 (5/6)** 1-8.

MAZVIMAVI D (2018) *Finding "New" Water to Address Conflicting and Competing Water Demands in the Nuwejaars Catchment, Cape Agulhas.* Water Research Commission (WRC) Report no. 2324/1/18, 135. WRC, Pretoria, South Africa.

MELLY BL, SCHAEL DM, RIVERS-MOORE N and GAMA PT (2016) Mapping ephemeral wetlands: manual digitisation and logistic regression modelling in Nelson Mandela Bay Municipality, South Africa. Wetlands, Ecology and Management **25** 313-330. https://doi.org/10.1007/s11273-016-9518-7.

MITSCH WJ and GOSSELINK JG (2015) *Wetlands*. 5th edition. John Wiley & Sons, United Kingdom.

MPUNGOSE N, THOITHI W, BLAMEY RC and REASON CJC (2022) Extreme rainfall events in southeastern Africa during the summer. Theoretical and Applied Climatology **150 (1-2)** 185-201.

MUCINA L and RUTHERFORD MC (2006) *The Vegetation of South Africa, Lesotho and Swaziland*. South African National Biodiversity Institute (Strelitzia), Pretoria, South Africa.

MUCINA L, GELDENHUYS CJ and RUTHERFORD MC (2006) Afrotemperate, subtropical and azonal forests. In: *The vegetation of South Africa, Lesotho and Swaziland*. In: MUCINA L and RUTHERFORD MC (Eds.). Strelitzia, SANBI, Pretoria, South Africa.

MULLISSA A, VOLLRATH A, ODONGO-BRAUN C, SLAGTER B, BALLING J GOU Y, GORELICK N and REICHE J (2021) Sentinel-1 SAR backscatter analysis ready data preparation in Google Earth Engine. Remote Sensing, **13. (10.)** 1954.

NAIDOO L, MATHIEU R, MAIN R, KLEYNHANS W, WESSELS K, ASNER GP and Leblon B (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 **105** 234-250. https://doi.org/10.1016/j.isprsjprs.2015.04.007.

NDLOVU NB (2013) *Quantifying indigenous forest change in DukuDuku from 1960 to 2008 using GIS and remote sensing techniques to support sustainable forest management planning*. MSc thesis, Stellenbosch University, Stellenbosch, South Africa. 84 pp.

NDLOVU MS and DEMLIE M (2020) Assessment of Meteorological Drought and Wet Conditions using two drought indices across KwaZulu-Natal Province, South Africa. Atmosphere **11** 623. http://doi.org/10.3390/atmos11060623.

NEAL MJ (2001) *The vegetation ecology of the lower Mkuze River floodplain, northern KwaZulu-Natal: A landscape ecology perspective*. MSc thesis University of KwaZulu-Natal, Durban, South Africa, 155 pp.

NEL JL, DRIVER AL, STRYDOM WF, MAHERRY AM, PETERSEN C, HILL L, ROUX DJ, NIENABER S, VAN DEVENTER H, SWARTZ ER, SMITH-ADAO LB (2011a) *Atlas of Freshwater Ecosystem Priority Areas in South Africa: Maps to support sustainable development of water resources*. Water Research Commission (WRC) Report No. K5/1801, WRC, Pretoria, South Africa.

NEL JL, MURRAY KM, MAHERRY AM, PETERSEN CP, ROUX DJ, DRIVER A, HILL L, VAN DEVENTER H, FUNKE N, SWARTZ ER, SMITH-ADAO LB, MBONA N, DOWNSBOROUGH L, NIENABER S (2011b) *Technical Report: National Freshwater Ecosystem Priority Areas project*. Water Research Commission (WRC) Report No. 1801/2/11, WRC, Pretoria, South Africa.

NEL JL, ROUX DJ, DRIVER A, HILL L, MAHERRY AC, SNADDON K, PETERSEN CR, SMITH-ADAO LB, VAN DEVENTER H and REYERS B (2016) Knowledge co-production and boundary work to promote implementation of conservation plans. Conservation Biology **30 (1)** 176-88. https://doi.org/10.1111/cobi.12560.

NHAMO L, MAGIDI J and DICKENS C (2017) Determining wetland spatial extent and seasonal variations of the inundated area using multispectral remote sensing. Water SA **43 (4)** 543-552.

NOSS RF (1990). Indicators for monitoring biodiversity: a hierarchical approach. Conservation Biology **4 (4)** 355-364.

O'CALLAGHAN JF and MARK DM (1984) The extraction of drainage networks from digital elevation data. Computer Vision, Graphics, and Image Processing **28 (3)** 323-344.

OLLIS DJ, EWART-SMITH JL, DAY JA, JOB NM, MACFARLANE DM, SNADDON CD, SIEBEN EJJ, DINI JA and MBONA N (2015) The development of a classification system for inland aquatic ecosystems in South Africa. Water SA **41 (5)** 727-745.

OLLIS DJ, SNADDON CD, JOB NM and MBONA N (2013) *Classification System for wetlands and other aquatic ecosystems in South Africa.* User Manual: Inland Systems, South African National Biodiversity Institute (SANBI) Biodiversity Series 22. SANBI, Pretoria, South Africa.

OMER G, MUTANGA O, ABDEL-RAHMAN EM and ADAM E (2015) Performance of Support Vector Machines and Artificial Neural Network for mapping endangered tree species using WorldView-2 data in DukuDuku Forest, South Africa. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing **99** 1-16.

PATRICK MJ and ELLERY WN (2007) Plant community and landscape patterns of a floodplain wetland in Maputaland, Northern KwaZulu-Natal, South Africa. African Journal of Ecology **45 (2)** 175-183.

PEKEL J-F, COTTAM A, GORELICK N and BELWARD AS (2016) High-resolution mapping of global surface water and its long-term changes. Nature **540** 418-422. http://dx.doi.org/10.1038/nature20584 or http://www.nature.com/articles/nature20584.pdf.

PETTORELLI N, OWEN HJF and DUNCAN C (2016) How do we want Satellite Remote Sensing to support biodiversity conservation globally? Methods in Ecology and Evolution **Special feature: 5th anniversary 7** 656-665.

PETTORELLI N, WEGMANN M, SKIDMORE A, MÜCHER S, DAWSON TP, FERNANDEZ M, LUCAS R, SCHAEPMAN ME, WANG T, O'CONNOR B (2016) Framing the Concept of Satellite Remote Sensing Essential Biodiversity Variables: Challenges and Future Directions. Remote Sensing in Ecology and Conservation **2** 122-131.

PICKETT STA, PARKER VT and FIEDLER PL (1992) *The new paradigm in ecology: Implications for conservation biology above the species level*. FIEDLER PI and JAIN SK (eds.) Conservation biology. New York, Chapman and Hall, United States of America, pp. 65-88.

PRETORIUS ML (2012) *A vegetation classification and description of five wetland systems and their respective zones on the Maputaland Coastal Plain.* MSc dissertation in Environmental Management at the University of South Africa (Unisa), Pretoria, South Africa.

PRETORIUS L, BROWN LR, BREDENKAMP GJ and VAN HUYSSTEEN CW (2016) The ecology and classification of wetland vegetation in the Maputaland Coastal Plain, South Africa. Phytocoenologia **46 (2)** 125-139.

PRETORIUS ML, VAN HUYSSTEEN CS, BROWN LR, GRUNDLING AT and DOWNS CT (2020) A characterisation of wetland soil types on the Maputaland Coastal Plain, South African. Journal of Plant and Soil **37 (5)** 389-403. https://doi.org/10.1080/02571862.2020.1814433.

RAIMONDO D, VON STADEN L, FODEN W, VICTOR JE, HELME NA, TURNER RC, JAMUNDI DA, MANYAMA PA (2009) *The 2009 red list of South African plants*. South African National Biodiversity Institute (SANBI), Pretoria, South Africa. http://hdl.handle.net/20.500.12143/260.

RAJKARAN A, ADAMS J and TAYLOR R (2009) Historic and recent state of mangroves in small estuaries from Mlalazi to Mtamvuna in KwaZulu-Natal, South Africa. Southern Forests **71 (4)** 287-296.

RAJKARAN A and ADAMS J (2011) Mangrove Forests of Northern KwaZulu-Natal: Sediment Conditions and Population Structure of the Largest Mangrove Forests in South Africa. Western Indian Ocean Journal of Marine Science **10 (1)** 25-38.

RAMJEAWON M, DEMLIE M, TOUCHER ML and JANSE VAN RENSBURG S (2020) Analysis of three decades of land cover changes in the Maputaland Coastal Plain, South Africa. Koedoe **62 (1)** a1642. https://doi.org/10.4102/koedoe.v62i1.1642.

RAUTENBACH K (2015) *Present state of macrophytes and responses to management scenarios at the St. Lucia and Mfolozi estuaries*. MSc Thesis. Nelson Mandela Metropolitan University, Port Elizabeth, South Africa.

RAW JL, VAN NIEKERK L, RIDDIN T, TSIPA V, BANDA SP and ADAMS JB (2021) *Scoping Study: A Blue Carbon Sinks Assessment for South Africa.* Department for Environment, Forestry & Fisheries (DEFF), Pretoria, South Africa.

REBELO AJ, SCHEUNDERS P, ESLER KJ and MEIRE P (2017) Detecting, mapping and classifying wetland fragments at a landscape scale. Remote Sensing Applications: Society and Environment **8** 212-223.

REPUBLIC OF SOUTH AFRICA (RSA) (1998) *National Water Act, Act No. 36 of 1998*. Available: http://www.dwaf.gov.za/Documents/Legislature/nw_act/NWA.pdf [2010, 10/01]. Government Printers, Pretoria, South Africa.

RICHARDSON JL (2001) *Wetland soils: Genesis, Hydrology, Landscapes, and Classification*. Lewis Publishers, Washington, D.C, United States of America.

RIEDEL M (2015) *Satellite-imagery-based classification of near-natural and used wetlands in a subtropical region. A case study on the impact of subsistence farming on the Maputaland Coastal Plain, South Africa.* MSc. Dissertation in Environmental Planning and Engineer Ecology at the Technische Universität München, München, Germany.

RIVERS-MOORE NA and GOODMAN PS (2010) River and wetland classifications for freshwater conservation planning in KwaZulu-Natal, South Africa. African Journal of Aquatic Science **35 (1)** 61-72.

RODHE A and SEIBERT J (1999) Wetland occurrence in relation to topography: a test of topographic indices as moisture indicators. Agricultural and Forest Meteorology **98** 325-340.

RONDEAUX G, STEVEN M AND BARET F (1996) Optimization of soil-adjusted vegetation indices. Remote sensing of environment **55 (2)** 95-107.

RUCKS-AHIDIANA Z AND BIERBAUM AH (2015) Qualitative Spaces: Integrating spatial analysis for a mixed methods approach. International Journal of Qualitative Methods **14(2)** 92-103.

SCOTT-SHAW CR and ESCOTT BJ (Eds) (2011) *KwaZulu-Natal Provincial Pre-Transformation Vegetation Type Map – 2011.* Unpublished GIS Coverage [kznveg05v2_0_11_public_wll.zip], Biodiversity Conservation Planning Division, Ezemvelo KZN Wildlife, P.O. Box 13053, Cascades, Pietermaritzburg, 3202, South Africa, 17 pp.

SIEBEN EJJ, MTSHALI H and JANKS M (2014) *National Wetland Vegetation Database: Classification and Analysis of wetland vegetation types for conservation planning and monitoring*. Water Research Commission (WRC) Report No. 1980/1/14, WRC, Pretoria, South Africa.

SINGH G, REYNOLDS C, BYRNE M and ROSMAN B (2020) A remote sensing method to monitor water, aquatic vegetation, and invasive water hyacinth at national extents. Remote Sensing **12 (24)** 4021.

SILLITOE P (1998) What, know natives? Local knowledge in development. Social Anthropology **6 (2)** 203-220.

SKOWNO AL, POOLE CJ, RAIMONDO DC, SINK KJ, VAN DEVENTER H, VAN NIEKERK L, HARRIS LR, SMITH-ADAO LB, TOLLEY KA, ZENGEYA TA, FODEN WB, MIDGLEY GH and DRIVER A (2019a) *National Biodiversity Assessment 2018: The status of South Africa's ecosystems and biodiversity. Synthesis Report.* South African National Biodiversity Institute, an entity of the Department of Environment, Forestry and Fisheries, Pretoria, South Africa. http://hdl.handle.net/20.500.12143/6362.

SKOWNO A, RAIMONDO D, POWRIE L, HOFFMAN MT, VAN DER MERWE S, HLAHANE K, FIZZOTI B and VARAIWA T (2019b) Chapter 3: Pressures and Threats. In: South African National Biodiversity Assessment 2018: Technical Report. Volume 1: Terrestrial Environment. South African National Biodiversity Institute (SANBI), Pretoria, South Africa. Report Number: SANBI/NAT/NBA2018/2019/Volx/A.

SKOWNO A, THOMPSON M, HIESTERMANN J, RIPLEY B, WEST AG and BOND WJ (2017) Woodland expansion in South African grassy biomes based on satellite observations (1990-2013): general patterns and potential drivers. Global Change Biology **23** 2358-2369.

SLAGTER B, TSENDBAZAR N, VOLLRATH A and REICHE J (2020) Mapping Wetland Characteristics using Temporally Dense Sentinel-1 and Sentinel-2 Data: A Case Study in the St. Lucia Wetlands, South Africa. International Journal of Applied Earth Observation and Geoinformation **86** 102009.

SMITH-ADAO L, PETERSEN C, NEL J, SILBERBAUER M, SCHERMAN P and GRENFELL M (2018) Chapter 2: Origin, development and improvement of the rivers dataset. *South African National Biodiversity Assessment 2018: Technical Report. Volume 2a: South African Inventory of Inland Aquatic Ecosystems (SAIIAE). Version 3, final released on 3 October 2019*. VAN DEVENTER *et al.* (Eds.). Council for Scientific and Industrial Research (CSIR) and South African National Biodiversity Institute (SANBI): Pretoria, South Africa. Report Number: CSIR report number CSIR/NRE/ECOS/IR/2018/0001/A; SANBI report number http://hdl.handle.net/20.500.12143/5847.

SMITHERS J, GRAY R, JOHNSON S and STILL D (2017) Modelling and water yield assessment of Lake Sibhayi. Water SA **43** 480-491.

SOLÓRZANO JV, GALLARDO-CRUZ JA, GONZÁLEZ EJ, PERALTA-CARRETA C, HERNÁNDEZ-GÓMEZ M, FERNÁNDEZ-MONTES DE OCA, A and CERVANTES-JIMÉNEZ LG (2018) Contrasting the potential of Fourier transformed ordination and gray level co-occurrence matrix textures to model a tropical swamp forest's structural and diversity attribute. Journal of Applied Remote Sensing **12 (3)** 036006-036006.

SØRENSEN R and SEIBERT J (2007) Effects of DEM resolution on the calculation of topographical indices: TWI and its components. Journal of Hydrology **347 (1-2)** 79-89.

STARKE AP, GELDENHUYS CJ, O'CONNOR TG and EVERSON CS (2019) Forest and woodland expansion into forestry plantations informs screening for native agroforestry species, Maputaland South Africa, Forests, Trees and Livelihoods **29 (1)**, https://doi.org/10.1080/14728028.2019.1670740.

STATISTICS SOUTH AFRICA (2021) Natural Capital Series 2: Accounts for Protected Areas, 1900 to 2020. Discussion document D0401.2. Produced in collaboration with the South African National Biodiversity Institute and the Department of Forestry, Fisheries and the Environment. Statistics South Africa, Pretoria, South Africa.

STEFFEN W, ANDREAE MO, BOLIN B, COX PM, CRUTZEN PJ, CUBASCH U, HELD H, NAKIDENOVIC N, SCHOLES RJ, TALAUE-MCMANUS L and TURNER II BL (2004) Abrupt Changes: The Achilles' Heels of the Earth System. Environment Science and Policy for Sustainable Development **46 (3)**, https://doi.org/10.1080/00139150409604375.

STORY M and CONGALTON RG (1986) Accuracy Assessment: A User's Perspective. Photogrammetric Engineering and Remote Sensing **52 (3)** 397-399.

STEINKE TD AND WARD CJ (1989) Some effects of the cyclones Domoina and Imboa on mangrove communities in the St Lucia Estuary. South African Journal of Botany **55 (3)** 340-348.

TAYLOR R (2011) Dynamics of the macrophyte vegetation of the Mgobezeleni floodplain and estuary, Northern KwaZulu-Natal. South African Journal of Botany **107** 170-178.

THOMPSON M (2019) *DEA E1434 Land-Cover. South African National Land-Cover 2018. Report and Accuracy Assessment. Public Release Report version 004*. Department of Environmental Affairs, Department of Rural Development and Land Reform, GeoTerraImage and Council for Scientific and Industrial Research, Pretoria, South Africa.

THOMPSON M, HIESTERMANN J, MOYO L and MPE T (2018) Cloud-based monitoring of SA's water resources. *Position IT Magazine* **March** 38-41. http://z.positionit.ee.co.za/2685/01-03-2018#page/38.

TUCKER CJ (1979) Red and photographic infrared linear combinations for monitoring vegetation. Remote sensing of Environment **8 (2)** 127-150.
UDDIN MP, MAMUN MA, AFJAL MI, and HOSSAIN MA (2021) Information-theoretic feature selection with segmentation-based folded principal component analysis (PCA) for hyperspectral image classification. International Journal of Remote Sensing **42 (1)** 286-321.

UNITED STATES FISH AND WILDLIFE SERVICE (2021) *Classification and types of wetlands used by the United States Fish and Wildlife Services.* Available online at https://www.epa.gov/wetlands/classification-and-types-wetlands#Marshes, accessed 25 October 2021.

VAERET L, KELBE B, HALDORSEN S and TAYLOR RH (2009) A modelling study of the effects of land management and climatic variation on groundwater inflow to Lake St Lucia, South Africa. Hydrogeological Journal **17** 1949-1967. http://doi.org/10.1007/s10040-009-0476-5.

VAN DER VALK A (2012) *The biology of freshwater wetlands*. Oxford University Press, United Kingdom.

VAN DEVENTER H (2000). *Using Geographical Information Systems for mapping commercial farmer's perceptions on land reform in Mpumalanga, RSA.* M.A. dissertation, Stellenbosch University. http://hdl.handle.net/10019.1/52043.

VAN DEVENTER H (2016) *Remote Sensing of wetland tree species in the iSimangaliso Wetland Park, KwaZulu-Natal, South Africa*. PhD thesis, University of KwaZulu-Natal, Pietermaritzburg, South Africa.

VAN DEVENTER H (2021) Monitoring changes in South Africa's surface water extent for reporting Sustainable Development Goal sub-indicator 6.6.1.a, South African Journal of Science **117 (5/6)** Art. #8806. https://doi.org/10.17159/sajs.2021/8806.

VAN DEVENTER H (2022) Wetlands. In: *State of the Coast: KwaZulu-Natal – A review of the state of KwaZulu-Natal's coastal zone*. GOBLE BG and VAN DER ELST RP (Eds.). KwaZulu-Natal Department of Economic Development, Tourism and Environmental Affairs, Pietermaritzburg, 55-58. Available online at: https://www.coastkzn.co.za/themes/state-of-the-coast-kzn/kzn-socr-overview/.

VAN DEVENTER H, ADAMS J, DURAND JF, GROBLER R, GRUNDLING P-L, JANSE VAN RENSBURG S, JEWITT D, KELBE B, MACKAY CF, NAIDOO L, NEL JL, PRETORIUS L, RIDDIN T and VAN NIEKERK L (2021a) Conservation conundrum – red listing of subtropical-temperate coastal forested wetlands of South Africa. Ecological Indicators **130** 108077. https://doi.org/10.1016/j.ecolind.2021.108077.

VAN DEVENTER H, ADAMS J, DURAND JF, GROBLER R, GRUNDLING P-L, JANSE VAN RENSBURG S, JEWITT D, KELBE B, MACKAY CF, NAIDOO L, NEL JL, PRETORIUS L, RIDDIN T and VAN NIEKERK L

(2021b) Water and Wetlands: South Africa's swamp forests are very likely critically endangered wetland ecosystems. The Water Wheel **November/December** 30-33. https://www.wrc.org.za/wp-content/uploads/mdocs/WW%20Nov%20-%20Dec%202021_web.pdf

VAN DEVENTER H and APLENI P (2021) *Ixhaphozi eMaputaland Coastal Plain*. http://hdl.handle.net/10204/12052 .

VAN DEVENTER H, CHO MA, MUTANGA O (2013) *Do seasonal profiles of foliar pigments improve species discrimination of evergreen coastal tree species in KwaZulu-Natal, South Africa?* In Conference proceedings of the 35th International Symposium on Remote Sensing of Environment (ISRSE). ISRSE, Beijing, China, 1-12.

VAN DEVENTER H, CHO MA, MUTANGA O (2017) Improving the classification of six evergreen subtropical tree species with multi-season data from leaf spectra simulated to WorldView-2 and RapidEye. International Journal of Remote Sensing **38 (17)** 4804-4830. http://www.doi.org/10.1080/01431161.2017.1320445.

VAN DEVENTER H, CHO MA and MUTANGA O (2019a) Multi-season RapidEye imagery improves the classification of wetland and dryland communities in a subtropical coastal region. ISPRS Journal of Photogrammetry and Remote Sensing **157** 171-187. https://doi.org/10.1016/j.isprsjprs.2019.09.007.

VAN DEVENTER H, NAIDOO L, CHO MA, JOB NM, LINSTRÖM A, SIEBEN E, SNADDON K and GANGAT R (2020a). Establishing remote sensing toolkits for monitoring freshwater ecosystems under global change. Water Research Commission Report No. 2545/1/19, http://wrcwebsite.azurewebsites.net/mdocs-posts/establishing-remote-sensing-toolkits-for-monitoring-freshwater-ecosystems-under-global-change/.

VAN DEVENTER H, LINSTRÖM A, DURAND JF and CHO MA (2022a) Deriving the maximum extent and hydroperiod of open water from Sentinel-2 imagery for global sustainability and biodiversity reporting for wetlands. Water SA 48 (1) 75-89. DOI: https://doi.org/10.17159/wsa/2022.v48.i1.3883

VAN DEVENTER H, LINSTRÖM A, NAIDOO L, JOB N, SIEBEN EJJ AND CHO MA (2022b) Comparison between Sentinel-2 and WorldView-3 sensors in mapping wetland vegetation communities of the Grassland Biome of South Africa, for monitoring under climate change. Remote Sensing Applications: Society and Environment **28** https://doi.org/10.1016/j.rsase.2022.100875.

VAN DEVENTER H, SMITH-ADAO L, COLLINS NB, GRENFELL M, GRUNDLING A, GRUNDLING P-L, IMPSON D, JOB N, LÖTTER M, OLLIS D, PETERSEON C, SCHERMAN P, SIEBEN EJJ, SNADDON K, TERERAI F and VAN DER COLFF D (2019b) *South African National Biodiversity Assessment 2018: Technical Report. Volume 2: Inland Aquatic (Freshwater) Component.* Council for Scientific and Industrial Research (CSIR) and South African National Biodiversity Institute (SANBI), Pretoria, South Africa. CSIR report number CSIR/NRE/ECOS/IR/2019/0004/A. SANBI handle: http://hdl.handle.net/20.500.12143/6230.

VAN DEVENTER H, SMITH-ADAO L, MBONA N, PETERSEN C, SKOWNO A, COLLINS NB, GRENFELL M, JOB N, LÖTTER M, OLLIS D, SCHERMAN P, SIEBEN E and SNADDON K (2018a) *South African Inventory of Inland Aquatic Ecosystems (SAIIAE).* Council for Scientific and Industrial Research (CSIR) report number: CSIR/NRE/ECOS/IR/2018/0001/A; South African National Biodiversity Institute (SANBI) report number: http://hdl.handle.net/20.500.12143/5847.

VAN DEVENTER H, SMITH-ADAO L, PETERSEN C, MBONA N, SKOWNO A and NEL JL (2018b) Review of available data for a South African Inventory of Inland Aquatic Ecosystems (SAIIAE). Water SA **44 (2)** 184-199. http://dx.doi.org/10.4314/wsa.v44i2.05.

VAN DEVENTER H, VAN NIEKERK L, ADAMS J, DINALA MK, GANGAT R, LAMBERTH SJ, LÖTTER M, MBONA N, MACKAY F, NEL JL, RAMJUKADH C-L, SKOWNO A and WEERTS SP (2020b) National Wetland Map 5 – An improved spatial extent and representation of inland aquatic and estuarine ecosystems in South Africa. Water SA, **46 (1)** 66-79. https://doi.org/10.17159/wsa/2020.v46.i1.7887.

VAN NIEKERK L, ADAMS JB, LAMBERTH SJ, MACKAY CF, TALJAARD S, TURPIE JK, WEERTS SP and RAIMONDO DC (2019) (Eds). *South African National Biodiversity Assessment 2018: Technical Report. Volume 3: Estuarine Realm.* CSIR report number CSIR/SPLA/EM/EXP/2019/0062/A. South African National Biodiversity Institute, Pretoria. Report Number: SANBI/NAT/NBA2018/2019/Vol3/A. http://hdl.handle.net/20.500.12143/6373.

VAN NIEKERK L, ADAMS JB, JAMES NC, LAMBERTH SJ, MACKAY CF, TURPIE JK, RAJKARAN A, WEERTS SP and WHITFIELD AK (2020) An Estuary Ecosystem Classification that encompasses biogeography and a high diversity of types in support of protection and management. African Journal of Aquatic Science **45** 199-216.

VAN WYK AE and SMITH GF (2001) *Regions of floristic endemism in Southern Africa.* Umdaus Press, Pretoria, South Africa.

VENTER I (2003) *The vegetation ecology of Mfabeni peat swamp, St Lucia, KwaZulu-Natal*. MSc Dissertation University of Pretoria, Pretoria, South Africa, 147 pp.

WEEPENER HL, VAN DEN BERG HM, METZ M and HAMANDAWANA H (2012) *The development of a hydrologically improved Digital Elevation Model and derived products for South Africa based on the SRTM DEM*. Water Research Commission (WRC) Report No. K5/1908, WRC, Pretoria, South Africa.

WESSELS NG (1991a) *Distribution, classification and description of swamp forests around Lake St Lucia.* Report delivered by the Council for Scientific and Industrial Research (CSIR) to the national Department of Water Affairs & Forestry (DWAF), CSIR, Pretoria, South Africa.

WESSELS NG (1991b) *The swamp forests of Lake St Lucia.* Report delivered by the Council for Scientific and Industrial Research (CSIR) to the national Department of Water Affairs and Forestry (DWAF). CSIR, Pretoria, South Africa.

WESSELS NG (1991c) *The syntaxonomy and synecology of swamp forests in the Lake St Lucia area.* Report delivered by the Council for Scientific and Industrial Research (CSIR) to the national Department of Water Affairs and Forestry (DWAF). CSIR, Pretoria, South Africa.

WESSELS NG (1997) *Aspects of the ecology and conservation of swamp forests in South Africa.* Unpublished M. Tech dissertation, Port Elizabeth Technikon, Port Elizabeth, South Africa, 155 pp.

WILKINSON M, DANGA L, MULDERS J, MITCHELL S and MALIA D (2016) *The design of a National Wetland Monitoring Programme. Consolidated Technical Report. Volume 1*. Water Research Commission (WRC) Report No. 2269/1/16, WRC, Pretoria, South Africa.

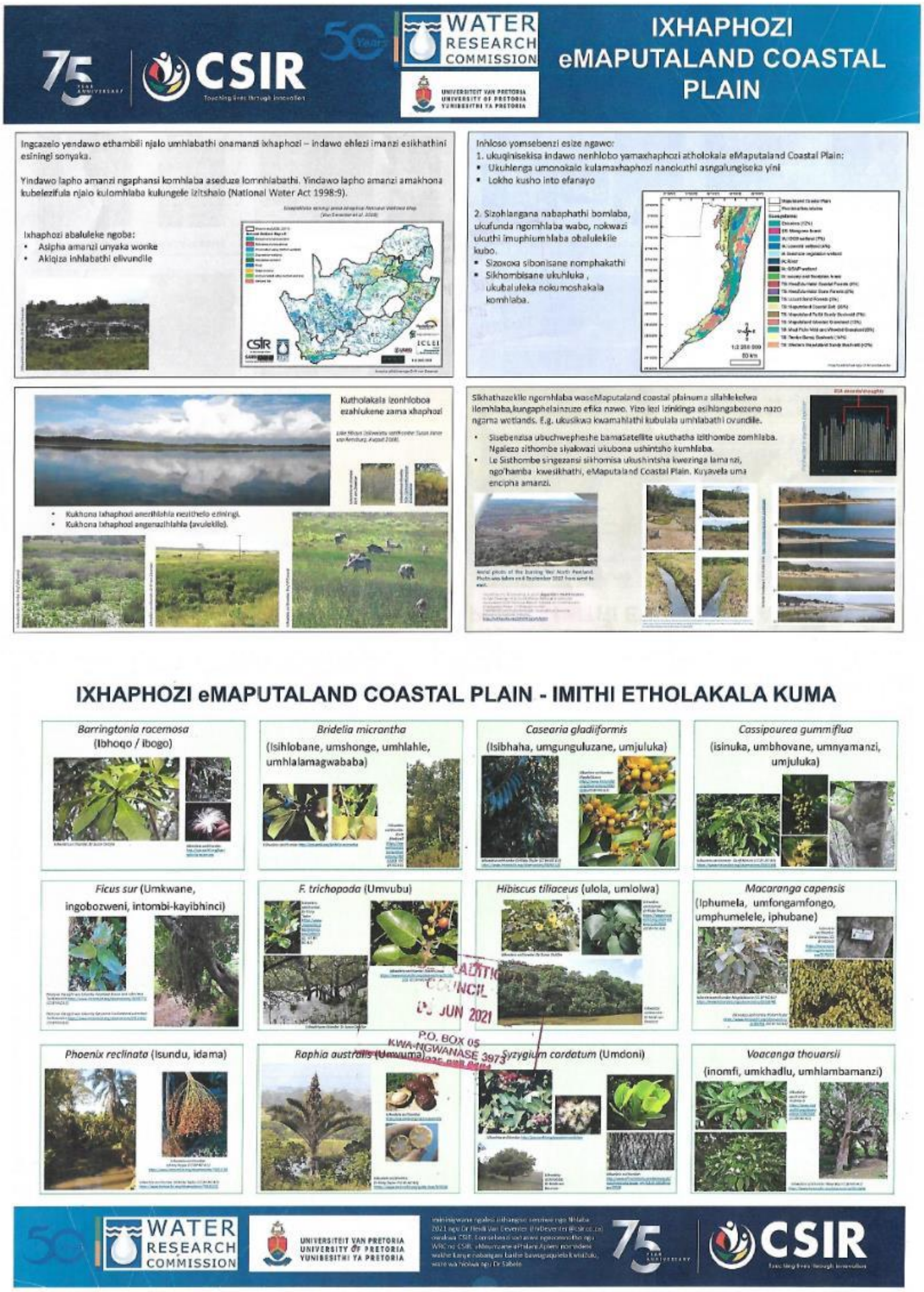
WRIGHT CI, LINDSAY P and COOPER JAG (1997) The effect of sedimentary processes on the ecology of the mangrove-fringed Kosi estuary/lake system, South Africa. Mangroves and Salt Marshes **1 (2)** 79-94.

ZHANG YY, WU W, and LIU H (2019) Factors affecting variations of soil pH in different horizons in hilly regions. PLoS ONE **14 (6)** e0218563.

ZHOU R, YANG C, LI E, CAI X, YANG J and XIA Y (2021) Object-based wetland vegetation classification using multi-feature selection of unoccupied aerial vehicle RGB imagery. Remote Sensing **13 (23)** 4910.

APPENDIX A: EVIDENCE OF APPROVAL RECEIVED FROM THE TEMBE TRADITIONAL COUNCIL

The Tembe Traditional Authority's council has stamped the second page of our poster printout, as evidence of their permission to work on their properties.



APPENDIX B: QUESTIONS ASKED DURING SOCIAL ENGAGAMENTS

Topics discussed and questions asked during the social engagements, included:

- A brief background about their community.
- What is your role within the community?
- Brief background of their household.
- Was wetland farming a skill transferred from one generation to the next?
- What type of crops are planted within the wetlands?
- Is there a market for the crops grown in the wetlands and sold to the community?
- How do you know which crops to plant in which season?
- How do you divide the plot of land within the wetlands for each family?
- What types of developments have taken place within this community?
- What is the communities' attitude towards change? Is the community in agreement about change or against change?

Questions relating to people's values of wetlands and the various types of wetlands:

- What are the historical landscape changes that have taken place over years?
- What is your understanding or perception of wetlands?
- What are the various types of wetlands and what are the common wetlands within your own area?
- What is the benefit of wetlands and how are the wetlands used within the Tembe or Mabaso community?
- Any sacred places within the wetlands?
- What are some of the tree species that can be identified within the wetlands?
- For how long has your family been farming in the wetlands? Is harvesting in the wetlands yearly or seasonal?
- What is the economic status of the people, are people poorer now or better off than in the past.
- Is wetland farming the main source of income?
- How much income can be generated from harvesting the vegetables grown within the wetlands?
- Has there been any decline in the wetlands surrounding the community? If so, what do you think is the cause of this change?
- Are you concerned about the change in the wetlands?
- How has landscape changes such as drought affected wetland farming? How was water sourced to water the crops within the wetland during dry spells?
- Can you recall drought periods within this area?
- Can you recall any heavy rains in the past years and what effect did this have on the crops planted within the wetlands?
- During the times of drought and heavy rains, was wetland farming affected and how did this affect the income-generation of the family?
- Is there any alternative to wetland farming?
- Research shows wetlands are depreciating, what can be done to resolve this issue?
- Is wetland farming mostly done by women in the community? Are the current generation interested in wetland farming?

Questions relating to different stakeholders and conservation institutions:

- How do you think timber plantations are contributing to the declining wetlands?
- Does your community work with any nature conservation organisations or institutions?
- Do you think communities can work hand in hand with nature conservation organisations or institutions?
- How can the community benefit from conservation?
- How has the iSimangaliso Wetland Park Authority contributed to the livelihood of the people within the community?
- What is causing the conflict between the community and the conservation organisations within this community?

Questions relating to climate change:

- What is your understanding of climate change?
- How does climate change affect the current status of wetlands?
- What can be done to resolve the current issue of wetlands drying out?
- What can the community do to conserve wetlands?

C.2 Questions asked in semi-structured interviews with business people and community members

Two sets of interview questions were developed for the semi-structured interviews, one for interviews with business people and the other for interviews with community members. The questions were as follows:

Questions for stakeholders from business/industry and government:

1) Please provide us with your name, the name of the institution/company you work for and your designation.
2) What is your experience with the Maputaland Coastal Plain?
3) Please can you explain what you understand the current status of wetlands on the Maputaland Coastal Plain is?
4) What kinds of maps do you find useful to use when making decisions? Are the types of categories sufficient for your purposes?
5) How often do you access data to support your plans and decisions? Is this sufficient – how often would you like to access data?
6) Should the degraded areas on the Maputaland Coastal Plain be rehabilitated, and if yes, who needs to take responsibility?
7) What do you think you can contribute to the improvement and management of wetlands of the Maputaland Coastal Plain?

Questions for community members:

1) Please tell us a little about the history of your community.
2) Please can you explain to us what you think wetlands are. Can you provide some examples?
3) Similarly, please explain what you think a coastal swamp forest is. Can you provide some examples?
4) Do you think wetlands and coastal swamp forests are important for communities? Please explain your answer.
    a. If yes, why do you think they are important?
    b. If not, why do you think are they not important?
5) Do people use the Maputaland Coastal Plain wetlands or coastal swamp forests for anything?
    a. How do people use them?
    b. For what purpose do they use them?
    c. How long have you been doing this?
    d. Can people use something else, that does not come from the wetlands or coastal swamp forests, that will give you the same outcome/benefit?
6) What do you think is the current state of the Maputaland Coastal Plain wetlands or coastal swamp forests?
    a. Do you think it is healthy or unhealthy?
    b. Do you think its health has been going up or down?
7) Is there anything the community does to protect wetlands and coastal swamp forests?
    a. Do you think they should be protected – why?
    b. If they need to be protected, who should protect them?
    c. Can or should communities do anything to protect them?
8) Does your community have any links/relationships with any nature conservation groups or institutions? Can you provide some details?

APPENDIX C: PUBLICATIONS EMANATING FROM THIS STUDY

A number of posters, popular articles and journal papers have emanated from this study, and are listed in this Appendix.

C1.1. List of popular and journal papers:

The following popular article was published: Van Deventer H, Nortje K, Naidoo L, Apleni P, Tsele P, Bester J, Grundling P-L, Janse van Rensburg S and Aucamp I (2022) Bringing remote sensing science and society closer together for the Maputaland Coastal Plain's wetlands. The Water Wheel, May/June, pp. 30-32.

Mr Philani Apleni's MSc results are drafted for submission to a remote sensing journal, and a popular article is planned for 2024.

Table C1.1. Conference papers presented (chronological listed):

Person	Date	Conference	Topic
Mr Philani Apleni	7 December 2021	Geographical Information Systems Society of South Africa (GISSA)	Mapping subtropical-temperate, wetland Ecosystem Functional Groups of the IUCN with Sentinel-1 and Sentinel-2 on the Maputaland Coastal Plain of South Africa
Dr Heidi van Deventer	17-19 May 2022	EUCOMARE 2021	Mapping subtropical-temperate, wetland Ecosystem Functional Groups of the IUCN with Sentinel-1 and Sentinel-2 on the Maputaland Coastal Plain of South Africa.
Mr Philani Apleni	24-27 October 2022	National Wetlands Indaba 2022 (NWI 2022)	Progress on quantifying changes in the extent of wetland types of the Maputaland Coastal Plain using remote sensing: Implications for Restoration and Conservation
Dr Heidi van Deventer	24-27 October 2022	National Wetlands Indaba 2022 (NWI 2022)	Implications of the post-2020 Global Biodiversity Framework and targets for wetlands of the Maputaland Coastal Plain, South Africa
Ms Nkosingizwile Ndlovu	28-30 September 2023	Southern African Association of Geomorphologists (SAAG) 2023	Assessing changes in the hydrological regime of lacustrine wetlands on the Maputaland Coastal Plain, South Africa
Mr Philani Apleni	28-30 September 2023	Southern African Association of Geomorphologists (SAAG) 2023	Quantifying changes in the extent of wetland types of the Maputaland Coastal Plain using remote sensing: Implications for Restoration and Conservation
Ms Lukho Goso	28-30 September 2023	Southern African Association of Geomorphologists (SAAG) 2023	Using Geographic Information Systems (GIS) to assess the biodiversity and protection levels of Africa's rivers
Ms Nkosingizwile Ndlovu	2-4 October 2023	Society of South African Geographers	Assessing changes in the hydrological regime of lacustrine wetlands on the Maputaland Coastal Plain, South Africa
Dr Heidi van Deventer	10-13 October 2023	GEO BON Global Conference: Monitoring Biodiversity for Action	A monitoring framework for reporting the extent of wetland restoration interventions relative to pressures and impacts for target 2 of the GBF
Dr Heidi van Deventer	23-26 October 2023	National Wetlands Indaba 2023 (NWI 2023)	Reporting the extent of wetland restoration interventions relative to pressures and impacts for target 2 of the GBF, using the Maputaland Coastal Plain as an example
Dr Ilse Aucamp	23-26 October 2023	National Wetlands Indaba 2023 (NWI 2023)	Perceptions of the value and changes in wetlands to traditional community members of the Maputaland Coastal Plain
Mr Philani Apleni	23-26 October 2023	National Wetlands Indaba 2023 (NWI 2023)	Results of quantifying changes in the extent of wetland types of the Maputaland Coastal Plain using remote sensing: Implications for Restoration and Conservation
Ms Nkosingizwile Ndlovu	23-26 October 2023	National Wetlands Indaba 2023 (NWI 2023)	Assessing changes in the hydrological regime of lacustrine wetlands on the Maputaland Coastal Plain, South Africa
Ms Lukho Goso	23-26 October 2023	National Wetlands Indaba 2023 (NWI 2023)	Using Geographic Information Systems (GIS) to assess the biodiversity and protection levels of Africa's rivers
Ms Lukho Goso	9 November 2023	The Conservation Symposium, 6-10 November 2023	Using Geographic Information Systems (GIS) to assess the biodiversity and protection levels of Africa's rivers

C1.2. Posters

Through the project, several sets of posters have been published. Two of these list the key tree species associated with forested wetlands of the MCP, both in English and isiZulu (Appendix B; Van Deventer and Apleni, 2021). These were printed and shared with the following organisations during our June 2021 fieldwork trip (5-12 June 2021):

- The Tembe Traditional and Mbasa TA;
- SAEON to give to the Mbilo TA; and
- The Tembe National Park.

Ms Camryn Oschger, and honours student from the University of Pretoria (UP), presented a poster with her results from her honours work on “Assessing the hydrological regime metrics of lacustrine wetlands for the Maputaland Coastal Plain of South Africa, from 1984 to 2022” at the National Wetlands Indaba 2022 (Appendix D).

The latest topographical maps and a poster showing the outputs of this study, have also been shared with the Mabaso and Tembe Traditional Authorities in our final feedback meetings of 20 and 23 November 2023, respectively.

Table C1.2. Post-graduate students supported:

Name	Post-graduate degree	University	Topic	Involvement in project
Mr Philani Apleni	MSc	University of Pretoria	Quantifying the extent and rate of changes in wetland types of the Maputaland Coastal Plain with remote sensing.	Funded by this WRC project. Registered with UP in 2021-23. Preparing for submission 8 December 2023.
Ms Lukho Goso	MSc	University of Pretoria	Using geospatial methods to assess the biodiversity and protection levels of Africa’s rivers	Funded by the Water RDI bursary in 2023 associated with this project.
Ms Camryn Oschger	Honours	University of Pretoria	Assessing the hydrological regime metrics of lacustrine wetlands for the Maputaland Coastal Plain of South Africa, from 1984 to 2022.	Benefitted from attending and presenting her poster at the National Wetlands Indaba 2022.
Ms Nkosingizwile Ndlovu	MSc	University of Pretoria	Assessing changes in the hydrological regime of lacustrine wetlands on the Maputaland Coastal Plain, South Africa,	Funded by the South African National Space Agency (SANSA). Benefitted from participating in workshops in September 2023 and presentation to the National Wetlands Indaba 2023.

APPENDIX D: MS OSCHGER'S POSTER AT NWI2022

Assessing the hydrological regime metrics of lacustrine wetlands for the Maputaland Coastal Plain of South Africa, from 1984 to 2022

C.J. Oschger[1] , H. Van Deventer [1,2], C.D. Hansen[1]

[1] Department of Geography, Geoinformatics and Meteorology, University of Pretoria (UP), Pretoria, South Africa

BACKGROUND

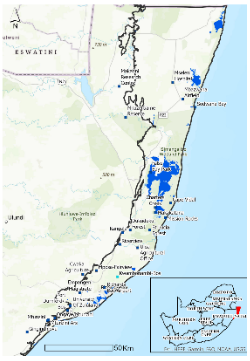


Figure 1: Overall location of the MCP, as well as the weather stations indicated and the

The hydrological regime of wetlands affects the way in which wetlands interact with the environment around them. Deriving metrics related to the hydrological regime of wetlands provides a better understanding of wetland diversity and changes that may occur as a result of anthropogenic and climate change pressures. Changes in the hydrological regime characteristics of lacustrine wetlands of the Maputaland Coastal Plain (MCP; Figure 1) in response to rainfall variability remains to be uncovered. With the increase in intensity of droughts and flood events, associated with pressures affect the hydrological regime of wetlands to inform sustainable water management. The **aim** of this project was to assess the correspondence between the hydrological regime of major/extreme precipitation events and inundation of lacustrine wetlands on the MCP. This was done by determining hydrological metrics for the lacustrine wetlands of the MCP, including (i) the temporal interval between extreme (high and low) precipitation events; (ii) the temporal interval between extreme (high and low) inundation extent of lacustrine wetlands; and (iii) the lag between selected precipitation and inundation extent of lacustrine wetlands.

METHODS

The extent of the study area was used as defined by Van Deventer et al.[4]. For the first objective, monthly rainfall data was obtained from the South African Weather Service[5] for the years from 1984 to 2022 for 20 weather stations (Figure 1). Rainfall graphs were created for each of the weather stations to show the annual rainfall for each station during this time. OriginLab was used to calculate the peaks in the rainfall data from the annual yearly rainfall data. Statistical analysis was performed on this data to find the minimum, maximum and average rainfall as well as the coefficient of variation of each rainfall station. This data was analysed geospatially to see the correlation between the geographical location of the weather station and the amount of rainfall an area receives. For objective two the Mzansi Amanzi[6] water products that derived the extent of open water for the MCP from Sentinel–1 and –2 data, was used to calculate the total extent of lacustrine wetlands for each month since January 2016. The total yearly inundation extent was found for the MCP by calculating the total area in km^2 for the wetlands in ArcGIS pro and Microsoft Excel. The inundation extent was then compared to the rainfall of each year.

Figure 2: Lake St Lucia on the 31st of December 2016. Image source:

Figure 3: Lake St Lucia on the 31st of January 2022. Image source: Google Earth [M]

RESULTS

- When observing the rainfall patterns throughout the MCP, the rainfall is geographically dependent and is evident by the variation in peak years (Figure 4).
- Over the past seven years, the total inundation extent of lacustrine wetlands in the MCP has increased by approximately 288 km2 from 163 km2 to 451 km2 (Figure 4).
- When looking at the change in extent of inundation for each year, it is clear that it takes several years for the aquifer to recover, and for wetlands to reach a maximum extent of inundation again (Figures 2 and 3).
- Periods of low rainfall correspond with the decadal drought of 2015/62, and Lake St Lucia showed a minimal extent of inundation of 21 km^2 during this El Nino event. In contrast, the most recent La Nina event caused a flooding of the system, recording a maximum inundation extent of Lake St Lucia in the past decade, of 338 km^2.
- Further research will evaluate the lag between the most recent major precipitation events and the inundation response of lacustrine wetlands.

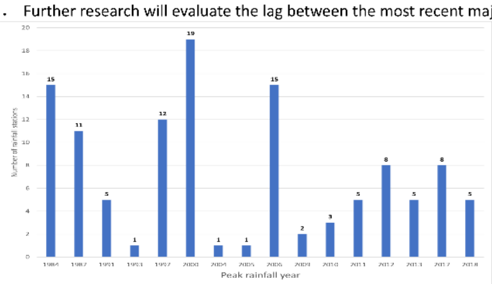


Figure 4: The number of rainfall stations that showed a peak per year.

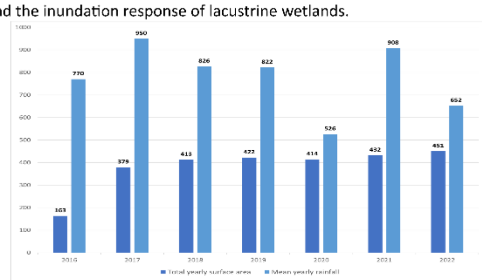


Figure 5: A comparison between the total wetland surface area (km^2) across the MCP and the Mean annual rainfall (mm) from 2016 to 2022.

Acknowledgements

In collaboration with WRC project number C2020-2021-000427, *'Quantifying the extent and rate of changes in wetland types of the Maputaland Coastal Plain with remote sensing'*

Contact Details

Camryn Oschger (coschger00@gmail.com)

References

1. Ndlovu, M.S. and Demlie, M. (2020) "Assessment of meteorological drought and wet conditions using two drought indices across Kwazulu-Natal province, South Africa," Atmosphere, 11(6). Available at: https://doi.org/10.3390/atmos11060623.
2. Malherbe, J. et al. (2016) "South African droughts and decadal variability," Natural Hazards, 80(1). Available at: https://doi.org/10.1007/s11069-015-1989-y.
3. Ramjeawon, M. et al. (2020) "Analysis of three decades of land cover changes in the Maputaland Coastal Plain, South Africa." Available at: https://doi.org/10.4102/koedoe.
4. van Deventer, H. et al. (2021) "Conservation conundrum – Red listing of subtropical-temperate coastal forested wetlands of South Africa," Ecological Indicators, 130. Available at: https://doi.org/10.1016/j.ecolind.2021.108077.
5. South African Weather Service (SAWS) (2018) Climate Date. Available at: http://www.weathersa.co.za/climate. (Accessed: March 25, 2022).
6. GeoTerraImage and EkoSource (2022) Mzansi Amanzi, South African National Space Agency. Available at: https://www.water-southafrica.co.za/ (Accessed: March 25, 2022).