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Assessment of the inland wetland ecosystem types in South Africa: threats and protection

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Ecosystem threat status (ETS) and ecosystem protection levels (EPLs) are headline indicators that can assess freshwater ecosystems at a country-wide scale. A spatial layer of freshwater, inland wetland ecosystem types of South Africa was combined with a range of spatial data sets to model their ecological condition. The ETS and EPL of each ecosystem type were determined using the area of that type in good ecological condition relative to a biodiversity target, which represented 20% of the total area of that ecosystem type. Thresholds were applied to distinguish four ETS categories ranging from Least Concern to Critically Endangered, and four EPL categories ranging from Not Protected to Well Protected. A total of 79% of the 135 of South African inland wetland ecosystem types were found to be threatened, of which 83 (62% of the number of types) are Critically Endangered, 12 (9%) are Endangered, 12 (9%) are Vulnerable and 28 (21%) of Least Concern. Of the 135 inland wetland types, 61% were Not Protected, with 6% being Well Protected, 3% Moderately Protected, and 30% Poorly Protected. Protected and Ramsar sites hosted only 7% of the total area of inland wetlands, which means that the Aichi Biodiversity Target 11 for 2020 (17%) was not met.

Keywords: biodiversity targets, ecological condition, ecosystems of conservation concern, freshwater ecosystem types, hydrogeomorphic units, inland aquatic ecosystems, top-down biodiversity assessment

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Introduction

Globally, the monitoring and reporting of changes in freshwater ecosystems at country-wide to global scales remains challenging, particularly for wetlands that are naturally dynamic ecosystems. Inland wetlands are globally considered the most threatened of the five Global Ecosystem Typology realms (Keith et al. 2022), with losses far exceeding those of forests (Díaz et al. 2019). Regardless, many countries lack wetland inventories to determine conservation targets and have no monitoring system to inform on the changes and trends in the ecological condition of wetlands. According to the 2018 United Nations (UN) synthesis report on the SDG Goal 6 targets, only 38 (or 19.5%) of the 195 countries in the world, or 20% of the 193 member states, had national datasets of wetlands (UN 2018). A total of 188 (94%) of the countries relied on Tier 1 data, derived from coarse-level, remotely sensed images for reporting the extent of large, open water, lacustrine wetlands (UN 2018). The results showed under-representation of the lacustrine wetland biome; no reporting of the palustrine wetland biome to the SDG sub-indicator 6.6.1a; and a poor representation of wetland biodiversity and monitoring thereof, globally. Further, information on the threat and protection status of wetland ecosystems at regular intervals is required for planning, management and monitoring of trends.

Two global indicators have been used to date for monitoring trends in changes to freshwater ecosystems. The Aichi Biodiversity Target 11 was originally used as an indicator to assess the protection of ecosystems, aimed at securing 17% of the extent of inland waters by 2020 (CBD 2016). However, with insufficient inventories, it was not clear whether countries had attained the target. More recently, the SDG indicator 6 track was used to ascertain changes in the areal extent of lacustrine and palustrine wetlands as one of four sub-indicators of SDG 6.6.1a (UN 2020). To date, only changes in larger lacustrine wetlands have been detected in global datasets such as the Global Surface Water products (Pekel et al. 2016), that were used for reporting on the SDG 6.6.1a targets. This dataset showed an under-representation of 87% for lacustrine and palustrine wetlands in South Africa (Van Deventer 2021). Significant efforts are required to improve the reporting and tracking of changes in inland water biodiversity by 2030, for reporting on the new targets of the Kunming-Montreal Global Biodiversity Framework, which aim to conserve 30% of each of the inland water ecosystem types (CBD 2021).

Complementary to these global monitoring efforts, a bottom-up approach to monitoring and reporting of changes in ecosystems is also facilitated through the International Union for the Conservation of Nature (IUCN) Red List of Ecosystems (RLE), guidelines using criteria to determine an ecosystem's status (Bland et al. 2017). Criteria include whether an ecosystem or habitat is range-restricted, shows trends of decline in extent, or changes in biotic and abiotic processes. The resultant threat status categories are analogous to the red listing of species, ranging from Least Concern (LC), Vulnerable (VU), Endangered (EN), Critically Endangered (CR), to Collapse (CO). This approach tends to support the listing of ecosystems that are easy to define and spatially delineate, and provides a focus on those with a restricted extent and which show unique species associations and abiotic processes. However, many wetlands show similar functionality in the larger landscape, with comparable floral species compositions at a landscape scale, and in addition, palustrine wetlands may be habitats to faunal species that are generalist in the landscape and not restricted to the aquatic habitats of lacustrine wetlands (see for example Van Deventer et al. 2021). This bottom-up approach therefore runs the risk of overlooking many changes in wetland ecological condition, ecosystem status and protection levels at a country-wide scale. A gap therefore exists to enrich a global top-down assessment with the detail of the red listing bottom-up approach.

South Africa undertakes a National Biodiversity Assessment (NBA) of the coastal, estuarine, freshwater, marine and terrestrial realms approximately every five to seven years (Skowno et al. 2019). Two headline indicators, the ETS and EPLs, are used for the consistent assessment of ecosystem status and protection levels across these realms. This paper demonstrates the steps that were taken at a desktop level in Geographical Information Systems (GIS), to determine the ETS and EPL of South African inland wetlands. South Africa's freshwater conservation goal was agreed through an inter-departmental, cross-sector policy development process (Roux et al. 2006, p x), stating that the intent was 'to conserve a sample of the full variety or diversity of inland water ecosystems that occur in South Africa, including all species as well as the habitats, landscapes, rivers and other water bodies in which they occur, together with the ecosystem processes responsible for generating and maintaining this diversity, for both present and future generations.' This target was therefore applied in the assessment of the ETS, with the ecological condition informing both the ETS and EPL assessment. The intent was to provide methods and procedures that can be implemented in other countries with a lack of inventories and monitoring for the continuous assessment of the status and protection of their wetlands.

Material and methods

Workflow process of determining the status of ecosystems in South Africa

The overall workflow steps taken to determine the ETS and EPL of South Africa's wetland ecosystem types are based on the work of the South African National Biodiversity Institute (SANBI) and United Nations Environment Programme–World Conservation Monitoring Centre (UNEP–WCMC) (2016), include:

(i) Mapping the spatial extent of the ecosystem types: for the freshwater component of the NBA 2018, this included lines for rivers and polygons for inland wetlands (Figure 1);
(ii) Determining the ecological condition of each wetland polygon as standardised categories; and
(iii) Determining the proportion of each ecosystem type relative to a biodiversity target and a set of thresholds for the ETS and EPL.

The following subsections provide more information on these steps applied to the South African inland wetlands.

Update of the South African National Wetland Map and inland wetland ecosystem types

The South African National Water Act (Act 36 of 1998; RSA 1998, p 18) defines 'wetlands' 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'. Wetlands occur in both the estuarine and freshwater aquatic ecosystems, defined as 'an ecosystem that is permanently or periodically inundated by flowing or standing water, or which has soils that are permanently or periodically saturated within 0.5 m of the soil surface' (Ollis et al. 2013, p 1). In the *Classification System for Wetlands and other Aquatic Ecosystems in South Africa* (Ollis et al. 2013, p 1), wetlands are defined as 'an area of marsh, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed ten metres'. Similarly, the Ramsar definition of wetlands is 'areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres' (Ramsar 2007, p 1).

The *Classification System for Wetlands and other Aquatic Ecosystems in South Africa* (hereafter '*Classification System*') offers a conceptual framework for the classification of the ecological diversity of inland wetlands, using a tiered level approach as previously described in detail in Van Deventer et al. (2016), and shortly listed here as a combination of (a) broad bioclimatic regions or the 'regional setting' at Level 2, and (b) functional diversity represented at Level 4A using hydrogeomorphic units. For the assessment of wetlands in the NBA 2011 (Driver et al. 2012; Nel and Driver 2012), ecosystem types were classified based on a combined approach of classification by expert, manual methods and modelling (previously reported in Van Deventer et al. 2016). The representation of the inland wetland ecosystem types was improved in preparation for the NBA 2018 in several ways, resulting in National Wetland Map version 5 (NWM5) (Van Deventer et al. 2018, 2020). Commission errors resulting from remote sensing classification were removed; new fine-scale datasets were incorporated; additional wetlands were captured for focus areas; hydrogeomorphic units were

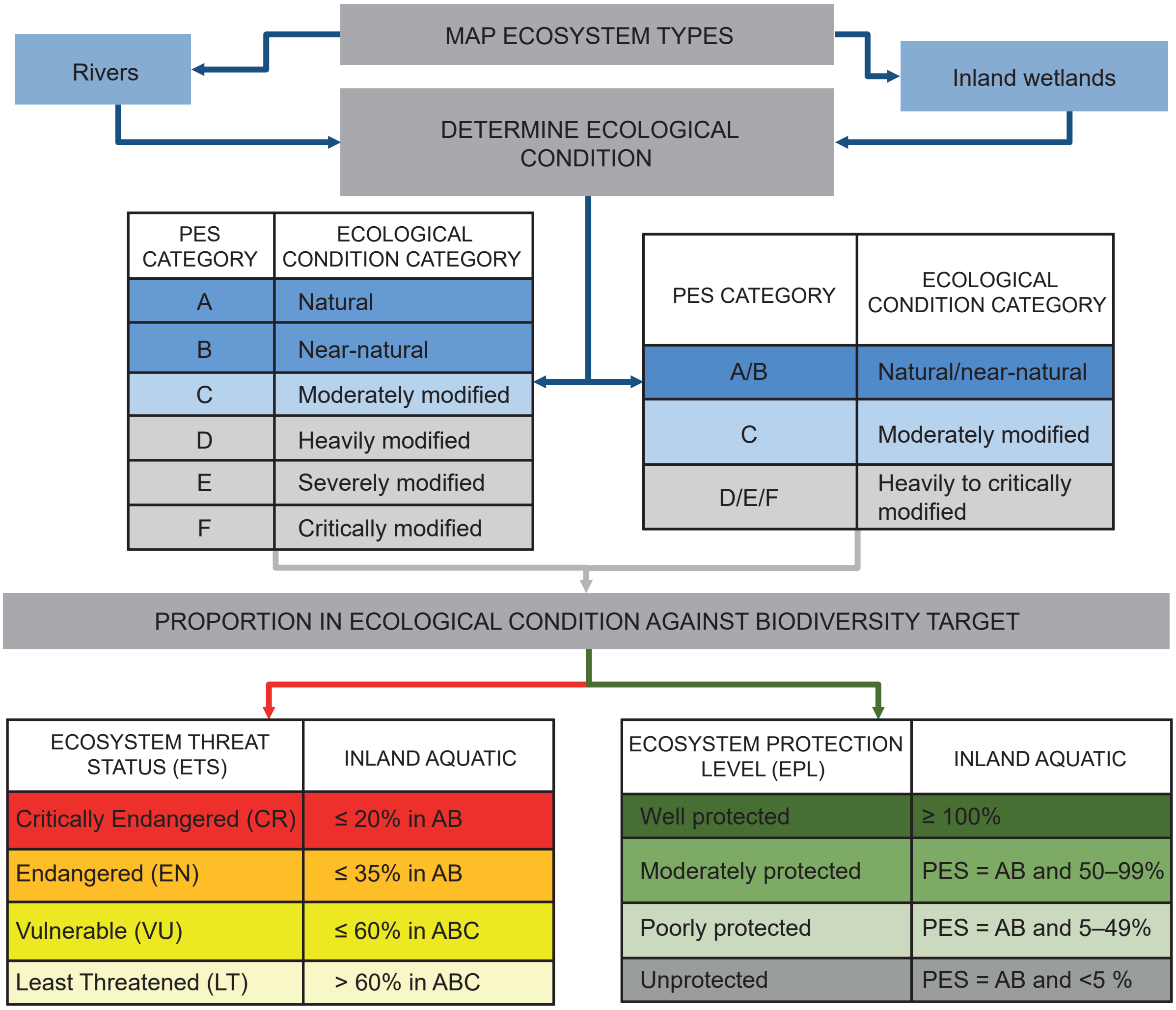

Figure 1: Steps to evaluate the categories of Ecosystem Threat Status (ETS) and Ecosystem Protection Level (EPL) for South Africa's inland aquatic ecosystems as used in the South African National Biodiversity Assessment of 2018

captured at a fine scale; artificial wetlands were extracted to a separate layer; and inland wetlands were better aligned with the extent of estuaries mapped for the NBA 2018 (Van Niekerk et al. 2019).

In addition to the improvements of the polygon extent and hydrogeomorphic units, the representation of the regional setting of wetlands were also improved, using updated bioregions from the National Vegetation Map of 2018 (Dayaram et al. 2019). Aquatic categories, such as azonal depressions of the National Vegetation Map 2018, were subsumed into adjacent vegetation types. Several other bioregions were also subsumed into adjacent bioregions, similar to the wetland vegetation types (Nel et al. 2011a; 2011b). These included the Alluvial Vegetation, Azonal Forests, Inland Saline Vegetation, and Zonal and Intrazonal Forests bioregions. Most of these bioregions are comparable to those published in Mucina and Rutherford (2006), except for the Eastern Strandveld (23 polygons extending over 1 375 ha where no wetland polygons have been mapped) and Seashore Vegetation (877 polygons extending over 42 067 ha containing 37 wetland polygons of 787 ha) which were new additions that are both thinly distributed on the coast.

The updated *Classification System* uses six hydrogeomorphic units, namely depressions, channelled valley-bottom wetlands, floodplains, seeps, unchannelled valley-bottom wetlands and wetland flats. Using imagery at a desktop level for classifying polygons as one of these six units, posed challenges in distinguishing the channelled and unchannelled valley-bottom wetlands from one another, since channels may be overgrown with vegetation or artificially introduced. Similarly, distinguishing depressions and wetland flats from one another is impossible at a desktop level, and would require on-site hydrological studies to accurately represent the hydrogeomorphic unit. Consequently, these hydrogeomorphic units were aggregated and only four hydrogeomorphic units were used for the NBA 2018, namely depressions, floodplains, seeps and valley-bottom wetlands.

The combination of 37 vegetation bioregions and the four amalgamated hydrogeomorphic units resulted in 148 potential inland wetland ecosystem types.

Modelling the ecological condition of inland wetland ecosystem types

After the delineation of ecosystem types, the ecological condition of the ecosystems was determined (SANBI and UNEP-WCMC 2016). While South Africa is in the process of establishing a National Wetland Monitoring System (Wilkinson et al. 2016), ideal sites for monitoring remain to be identified for implementation. Several frameworks guide the assessment of the ecological condition of wetlands at a fine-scale level (e.g., MacFarlane et al. 2009; 2020), yet many of these require infield validation, which has not occurred extensively and consistently across the country. Therefore, the ecological condition of the NWM5 polygons had to be modelled using GIS.

Ecological condition categories used

Six broad ecological categories called the 'Present Ecological State' (PES) categories have been defined for aquatic ecosystems by Kleynhans et al. (2005) and implemented by the South African Department of Water and Sanitation (DWS). These categories range from A to F, where an A&B category is regarded as a natural or near-natural ecological condition, and an F category is a system heavily to severely or critically modified (Figure 2). The DWS categories are based on pressures on ecosystems (Table 1), which were made from a review of literature and historic in-field and modelled desktop assessments (Kleynhans and Louw 2007), while noting that impact can only be verified in the field. Impacts may vary because of the type, magnitude, and duration of the pressure, as well as the ability of a system to recover from the impact (Table 1). The ecological condition of inland wetlands followed the DWS PES categories too, describing the degree of wetland modification compared to its natural condition (ecological category 'A') by humans (Nel and Driver 2012). An integration of the DWS PES categories, and those of the IUCN was done for the NBA 2018 to ensure cross-realm alignment in reporting.

In the absence of field survey data for inland wetlands, the ecological condition of inland wetlands had to be modelled, similar to the NBA 2011 (Nel and Driver 2012). Given the high uncertainty in the modelling of the ecological condition of inland wetlands at a country-wide scale, some PES categories were grouped, leaving three main categories as 'A/B', 'C' and 'D/E/F' (Table 1). These refer to the three associated ecological conditions, namely 'natural or near-natural', 'moderately modified', and 'heavily to severely/critically modified'.

Ideally, inland aquatic ecosystems of high integrity or in a natural to near-natural ecological condition should be selected for the purposes of conserving biodiversity. These natural ecosystems tend to be more self-sustaining, requiring less conservation management. The cost of rehabilitating rivers or inland wetlands in good condition is also lower than the cost of rehabilitating modified systems, and the likelihood of success is greater. Ecosystem types that are at risk of collapse (see definition in Bland et al. 2017) are identified as Not Protected or Poorly Protected (termed 'highly threatened and unprotected types'). Therefore, in the assessment of the ETS and EPL, only inland wetland ecosystem types in a natural to near-natural ecological condition were considered.

Steps to model the ecological condition of inland wetland ecosystem types

The use of the minimum percentage natural land cover within the wetland and buffers outside the wetland (50, 100 and 500 m), was developed in the NBA 2011 and reported by Nel and Driver (2012) and Van Deventer et al. (2016). This method was adopted for the NBA 2018 using the 2014 land cover dataset developed by GeoTerraImage Pty Ltd (GTI 2015) to extract the natural land cover for the three buffer regions. Additional ancillary datasets (Table 2) were incorporated to model the ecological condition of inland wetlands not previously available. These included the use of the river ecological condition as monitored by the Department of Water and Sanitation (line dataset): active and abandoned mines (point dataset); waste-water treatment works (WWTW, point dataset); aquaculture facilities (point dataset); roads and railways

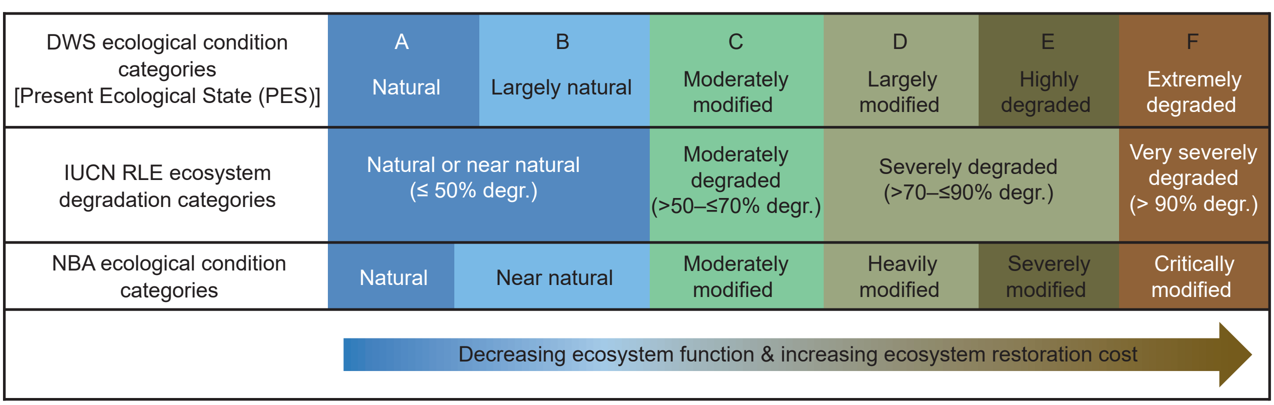

Figure 2: The ecological condition categories used in the National Biodiversity Assessment of 2018 (NBA 2018), showing the original Present Ecological State (PES) categories used by the South African Department of Water and Sanitation (DWS) framework in the top row, with the letters A–F applied to rivers, inland wetlands and estuaries. The second row reflects the International Union for Conservation of Nature (IUCN) Red List of Ecosystems (RLE) approach of percentage degradation of ecosystems or percentage disruption of biotic processes used by the terrestrial realm and the aligned categories and terms used for the NBA 2018

(line dataset); artificial wetlands or dams (polygon dataset); and desiccated or burning peatlands (point and polygon dataset). Since the ancillary data was mostly captured at a finer scale compared to the land cover data, the ecological condition of wetland polygons that coincided with the ancillary data was first used to determine the PES categories of relevant inland wetland polygons. Thereafter, the ecological condition of the remaining wetland polygons was assigned PES categories using the minimum percentage land cover within the four zones (Table 2). Skowno et al. (2019) captured secondary fields from historical topographical maps; which are old crop fields that were abandoned and no longer under cultivation. The extent of secondary fields was erased from the natural land cover categories extracted. The remaining natural land cover was reclassified to natural (including 'Natural' and 'Open water – natural'; code 1) or transformed (code 2) classes. The percentage natural land cover for each wetland within the different buffer regions around it was then calculated as a percentage of the total natural and transformed pixels for each buffer zone. The zone with the smallest percentage of natural land cover was then used to determine the PES categories, similar to NBA 2011 (Nel and Driver 2012; Table 2), to allow for pressures that have a small spatial footprint but large impact on wetland ecological condition, which are common to wetlands in South Africa.

Calculating the Ecosystems Threat Status (ETS) for inland wetlands

In this step, the total areal extent of each inland wetland ecosystem type in a good ecological condition (natural or near-natural), relative to the biodiversity target set for the ecosystem type, were assessed.

Biodiversity targets used

A biodiversity target is considered '(t)he minimum proportion of each ecosystem type that needs to be kept in a good ecological condition in the long term in order to maintain viable representative samples of all ecosystem types and the majority of species associated with them. Expressed as a percentage of the historical extent of an ecosystem type (measured as area, length or volume). For species: The minimum number of occurrences or populations that need to be kept extant (ideally with some form of protection) in order to ensure the persistence of the species, or the minimum amount of suitable habitat that needs to be kept in good ecological condition in order to ensure the persistence of a minimum viable population of the species.' (SANBI 2016, p 45). For ecosystems, it is the minimum extent of each ecosystem type that should remain in a natural or near-natural ecological condition. Owing to insufficient available data for determining ecologically differentiated targets, a wide range of stakeholders from related sectors agreed on a negotiated biodiversity target of 20% for inland aquatic ecosystems at a workshop held in 2006, which was subsequently written into water protection policy (Roux et al. 2006; Nel et al. 2011a; 2011b).

Ecosystem Threat Status (ETS) categories used

ETS is a key indicator of the degree to which South Africa's ecosystems are still intact, or alternatively losing vital aspects of their structure and functioning. Thresholds for determining the ETS categories were developed during the NBA 2011 (Nel and Driver 2012), and based on the use of the biodiversity target and incremental increases from this target (Table 3). These categories remain consistent with those from the updated guideline for the red list of ecosystem categories of Bland et al. (2017) where the

Table 1: Description of ecological categories and associated ecological conditions for inland wetland ecosystems. DWS = Department of Water and Sanitation

DWS ecological category	Description of ecological conditions	Examples
A/B	Natural or near-natural state with few modifications. A small change in natural habitats and biota may have occurred but the ecosystem functions are essentially unchanged.	Low levels of grazing and infrequent subsistence use of ecosystem services by a small group of people.
C	Moderately modified. A loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged.	Historical ploughing (secondary natural); grazing, water abstraction; land uses which have limited impact on dominant water supply; artificial wetlands, transport infrastructure (connecting communities or cities) or weirs in large systems (hypothetically > 500 ha). Water quality impacts in large systems. Persistent use of ecosystem services.
D/E/F	Heavily to severely/critically modified. A large loss of natural habitat, biota and basic ecosystem functions have occurred and may have reached a critical level and the system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances, the basic ecosystem functions have been destroyed and the changes are irreversible.	Waste Water Treatment Works (WWTWs) within 500 m from an active or abandoned mine; large dams (up or downstream); canals; overgrazing; invasive species, peatlands burnt, medium to high water abstraction; land uses which impact the water supply; artificial wetlands; transport infrastructure or weirs in small (hypothetically ≤ 500 ha) systems. Water quality has been severely affected, particularly in small systems, fragmented isolated systems which had previously been part of clusters or linear systems.

Table 2: Selected pressures and associated spatial data and thresholds used to model the ecological categories of inland wetlands. PES = Present Ecological State; WWTW = Waste Water Treatment Works

Pressure dataset	Motivation and selection criteria	Number (and percentage of the total number) of inland wetlands affected	Modelled ecological category
Rivers in poor condition	The condition of an inland wetland is influenced by the hydrological regime and water quality of the river feeding the inland wetland. Select inland wetlands which intersect rivers with a PES scored of D, E or F.	3 306 (2.2%) 990 042.8 ha (37.4%)	D/E/F
Active and abandoned mines	Inland wetlands within 500 m from an active or abandoned mine would have experienced chemical and sediment pollution through air, surface run-off, interflow and groundwater sources. The land cover 2014 dataset includes some mines, however, adjacent fields and wetlands/water bodies were coded as natural based on the land cover dataset, but may be situated within 500 m from the adjacent mine infrastructure. Ancillary data is therefore important to supplement the land cover dataset. This excludes salt mines in the arid regions since these were not properly represented by the dataset.	1 846 (1.3%) 438 378.7 ha (16.5%)	D/E/F
WWTW	The condition of an inland wetland is affected by both the volume of water effluent of the WWTW as well as the water quality of the WWTW. Where an inland wetland is within 500 m downstream of a WWTW.	284 (0.2%) 134 531.4 ha (5.1%)	D/E/F
Aquaculture facilities	Inland wetlands within 500 m downstream of aquaculture facilities were assumed to be at risk of nutrient pollution, chemical pollution, parasites or escapees. Inland wetlands up and downstream of such facilities were therefore selected and assigned a PES score.	37 (0.03%) 4 740.1 ha (0.2%)	D/E/F
Roads and railways	Roads and railways affect both the hydrological regime of inland wetlands as well as water quality. Often highways have sufficient culverts to minimise the impact on hydrology, however, other roads will still impact the water quality of inland wetlands. All roads which intersected inland wetlands are expected to modify the natural condition of inland wetlands. In wetlands > 500 ha the impacts were assumed to be less compared to smaller wetlands.	> 500 ha; 536 (0.4%) 1 279 005.6 ha (48.3%)	C
	Where a wetland was ≤ 500 ha, the impact was assumed to be severe. Natural vegetation is removed to an extent up to 60 m for road access, construction and the road reserve. This amounts to at least 1/3 (0.36%) of a wetland of 100 ha to be impacted, and up to 10% for a wetland of 500 ha.	≤ 500 ha; 16 136 (11%) 634 581.8 ha (23.9%)	D/E/F
Artificial wetlands or dams	Instream dams modify the flow of inland wetlands. The impact depends on the height and type of structure of a dam wall. An assumption was made that large dams with concrete structures, as listed in the dams register, affect rivers more than wetlands, and that farm dams are more often found instream of inland wetlands, both valley-bottom, floodplains, seeps and depressions. These dam walls can, however, be easily breached and therefore their impact is more minimal, compared to the dams built in rivers.	16 413 (11.2%) 1 627 861.2 ha (61.4%)	C
Inland wetlands which have become desiccated or burnt since 1996	A total of 17 inland wetlands, identified by wetland experts, have become desiccated or burnt since 1996. The hydrological regime of these systems has been altered to such a degree, that both the substrate and above-ground biomass have been destroyed and therefore altered severely from its original state. Of the 17 sites, two were located within an estuarine functional zone (EFZ) and two sites were only added after the condition, ecosystem threat and protection level assessments have been completed. These include sections of the Lajuma Wetland in the Limpopo province, where the ecological condition was modelled to be in an A/B ecological category at the time of the assessment, and a section of the Onrus Peatland, caused by the Betty's Bay fire in January 2019, where the ecological condition was modelled in a D/E/F ecological category.	8 (0.005%) 13 354.1 ha (0.5%)	D/E/F
Percentage remaining land cover	If the minimum percentage land cover within the wetland or within the 50, 100 or 500 m buffer zones of an inland wetland is predominantly natural (≥ 75%), the inland wetland is presumed to be in a good condition.		A/B
	If the minimum percentage land cover within the wetland or within the 50, 100 or 500 m buffer zones of an inland wetland is mostly natural (> 25% and < 75%), the inland wetland is presumed to be in a fair condition.	117 990 (80%) 544 668 ha (20.6%)	C
	If the minimum percentage land cover within the wetland or within the 50, 100 or 500 m buffer zones of an inland wetland is predominantly transformed (≤ 25%), the inland wetland is presumed to be in a poor condition.		D/E/F

CR, EN and VU are 'threatened' categories. The original thresholds for ETS categories were adopted for inland wetlands as follows (derived from Nel and Driver 2012):

- Critically Endangered (CR): Owing to insufficient data in determining ecologically differentiated targets, the biodiversity target was set to 20% for inland aquatic ecosystems (Nel and Driver 2012). A river or inland wetland ecosystem type was thus considered CR if less than 20% of its total length or spatial extent is in good condition (A or B ecological category, or natural to near-natural according to the NBA 2018 terms).
- Endangered (EN): Set as the CR threshold plus an additional buffer of 15% of the spatial extent of that ecosystem type. Thus, river and inland wetland ecosystem types with 20–35% of their total extent in a good condition (A or B ecological category, or natural to near-natural according to the NBA 2018 terms) were classified as EN.
- Vulnerable (VU): A less stringent threshold was set requiring at least 60% of the total extent of the ecosystem type in a good condition OR in a moderately-modified condition (A, B or C ecological category). This threshold acknowledges that moderately-modified rivers and inland wetlands support some biodiversity pattern and ecological functioning, albeit impaired. Here is it recognised that moderately modified wetlands (C ecological category) contribute important ecological functions and can still be restored to a good condition (A/B ecological category) for conservation purposes (Nel et al. 2007).
- Least Concern (LC): An ecosystem type with > 60% of its total extent in a good OR moderately modified (A, B or C ecological category) was classified as LC.

Deriving Ecosystem Protection Levels (EPL) for inland wetlands

Protected areas are crucial for the ecological sustainability of inland wetlands and provide resilience to species and humans against climate change impacts (Nel and Driver 2012). Protected areas may be considered less effective if excessive water abstraction occurs or the incoming rivers are severely impacted upstream of the protected area (Mancini et al. 2005; Abell et al. 2007; Hermoso et al. 2016). Protected areas may result in several benefits within a catchment, serving as a catalyst for effective integrated catchment management (Nel and Driver 2012).

EPLs were assessed by examining the contribution that protected areas make to achieving the biodiversity target of each inland wetland ecosystem type. Protected areas were defined as areas of land or sea that are formally protected in terms of the South African Protected Areas Act and managed mainly for biodiversity conservation. This includes state-owned protected areas (e.g., national parks and nature reserves) and contract protected areas (e.g., private protected areas through, for example, formal biodiversity stewardship) (SANBI 2016). A single integrated dataset of National Protected Areas was collated for NBA 2018 (Skowno et al. 2019; Supplementary Figure S1 and Table S1).

The EPLs of inland wetland ecosystem types were determined by a union overlay process in ArcGIS 10.6 (ESRI 1999–2017) of the ecosystem types in a natural or near-natural (PES = 'A/B') ecological condition and the National Protected Areas. For each inland wetland ecosystem type, the spatial extent was expressed as a percentage of the area required by the biodiversity target, therefore, 20% of the total spatial extent of each ecosystem type (Nel and Driver 2012). Ecosystem types were considered Well Protected if ≥ 100% of the extent of the ecosystem's biodiversity target was met and in a natural to near-natural ecological condition (Table 3). The inland wetland ecosystem types were classified as Moderately Protected if at least 50% of the extent was within the biodiversity target, otherwise it was classified as Poorly Protected if < 50% and Not Protected if < 5%.

Identifying Ecosystems of Conservation Concern and range-restricted types

The results of the ETS and EPL ranking were combined to determine the levels of risk for inland wetland ecosystem types. Inland wetlands that were ranked as CR and NP, were considered as Ecosystems of Conservation Concern that could be prioritised for intervention. Lastly, the inland wetland ecosystem types with a restricted range < 50 ha that could potentially be considered for a bottom-up, red listing of ecosystems approach were considered.

Table 3: Ecosystem Protection Levels (EPLs) with biodiversity targets and ecological condition for inland wetland ecosystem types*. PES = Present Ecological State

EPL	Thresholds applied to inland wetland ecosystems
Well Protected (WP)	Extent (ha) of inland wetland ecosystem types in natural or near-natural ecological condition (PES = A or B) with ≥ 100% of the biodiversity target located within a formal or de facto protected area.
Moderately Protected (MP)	Extent (ha) of inland wetland ecosystem types in natural or near-natural ecological condition (PES = A or B) with between 50 and 99% of the biodiversity target located within a formal or de facto protected area.
Poorly Protected (PP)	Extent (ha) of inland wetland ecosystem types in natural or near-natural ecological condition (PES = A or B) with between 5 and 49% of the biodiversity target located within a formal or de facto protected area.
Not Protected (NP)	Extent (ha) of inland wetland ecosystem types in natural or near-natural ecological condition (PES = A or B) with ≤ 5% of the biodiversity target located within a formal or de facto protected area.

** No known severe impact of a pressure, such as excessive water abstraction or invasive species, which should ideally be known and monitored for the protected area. These cases were downgraded to a lower EPL.*

Results

Number and areal extent of South African inland wetland ecosystem types

Of the 148 possible inland wetland ecosystem types (37 vegetation bioregions and 4 aggregated hydrogeomorphic units) only 135 inland wetland ecosystem types show spatial representation or extent in the spatial data layer, because not all four hydrogeomorphic units are present in each 37 vegetation bioregions (Figure 3a). The Eastern Strandveld Bioregion, for example, with a spatial extent of 1 375 ha and a maximum width of < 1 km along the KwaZulu-Natal coastline, has no inland wetlands mapped (Van Deventer et al. 2019). Vegetation bioregions with large extent (> 8 000 ha) show an above-average percentage (> 2.2%) of inland wetlands (Figure 3b; Table 4). Of these large extent bioregions, the Bushmanland Bioregion has the highest percentage of inland wetlands (4.2%) followed by the Mesic Highveld Grassland Bioregion (3.8%). The South Strandveld Bioregion, a small bioregion on the south coast of the Western Cape, has the highest spatial extent of wetlands (10.6%) of all bioregions (Table 4). Of the smaller-extent bioregions (<1 300 ha), several bioregions show above-average percentage of inland wetland extents, including the East Coast Renosterveld Bioregion in the Western Cape (7.1%), the Southern Fynbos Bioregion (5.5%), the Indian Ocean Coastal Belt (4.8%), Gariep Desert (4.3%) and the Namaqualand Cape Shrublands (3.5%) bioregions (Table 4).

The Mesic Highveld Grassland Bioregion show the largest extent of all four hydrogeomorphic units in comparison to the other vegetation bioregions (Figure 3a). In general, most vegetation bioregions vary in extent of hydrogeomorphic units (Figure 2a and 2b). The majority of the vegetation bioregions are dominated (> 37% of the spatial extent of all inland wetlands in a bioregion) by either depressions or valley-bottom systems (28 of the 37), with fewer dominated by floodplains (6) and seeps in the case of the Sub-Escarpment Grassland Bioregion (Table 4; Figure 4).

Ecological condition of inland wetland ecosystem types of South Africa

The number of inland wetland polygons which are affected by various pressure datasets are indicated in Table 2 as a total of the maximum number of inland wetlands mapped in NWM5 (147 029 or 2 650 509 ha). Of these, the ecological condition for the majority of wetland areas (>2 million ha or 79% of the extent) has been modelled through ancillary data, whereas only 21% of the extent had ecological categories assigned based on the minimum percentage of land cover.

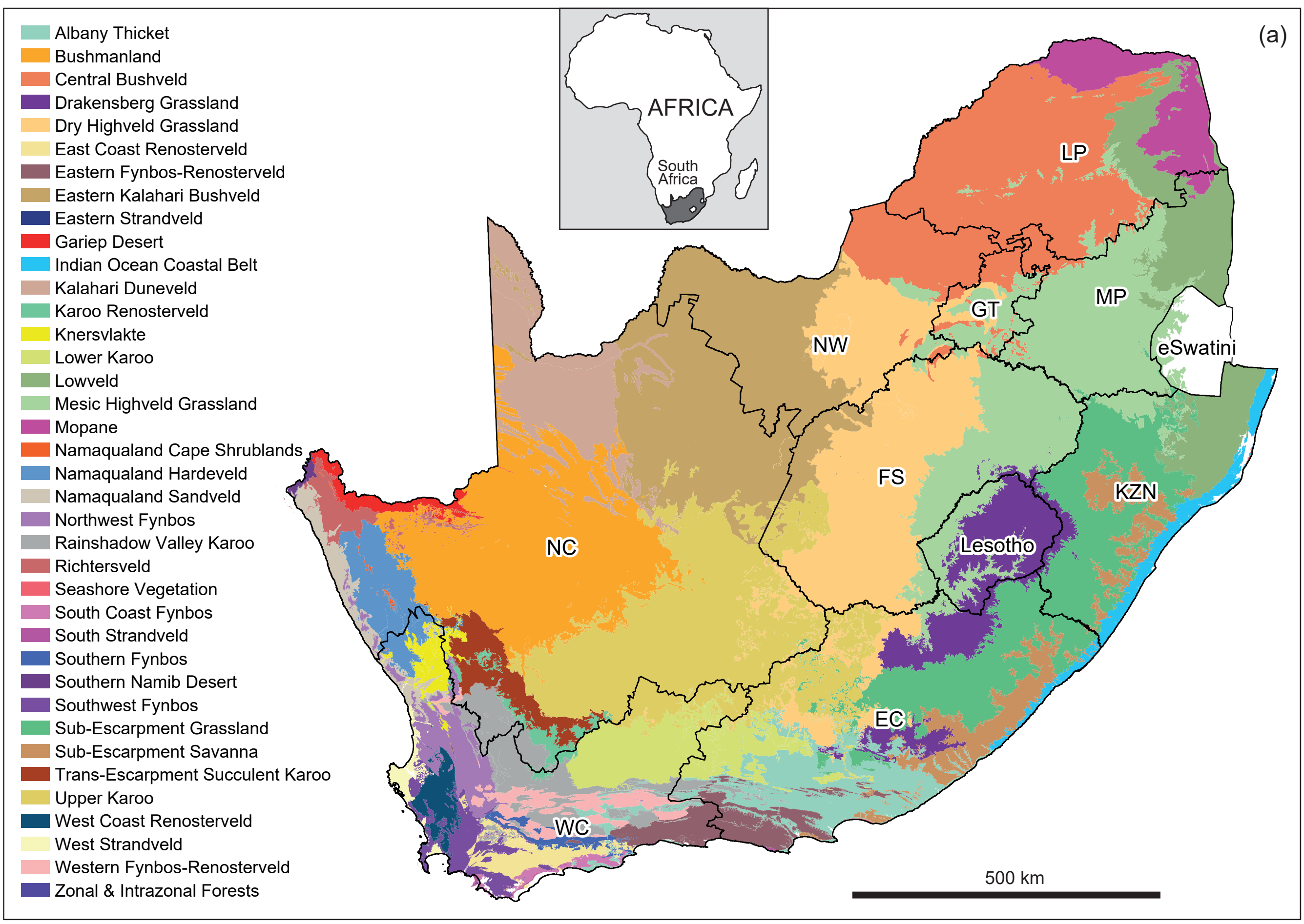

Figure 3(a): The spatial distribution of vegetation bioregions in South Africa

The majority of inland wetlands are in a poor ecological condition with 68% of the total spatial extent categorised as an ecological category 'D/E/F', heavily to severely/critically modified (Figure 5a and 5b). Less than 15% of the inland wetlands are in a natural to near-natural ecological condition ('A/B') whereas 17% of the inland wetlands show their ecological condition to be moderately modified ('C').

A comparison between the ecological condition across hydrogeomorphic units show that depressions have the highest percentage of systems in a natural to near-natural ecological condition (35%; Supplementary Table S2). The other hydrogeomorphic units show that < 15% of their extent are in a natural to near-natural ecological condition. In fact, > 64% of all the hydrogeomorphic units are largely to critically modified, except depressions (41%). Floodplains show the lowest percentage of inland wetland ecosystems in a natural to near-natural condition (1.7%) and are found to be the most transformed (91%).

Geographically, the ecological condition of inland wetlands within and around the metropoles are largely transformed ('D/E/F'), as well as those regions where crops are cultivated (irrigated and dryland) in the Gauteng, KwaZulu-Natal, Mpumalanga, North West and Western Cape provinces (Figure 5a). Inland wetlands in the more arid Eastern

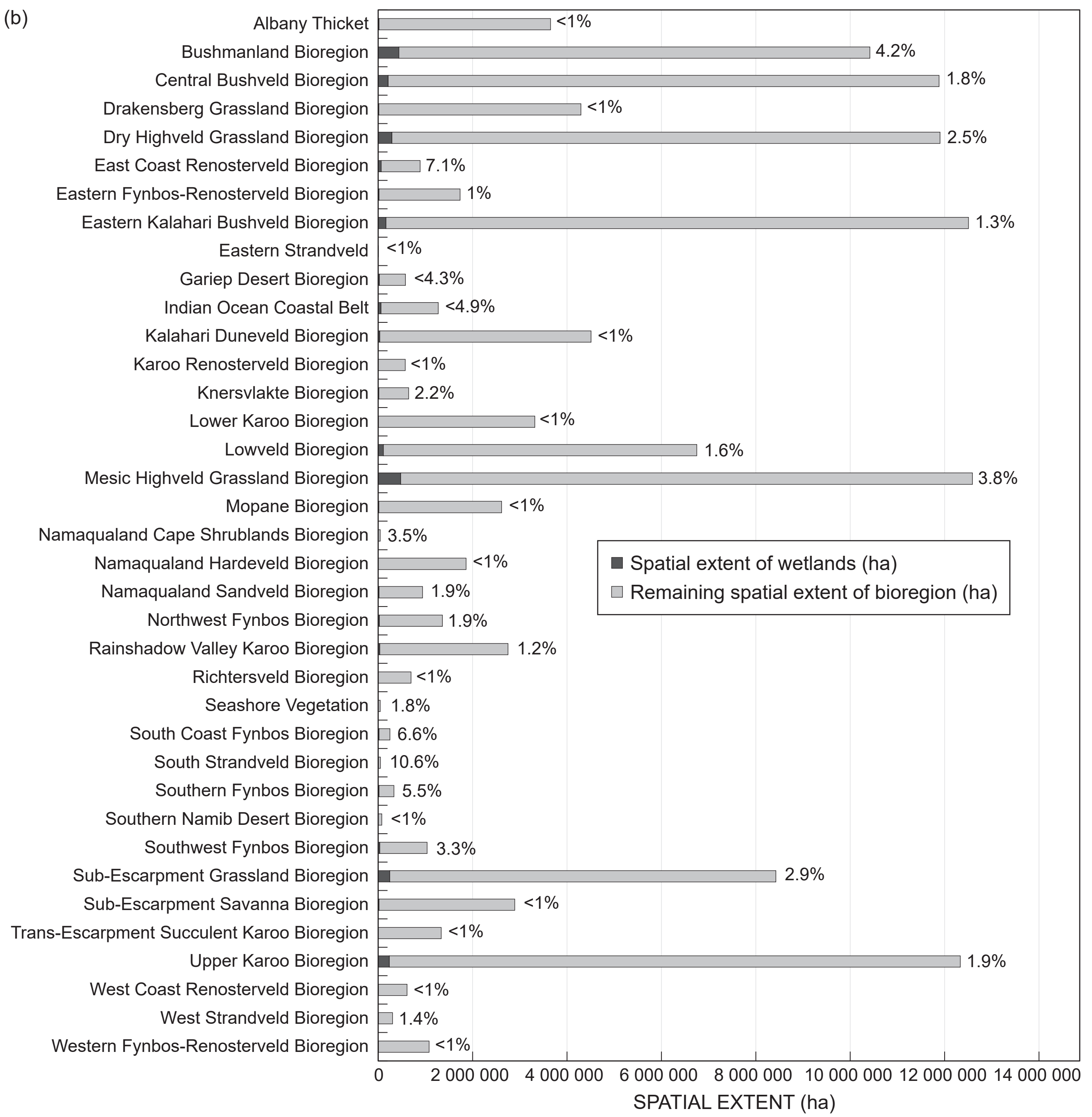

Figure 3(b): The extent of wetlands in each of these bioregions shown in hectares

Table 4: Percentage of the spatial extent of inland wetlands per bioregion

Wetland bioregion	Extent of bioregion	Spatial extent of wetlands (ha)	Percentage of area represented by wetlands
Albany Thicket	3 652 579.1	18 760.0	0.5
Bushmanland Bioregion	10 418 121.6	438 327.3	4.2
Central Bushveld Bioregion	11 881 131.0	213 874.6	1.8
Drakensberg Grassland Bioregion	4 297 538.7	14 875.6	0.3
Dry Highveld Grassland Bioregion	11 906 072.9	293 395.6	2.5
East Coast Renosterveld Bioregion	890 634.8	63 228.4	7.1
Eastern Fynbos-Renosterveld Bioregion	1 734 398.4	16 975.0	1.0
Eastern Kalahari Bushveld Bioregion	12 504 589.6	167 806.0	1.3
Eastern Strandveld	1 375.3	-	-
Gariep Desert Bioregion	578 124.6	24 855.5	4.3
Indian Ocean Coastal Belt	1 273 332.4	61 749.1	4.8
Kalahari Duneveld Bioregion	4 510 605.2	35 478.4	0.8
Karoo Renosterveld Bioregion	575 075.1	2 080.3	0.4
Knersvlakte Bioregion	647 605.4	14 287.6	2.2
Lower Karoo Bioregion	3 320 749.7	4 244.4	0.1
Lowveld Bioregion	6 751 912.2	109 069.0	1.6
Mesic Highveld Grassland Bioregion	12 589 272.6	475 386.8	3.8
Mopane Bioregion	2 615 097.4	12 422.0	0.5
Namaqualand Cape Shrublands Bioregion	41 933.1	1 462.6	3.5
Namaqualand Hardeveld Bioregion	1 861 224.5	1 347.7	0.1
Namaqualand Sandveld Bioregion	938 504.0	17 797.4	1.9
Northwest Fynbos Bioregion	1 360 346.5	25 449.9	1.9
Rainshadow Valley Karoo Bioregion	2 750 571.1	34 086.2	1.2
Richtersveld Bioregion	694 644.3	560.6	0.1
Seashore Vegetation*	42 067.0	787.2	1.9
South Coast Fynbos Bioregion	248 928.4	16 467.0	6.6
South Strandveld Bioregion	46 885.4	4 969.7	10.6
Southern Fynbos Bioregion	336 236.1	18 557.7	5.5
Southern Namib Desert Bioregion	79 108.2	16.3	0.0
Southwest Fynbos Bioregion	1 037 345.1	34 287.4	3.3
Sub-Escarpment Grassland Bioregion	8 427 401.2	244 410.1	2.9
Sub-Escarpment Savanna Bioregion	2 893 842.3	18 367.2	0.6
Trans-Escarpment Succulent Karoo Bioregion	1 334 156.6	2 022.7	0.2
Upper Karoo Bioregion	12 332 362.3	236 551.5	1.9
West Coast Renosterveld Bioregion	610 182.4	4 111.8	0.7
West Strandveld Bioregion	304 629.8	4 354.9	1.4
Western Fynbos-Renosterveld Bioregion	1 078 542.9	4 796.1	0.4

*Wetlands mapped within the Seashore Vegetation zone should be investigated to assess whether these are inland wetlands or estuarine in nature.

Cape, Free State, Limpopo and Northern Cape provinces show less density of inland wetlands, probably a result of underrepresentation of inland wetlands in these areas (low confidence that the extent of inland wetlands has been mapped). The western part of the Free State as well as the Northern Cape provinces show a higher areal percentage of wetlands in a natural to near-natural condition, considering that the ancillary data and land cover data reflect little pressures and transformed land in these provinces.

When the ecological condition of inland wetland ecosystem types is compared amongst the vegetation bioregions, the majority of the ecosystem types (79%) have more than a third of the extent largely to critically modified from natural condition (Supplementary Table S3). Only 30% of the inland wetland ecosystem types have more than a third of their spatial extent still in a good ecological condition. Six ecosystem types show no modification from natural condition (extent is 100% in natural or near-natural ecological condition, DWS ecological category A/B). The Gariep Desert Bioregion Depressions, Kalahari Duneveld Bioregion Seeps, Kalahari Duneveld Bioregion Valley-bottoms, Namaqualand Cape Shrublands Bioregion Floodplains, Richtersveld Bioregion Seeps and Trans-Escarpment Succulent Karoo Bioregion Floodplains, most of which are located in the arid regions where land cover transformation is minimal and the impact of grazing is not represented in the land cover data. In 49 of the 135 inland wetland ecosystem types, > 80% of the extent is largely to critically modified from natural condition, dispersed across the country.

Results for the Ecosystem Threat Status (ETS) of inland wetlands of South Africa

A large proportion of the inland wetland ecosystem types (79%) are threatened (Figure 6). Of South Africa's 135 inland wetland ecosystem types, 83 (62%) are

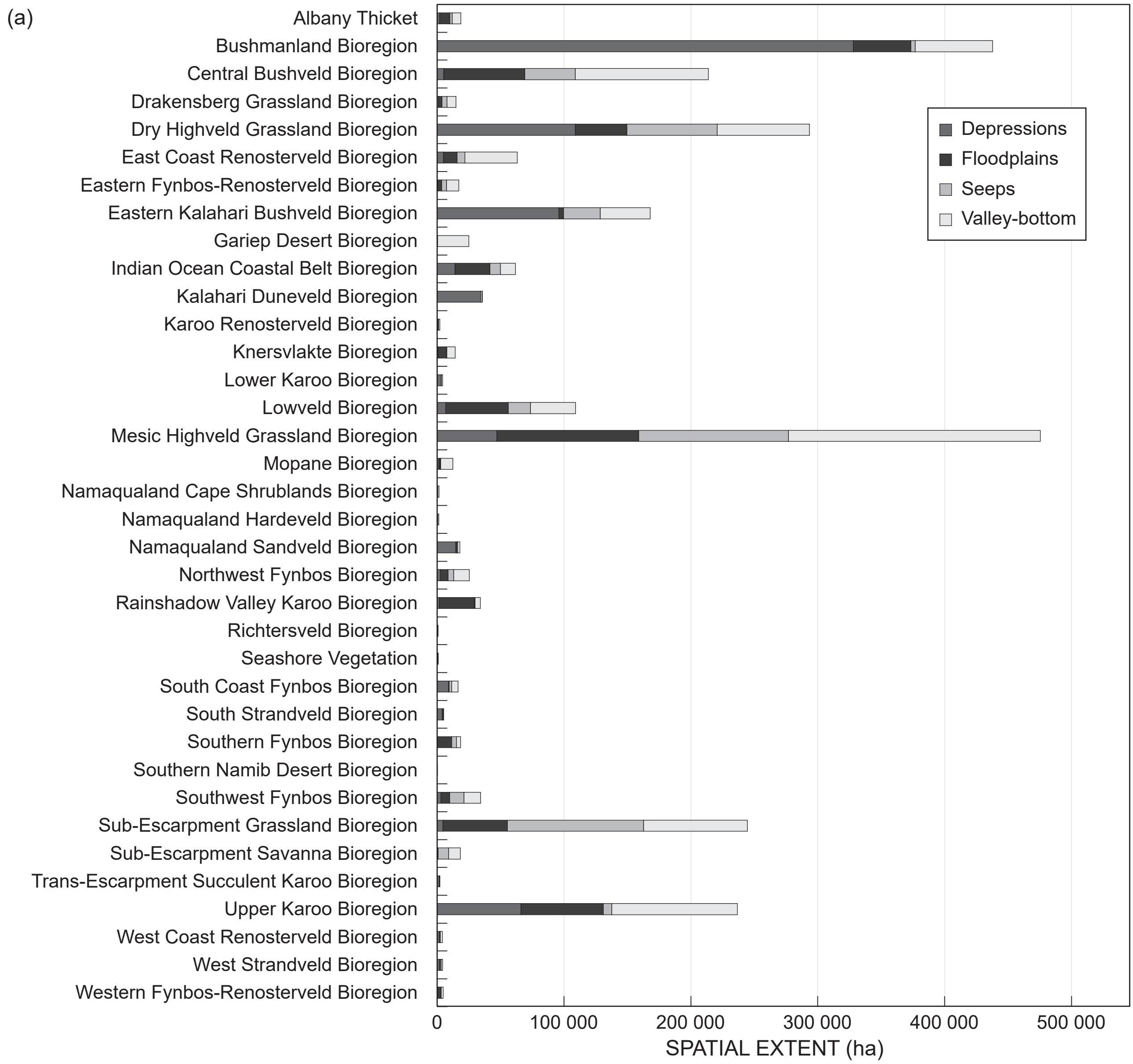

Figure 4(a): Spatial extent (ha) of hydrogeomorphic units across inland wetland ecosystem types used for the South African National Biodiversity Assessment of 2018

CR, 12 (9%) are EN, 12 (9%) are VU and 28 (21%) of LC. Inland wetland ecosystem types in at least four vegetation bioregions are found to be 100% CR, namely the East Coast Renosterveld, Seashore vegetation, West Coast Renosterveld and West Strandveld bioregions (Supplementary Figure S2). In contrast, two vegetation bioregions are classified as LC (100%), namely the arid Lower Karoo and Southern Namib Desert bioregions. In five of the inland vegetation bioregions, a large proportion (≥ 50%) is still of LC, including the Drakensberg Grassland, Karoo Renosterveld, Namaqualand Cape Shrublands, Richtersveld and Trans-Escarpment Succulent Karoo bioregions. Most inland vegetation bioregions are, however, largely threatened, particularly those in the semi-arid regions, as opposed to the arid regions.

More than 93% of the valley-bottom and floodplain hydrogeomorphic units of inland wetlands are threatened, followed by 71% of seeps and 61% of depressions (Supplementary Figure S3b). CR ecosystem types are primarily distributed in large parts of the Gauteng province, the western half of the Mpumalanga, the KwaZulu-Natal provinces, the central parts of the Northern Cape province and the southern part of the Western Cape province (Figure 7). Importantly, an inland wetland ecosystem type can include a range of ecological conditions, while only having a single ETS assigned to it. For example, the Bushmanland Bioregion Depression inland wetland ecosystem type, which includes a large depression called 'Hakskeenpan' in the Kalahari region, has about 16% of the total extent of the wetlands in a natural and near-natural ecological condition (A/B ecological

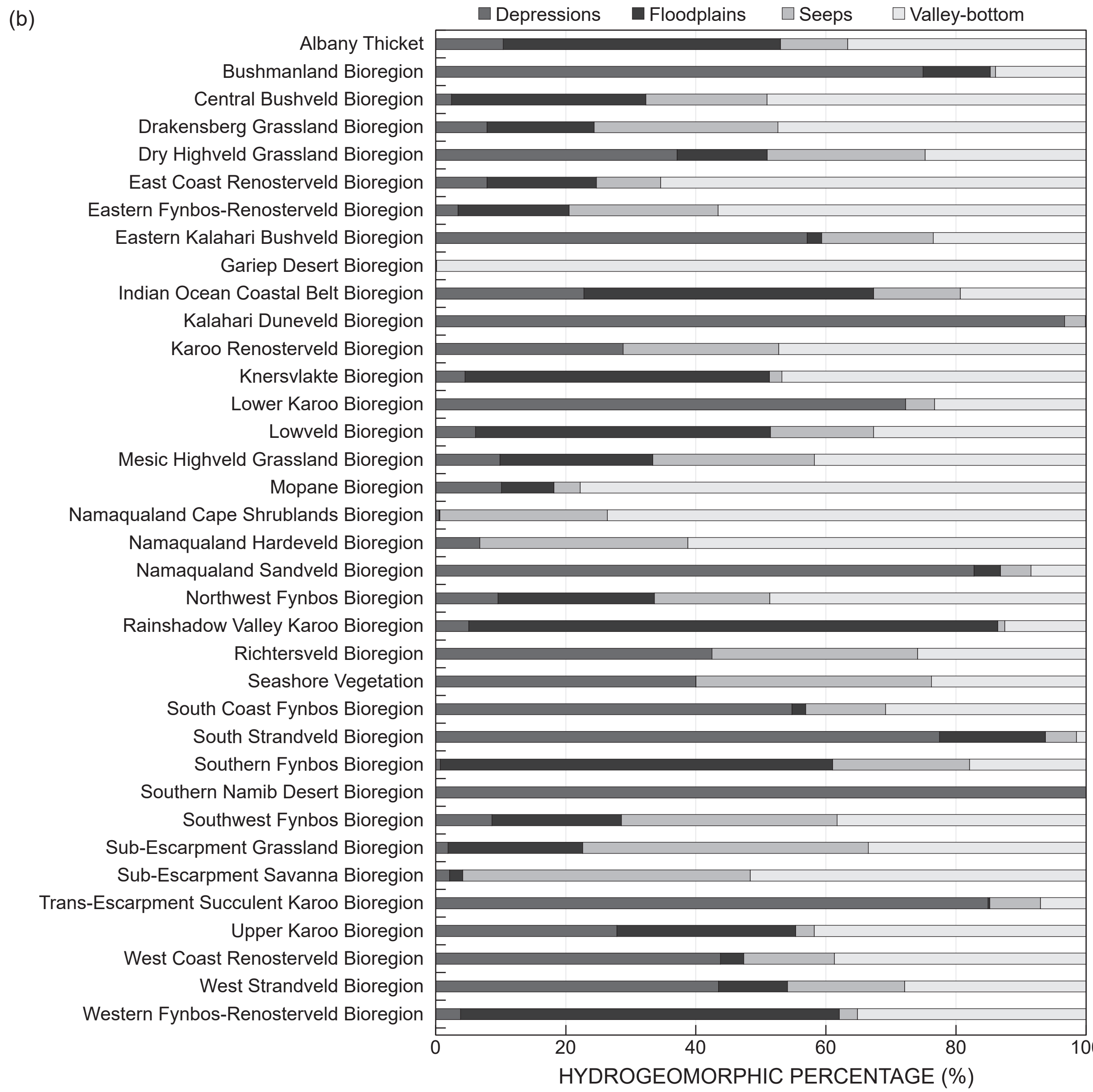

Figure 4(b): Percentage of hydrogeomorphic units across inland wetland ecosystem types used for the South African National Biodiversity Assessment of 2018

category), almost 34% in a moderately modified condition (C ecological category) and 50% in a heavily to severely/critically modified (D/E/F ecological category) ecological condition. The inland wetland ecosystem type is listed as CE based on the percentage of natural and near-natural extent being below the biodiversity target of 20% of the full spatial extent of this inland wetland ecosystem type.

Inland wetland ecosystem types ranked as VU show distributions in between CR and EN ecosystems, most noticeably in the eastern parts of the Mpumalanga and KwaZulu-Natal provinces, the western part of the Free State and eastern part of the Northern Cape provinces, as well as in the western part of the Western Cape. Three provinces show wide distributions of LC ecosystems: the north-western part of the Free State province, the western half of the North West province and the eastern to northern third of the Northern Cape province.

Results of the Ecosystem Protection Levels (EPLs) of inland wetlands

The majority of the inland wetland ecosystem types are Not Protected (60.7% of 135), whereas only 5.9% are Well Protected, 3% Moderately Protected, and 30.4% Poorly Protected. Extensive areas of inland wetland ecosystem types are Not Protected, corresponding to regions where the inland wetlands show to be CR. Well Protected wetland ecosystem types are particularly scarce in the eastern part of the Mpumalanga province, the

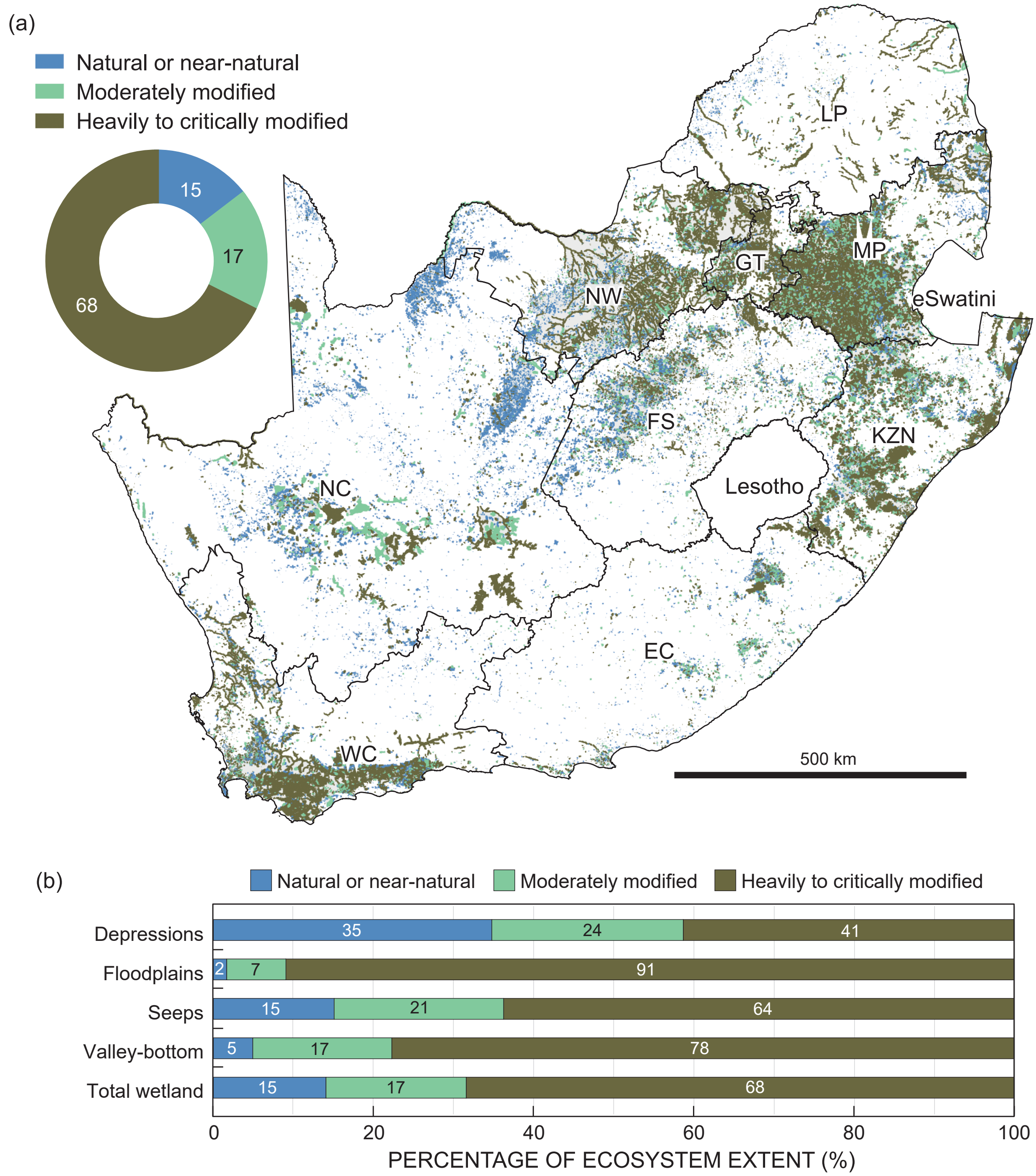

Figure 5: Ecological condition of the inland wetlands of South Africa. (a) The extent of inland wetlands within each ecological condition class with outlines around the polygons of inland wetlands accentuation (0.5 pnts) for visual purposes. (b) The extent of inland wetlands within each ecological condition class expressed as a percentage of the number of hydrogeomorphic units

north-eastern region of the KwaZulu-Natal province and parts of the Western Cape (Figure 8a).

In general, Ramsar sites not overlapping with the formal protected area network added another 936.6 ha (Table 5) of inland wetland extent to the extent of protected areas, totalling 7.4% of the extent of all inland wetlands (irrespective of the ecological condition). The majority (> 78%) of the inland wetlands within the protected area network are in a poor ecological condition within the protected area network and Ramsar sites, with < 1.6% of the extent of the inland wetlands within Ramsar sites estimated to be in a natural or near-natural ecological condition.

A total amount of 180 ha of inland wetlands, in a natural or near-natural ecological condition, is conserved by Ramsar sites that are not within protected areas (Supplementary Table S4). Most of these Ramsar areas protect a total extent of < 10 ha of individual wetland ecosystem types, except the Verloren Vallei Nature Reserve, where the (remaining)

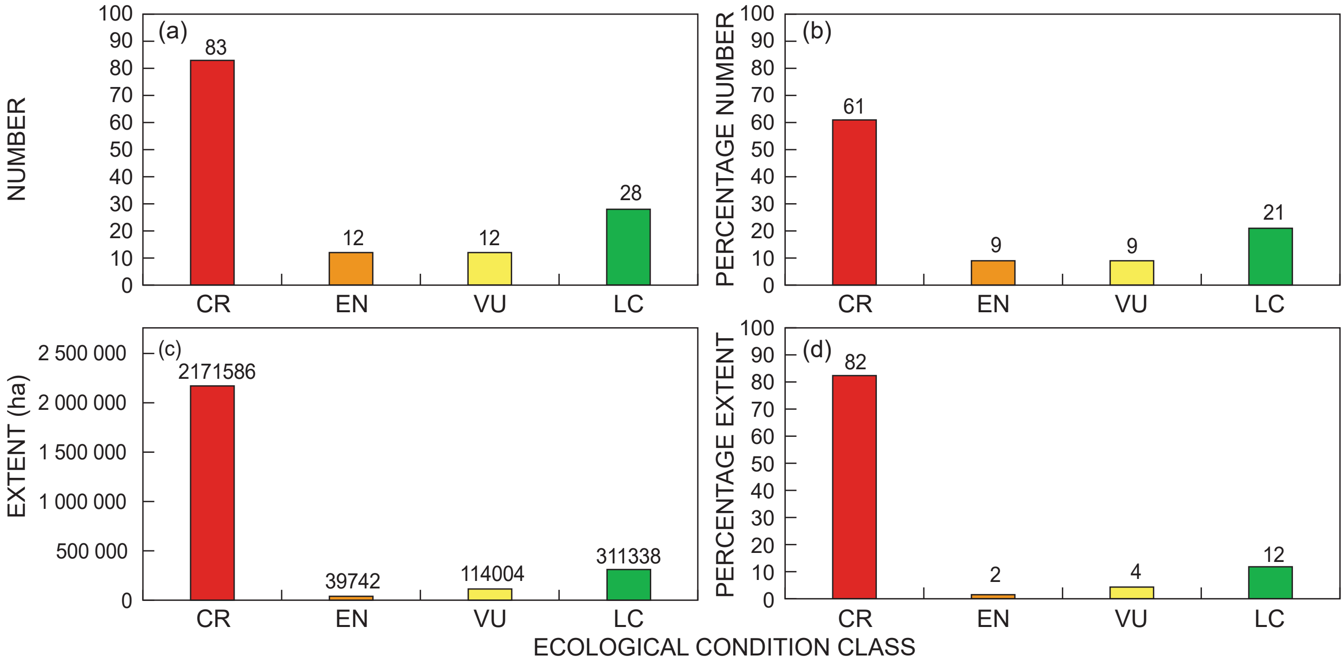

Figure 6: Summary of the Ecosystem Threat Status (ETS) for inland wetland ecosystem types: (a) according to the number of ecosystem types threatened and (b) percentage of the number of ecosystem types; (c) the extent in hectares; and (d) the percentage of extent. The percentage (%) of ecosystem types was calculated as the number of ecosystem types in the ETS category expressed as a percentage of the total number of ecosystem types (n = 135). Similarly, the percentage (%) of vegetation bioregions was calculated using the number of vegetation bioregions in each category, where the total number of vegetation bioregions = 36. ETS categories include Critically Endangered (CR), Endangered (EN), Vulnerable (VU) and Least Concern (LC) ecosystems

Ramsar sites protect 160 ha of the Mesic Highveld Grassland Bioregion Seep type in a natural or near-natural ecological condition.

Inland wetland ecosystem types at risk, Ecosystems of Conservation Concern and range-restricted types

Sixty-one of the 135 (45%) inland wetland ecosystem types are both CR and Not Protected and therefore considered as Ecosystems of Conservation Concern (Table 6). A total of 99 (73%) of inland wetland ecosystem types (total n = 135) are threatened with EPL between Not Protected or Poorly Protected, making them highly threatened and unprotected.

Eight of the 135 inland wetland ecosystem types have extents of < 50 ha and are further investigated as potential sites for red listing of ecosystems using a bottom-up approach. Of the eight, five were LC and Not Protected, and three CR and Not Protected (Table 7). The five ecosystems that were LC and Not Protected show a low confidence that the extent and hydrogeomorphic units are correctly or comprehensively mapped, while the other three are either low to medium or medium confidence, with recommendations to address shortcomings listed in Table 7.

Discussion

This paper applied steps that countries can undertake at a desktop, country-wide scale to determine the ETS and EPL status of inland wetlands. This level of reporting fills a gap at national scale, offering more refined categories compared to global indicators, and addressing the lack of data for habitats that prohibits bottom-up red listing of ecosystems. These steps can enable countries to use the ETS, EPL and Ecosystems of Conservation Concern to inform further conservation planning, intervention and policy. The implications of these findings are discussed in several related topics in the following subsections.

Enabling country-wide reporting of the threat status and protection levels of inland wetland ecosystem types

The two global biodiversity targets, the former Aichi Target 11 for 2020 and the SDG Indicator 6, aimed to assess changes in the extent and protection of inland wetlands, but not its ecosystem threat status. The indicators under Goal A of the Kunming-Montreal Global Biodiversity Targets, which expands on the reporting of biodiversity types, require reporting of changes in the extent, ecological condition and connectivity of all ecosystems (CBD 2021). This paper executed the proposed steps of the *Mapping biodiversity priorities* guideline (SANBI and UNEP–WCMC 2016) at a country-wide scale for assessing the ecosystem threat status of inland wetland ecosystem types, resulting in categories of increasing risk of collapse from LC to CR, aligned with the red listing of ecosystems guidelines of the IUCN (Bland et al. 2017). The red list of ecosystem guidelines is often applied in a bottom-up approach, ranging from single wetland habitats (Van Deventer et al. 2021) to those occurring at a wider landscape scale (IUCN-CEM 2022). The approach facilitates the calculation of these red

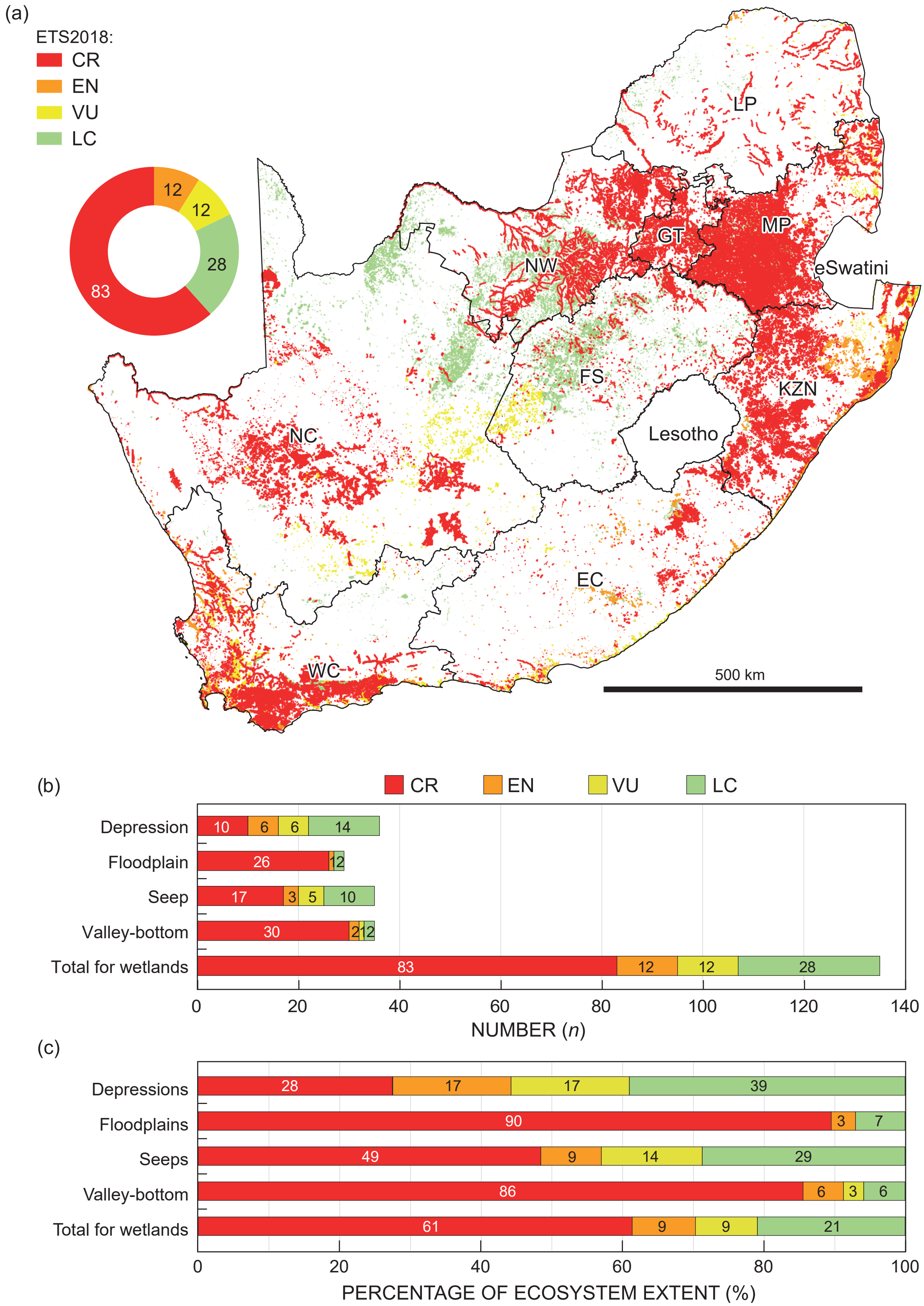

Figure 7: Ecosystem Threat Status (ETS) for (a) inland wetland ecosystem types per province; (b) number (n = 135); and (c) percentage of the number per hydrogeomorphic (HGM) units. The boundaries of the wetlands have been enhanced (0.5) to allow better visualisation in (a). The inset doughnut shows the number of ecosystem types per threat category. ETS categories include Critically Endangered (CR), Endangered (EN), Vulnerable (VU) and Least Concern (LC) ecosystems

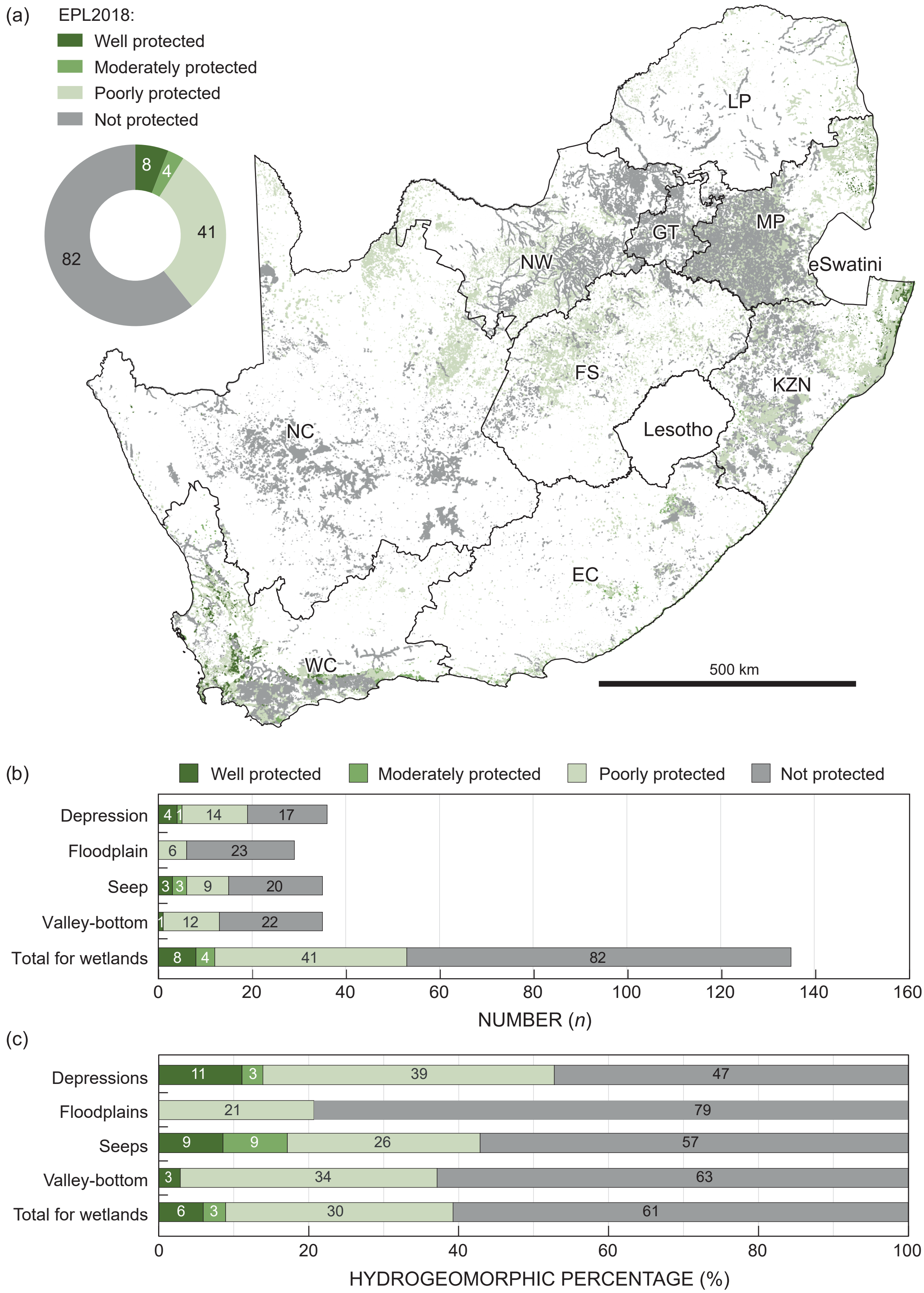

Figure 8: Ecosystem Protection Levels for inland wetland ecosystem types (a) for the whole country; (b) number (n = 135); and (c) percentage of the number per hydrogeomorphic (HGM) units. The boundaries of the wetlands have been enhanced (0.5) to allow better visualisation). The inset doughnut shows the number of ecosystem types per protection level category

Table 5: Extent (ha) of inland wetlands within the National Protected Area (NPA) network and Ramsar sites of South Africa. Figures in parentheses indicate the percentage of the protected area type out of the total extent of protected area types (formal protected areas and Ramsar sites)

Protected area type	Total extent of inland wetlands within the protected area network in hectares (with percentage of all inland wetlands within protected area network in parentheses)	A/B ecological condition	C & D/E/F ecological condition
NPAs and Ramsar	194 332.7 (99.5%)	42 066.1 (21.6% *)	152 266.6 (78.4%)
Ramsar additional to NPAs	936.6 (0.5%)	180.4 (19.3% *)	756.2 (80.7%)
Total	195 269.3 (7.4% **)	42 246.4 (1.6% **)	153 022.8 (5.8% **)

* Calculated as percentage of all inland wetlands within the National Protected Area (NPA) and Ramsar
** Calculated as percentage of all inland wetlands mapped in the National Wetland Map version 5

Table 6: Risk categories for inland wetland ecosystem types and number of inland wetland ecosystem types (total *n* = 135) within the risk category (indicated in parentheses). CR = Critically Endangered; EN = Endangered; LC = Least Concern and VU = Vulnerable

Ecosystem Threat Status (ETS) across / Ecosystem Protection Level (EPL) down	CR	EN	VU	LC	Total
Well Protected (WP)	C5 (0)	C4 (1)	C3 (5)	C1 (2)	8
Moderately Protected (MP)	C8 (1)	C7 (0)	C6 (1)	C2 (2)	4
Poorly Protected (PP)	C15 (23)	C13 (9)	C11 (2)	C9 (9)	41
Not Protected (NP)	C16 (61)	C14 (0)	C12 (4)	C10 (15)	82
Total	83	12	12	28	135

list categories at a country-wide scale, and offers a means of reporting changes in status over time, while also informing conservation planning, management and prioritisation at this scale. Through this approach, a complete coverage of all wetlands at a country-wide scale can be assessed and monitored. This is often ignored in the global biodiversity reporting or bottom-up approaches, in the case of the latter, owing to insufficient data on extent, rate of change and clearly distinguishable biotic and abiotic processes.

This approach can be considered as an indicator for countries to report to the Kunming-Montreal Global Biodiversity Framework targets related to ecosystems (Goal A, targets 1–3) and to SDG goal 15, 'Life on land', which is more suited for tracking changes in biodiversity compared to SDG goal 6. The implementation of wetland inventories ensuring more detailed ecosystem type categories, and consistent methods of determining the ecological condition of wetlands, are seen as major challenges for execution by many countries. In addition, different approaches to inventorying and classification of ecological condition, will make comparison between countries difficult.

Issues of scale and approach in the classification of wetland ecosystem types

South Africa used a hydrogeomorphic approach to the classification of inland wetland ecosystem types, as guided by its national framework, the *Classification System for Wetlands and other Aquatic Ecosystems in South Africa* (Ollis et al. 2013; 2015). The framework, and subsequent studies by Van Deventer et al. (2016) demonstrated that a combination of expert and manual classification of polygons can be combined with modelling of hydrogeomorphic units to effectively classify these ecosystems (Van Deventer et al. 2016). In the updated version of the NWM5, all polygons were checked against available aerial and satellite images and classified to hydrogeomorphic units manually, in an attempt to remove errors that have resulted from the modelling of some of the hydrogeomorphic units of the map used in the NBA 2011. Owing to the limitations in the temporal and spatial resolutions of these images, all six hydrogeomorphic units could not have been used and had to be aggregated into four major hydrogeomorphic units. This illustrates how the scale of images and methods influence the wetland ecosystem types that could be discerned and reported at particular scales. Refinement of the four aggregated hydrogeomorphic units to the original six envisaged in the *Classification System*, will require in-field visits to determine the presence of natural channels (not formed through erosion) to differentiate between the channelled and unchanneled valley-bottom wetlands, and the primary sources of water to distinguish between depressions and wetland flats. In addition, in-field validation of the occurrence and aerial extent of hillslope seeps, particularly in the arid regions, would be critical during their wet cycles. In some arid bioregions, no hillslope seep wetlands were found (Kotze et al. 2002), however, other arid bioregions remain to be assessed. The six hydrogeomorphic units would therefore be more suited for fine scale to regional reporting.

Hydrogeomorphic approaches to classification offer the benefit that modelling of the extent and type can be automated in GIS, using digital elevation models (DEMs) or digital terrain models (DTMs). The use of a suitable DEM and appropriately modified DTM is critical to inform the correct spatial resolution required to represent wetlands. In South Africa, where about 72% of the extent is considered to be semi-arid to arid (Van Deventer et al. unpublished), wetlands are narrow and small. The use of the freely available Shuttle Radar Topography Mapper (SRTM) Digital Surface Models (DSMs) at 90 m spatial resolution

Table 7: Recommendations for assessing whether the eight inland wetland ecosystem types with extents < 50 ha are unique and range restricted. Confidence levels are from Van Deventer et al. (2018). CR = Critically Endangered; ETS = Ecosystem Threat Status; EPL = Ecosystem Protection Level; LC = Least Concern; NP = Not Protected

Ecosystem type	Number of polygons	Extent (ha)	ETS	EPL	Confidence of mapping extent and HGM units	Recommendation
Gariep Desert depressions	1	14.2	LC	NP	Low (1)	Undermapping of ecosystem type.
Gariep Desert seeps	1	19.2	CR	NP	Low (1)	Undermapping of ecosystem type.
Kalahari Duneveld valley-bottom wetlands	1	33.9	LC	NP	Low (1)	The bioregion is a narrow corridor along the Molopo River. Verify whether a valley-bottom is formed along these reaches of the river.
Namaqualand Cape Shrublands depressions	11	7.4	CR	NP	Low to Medium (2)	This vegetation bioregion is quite small (696 ha) and is entirely surrounded by the Namaqualand Hardeveld Bioregion (hosting 78 depressions with a total extent of 91 ha). These systems are believed to be unique (Dr Sieben, pers. comm.) owing to their location on different geological strata and elevations. The completeness of the depressions should be investigated. One of the depression polygons transcends the border between these two vegetation bioregions, and in-field verification is required to ensure and confirm its association.
Namaqualand Cape Shrublands floodplains	1	1.5	LC	NP	Medium (3)	In-field verification is required to assess whether this ecosystem type is unique and restricted in range.
Seashore vegetation floodplain	1	0.29	CR	NP	Low to Medium (2)	The boundary of the vegetation bioregion has cut through a floodplain polygon which transcended the Seashore vegetation and Southwest Fynbos Bioregions, resulting in a sliver. It should be decided whether the Seashore vegetation bioregion would host any inland aquatic ecosystems separate from adjacent bioregions.
Southern Namib Desert depressions	3	16.3	LC	NP	Low (1)	Underrepresentation of ecosystem type extent.
Trans-escarpment succulent Karoo	1	5.9	LC	NP	Low (1)	A section of this wetland polygon has been split into a floodplain, whereas the majority is mapped as a valley-bottom wetland, which therefore appears to be a mapping error.

are completely inappropriate for representing wetland occurrences, while even the 30 m spatial resolution products may show a large underrepresentation of wetland occurrence. In addition, in areas of high canopy cover, the DSM should be adjusted to DTM to better represent flow and accumulation in the landscape. Furthermore, using this approach in modelling the extent and types of wetlands in flat areas proved particularly limiting (Collins 2018).

In contrast to the hydrogeomorphic approach of classification, floristic approaches facilitate better reporting across scales and reporting levels. The SDG Indicator 6, for example, uses the lacustrine and palustrine biomes of wetlands, proposed by the IUCN global ecosystem typology (Keith et al. 2022). At finer scales, the ecosystem functional groups distinguish between forested and marsh vegetation, which can easily be distinguished and monitored temporally using freely available optical and radar remote sensing images. An additional category of large macrophytes was also suggested to expand on these first two ecosystem functional groups in, while the possibility of finer wetland vegetation communities can potentially be monitored with drone images or hyperspectral data (Van Deventer et al. 2022), and aligned with vegetation sampling observations.

Comparison of NBA 2018 results for inland wetlands to those of NBA 2011

Assessing trends in the changes of ETS and EPLs between the two assessments of inland wetlands in the NBA 2011 and NBA 2018 is difficult, with a number of differences:

a) *Extent*: Significant improvement in reducing omission and commission errors, that were prevalent in NWM4 that was used in the NBA 2011 (Van Deventer et al. 2016), in NWM5 of the NBA 2018 (Van Deventer et al. 2020). It is estimated that commission errors from remote sensing prediction of occurrence were up to 30% in some places, while nationally NWM5 mapped 23% more than the previous version.

b) *Types*: For the NBA 2011, 331 wetland vegetation groups were used and seven hydrogeomorphic units, which resulted in 791 inland wetland ecosystem types, whereas for the NBA 2018, a combination of 37 vegetation bioregions and four aggregated hydrogeomorphic units resulted 135 inland wetland ecosystem types.

c) *Data for ecological condition modelling*: Improved representation of pressures using point, line and area data in the modelling of ecological condition of NWM5 for NBA 2018, whereas for the NBA 2011, only the minimum percentage of natural land cover method was used in the ecological condition modelling of wetlands for the NBA 2011.

What remained consistent across the two assessments, was the biodiversity target, criteria and thresholds used and four categories for each of the two headline indicators. In comparison, the NBA 2011 reported that 48% of inland wetlands were CR, with 12% EN and 5% VU, totalling 65% as threatened. The NBA 2018 found 79% of the 135 ecosystem types were threatened, and 62% CR, 9% EN, and 9% VU. Differences in the EPL results of the two assessments differed less, with the NBA 2011 reporting that only 11% were Well Protected, 6% Moderately Protected, 12% Poorly Protected and 71% Not Protected; while the NBA 2018 reported inland wetlands to be 5.9% being Well Protected, 3% Moderately Protected, 30.4% Poorly Protected and 60.7% Not Protected. Most of the differences would be attributed to the differences of ecological condition datasets and methods used.

Challenges with scale, monitoring, validation and modelling ecological condition

The biggest challenge and limitation foreseen with using this proposed approach, is the modelling of the ecological condition of inland wetland ecosystem types, that is used to inform both the ETS and EPL headline indicators. In particular, the accurate and comprehensive representation of multiple pressures in the landscape, the interpretation of their severity on wetlands and validation of these assumptions are challenging.

At a regional to country-wide scale, accurate and comprehensive pressures cannot be well represented, and therefore surrogates of these pressures need to be used in a way that they best represent some of the key pressures in the landscape. In the subtropical-temperate, coastal plains of South Africa, provincial land cover datasets showed an under-representation of the type and extent of land transformation that occurred in the forested wetlands (Van Deventer et al. 2021). Pressures for depressional wetlands are generally poorly represented in land cover datasets, since they were merely indicated as ‘pans’, and ancillary data likely played an important role in a better representation of pressures for these hydrogeomorphic units. Using ancillary point and line data in this assessment improved the representation of pressures in the landscape, however, the severity of the impact of roads and railways on wetlands would likely vary across regions and sizes of wetlands. Similarly, the extent and degree to which point-source pollution affects wetlands downstream depends on multiple factors that cannot be consistently represented at a country-wide scale. Without proper monitoring and validation of representative wetland ecosystem types across a country, modelling approaches will remain conceptual.

Wetland health assessments are conducted at a site level in South Africa, which is based on a weighted ranking of a wetland specialist as observer for three components of wetlands, including hydrology, geomorphology, and vegetation (Macfarlane et al. 2009). In a recent update of the assessment protocols, a comparison between different specialists of the same wetland, highlighted discrepancies in field assessments (Macfarlane et al. 2020). It can therefore be expected that such discrepancies can persist spatially and temporally, making validation difficult for any status and protection level assessment where ecological condition is used as a filter. The differences between the field validated data and those modelled from GIS and remote sensing images are related both to the scales and spatial resolutions used, as well as to the lack of having validation for wetlands across their hydrological cycles.

Very little data is available to validate the findings in ecological condition in South Africa. The result of the ecological condition modelled for inland wetlands of the KwaZulu-Natal province supports the findings of Begg (1988) where 58% of the inland wetlands in the iMfolozi secondary catchment (KwaZulu-Natal province) were found to be highly modified and ‘lost’. Historically, the iMfolozi catchment hosted 50 244 ha of inland wetlands, comprising 5% of the extent of the catchment, according to Begg (1988), of which 21 244 ha (42%) of the extent of all the wetlands in the iMfolozi catchment, remained unmodified. The NWM5 (Van Deventer et al. 2018; 2020) mapped the extent of 42 347 ha of inland wetlands in the iMfolozi catchment, of which 12.4% were now modelled to be in a natural or near-natural ecological condition. This indicates that the modelling under-represents the loss of ecosystem condition (42% surveyed historically cf. 12% modelled more recently). Comparison between studies that use different extents, biodiversity types and ecological condition assessments, remains challenging and offers limited reliable information on trends for assessments of rates of change. The ecological condition in the arid Northern Cape province is particularly difficult to model, since pressures in these arid areas are related to overgrazing or invasive species around the riparian zones (Kotze et al. 2019). These pressures are poorly represented in the data used to model the ecological condition of inland wetlands in arid systems.

Challenges in protection level assessment

To date, nearly 200 000 ha of inland wetlands are included in the National Protected Areas and Ramsar Sites in South Africa. This means that an additional 450 600 ha (~10%) of inland wetlands should have been within protected areas by 2020 for South Africa to attain the Aichi Target 11 of 17% for freshwater ecosystems. The current rates of including inland wetlands in protected areas has been calculated as on average 500 ha/year, whereas to meet the Aichi Target 11 of 2020 by 2030, it should increase to an average of

45 000 ha/year. The Global Biodiversity Framework's Target 3 for protection is, however, set at 30% (CBD 2021), which will require an additional extent of 464 118 ha of inland wetlands to be in protected areas by 2030. Considering that even NWM5 is an underrepresentation of the true extent of wetlands, and the percentage of true representation of wetland extent is unknown, a higher amount of wetland extent should be planned for restoration (Target 2) and protection (Target 3) for 2030. These amounts furthermore focus only on the extent of the actual delineated wetland ecosystems and do not consider the landscape required to maintain their ecological condition. The nomination and declaration of additional Ramsar sites should be strategically planned for this mechanism to effectively contribute to protection of inland wetland ecosystem types in South Africa. Consequently, a combination of funding for both formal protected areas and stewardship programmes are necessary to effect improved inland wetland protection (as per Nel et al. 2009).

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