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Conservation conundrum – Red listing of subtropical-temperate coastal forested wetlands of South Africa

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ABSTRACT

Africa's range-restricted and transitional subtropical-temperate coastal forested wetlands are facing interlinking threats of climate and anthropogenic pressures. We assessed their conservation status using the criteria of the International Union for Conservation of Nature (IUCN). Their total areal extent was hind-casted to the reference epoch 2000, followed by the quantification of subsequent total losses in areal extents for the epochs 2005, 2008, 2011 and 2017. South Africa had 120 km^2 of coastal swamp and floodplain forests in 2000 of which the majority (116.5 km^2) occurred on the Maputaland Coastal Plain (MCP). By 2011, 20% of the areal extent was lost, and at the lowest rate of decline we estimate that ≥ 80% of the rest will be lost in the next 50 years. An ecosystem collapse assessment therefore indicated that the habitat is very likely Critically Endangered. Fragmentation and types of transformations were used as degradation indices to show functional collapse. These results showed that

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forest patches became increasingly fragmented, from 511 to 1 145 patches between 2000 and 2017 and that > 23% of the areal extent showed severe transformation. Several faunal species, with a close association to the forested wetlands of the MCP, are considered threatened with numbers declining because of transformation to timber plantations or agriculture and coupled with a prolonged drought. Of these, a sub-species of the Samango monkey, *Cercopithecus mitis erythrarchus,* considered to be a primary ecosystem engineer of the habitat, was red listed with a restricted distribution, being endemic, Near Threatened and declining. Also under pressure, because of habitat fragmentation and degradation is the Peregrine crab (*Varuna litterata*), a euryhaline species requiring connectivity across the land-seascape, ranging from freshwater forested wetlands to estuarine and off-shore environments. Functionally, these coastal forested wetlands are therefore also considered Critically Endangered. The final IUCN conservation status of South Africa's subtropical-temperate coastal forested wetlands are recommended to be very likely Critically Endangered. Irrespective of 62% of the areal extent of these forested wetlands being within protected areas, severe degradation (metrics of fragmentation and transformation) were observed even inside these areas for the past two decades. The conservation conundrum is that despite existing legislation and management measures, there has been no stop or reversal of the negative trends to date. As a supplementary method, we therefore recommend a transdisciplinary community-based approach to conservation practice, continued and improved monitoring of the habitat losses, the identifying priority areas for rehabilitation and addressing data deficiencies in important species associations.

1. Introduction

Even though wetlands are globally considered highly threatened and poorly protected (IPBES, 2019), and ecosystem risk assessment is argued to be as valuable as species assessments, very few red listing of aquatic ecosystems assessments have been undertaken (IUCN-CEM, 2016). In Africa south of the Sahara, no red list assessments of aquatic ecosystems have ever been undertaken (IUCN-CEM, 2016). Rivers and open waterbodies of Africa have all been well represented in global datasets (e.g. Linke et al., 2020; Pekel et al., 2016), but there is a dearth of information on palustrine wetlands, particularly swamp and floodplain forests of Africa.

Forested wetlands[13] are recognized by the IUCN as a transitional zone between aquatic and terrestrial systems and listed under the palustrine ecosystem biome (Keith et al., 2020). They are distinguishable from other terrestrial forests because they are associated with peat and/or have adapted to elevated levels of soil saturation to inundation (Martin-Smith, 2004). The IUCN recognizes two types of Transition Forest (TF) ecosystems, the first being tropical flooded forests and peat forests (TF1.1), and the second, subtropical-temperate forested wetlands (TF1.2). According to Keith et al. (2020), tropical systems have a higher canopy cover, above-ground biomass, and are considered as higher energy systems, whereas the subtropical-temperate forested wetlands may have more open gaps between the tree canopies and exhibit a seasonal hydrological regime (Keith et al., 2020). Four types of forested wetlands are noted by Martin-Smith (2004), including swamp (permanently waterlogged, peat-poor soils), peat bogs (peat-rich soils), floodplain (fluvial influence from a river) and mangrove forests (coastal fringes).

The uplift of the southern African continent between 5 and 20 million years ago, resulted in a physical divide between inland and coastal forests (Burgess et al., 1998; Partridge and Maud, 1987). Subsequently, other climatic changes have resulted in pertinent differences between these forests phytogeographically, functionally and in species association. Coastal forests on the narrow, eastern coastal plains of Africa are small in areal extent ($\leq$ 20 km^2) and highly fragmented, compared to the more extensive, closed-canopy systems of central African inland forests (Burgess et al., 1998). Moreover, coastal swamp and floodplain forests have strong associations and connectivity with estuaries and off-shore environments, as exemplified by some aquatic species like the Peregrine crab (*Varuna litterata*; Fabricius, 1798) that depends on all three realms to complete its life-cycle. Many species on the eastern coast of Africa are considered relics of the inland forests, with morphological adjustment, sub-speciation and endemics resulting from isolation (Burgess et al., 1998). We postulate that African swamp and floodplain forests south of the Sahara could occur in one of four ecosystem functional groups, 1) inland tropical, 2) inland subtropical, 3) coastal tropical and 4) coastal subtropical, forested wetland ecosystems.

The areal extent and species associations of Africa's forested wetlands are poorly understood. A recent survey of the Cuvette Centrale in the Republic of Congo and Democratic Republic of Congo mapped a total areal extent of 145 500 km^2 (Dargie et al., 2017) with peat substrate constituting > 65% organic matter within a depth of 0.3 m, and depths ranging between 2 m and 5.9 m on the edge to the central parts of the system, respectively. Two subtypes of floodplain forested wetlands were identified based on dominant tree species, namely hardwood, dominated by *Uapaca paludosa* (Aubrév. and Leandri, 1935), *Carapa procera* (DC., 1824) and *Xylopia rubescens* (Oliv., 1868); and palm, where *Raphia laurentii* (De Wild, 1905) was predominant in depressions, and *R. hookeri* (Mann and Wendl, 1864) along riparian channels (Dargie et al., 2017). Comparatively, peatland surveys on the eastern coastal plains of Mozambique and South Africa showed lower levels of organic matter, 30% at 0.3 m depth, with depths of up to 6 m (Grundling et al., 2017). A much wider range (thirteen) of key indicator tree species associated with coastal swamp and floodplain forests in this southern region includes: *Barringtonia racemosa* ([L.] Spreng., 1753; Powderpuff tree), *Bridelia micrantha* ([Hochst.] Baill., 1863; Mitzeerie), *Casearia gladiiformis* (Mast., 1871; Sword-leaf), *Cassipourea gummiflua* (Tul., 1856; Large-leaved Onionwood), *Ficus sur* (Forssk., 1775; Broom-cluster fig), *F. trichopoda* (Bak., 1883; Swamp fig), *Hibiscus tiliaceus* (L., 1753; Lagoon hibiscus), *Macaranga capensis* ([Baill.] Sim, 1907; Wild poplar), *Phoenix reclinata* (Jacq., 1858; Wild date palm), *R. australis* (Oberm. and Strey, 1969; Kosi palm), *Rauvolfia caffra* (Sond., 1850; Quinine tree), *Syzygium cordatum* (Hochst., 1844; Water berry) and *Voacanga thouarsii* (Roem. and Schult., 1819; Wild frangipani) (Adams et al., 2016; Bandeira et al., 2014; DWAF, 2003; Gabriel et al., 2017; Grobler, 2009; Grundling et al., 1998a; Grundling et al., 2000; Neal, 2001; Riddin and Adams, in review; Scott-Shaw and Escott, 2011; Sieben et al., 2014; Taylor, 2016; Venter, 2003; Wessels, 1991a; Wessels, 1991b; Wessels, 1991c).

An increase in population pressures and associated conversion from coastal forests to agriculture for food production, raises concerns about the status of coastal forests, and more so the coastal forested wetlands of Africa (Conservation International, 2003). These systems are naturally highly fragmented and thus are easier to access during dry periods compared to the tropical forests, and consequently have higher degrees of degradation (Burgess et al., 1998). Coastal forested wetlands in the subtropical-temperate regions occur in areas with lower precipitation

[13] According to the Global Forest Resources Assessment of 2020 (FAO, 2018), a forest is defined as land spanning >0.5 ha with trees higher than 5 m, a canopy cover of >10%, and a minimum width of 20 m.

compared to the tropics, and are exposed to longer periods of low rainfall before reset events[14], making them more vulnerable to the combined effect of climate and anthropogenic impacts (Eeley et al., 1999). The southernmost part of the Mozambican Coastal Plain transitions from a tropical to subtropical-temperate climatic region (Kottek et al., 2006). In South Africa, at the southernmost extent of the coastal plain, called the Maputaland Coastal Plain (MCP), the climate grades from subtropical in the North (at the Mozambican border) to temperate in the South (Mucina and Rutherford, 2006). This northeastern region of South African indicates a long-term 18-year (9-year wet, 9-year dry) cyclicity since the 1900s (Kelbe et al., 1983; Tyson, 1986). In the most recent national assessment of South African freshwater ecosystems, it was proposed that swamp forests be considered for red listing (Van Deventer et al., 2019b) as they are range restricted; and show evidence of ongoing decline from Grundling and Grundling (2019) and Janse van Rensburg (2019). A risk assessment is required to determine the status of these subtropical-temperate coastal forested wetlands of Africa.

This study aimed to assess the subtropical-temperate coastal forested wetlands of South Africa, as a sub-type of the ecosystem functional type subtropical-temperate forested wetlands or TF1.2, using the recent IUCN guidelines for assessing the conservation status of ecosystems (Bland et al., 2017). We focus on the swamp and floodplain forests occurring adjacent and inland from the mangrove forests. An overview of the key abiotic and biotic features of the ecosystem is firstly provided, and key interactive processes of the system discussed, followed by an overview of the current threats. We applied the IUCN criteria to determine the threat status according to the five red listing of ecosystems criteria. The first two criteria are spatial indicators of ecosystem collapse: A - Reduction in distribution and B - Restricted distribution, followed by the second two criteria that are indicators of functional collapse: C - Environmental degradation and D - Disruption of biotic processes and the final criteria, E - Quantitative analysis, provides the overall assessment of the conservation status of the ecosystem. Our recommendations focus on the identification of knowledge gaps and the conservation of this ecosystem functional group.

2. Methods

2.1. Ecosystem description

2.1.1. Study area

The South African forest biome (Fig. 1a) covers an area of 4 981.5 km^2, or 0.4% (derived from the updated vegetation map of Dayaram et al., 2019) of the extent of the landmass of South Africa (1 219 735.6 km2). Coastal swamp and floodplain forests are expected to be closely associated with watercourses, rivers and groundwater systems of the Indian Ocean Coastal Belt Biome, that extends from the Great Kei Estuary (±30°40′S, not shown on map) northwards along the coast to the Kosi Estuary on the border with Mozambique (Fig. 1b). The region ranges from temperate in the South to subtropical in the North (Mucina and Rutherford, 2006), though the transition between these climatic regions along the latitudes is subtle.

[14] Reset events are defined as excessive, decadal rainfall or drought events within catchments and aquatic ecosystems (Jones, 2013), marking the start of a new long-term hydrological cycle of a catchment. These events influence the hydrological regime and ecological functional characteristics of aquatic ecosystems at a regional scale. Flooding reset events contribute to tremendous inundation, which on the one hand facilitates a high level of connectivity between isolated patches and subsequent exchange between these populations to ensure population diversity. The flooding also mobilizes sediments and high energy that supplies beaches with sand deposition (Harris et al., 2019) and estuaries with nutrients. It may also force the opening of the river mouth and in this way, facilitate decadal reconnection to the off-shore environment. Flooding contributes to landscape reconnections of wetlands promoting the dispersal and migration of faunal species.

Various parts of the MCP have been under different levels of protection since 1895 because of its rich biodiversity and high levels of endemism. Today, approximately 28% of the areal extent of the MCP is under protection, consisting of 20 National Protected Areas, a World Heritage Site and five Ramsar Sites, with overlap in extent (Fig. 1c). The iSimangaliso Wetland Park, which means 'miracle and wonder', was South Africa's first World Heritage Site (#914) declared in in 1999 (https://whc.unesco.org/en/list/914/).

2.1.2. Abiotic features

The Mean Annual Precipitation ranges from 1000 to 1500 mm (Bailey and Pitman, 2016), with gradients of decline westward and to the South (Bruton and Cooper, 1980; Clulow et al., 2013). Temperatures range between a minimum of 18 °C, average 22 °C and maximum of 26 °C (Harris et al., 2013). Recharge of the aquifer is dependent on sustained rainfall as opposed to localized reset events.

The coastal plain is elevated at < 60 m above mean sea level, and comprises of a porous sandy material underlain with a Cretaceous clay layer which perches the aquifer in places at 10 to 15 m in depth below dunes and at or just below surface at inter-dune settings (Partridge et al., 2010; Grundling, 2014; Bate et al., 2016). Most of the rainfall infiltrates the sandy upper layer to supplement the shallow and unconfined aquifer at a depth of 1–3 m (Bate et al., 2016) forming a range of predominantly perched and deeper-connected wetlands, but forming no major river systems, across the landscape. The MCP has the highest density, and the largest areal extent of peatlands in South Africa (Ellery et al., 2012; Grundling et al., 1998b; Thamm et al., 1996). Peat substrates range between 1 and 10 m and form the substrate of palustrine wetlands, with vegetation types such as grass-sedge, papyrus and coastal swamp and floodplain forests. Waters draining from these coastal peatlands to estuarine ecosystems are high in humic acid, and are referred to as 'black water systems', as opposed to clear water systems where no peat is found (Bate et al., 2020). The high level of organic material from the peat influences the water column color, transparency and chemistry as well as the substrate color, supporting a unique estuarine food web (Bate et al., 2020). The coastal swamp and floodplain forests consequently play a critical role in carbon sequestration (teal carbon) and regulation of groundwater seepage.

Hydrologically the distribution of South Africa's coastal swamp and floodplain forests occurs along drainage lines, ranging from low-energy seep zones to relatively higher energy riparian channels and valley-bottoms. On the MCP, these forested wetlands occur as aquifer-dependent ecosystems on seep zones along inter-dune settings and valley-bottoms towards the estuaries or coastal lakes (Wessels, 1991a; Wessels, 1991b; Wessels, 1991c; Grobler, 2009; Gabriel et al., 2017).

2.1.3. Biotic features

The MCP forms part of the Maputaland-Pondo-Albany biodiversity hotspot and is recognised as a centre of endemism (Van Wyk and Smith, 2001; Darbyshire et al., 2019). It is also characterised by a high species richness of freshwater species, including amphibians, dragonflies, freshwater fish, mammals and reptiles (Skowno et al., 2019; Van der Colff et al., 2019). While many of the faunal species traverse the landscape and are not exclusively associated with the coastal swamp and floodplain forests, wetlands in general, serve as refugia to all fauna during the dry years and drought periods (Taylor et al., 2006).

Three studies explored the floristic composition of the coastal swamp and floodplain forests of KZN. A total of 63 plots between the uMsunduzi arm of the iMfolozi/uMsunduzi Estuary and Sodwana Bay, showed a composition on average of 42.7% tree cover, compared to 15.7% creepers and 10.1% ferns (Wessels, 1991a). Higher percentages of canopy cover were observed north of Sodwana, in the Kosi region that borders Mozambique, of up to 80% tree cover, with an average of 29%, with an average 24% for shrubs and 76% for herbs (Grobler, 2009; Appendix A). Venter (2003) sampled 10 of 201 vegetation plots in the Mfabeni Swamp Forest, and distinguished three coastal swamp forest

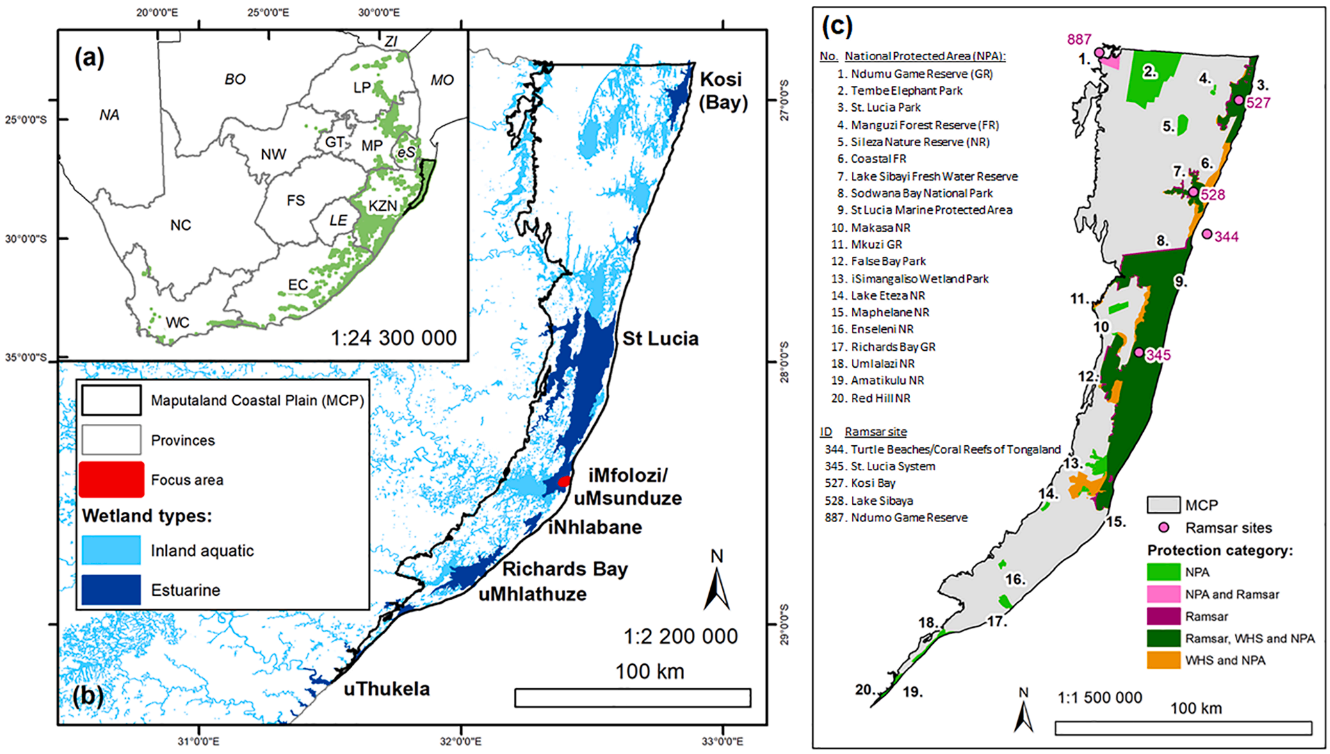

Fig. 1. Location of (a) the forest biome (Dayaram et al., 2019) across South Africa and the Maputaland Coastal Plain (MCP) and (b) wetlands of the KwaZulu-Natal (KZN) Province as represented in the National Wetland Map version 5 (Van Deventer et al., 2020). The outline of the forest biome and focus area polygons are displayed at two points for visual recognition. (c) Areal extent of National Protected areas (NPAs), World Heritage (WHS) and Ramsar sites of the MCP. Abbreviations for provinces in map (a): EC = Eastern Cape; FS = Free State; GT = Gauteng; KZN = KwaZulu-Natal; LP = Limpopo Province; MP = Mpumalanga Province; NC = Northern Cape; NW = North West; WC = Western Cape. Abbreviations for neighbouring countries: BO = Botswana; eS = Kingdom of eSwatini; LE = Lesotho; MO = Mozambique; NA = Namibia; ZI = Zimbabwe.

communities: *B. racemosa* (Powder-puff tree) along the streams, *F. trichopoda* (Swamp fig) associated with wetter conditions and *S. cordatum* (Waterberry) in the drier parts.

Thirteen key indicator tree species are often listed for the MCP coastal swamp and floodplain forests (see introduction). Peat substrate was observed under the majority of these tree species, except for *B. racemosa* and *H. tiliaceus* that grow in areas where a lower percentage of organic material occurs compared to the other tree species (Grundling et al., 1998a; Grundling et al., 2000). While some of these tree species form uniquely recognisable canopy crown shapes which assist in mapping at desktop level (e.g. *F. trichopoda*, *H. tiliaceus* and *R. australis*) the other indicator tree species have less conspicuous tree crowns and do not dominate the canopy or are intermixed with other crowns, which make them difficult to distinguish on images from adjacent terrestrial forests.

The aquatic ecosystem continuum, which in the MCP is now under threat, supports species with complex lifecycles and environmental cues that show an aspect of timing as they move through realms. Wet coastal swamp and floodplain forests offer habitat to *V. litterata* (Peregrine crab; Fabricius, 1798) during its adult phase. *V. litterata* is a tropical, Indo-Pacific freshwater crab which spends it adult phase up to 20 km inland in freshwater ecosystems (Ng, 1998), while cyclically moving across estuarine ecosystems to spawn in the off-shore marine environment in late summer (end of the austral wet season). During the autumn, the larvae migrate back through the estuaries to the inland freshwater ecosystems where they re-enter forested wetlands (Connell and Robertson, 1986).

2.2. Threatening processes and ecosystem collapse

In the past 100 years, two main drivers have disrupted this ecosystem's equilibrium: large-scale extractive land uses, specifically commercial and semi-commercial crop production and the expansion of water-intensive timber plantations, as well as the intensification of decadal droughts associated with climate change (Snaddon et al., 2019; Ndlovu and Demlie, 2020; Ramjeawon et al., 2020). These drivers have resulted in a decline in water availability and lowering of the water table, thus making coastal aquatic ecosystems more accessible by subsistence farmers for the cultivation of crops that have progressed technologically to the use of modern tools (e.g. the use of chain-saws) and subsequently, accelerated transformation of the forested wetlands to croplands.

A severe decline in the groundwater table has been observed in the catchments of Mbazwana, Vazi Pan, the uMgobezeleni Estuary and Lake Sibaya (South Africa's largest freshwater lake with an areal extent of 77.5 km^2), of which the latter had shown an alarming drop in water levels over the past 20 years as a result of expansion of timber plantations (Vaeret et al., 2009; Bate et al., 2016; Everson et al., 2019; Graham et al., 2020). These impacts have been mainly attributed to anthropogenic activities, particularly the rapid expansion of timber plantations in these areas over the past 20 years. During the decadal drought of 2015–6 (following the previous one of 1991–2 [Malherbe et al., 2016]), severe dry conditions coupled with increased anthropogenic pressures resulted in a decline in the water table. Cumulative impacts of inappropriate land uses during the dry periods with water abstraction and exotic *Pinus* and *Eucalyptus* plantations on the MCP, have resulted in draw-down zones extending to over 2 km from the edge of the timber plantations (Bate et al., 2016; Smithers et al., 2017; Graham et al., 2020).

The draw-down of the groundwater table resulted in the exposure of the peat substrate and consequently oxidation of the organic material (Grundling et al., 2021). A significant increase in the number and frequency of desiccated peatlands and subsequent ignition and burning of peat substrates have been observed on the MCP, from 13 observed between 1990 and 2015 to 34 sites in the past five years, with an average of 29% of the depth of the peat substrate desiccated or burnt (Grundling et al., 2021). Since the coastal swamp and floodplain forests has an average rooting depth of about 1–2 m in peat, prolonged lowering of the water table to below the root zone could likely result in the die-off of these forests.

An increase of 0.2 °C per decade in air temperatures, associated with climate change, were observed for Africa over an 85-year period (Kruger and Nxumalo, 2017), with an increased rate of 0.4 °C per decade observed more recently between 1961 and 2014 (Davis-Reddy and Vincent, 2017). Predictions associated with rainfall remains highly uncertain for this coastal region, however, with contradictions reported in the increase or decline of cyclonic events (Snaddon et al., 2019). The increase in air temperatures is expected to increase evapotranspiration rates within wetlands, and impact on the water quantity and hydrological regime.

2.3. Assessment of risk using the IUCN criteria

2.3.1. Criterion A: Determining the areal extent lost and rate of loss of coastal forest wetlands

For criterion A1, the total loss of areal extent of the ecosystem over the past 50 years was calculated at two scales. The areal extent of coastal swamp and floodplain forests was integrated from a variety of available datasets for the whole of KZN, and then aligned to all other coastal and mangrove forests of the MCP in a single spatial data layer for the reference epoch of 2000 (see Appendix B for extended description). Firstly, at a regional scale the MCP was used to determine whether broad landscape changes to coastal swamp and floodplain forests took place in the past two decades. The MCP was chosen because the known extent of the forested wetlands in this region was much wider and more extensive, and therefore more likely to show changes against the 20 m spatial resolution land cover datasets of the province (Year 2005 – EKZNW, 2011; Year 2008 – EKZNW, 2013a; Year 2011 – EKZNW, 2013b; Year 2017 – EKZNW and GTI, 2018). The systems further south of the MCP are narrow and small in extent, and may not fill a single pixel value, and could easily been misclassified in the land cover data due to the edge effect in reflectance influence from adjacent pixels. In addition, rulesets and ancillary data used in land cover datasets may result in errors and anomalies in the quantification of the loss of areal extent.

Broad landscape changes were assessed through aggregating the land cover classes to five aggregated categories, namely those which have remained natural, compared with those transformed to various levels (degraded, crops, timber plantations and transformed [urban and roads]). Losses in the coastal swamp and floodplain forests were compared to the other forest types on the MCP, to assess whether the changes were across board, or pertaining only to the coastal swamp and floodplain forests. Changes at the broad landscape scale and focus area are reported for criterion A1 as the total areal extent lost to the transformation categories and percentage of total extent.

For criterion A2 (reduction across a 50-year period, past (A2a), present (A2b) and future [A2c]) the rate of change was calculated as the absolute rate of decline (ARD) (Keith et al., 2009), expressed in Equation 1, where t represents time period 1 and 2.

$$ARD = \frac{[Area(t2) - Area(t1)]}{[Year(t2) - Year(t1)]}$$

Equation 1. Formula for the calculation of absolute rate of decline (ARD) in units km^2/year for an ecosystem (Keith et al., 2009)

To estimate the year of potential collapse of coastal swamp and floodplain forests, four ARDs were calculated, applied to the total areal extent of 120 km^2, and then compared to one another: (i) The ARD calculated at a regional level for the MCP in this study; (ii) the ARD calculated for the focus area; (iii) the ARD derived from Wessels (1997); and the ARD deducted from Jewitt (2018). Historically, between 1937 and 1996, Wessels (1997) estimated the MCP coastal swamp and floodplain forests extent as 67.62 km^2 based on aerial photography of 1937 and reports a loss of 23.16 km^2 by 1996. This equates to a loss of 0.4 km^2 per annum. In another part of the study area, natural growth over the same time period was calculated as a 17.51 km^2 increase in coastal swamp forest, accounting for an increase of 0.3 km^2 per annum. In the assessment done by Jewitt (2018), using an extent of 86.5 km^2, a total loss of 33 km^2 (38% of the original reference extent of 1994) occurred between 1994 and 2011 (17 years), totalling an average loss of nearly 2 km^2 per annum. We used a linear extrapolation to determine the year of collapse, defined here as the total loss of areal extent of swamp forest, against the potential areal extent of natural growth or expansion.

2.3.2. Criterion B: Assessing whether South Africa's subtropical-temperate coastal forested wetlands are range-restricted wetland types

The total areal extent of the coastal swamp forest for the reference epoch of 2000 was evaluated as criterion B1 where the Extent Of Occurrence (EOO) should be $< 50\,000$ km^2 to be considered threatened (Bland et al., 2017). Simultaneously, evidence of an imminent or future threat (i.e. evidence of continuing decline) to the ecosystem needed to be considered in addition to the range extent to qualify as threatened under this criterion, and for this purpose, we also incorporated criteria A, C and D in the overall assessment.

2.3.3. Criterion C: Indicators of environmental degradation

Changes in the degree of fragmentation were also evaluated since the year 2000 and four subsequent years of change (2005, 2008, 2011 & 2017). Using the rasterised version of the swamp and floodplain forest polygons in the fragmentation analysis at a 20 m spatial resolution (to match those of the land cover datasets), changes in fragmentation were calculated using Fragstats 4.2.1 (University of Massachusetts Amherst, MA, USA). The metrics were the number of patches, patch density, edge density, perimeter-area ratio mean and the aggregation index. The 8-cell neighbourhood rule was used.

The severity of the areal extent of loss of habitat extent (inferred from in criterion A) was interpreted in terms of habitat to threatened and Taxa of Conservation Concern (ToCCs) species (next criterion). Species dependent on the canopy as a food resource, experience an immediate loss of habitat if cut down, and consequently habitat transformation observed through the land cover data (criterion A) was interpreted with this in mind (severity rank is $\geq 80\%$ as per Bland et al., 2017). It was assumed that regrowth or rehabilitation of such areas would require 10–30 years before the trees mature to offer food to such species again.

2.3.4. Criterion D: Loss of biotic processes

Threatened species and ToCCs that are closely associated with the coastal swamp and floodplain forests, or that use them temporarily on migration routes were listed and the dependency of these species on the habitat were discussed.

2.3.5. Criterion E: Quantitative analysis

The resultant category of the conservation status of each component of the swamp and floodplain forests are summarized combined with the probability of occurrence categories of the IUCN guidelines (Bland et al., 2017). The final conservation status, as a category along a likelihood of the risk of collapse as per Bland et al. (2017:7), was assigned as the most severe category to any of the sub-criteria (Bland et al., 2019; Sievers et al., 2020).

In addition to the five IUCN criteria, we assessed the percentage of the areal extent of coastal swamp and floodplain forests within the National Protected Areas, World Heritage and Ramsar sites. The spatial layers of the National Protected Areas and Ramsar Sites from the NBA 2018 (Van Deventer et al., 2019b) were unioned with the reference spatial layer of the coastal swamp and floodplain forests in ArcGIS 10.6 (ESRI, 1999–2017). The percentage of coastal swamp and floodplain forests under the types of protected area categories were calculated relative to the total extent of these forests on the MCP.

3. Results

3.1. Criteria A & B - Evidence of reduction in the distribution of a range-restricted ecosystem

We report on criterion B, the areal extent of the ecosystem mapped in the reference epoch (2000) first to provide an overview of the system, and whether it is range-restricted (criteria B), before we report on the reduction (criterion A) from this reference epoch.

3.1.1. Sub-criterion B1 – Extent of occupancy at the time of the reference epoch (2000)

The resultant spatial reference data layer (epoch 2000) of coastal swamp and floodplain forests showed that an area of 120 km^2 is distributed primarily in the KZN Province (99.7%), with a small fraction on the border with the Eastern Cape Province (Table 1; Fig. 2). The uMtamvuna Estuary (±31°5′S) on the border between the two provinces, has the southernmost distribution of coastal swamp and floodplain forests of South Africa and the African continent. Two distinct regions are noted: 1) from the uMthavuna Estuary northwards, predominantly floodplain forests occur in very narrow bands upstream of the estuaries, because they are in fact on the seep zones of these in deeply incised river gorges with areal extents approximately < 30 m in diameter (therefore not really floodplains; see Fig. 2). There the characteristically older complex geology of the Cenozoic, Palaeozoic and Molkolian Era are associated with arenites, shales and gneiss. 2) At the uThukela Estuary, the geology and slope change northwards towards the MCP (underlain with Quaternary sediments) and on to the border with Mozambique at the Kosi Estuary, where more extensive swamp and floodplain forests are found (Table 2).

The MCP hosts 97% of the areal extent of South Africa's coastal swamp and floodplain forests with the most extensive swamp forests occurring at the Kosi Estuary on the border with Mozambique (Table 2). Swamp and floodplain forests forms 13% of the areal extent of forest types on the MCP. The forested wetland types, including the Lowveld Riverine, mangrove, coastal swamp and floodplain forests, make up 17% of the areal extent of forests on the MCP, but < 2% of the areal extent of the MCP.

3.1.2. Subcriterion A1 – Loss of the areal extent of swamp and floodplain or other forest types on the MCP

The coastal swamp and floodplain forests showed a loss of about 11% of its original extent between the reference epoch of 2000 and the year 2005 (Fig. 3), while further losses occurred between 2005 and 2008 and 2008–2011 (20%) but showing some recovery of 2% by 2017. The latter could be attributed to a possible error in the land cover classification as a result of the rule-set for predicting wetland and forest classes. Mangrove and Licuati forests showed losses over the assessment period (from the reference epoch of 2000 to 2017) of ≤ 11%, whereas the Coastal (dryland) Forests recorded a maximum loss of 19%, the Dune Forests 24% and the Lowveld Riverine Forests 34%. Maximum values between 38% and 45% were recorded for the remainder of the MCP (non-forest).

Table 1
Aerial extent of coastal swamp and floodplain forests of South Africa across the Eastern Cape and KwaZulu-Natal provinces as mapped for the reference epoch of 2000.

Province	Extent (km^2)	Percentage of all coastal swamp and floodplain forests of South Africa
Eastern Cape	0.05	0.04
KwaZulu-Natal	119.6	99.96
South Africa	119.65	100.00

A higher percentage of loss – 49% – was observed in the focus area (Appendix C).

3.1.3. Subcriterion A2b – Results in the absolute rate of decline between 2000 and 2060

Four of the six forest types of the MCP showed average ARDs of > 1% per annum (Fig. 4a). The coastal swamp and floodplain forests initially showed a negative trend (a loss of 3% per annum) between 2000, 2005 and 2008, whereafter the slope of decline lowered between 2008, 2011 and 2017 (a loss of < 0.5% per annum). The dune and coastal (dryland) forests showed steeper losses of 8.5% per annum between 2005 and 2008, compared to the average of < 1% of decline per annum, not considering the extreme values recorded by the dune and coastal (dryland) forests. Mangrove and the Lowveld Riverine Forests showed an average ARD < 1% per annum for the period assessed.

Changes from the land cover assessment were the highest in the focus area at 3.3 km^2 per annum or 2.75% of the areal extent of all swamp and floodplain forests (Appendix C), followed by the ARD at a regional scale (2.4 km^2 per annum or 2% per annum) and those observed by Jewitt (2018) being 2 km^2 (or 1.67%) per annum (Fig. 4b). The post-1994 assessments, show a much higher rate of decline compared to that observed by Wessels (1997) before 1996. Through natural expansion, the coastal swamp and floodplain forests could have reached an areal extent of 138 km^2 by 2060. However, should the rate of ARD observed in the focus area be extrapolated to the whole of the MCP, the date of collapse could be in < 8 years (before 2030). At the rate observed from this assessment using the land cover data, the coastal swamp and floodplain forests could be all lost by 2040 or within < 30 years using the rate of Jewitt (2018) or 50% of the areal extent could be lost by 2175 at the rate of Wessels (1997).

3.2. Criterionc C – Results of degradation through fragmentation metrics

The results of the fragmentation analysis showed a subsequent loss in detail of areal extent, the area of swamp and floodplain forests declined from 116 km^2 in 2000 on the MCP to 93 km^2 in 2011, rising slightly to 95 km^2 in 2017 (potential anomaly). The number of swamp and floodplain forest patches increased over time, from 511 in the reference year 2000, to 817, 1 085, 1 157 and 1 145 (doubled) for the years 2005, 2008, 2011 respectively, stabilizing in the year 2017 (Table 3). Similarly, patch density (number per 100 ha) increased from 0.06/ha to 0.1407/ha over the period. The edge density also increased over time from 2.42 m/ha to 2.78 m/ha. The mean perimeter to area size ratio increased from 825 to 1 083 peaking at 1 109 in 2008. In contrast, the average patch size decreased in this time (Table 3). The patches became less aggregated over time decreasing from 91.5% to 88.2%.

The focus area showed a five-fold increase of the number of patches between 2002 and 2019, from one single large 6 km^2 patch in 2002 to 31 patches in 2012 and 2019, averaging < 3 km in size for these years and totalling 2.8 km^2 in 2019 (Appendix C).

In 2011, a maximum habitat loss of 23% of the swamp and floodplain forests was recorded on the MCP (Fig. 4a). Although an improvement of 2% in the natural extent of these forests were observed by 2017, we take this as an artefact of the limited number of bands and/or areas of interest representing the swamp and floodplain forests accurately, since the forests could not recover within six years to its original climax state. This extent of decline against the relative severity (considered to be ≥ 80%), does not qualify these forests as threatened according to Bland et al. (2017). However, results of the focus area (Appendix C) suggest that the land cover datasets underreport losses to swamp and floodplain forests between 2% (2017–2019) and 40% (2011–2012). For this reason, we suggest a rating of Near Threatened based on the severity of loss.

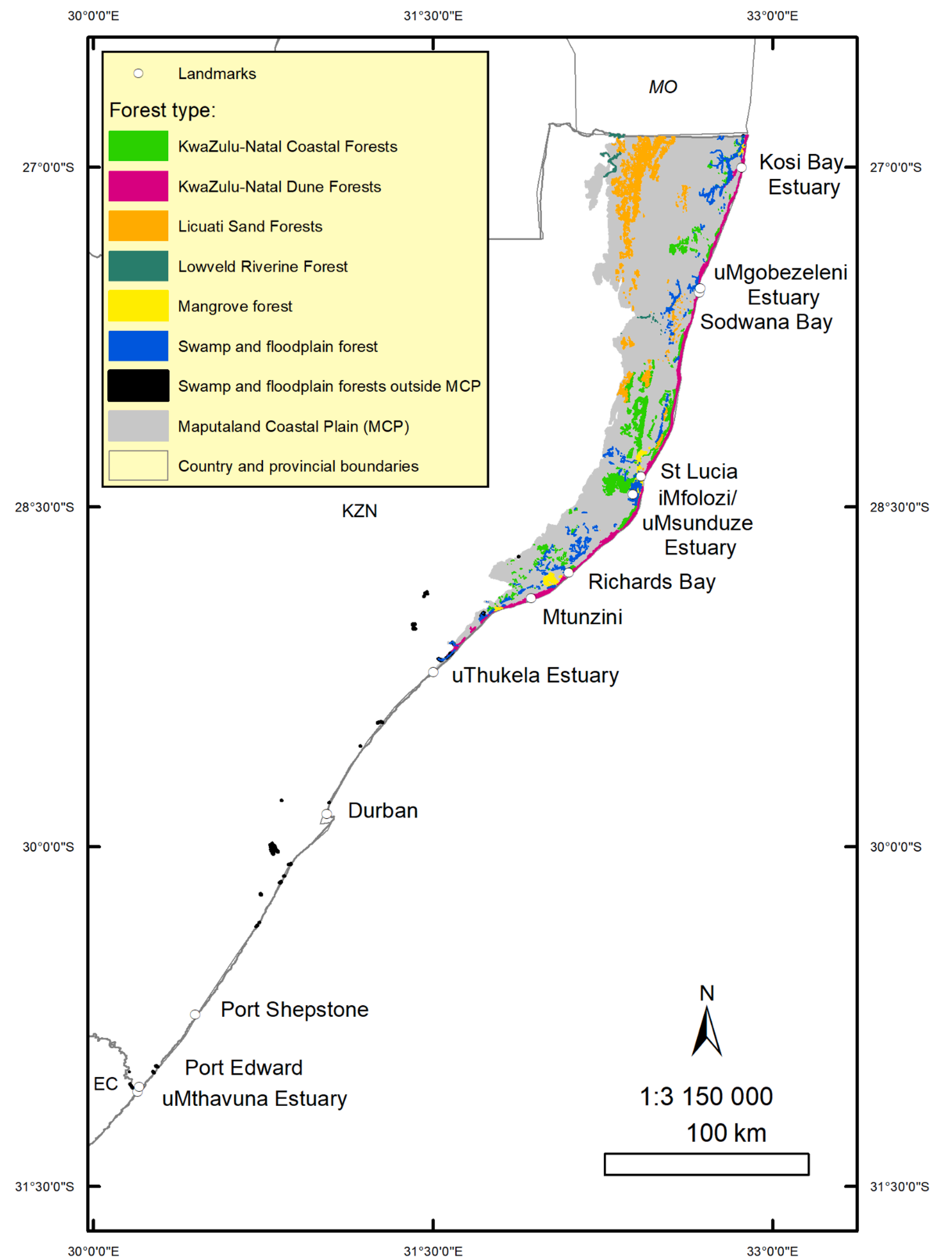

Fig. 2. The areal extent of swamp and floodplain forests for the reference epoch of 2000, relative to the Maputaland Coastal Plain (MCP). The outline of swamp and floodplain forest polygons outside the MCP and the mangrove forests have been enhanced to 1.5 points to be visible. Abbreviations: EC = Eastern Cape Province, KZN = KwaZulu-Natal Province, MO = Mozambique.

3.3. *Criterion D – Results on the disruption of biotic processes and interactions.*

Although species were not exclusively associated to the coastal swamp and floodplain forests, several species demonstrate close association to these habitats. Table 4 shows that one floral species, *R. australis* (Kosi palm) has a very restricted distribution range around the Kosi Estuary and further into Mozambique around Maputo Bay. A range of threatened faunal species and ToCC all have declining trends.

A contentious issue is observed in the red listing of faunal species, in that sub-speciation is not always considered. For example, *Cercopithecus albogularis / mitishas* (Sykes, 1831) a wide distribution in tropical and subtropical and Afromontane forests and is therefore listed as Least Concern. However, *Cercopithecus* subspecies have a much more limited distribution however and Lawes and Masters (2020) list *Cercopithecus mitis* ssp. *labiatus* (Saint-Hilaire, 1842) as Vulnerable and declining as a result of high levels of forest fragmentation and increase of habitat loss of their habitat range across Africa. Linden et al. (2016) have indicated that the sub-species, *C. a. erythrarchus* (Peters, 1852), has a much more range-restricted distribution on the MCP, and is therefore endemic to the region, with a threat status of Near Threatened.

3.4. *Criterion E – Overall assessment and protection levels*

More than half (53% of 116.5 km^2) of the coastal swamp and floodplain forests on the MCP are situated within a combination of National Protected Areas, World Heritage and Ramsar site boundaries (Table 5).

Land transformation to crop production (inside and outside protected areas) and timber plantations are key drivers that are very likely to persist during the dry cycles of the MCP. It is very likely that the current decline of this range-restricted ecosystem type is underreported,

Table 2
Aerial extent of forest types on the Maputaland Coastal Plain (MCP) for the reference epoch of 2000.

Category:	Extent (km^2):	Percentage of the areal extent of all forest types	Percentage of areal extent of the MCP
KZN Coastal (dryland) Forests*	321.0	35.6	3.9
KZN Dune Forests*	166.7	18.5	2.1
Licuati Sand Forests*	258.2	28.7	3.2
Lowveld Riverine Forest*	13.8	1.5	0.2
Mangrove Forests*	25.3	2.8	0.3
Coastal Swamp and Floodplain Forests	116.5	12.9	1.4
Total MCP forests:	901.4		11.1
Total MCP not forests:	7 239.3		88.9
Total MCP:	8 140.7		100.0

* Names associated with the KwaZulu-Natal (KZN) vegetation types map (Scott-Shaw and Escott, 2011).

and likely that the decline would persist or even accelerate in the next 50 years, which will likely reach collapse by 2060 (Table 6). Consequently, it is unlikely that current conservation interventions will reverse the trend within the next twenty years, considering that the dominant canopy may require 10–30 years to mature. The severity of the stress during dry climatic cycles, the intensification of droughts and an increase in air temperature associated with climate change, as well as the increase in commercial and subsistence timber plantations together with habitat loss, have a negative impact on the functionality of the system and species. Excessive habitat loss will likely result in the increase of erosion of the peat substrate, or under extremely dry conditions, exposure of peat substrate, desiccation or the burning of the peat substrate, and ultimately turning this sink into a source of carbon dioxide.

4. Discussion

We developed a bottom-up approach in assessing the conservation status of subtropical-temperate coastal forested wetlands (including swamp and floodplain forests) of Africa, as a subtype to ecosystem functional group category TF1.2 (Keith et al., 2020). The approach uses a combination of available land cover and species data to inform on the red listing of this ecosystem. The ecosystem was found to be very likely Critically Endangered, based on criterion B (range-restricted) and likely to collapse within 50 years. Furthermore, associated with this ecosystem type is Near Threatened and declining *C. a. erythrarchus,* an endemic subspecies of the Samango monkey (Linden et al., 2016). Despite the implementation of top-down measures of conservation planning and management (effecting conservation through policy and legislative measures by the state using global treaties and national implementation mechanisms), the trends and losses have increased over the past 17 years, leaving us with a conservation conundrum. These challenges, and their associated limitations and recommendations are discussed in subsections.

4.1. *Conservation conundrum – Failure of top-down approaches*

Since 2006, a 100% conservation target has been assigned to South Africa's coastal swamp and floodplain forests concurring with two national and one provincial assessment (Berliner, 2005; Berliner, 2009; Jewitt, 2018; Mucina and Rutherford, 2006). More than a fifth of the MCP had various levels of national and international protection at the time of the reference epoch of 2000, with 62% of the areal extent of coastal swamp and floodplain forests in these protected areas. The loss and transformation of these coastal swamp and floodplain forests are primarily attributed to land conversion to agricultural crop production, inside and outside the protected areas and Ramsar sites. The ARD calculated for the MCP is 2.4 km^2 (or 2%) per annum, comparable to average habitat loss of tropical forests reported in Keith et al. (2009). However, the ARD for the focus area was higher at 2.4 km^2 (or 2.75%) and above the global average of deforestation. To date, evidence of trees dying off in the swamp and coastal forests remain deficient. One can therefore conclude that these top-down measures (i.e., conservation

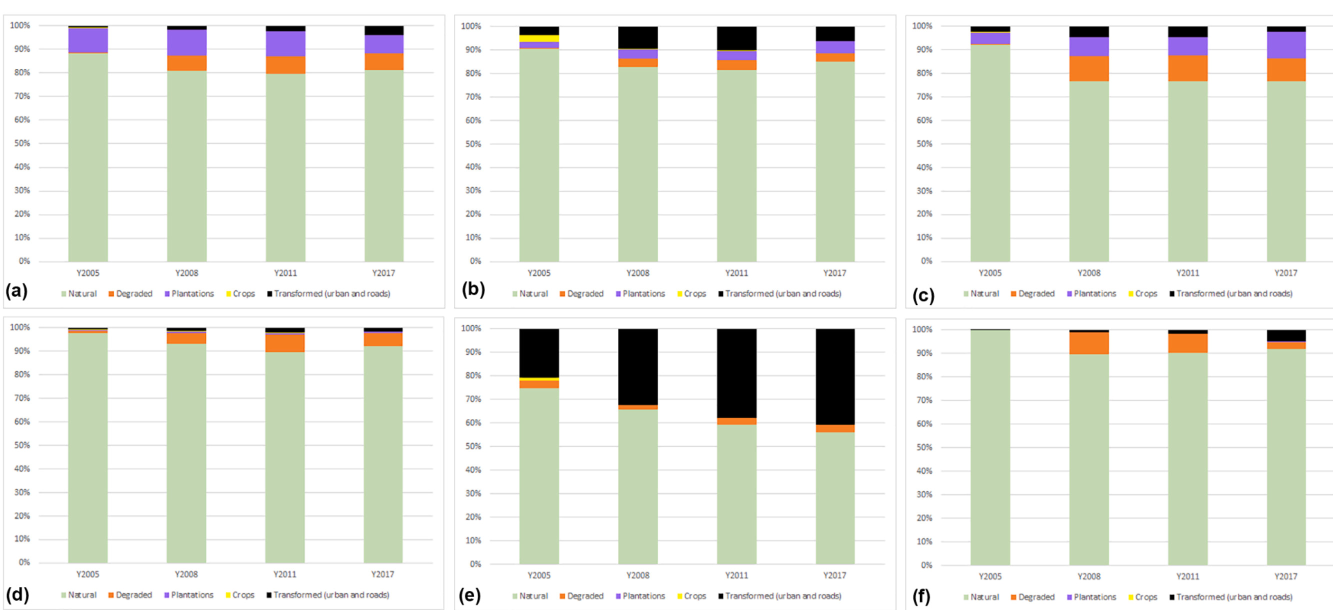

Fig. 3. Changes in the percentage of areal extent (y-axis) of forest types over the epochs of 2005, 2008, 2011 and 2017 (x-axis) for the Maputaland Coastal Plain (MCP), relative to the total areal extent mapped for the reference epoch of 2000, including (a) coastal Swamp and Floodplain Forests; (b) Coastal (dryland) Forests; (c) Dune Forests; (d) Licuati Sand Forests; (e) Lowveld Riverine Forest; and (f) mangroves. Note that 75% of all KwaZulu-Natal's Lowveld Riverine Forests (100.8 km^2) are found on the MCP.

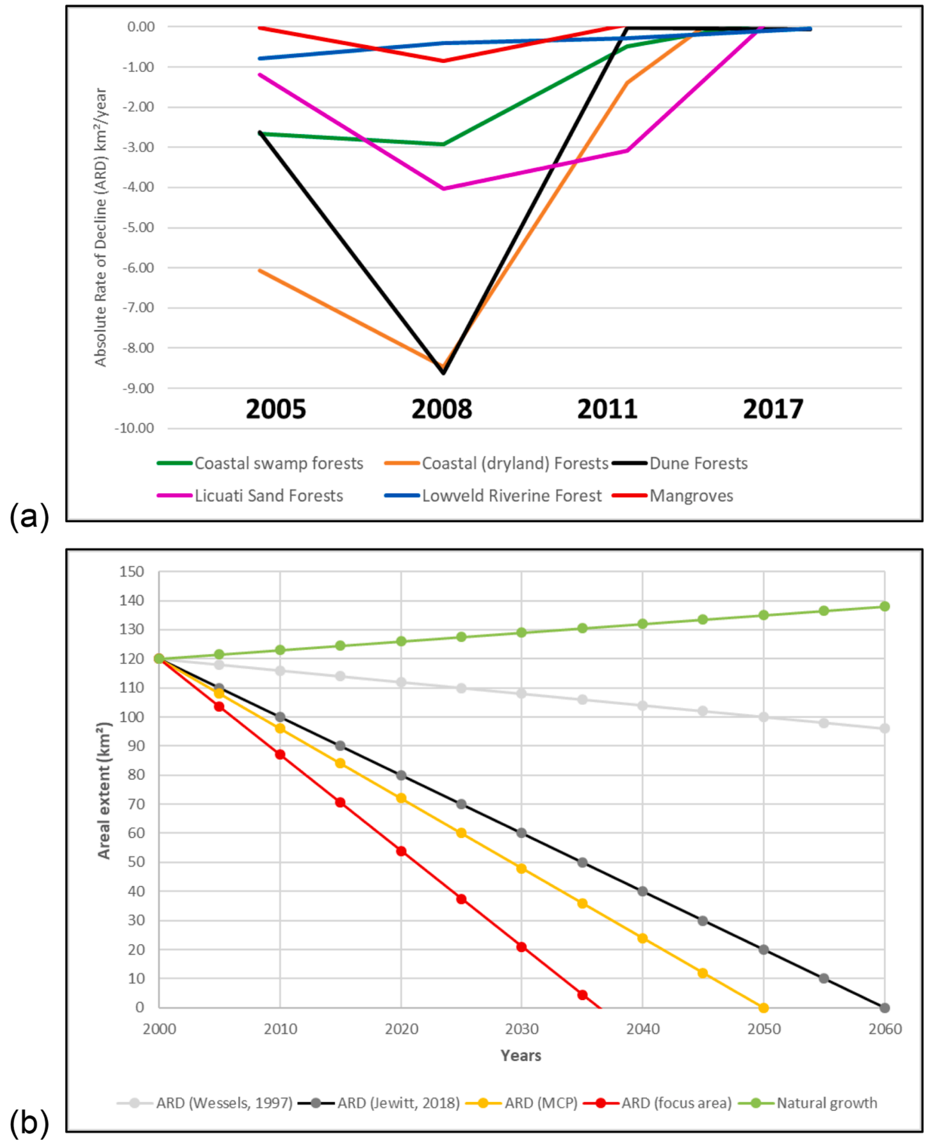

Fig. 4. Absolute rate of decline of forest types on the Maputaland Coastal Plain with (a) showing changes for the assessment period (2005–2017) against the areal extent mapped in the reference epoch of 2000 and (b) trajectories of years to collapse based on the ARD from this assessment against Jewitt (2018).

Table 3
Fragmentation statistics for coastal swamp and floodplain forests on the Maputaland Coastal Plain for the reference epoch of 2000 and changes observed in 2005, 2008, 2011 and 2017.

Year	Area (km^2)	Mean patch size (ha)	No. of patches	Patch density (no per 100 ha)	Edge density (m per ha)	Mean perimeter-area ratio	Aggre-gation Index (%)
2000	116.5	22.8	511	0.06	2.42	825	91.55
2005	103.3	12.7	817	0.10	2.32	990	90.92
2008	94.6	8.7	1 085	0.13	2.71	1 110	88.40
2011	93.1	8.1	1 157	0.14	2.80	1 106	87.84
2017	95.1	8.3	1 145	0.14	2.78	1 084	88.17

measures implemented by the state through policy and legislation) have failed to date, and have not influenced a turn-around in the current rate of degradation. We suggest that supporting a bottom-up, community-based approach (i.e., community-based decision making and planning to influence conservation) might also be required to achieve conservation outcomes. The IUCN red list status, as assessed in this article, could likely effect the prioritisation and focused efforts towards intervention in this area in a more hybrid and integrated top-down and bottom-up approach. Importantly, solutions in the form of a multi-stakeholder approach that will require commitment from national, provincial and local government, conservation bodies (including Ramsar and the World Heritage Organisation), non-governmental organisations, researchers, and local communities should be considered. Transdisciplinary co-learning approaches (Cockburn et al., 2016; Polk, 2015; Van Breda and Swilling, 2019) within such a community of practice will likely be more successful in fostering community ownership, collaborative conservation, and a co-generation of knowledge and awareness of the remaining aquatic resources that these communities are dependent on.

Table 4
Threatened species and Taxa of Conservation Concern (TOCC) that shows close association with the subtropical-temperate, coastal swamp and floodplain forests of South Africa.

Species (down) / assessment information (across)	Association to coastal swamp and floodplain forests	Sufficient knowledge on their habitat, dispersal and migration requirements	Global and national red list assessment	Subspecies assessment
Floral species				
Raphia australis (Oberm. and Strey., 1969) Kosi palm	Coastal swamp and floodplain forests on edge of estuaries of Maputo Bay.	Yes	Vulnerable, D2 (range restricted) (Matimele et al., 2016)	N.A.
Cassipourea gummiflua (Tul., 1856) Large-leaved onionwood	Sand Forest, Northern Coastal Forest, Scarp Forest, Southern Mistbelt Forest, Swamp Forest, Lowveld Riverine Forest.	Yes	Vulnerable A4dc (Raimondo et al., 2009)	N.A.
Vertebrate species				
Aonyx capensis (Schinz, 1821) African clawless otter	African clawless otters occur in rivers where they feed on crabs and other small animals. They occur in the southern, eastern and northern parts of South Africa and are common in sub-Saharan Africa. They use swamp and floodplain forests as migration and dispersal corridors as well as feeding habitats.	No	Near Threatened, decreasing (Jacques et al., 2015).	N.A.
Cercopithecus albogularis ssp. *erythrarchus* (Peters, 1852) Samango monkey	Samango monkeys occur in a range of evergreen coastal and Afromontane forests. Swamp and floodplain forests serve as feeding, migration and dispersal habitats. Being a canopy dwelling frugivore, it is likely a main ecosystem engineer of the swamp and floodplain forests.	No	Vulnerable, decreasing in South Africa (Lawes and Masters, 2020)	*C. a. erythrarchus*Near Threatened, endemic and decreasing (Linden et al., 2016)
Hydrictis maculicollis (Pocock, 1921) Spotted-necked otter	This species feed primarily in open inland waters associated with wetlands and rivers, and would very likely occur around Lake Sibaya on the MCP. Swamp and floodplain forests around Lake Sibaya would serve as migration and dispersal corridors.	No	Near Threatened, decreasing (Reed-Smith et al., 2015)	N.A.
Myosorex sclateri (Thomas and Schwann, 1905) Sclater's mouse shrew	The species is described as an "endemic to subtropical swamps, wetlands and coastal forests in northern KwaZulu-Natal and requires intact habitats to persist. Its habitat is fragmented and it is continuously being lost due to coastal development and other development pressures (Taylor et al., 2016)." Van der Colff et al. (2019).	No	Vulnerable and decreasing (Taylor and Baxter, 2020)	N.A.
Natalobatrachus bonebergi (Methuen and Hewitt, 1912) Kloof frog	Endemic and restricted to freshwater ecosystem habitats within coastal forests of southern KwaZulu-Natal and northern Eastern Cape provinces, at altitudes below 900 m.	No	Endangered, decreasing (IUCN SSC Amphibian Specialist Group and SA-FRoG, 2016)	N.A.
Invertebrate species				
Potamonautes lividus (Gouws et al., 2001) Blue River or Swampforest River Crab	Association with coastal swamp and floodplain forest species *Barringtonia racemosa, Syzygium cordatum,* and *Ficus trichopoda* (Gouws et al., 2001).	No	Vulnerable (Cumberlidge, 2008; Daniels et al., 2020)	N.A.
Varuna litterata (Fabricius, 1798) Peregrine crab	No, but life phases across freshwater (including wet swamp and floodplain forests), estuarine and marine realms (Bruton, 1980; Connell and Robertson, 1986).	No, inland reach into freshwater coastal swamp and floodplain forests remains to be determined	Endangered as per National Biodiversity Assessment of 2018 (Raimondo et al., 2019)	N.A.

Table 5
Areal extent of the coastal swamp and floodplain forests as mapped for the reference epoch of 2000 within protected areas on the Maputaland Coastal Plain (MCP) as well as percentage of all coastal swamp and floodplain forests on the MCP.

Protection area categories	Areal extent of swamp and floodplain forests within protected areas (km^2)	Percentage of total areal extent of swamp and floodplain forests on the MCP ($\Sigma = 116.5\ km^2$)
National Protected Areas (NPAs)	3.8	3.2
NPAs & Ramsar sites	0.5	0.4
Ramsar sites	0.2	0.2
Ramsar sites, World Heritage Sites (WHS) & NPA	53.1	45.6
WHS & NPA	4.3	3.7
Total:	**61.9**	**53.1**

Table 6
Red list assessment evaluation of the subtropical-temperate coastal forested wetlands (swamp and floodplain) in South Africa according to the IUCN criteria (Bland et al., 2017). Threat status: CR = Critically Endangered; EN = Endangered; NT = Near Threatened; VU = Vulnerable. Other categories: DD – Data Deficient; NE – Not Evaluated.

Criterion (across); subcriterion (down):	Criterion A	Criterion B	Criterion C	Criterion D	Criterion E
Subcriterion 1	**CR**^{3} A2a	**CR**^{3} B1 (a)i	**DD**	**NT**^{1} *	**CR**^{3}
Subcriterion 2	**CR**^{3} A2b	**CR**^{1}	**DD**	**DD**	
Subcriterion 3	**CR**^{3} A2c	**CR**^{1}	**DD**	**DD**	

Accuracy levels: ^{1}Virtually certain (99–100% probability); ^{2}Very likely (90–100%); ^{3}Likely (66–100%); ^{4} More likely than not (50–100%); ^{5}About as likely as not (33–66%); ^{6}Unlikely (0–33%); ^{7}Very unlikely (0–10%); and ^{8}Exceptionally unlikely (0–1%). * Faunal species association.

Even though the observed lowering of the groundwater levels may not have caused the immediate loss of the habitat to date, the likelihood of secondary impact may be imminent, given the significant increase in peat desiccation and substrate fires observed for marsh wetlands of the MCP in the recent five years. The geographic positioning of groundwater monitoring boreholes relative to the coastal swamp and floodplain forests should be established. Data from these observation points could inform modelling of the variation of the groundwater compartments relative to inter-annual cycles across the 18-year, wet/dry hydrological cycle, and review the allocated water-use licenses, particularly for *Eucalyptus* spp. plantations. An immediate recommendation would be to remove all timber plantations within 2 km of the edge of swamp and floodplain forests and other wetland types too.

Forests on the MCP contribute to the habitat of the Near Threatened Samango monkey, with patch sizes of > 1.5 km^2 estimated as more suitable habitats (Lawes and Masters, 2020; Linden et al., 2016). Further analysis of our reference layer of forest types (epoch 2000) shows that $>$ 98% of each of the six forest types and all MCP forests collectively, are $\leq$ 1.5 km^2. The Forest Biome in South Africa is the smaller biome, which covers only about 5% of the areal extent of the South African land mass, and is considered naturally highly fragmented, with most forest patches predominantly < 1 km^2 (Eeley et al., 1999). The impact of further fragmentation in the landscape remains unclear, while increase distances between patches may result in higher mortality rates (Linden et al., 2016) and a change in diet may negatively impact the health of the monkeys (SABC, 2012). A change in diet to fruit crops will also reduce the natural spread of plants associated with the swamp and floodplain forests. The Samango monkey is a critical ecosystem engineer for these forests, spreading the fruit of the key indicator tree species, and ensuring new growth and sustainability of the forests (Linden et al., 2015). Their survival is therefore critically interlinked. Further work is therefore important to understand the changes in mortality rate and diet with habitat transformation and increased fragmentation and using remote sensing methods to map the canopy at species level.

Swamp and floodplain forests also show a high vulnerability to climate change, since they occupy geographically narrow habitat ranges, being dependent on peat and inundation regimes since peatlands occupy only about 1% of the extent of wetlands in South Africa (Grundling et al., 2017), and wetlands are mapped for 2.4% of South Africa (Van Deventer et al., 2020). The ability of Samango monkeys to utilize this habitat becomes more difficult under climate change scenarios (Eeley et al., 1999). This poses a problem for the survival of swamp and floodplain forests if the movement of Samango monkeys as the main distributors of the seeds of the forest trees is restricted. In addition, their close association with the coastal climate in South Africa, result in a high level of vulnerability to any climate changes, as evident from their historic vulnerability (Eeley et al., 1999). Management and protection of these habitats in their current distribution range are therefore critical.

4.2. Improvement in quantifying habitat and loss of functionality

Improvements in the detection of degradation in the landscape are critical in improving the accuracy of this assessment. The areal extent lost is underestimated for the land cover data sets where *Satellite Pour l'Observation de la Terre* (SPOT) images with only four traditional bands were used, including 2005, 2008 and 2011. This is attributed to the limitations of the traditional sensors in separating tree species associated with different forests from one another and also cultivated fruit crops (Van Deventer et al., 2019a). The 2017 land cover data showed a huge improvement in the accuracy of the classification in this regard, where the Sentinel-2 sensor improved the separability between classes (Van Deventer et al., 2019a), and identified 47% of the remaining area as natural, which was more congruent to the fine-scale assessment of 49% remaining natural coastal swamp and floodplain forests in 2019 for the focus area (Appendix C).

Classes used in the land cover classification do not reflect ecological degradation of wetlands. Successive transitional degradation phases, from trees being cut down, to slash-and-burn, artificial channelling to drain the system; the cultivation of *Colocasia esculenta* ([L.] Schott, 1832; Madumbes); vegetables (tomatoes, sweet potato and spinach) and ultimately fruit tree crops (especially bananas, transforming then from subsistence to commercial and profitable crop production) as the soils dry out (Grobler, 2009), have been detected in the focus area, and may serve as possible degradation categories to monitor in future. Timing of change detection is also critical, and the capability of remote sensing to monitor at higher temporal intervals will be a critical advantage for an advanced monitoring system. Early detection and monitoring is key for future management, compliance and ecosystem restoration interventions.

4.3. Distribution of subtropical-temperate coastal forested wetlands in South Africa

Clear boundaries between the tropical and subtropical-temperate regions of the eastern African coastal plains remains a challenge to define. While many of the key indicator tree species show large overlaps with the distribution of tropical African swamp and floodplain forest, the distribution range of *R. australis* occurs from north of Maputo Bay in Mozambique to as far south as Lake Amanzimyama, the most southern lake of the Kosi Lake system, and the Siyadla River south of it. The species are significantly different from *Raphia* spp. in tropical Africa, and hence may be indicative of the subtropical region characteristics of coastal swamp and floodplain forests, extending into southern Mozambique (Bandeira et al., 2014).

From an estuarine perspective, the northern parts of the MCP are, however, considered more likely tropical with the Kosi and uMgobezeleni estuaries also hosting aquatic floral and faunal species associated with tropical climates, including the *Halodule uninervis* ([Forssk.] Asch., 1882) seagrass and three mangrove tree species (*Lumnitzera racemosa* [Willd., 1803], *Ceriops tagal* [(Perr.) C.B.Rob., 1908] and *Xylocarpus granatum* [J. Koenig, 1784]). Both these estuaries are also adjacent to the off-shore distribution of the Western Indian Ocean coral reefs that are not found further south in other South African estuaries or adjacent off-shore environments (DWS, 2016; Van Niekerk et al., 2020).

5. Conclusions

The red listing of South Africa's coastal swamp and floodplain forests would potentially be the first IUCN red listed aquatic ecosystem for Africa south of the Sahara. This assessment could also set an example of a bottom-up conservation status assessment of aquatic ecosystems in Africa, rather than top-down assessment through country-wide wetland classification systems. We propose the further subdivision of the global tropical and subtropical-temperature ecosystem functional types to recognize the phytogeographic divide created by the African uplift, dividing forested wetlands at the next tier into coastal and inland forested wetlands. Although the areal extent of South Africa's coastal swamp and floodplain forests are well within the biodiversity target of the habitat, degradation inside protected areas persists, challenging a new multi-sectoral, community-based and bottom-up approaches to this conservation conundrum.

CRediT authorship contribution statement

H. Van Deventer: Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Project administration, Software, Writing - original draft, Writing - review & editing. **J.B. Adams:** Resources, Writing - review & editing. **J.F. Durand:** Investigation, Resources, Writing - review & editing. **R. Grobler:** Investigation, Resources, Writing - review & editing. **P.L. Grundling:** Investigation, Resources, Writing - review & editing. **S. Janse Rensburg:** Investigation, Resources, Writing - review & editing. **D. Jewitt:** Formal analysis,

Methodology, Resources, Software, Writing - review & editing. **B. Kelbe:** Investigation, Resources, Writing - review & editing. **C.F. MacKay:** Investigation, Resources, Writing - review & editing. **L. Naidoo:** Formal analysis, Investigation, Methodology, Resources, Software, Validation, Writing - review & editing. **L. Nel Jeanne:** Conceptualization, Writing - review & editing. **L. Pretorius:** Investigation, Resources, Writing - review & editing. **T. Riddin:** Investigation, Resources, Writing - review & editing. **L. Van Niekerk:** Conceptualization, Resources, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

The extent of the MCP, coastal swamp forest and related datasets are available on request.

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Disclaimer

The views and opinions expressed in this article are those of the author and do not necessarily reflect the official policy or position of any affiliated agency of the author.

Appendix A. Supplementary data

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