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Contributions of Red Lists of Ecosystems to risk-based design and management of protected and conserved areas in Africa

Abstract

Protected and Conserved Areas (PCAs) are key ecosystem management tools for conserving biodiversity and sustaining ecosystem services and social co-benefits. As countries converge on a 30% target for protection of land and sea under the post-2020 framework of the United Nations Convention on Biological Diversity, a critical question emerging is, “which 30%?”. One approach to an answer is risk-based: we should protect the 30% that returns the greatest reductions in risks of species extinction and ecosystem collapse. IUCN Red List protocols provide practical methods for assessing these risks. All species, including humans, depend on the integrity of ecosystems for their well-being and survival. Africa is strategically important for ecosystem management due to convergence of high ecosystem diversity, intense pressures and high levels of human dependency on nature. We reviewed the outcomes of a symposium at the inaugural African Protected Areas Congress convened to discuss applications of the IUCN Red List of Ecosystems to the design and management of PCAs. We found significant recent progress in red listing, with c. 1000 ecosystem types assessed across 21 countries. While these span a diversity of environments across the continent, the greatest thematic gaps are in

freshwater, marine and subterranean realms and large geographic gaps exist in north Africa and parts of west and east Africa. The projects are implemented by a diverse community of government agencies, NGOs and researchers. Already, they are having impact on policy and management, informing extensions to formal Protected Area networks, supporting decision making for sustainable development and informing ecosystem conservation and threat abatement, both within boundaries of PCAs and in surrounding landscapes and seascapes. We recommend further integration of risk assessments into environmental policy and enhanced investment in ecosystem red listing to fill current gaps.

Introduction

Ecosystems are critical components of biodiversity and play important roles in social, economic and health dimensions of human well-being (IPBES 2019). They represent higher levels of ecological organisation, comprising multiple species, their genes and physical environments, and the typically complex interactions and dependencies among them. The full diversity of Earth's ecosystem types encompasses variations in ecological processes that are key to maintaining the diversity of life and ecological functions throughout the planetary system (Keith et al. 2022). For people, ecosystems underpin the supply of essential resources, livelihoods, cultural and spiritual fabric of societies, and contribute to mental and physical health (IPBES 2019). By protecting ecosystems, natural habitats and the ecosystem services they provide, Protected and Conserved Areas (PCAs) act as nature-based solutions that help people cope with the impacts of climate change, health and disaster risks (APAC 2022).

Ecosystem risk assessment emerged as a framework for ecosystem management when the International Union for Conservation of Nature (IUCN) adopted the Red List of Ecosystems (RLE) categories and criteria as a global standard in 2014 (Keith et al. 2015). The RLE protocol enables ecosystem types to be assigned to ordinal categories of risk based on five main symptoms of ecosystem collapse (Keith et al. 2013): A) declines in distribution; B) restricted distribution; C) environmental degradation; D) disruption of biotic processes; and E) estimated probability of ecosystem collapse over the next 50 years. Ecosystem collapse signals transformation of identity, loss of defining features, and replacement by a novel ecosystem (Keith et al. 2013). An RLE assessment produces an understanding of which ecosystem types are at greatest risk of collapse, and the underlying causes of high risk, and establishes the foundations for management strategies aimed at ecosystem conservation and sustainability (Keith et al.

2015). RLE may be applied systematically to assess risks to all ecosystem types within a specified area (e.g. a country) or strategically to one or a few priority ecosystem types or sub-systems, focussing on diagnosis of the underlying causes of risk as a basis for developing risk-reduction strategies (Bland et al. 2019).

Africa contains very high ecosystem diversity, with 83% of the world's terrestrial, freshwater and marine shelf Ecosystem Functional Groups represented on and around the continent (Keith et al. 2022). Eighteen of the 20 countries with the lowest Human Development Index (HDI) are in Africa and all African countries are classified as Developing Nations with HDI<0.8 (UNDP 2019). This suggests a convergence of high biodiversity value and irreplaceability, high human dependency and high pressures on ecosystems, from both local use and industrial-scale development. For example, one-quarter of the world's 36 terrestrial biodiversity hotspots (high levels of both endemism and habitat loss) are in Africa (Conservation International 2022) and one-third of Africa's tropical flora is potentially at risk of extinction in the next 100 years (Stévart et al. 2019).

Protected and Conserved Areas (PCAs) are one, among a suite of ecosystem management tools to conserve biodiversity and sustain ecosystem services and social co-benefits (Oldekop et al. 2016). In Africa, PCAs have long been recognised as a means for conserving threatened biodiversity, as local and national economic assets and income streams, and as linchpins for sustainable harvest of wildlife and fisheries in surrounding landscapes and seascapes (Harrison et al. 2012). In some regions, they represent the last remaining refuges for native biodiversity in landscapes and seascapes that are now highly transformed by human activity (Joppa et al. 2008). However, the effectiveness of PCAs in conservation depends on sustained ecosystem management activities (Tranquilli et al. 2014; Oldekop et al. 2016).

In July 2022, the inaugural IUCN Africa Protected Areas Congress under the theme "For People and Nature" resolved to identify priority actions to strengthen Africa's PCAs in a manner that is just, equitable and fair and that will deepen the involvement of Indigenous Peoples and local communities (APAC 2022). In this contribution, based on an APAC symposium on the Red List of Ecosystems, we aim to distil lessons learnt from African RLE assessments to address challenges posed by data scarcity, resourcing, socio-political context and management implementation. We first describe continent-wide progress on Red List assessments of African ecosystems, then review selected case studies of systematic and strategic assessments of diverse ecosystem types across Africa and conclude with insights into how RLE assessments are guiding effective development of PCA networks and their sustainable management.

Progressing risk assessments of African ecosystems

Based on IUCN's global ecosystem typology (Keith et al. 2022), at least 81 ecosystem functional groups (83% of world total excluding pelagic ocean waters and the deep sea floor) are represented in Africa and its marine shelf (Fig. 1). Africa harbours more than three-quarters of the world's Trophic savannas (T4.1), one-third to one-half of Tropical and Subtropical Dry Forests (T1.2), up to one quarter of Tropical rainforest and more than 40% of Pyric tussock savannas (T4.2), Semi-desert steppes (T5.1) and Hyperarid deserts (T5.5) (Fig. 1). Small, but globally important areas of other ecosystem groups found in Africa include Seasonally dry temperate heath and shrublands (T3.2), notably the diverse fynbos of the Cape Floristic region, and Tropical alpine ecosystems (T6.5), associated permanent ice and glaciers (T6.1), and Artesian springs and oases (F2.8).

Red List assessments have been carried out for ecosystem types representing 31 functional groups in four main areas (Table 1). In total, RLE assessments have been undertaken for 940 ecosystem types across 28 countries, approximately 20% of the current global tally (IUCN, unpubl. data). Terrestrial biomes are well represented in these assessments (75% of total), whereas marine, freshwater, subterranean and transitional biomes are under-represented. Geographically, Red List assessments currently cover southern Africa, parts of east and central Africa, and limited areas in west and north Africa (Fig. 2).

More than 1.8 million km^2 of tropical forest have been assessed over the Congo region, Madagascar, South Africa and Mozambique, and at least 1.6 million km^2 of savannas and deserts have been assessed in South Africa and Mozambique (Table 1), but extensive occurrences of these biomes in the Sahel and Sahara are yet to be assessed. Smaller areas of the temperate forests (T2, 1000 km^2) and shrublands biome (T3, 80,000 km^2) have been assessed, but these represent large proportions of their extent in Africa.

Among its 18 freshwater ecosystem functional groups, Africa contains up to half of the world's artesian springs (F2.8) and seasonal floodplains (TF1.4), as well as major occurrences of seasonal rivers (F1.4, F1.5), episodic arid streams (F1.6) and floodplains (TF1.5), and large permanent rivers (F1.1) and lakes (F2.1). A large majority of those in Africa remain unevaluated or data deficient, although Red List assessments have been undertaken for important freshwater ecosystems in Egypt (Ghoraba et al. 2019), Congo basin (Shapiro et al. 2021), Senegal/Mauritania (Keith et al. 2013) and some in Mozambique (Lötter et al. 2021).

Much of the African marine shelf is narrow, but it contains important representations of seagrass meadows (M1.1), coral reefs (M1.3) and upwelling zones (M1.9). A regional assessment of coral reefs (M1.3) of the Western Indian Ocean (Obura et al. 2022) and the Upwelling zone (M1.9) of the Southern Benguela current (Bland et al. 2018) account for a large proportion of the African representation of those ecosystem functional types. The South African national assessment and a European Union assessment of the Canary and Madeira Islands waters include a broader range of marine ecosystems, but use non-standard Red List approaches (Gubbay et al. 2016; Sink et al. 2019) and are excluded from Table 1.

The transitional biomes along the coastal regions include shorelines, supralittoral vegetation, and the complex interface of freshwater, marine and terrestrial realms. More than 13,000 km^2 of Mangroves (MFT1.2) and Salt marshes (MFT1.3) and almost 18,000 km^2 of supralittoral vegetation (MT2.1) and sandy beaches (MT1.3) are included in national and regional assessments of the Congo basin, South Africa, Mozambique and Madagascar (Table 1).

Red List assessments in Africa

We reviewed a sample of six African case studies (three strategic, three systematic) to gain insights into the motivations and data needs for Red List of Ecosystem assessments and how they are contributing to the design and management of PCAs.

Strategic assessments

Burullus Protected Area, Egypt

Burullus Protected Area is one of the most important of 30 protected areas covering more than 15% of Egypt's land area. It includes a Ramsar wetland an Important Plant Area and an Important Bird Area , as well as unique sand plain and salt marsh ecosystems (Khalil, 2013, 2018). Strategic risk assessments of wetland, sand plain, and salt marsh ecosystems were carried out using RLE methods and tools (Bland et al. 2017; https://iucnrle.org/rle-material-and-tools) during 2017-20 to support the management of the Burullus Protected Area.). Outputs of the project included a time series of ecosystem maps showing changes in extent and two peer-reviewed publications detailing the assessments.

The RLE assessments advanced understanding of ecosystem dynamics, the current status of ecosystems and the underlying causes of risk. Sand plain and salt marsh ecosystems qualified as critically endangered due to declines in distribution caused by socio-economic activities, e.g., urban expansion, land reclamation, and farming (Ghoraba et al., 2021). The wetland qualified for endangered status due to degradation of ecosystem integrity caused by the discharge of agricultural and domestic effluents (Ghoraba et al., 2019). Abatement of risks hinges on enhanced development planning processes to avoid further loss of sand plain and salt marsh and effective pollution control for the wetland, not only within the Burullus Protected Area, but in its catchment beyond its boundary. Ecosystem risk assessment can inform the management of the protected area by framing goals that focus on reducing and reversing current risks, particularly those that emanate from beyond the protected area boundary, and by prioritizing the most threatened ecosystems for restoration. Although limitations on data availability and consistency were overcome, regular ecological monitoring of informative indicators of ecosystem collapse are essential to ongoing assessments.

Fathala forest, Senegal

In Senegal, like much of the Sudano-Sahelian zone, forest formations are heavily degraded, marked by decreases in wooded areas, reduced species density and changes in their structure. This strong degradation of ecosystems in the Sudano-Sahelian zone is due to regional climatic drying, with increasing periods of drought and rainfall deficit (Le Borgne, 1988), combined with increasing exploitation of plant and soil resources (Toure, 2002). The Fathala forest is an important protected area in the southwest of Senegal that contains two types of forest (‘gallery’ and ‘clear' forest), which are home to a northern population of the Endangered African Colobus monkey, *Piliocolobus badius temminckii* Kuhl. Forest degradation poses threats to the tree-dependent African colobus and other animal species (Diouck and Akpo, 2007). The imperative to reverse the degradation of the Fathala forest ecosystem and restore its biodiversity prompted a risk assessment based on the Red List protocol (Bland et al. 2017).

The Red List assessment revealed major declines in both the density of tree stems and tree recruitment rates over the past 40 years, as well as significant shifts in composition to dryland tree species, supporting critically endangered status for both gallery forest and clear forest (Kaly et al. 2021). The causes of forest decline were attributed to climatic drying and anthropogenic disturbance, which make conditions less suitable for survival and recruitment of trees and for animal seed dispersers. Following early exploitation for wood and some cultivation for crops, a fenced zone was allocated to private interests for ecotourism and introduction of large herbivores and predators. Initially, these activities reduced tree density, but restricted access later promoted regeneration of trees.

Recommendations arising from the assessment to reduce risks of forest collapseinclude: total fencing of the forest to increase protection against human access and disturbance; assisting natural regeneration of vegetation; extending artificial watering holes to encourage seed dispersal by animals and seedling establishment; and planting additional trees when conditions are favourable to initiate restoration of forest structure. Several projects are now in development to save the forest ecosystem and the threatened colobus monkey.

South Benguela upwelling system, South Africa

An eastern boundary upwelling marine system off the west coast of South Africa and the closely interlinked Agulhas Bank system on the south and east coasts (Kirkman et al. 2016) comprise “the broader Southern Benguela”, a productive pelagic fishery ecosystem. An RLE assessment based on research surveys, reported catches, ecosystem modelling and environmental monitoring, listed the broader Southern Benguela as Endangered in 2015 (Bland et al. 2018). However, several indicators showed improvement over time and the authors recommended spatially disaggregated modelling and indicator-based assessments to account for spatial changes in ecosystem components and threats.

The recommendation was refined in the subsequent National Biodiversity Assessment, which adopted a finer-grained approach, using 31 anthropogenic pressures as proxies for ecological condition (Sink et al. 2019) to assess degradation in 150 marine ecosystem types (Sink et al. 2019). Only 5% of the ocean area off South Africa was assessed as threatened, but this accounted for half the ecosystem types examined. More threatened ecosystem types were identified in the Southern Benguela ecoregion than on the Agulhas Bank and further east (Sink et al. 2019), highlighting the need for careful spatial management to prevent biodiversity loss in the Southern Benguela.

Recognising the need for further development of methods and data, Red List assessments of the broader Southern Benguela are encouraging iterative development of marine spatial planning via the National National Coastal and Marine Spatial Biodiversity Plan (Harris et al. 2022a, b). This identifies protection of Critical Biodiversity Areas, Key Biodiversity Areas, Ecologically and Biologically Significant Areas as important risk reduction measures. Future refinement of RLE assessment, including model scenarios of plausible futures, will be valuable for assessing the benefits of protecting these areas.

Systematic RLE assessments

Mozambique

A rapid systematic Red List assessment of Mozambique's terrestrial and wetland ecosystems was carried out with existing information to support sustainable development policies during an era of rapid land use change (Lötter et al. 2021). The preliminary outcomes of the assessment reveal that almost half (45%) of Mozambican ecosystems are threatened, primarily forests and savannas along the coastal belt and throughout the central-west of the country. The major threatening process driving these results is deforestation and clearing of native vegetation to facilitate subsistence agriculture, charcoal production, urban expansion, mining and oil and gas projects . Between 2000-2016, over 250,000 hectares of native vegetation was lost each year (República de Moçambique 2018).

While Mozambique's RLE is still being finalised, the results will inform conservation practice and policy in several ways. Primarily, RLE results will be integrated into the application of Mozambique's biodiversity legislation (República de Moçambique 2017), which requires project developers to avoid impacts wherever possible, and to compensate for residual impacts on biodiversity. Threatened ecosystems are likely to be priority areas for avoidance of development impacts, because impacts on them mandate substantially higher offset requirements than impacts on non-threatened ecosystems. This encourages project developers to screen for threatened ecosystems at the project planning stage, and design development plans to avoid impacting threatened ecosystems before work commences (Ekstrom et al. 2015).

The status of different ecosystem types documented in Mozambique's Red List assessment, in combination with ancillary data on environmental degradation (e.g. NDVI trends, human pressure maps), will help identify potential offset receiving sites, where restoration activities are likely to produce the greatest risk-reduction outcomes to compensate residual ecological impacts caused by development projects. This is already codified in national legislation, and initial scoping from Red List assessments should guide detailed site assessments to verify site feasibility and estimates of offset benefits. Spatial information on risks to ecosystems from Mozambique's Red List assessment will also inform identification of priorities for potential designation of new protected areas, and expansion of existing ones, through application of IUCN's Key Biodiversity Areas standard (IUCN 2016), and systematic conservation planning analyses.

South Africa

South Africa is one of the few countries that initiated an ecosystem threat assessment program before the IUCN RLE criteria were developed, and one of very few with a time series of successive systematic Red List assessments that enable ecosystem status to be tracked over two decades across terrestrial, freshwater, coastal and marine realms (Botts et al. 2020). Indicators of ecosystem status, modelled on the Red List of Species were developed for systematic conservation planning and national scale reporting in the early 2000's. Systematic national-scale assessments were conducted in 2004 and 2011 using methods akin to the RLE (Botts et al. 2020). Strong links between the national threatened ecosystem list (equivalent to the RLE) and systematic conservation planning and land use decision-making were established from the start of the process; and culminated in enactment of legislation that formalised and reinforced the protections afforded to Endangered and Critically Endangered ecosystems.

In 2019 a three-year process to reassess ecosystems across all realms was completed (Skowno et al, 2019; Botts et al. 2020). The methods of assessment generally followed the RLE framework but full alignment was only achieved for the terrestrial realm (Skowno & Monyeki 2021). Almost half of the 1021 ecosystem types assessed across terrestrial, freshwater, coastal and marine realms, were categorised as threatened (Skowno et al 2019). Risks to coastal ecosystems were generally greater than those to non-coastal ecosystems, even though 87% of ecosystem types in coastal areas are now afforded some protection (Harris et al. 2022b).

Threatened ecosystems identified in the Red List continue to be key inputs into systematic conservation plans, protected area expansion plans, prioritisation for ecosystem restoration, and land-use planning and decision making in South Africa. Alongside species of concern, heritage assets, proximity to existing Protected Areas and operational factors, the ecosystem types most at risk are used to prioritise land parcels for protected area expansion. In the Fynbos biome, 25-100% of the expansion footprint for National Parks is driven by threatened ecosystems; in Table Mountain National Park, and urban park, it is 98%. The park expansion footprint for all National Parks is also incorporated into South Africa's National web-based Environmental Screening Tool, a legal instrument, which stipulates strict requirements for development. More broadly, planning instruments that identify Critical Biodiversity Areas, including those that make irreplaceable contributions conservation targets for Red-listed ecosystems beyond the formal Protected Area network, have proven effective in reducing risks of loss through irreversible land use changes (von Staden et al. 2022). Many of these planning activities leverage ecosystem spatial data used in Red List assessments, which are continually updated and improved since the first national assessment in 2004 (Skowno & Monyeki 2021).

Western Indian Ocean coral reefs

The Western Indian Ocean (WIO) contains 16% of the world's coral reefs, and is a globally important hotspot for coral reef biodiversity (Obura 2012). Coral reef ecosystems underpin national economies in the region, particularly fisheries and tourism sectors, and have an estimated asset value of US$ 18.1 billion (Obura et al. 2017). Through funding from Norad (Norway), CORDIO coordinated scientists from more than 35 organizations, to assess risks of coral reef ecosystem collapse at regional and ecoregional scales in the Western Indian Ocean (WIO). The assessment was based on indicators of ecosystem extent, response to future warming, and interactions among key ecosystem compartments (corals, algae, parrotfish and groupers) (Obura et al. 2021). Overall, WIO coral reefs were classified as Vulnerable, while reefs in 11 nested ecoregions ranged from Critically Endangered (islands, driven by future warming) to Vulnerable (continental coast and Seychelles North, driven by fishing pressure).

The assessment leveraged data from the Global Coral Reef Monitoring Network (GCRMN) and forged innovations in ecosystem risk assessment including bootstrapping to account for uncertainty in initial states, and a structured (sequential) model of ecosystem decline. This novel assessment approach can be adapted to reef ecosystems in other regions and related ecosystem types, such as mangroves and seagrass beds.

A key advantage of this systematic regional-scale analysis and its standardised outputs is in promoting consistent and co-ordinated policies and actions across countries (Momanyi, 2016). Policy and management implications for WIO coral reefs were detailed in a policy White paper developed for the Nairobi Convention's science-policy forum. Potential actions range from mitigating climate warming and minimizing its impact, to ecosystem-based management at local scales to build resilience of coral reefs and their socio-economic values to climate change. Strategic location and management of marine protected areas is critical to sustaining reef ecosystems and their fisheries (Harrison et al. 2012), which are pivotal to local economies.

Local management actions have significant potential to maintain or improve reef health in ecoregions less threatened by future warming, i.e. on the mainland coast (McLeod et al., 2019). 'National Coral Reef Assessments' in Kenya, Tanzania, Mozambique will leverage the data streams and analysis from the regional RLE to identify priority reef areas requiring protected area designations or other effective conservation measures.

Insights into risk-based Protected Area Management and design

Ecosystem risk assessment has progressed rapidly in Africa since IUCN adopted the Red List of Ecosystems standard in 2014. Almost half of all African countries have at least one RLE assessment, with further assessments underway. Red List projects originated from diverse sources including government agencies (Skowno et al. 2018), non-government organisations and foreign aid agencies (Lötter et al. 2021, Obura et al. 2022), research institutions (Kaly et al. 2021; Bland et al. 2018) and postgraduate studies (Ghoraba et al. 2019, 2021). Resourcing levels and available data varied widely among the case studies, although strategic assessments were generally less resource-demanding than systematic assessments, depending on initially data availability. Some assessments leveraged substantial bodies of existing data (Skowno et al. 2018; Obura et al. 2022). The design and management of PCAs is a key focus of many African Red List of Ecosystem assessments, including the case studies examined here.

The major gaps in coverage are for assessments of freshwater ecosystems, marine shelf ecosystems except coral reefs, and terrestrial ecosystems primarily in north Africa and parts of west and east Africa. Expansion of systematic ecosystem Red List assessments to fill the thematic and geographic gaps should provide African countries with a strong foundation for achieving targets of the post-2020 CBD agenda (OEWG-GBF 2021). Our case studies show how RLE assessments are reducing risks to ecosystems by informing additions to Protected Area networks in pursuit of 30% targets for protection of land and sea (Target 3); supporting spatial planning decisions envisaged in Target 1; and guiding ecosystem restoration activities required under Target 2. South Africa's systematic RLE is used to identify priorities for Protected Area additions and to identify statutory Critical Biodiversity Areas (based on Critically Endangered and Endangered ecosystems) that receive regulatory protection outside the formal Protected Area network. Recent analyses show that these areas have reduced risks of land use conversion and ecosystem destruction relative to other areas that do not receive regulatory protection (von Staden et al. 2021). Similarly, newly initiated Red List assessments in Mozambique, Malawi, Namibia and South Africa will help identify Key Biodiversity Areas and support systematic conservation plans.

Strategic RLEs have been instrumental in diagnosing risks to ecosystems already within PCAs. Conceptual models, a recommended step in Red List assessments (Keith et al. 2013) were powerful diagnostic tools for understanding the mechanisms and causes of threats to ecosystems in the Burullus Protected Area (Ghoraba et al. 2019, 2021), the Southern Benguela (Bland et al. 2018) and Western Indian Ocean coral reefs (Obura et al 2022). In these cases, as well as the Fathala forest Protected Area (Kaly et al. 2021), the Red List assessments highlighted the permeability of Protected Area boundaries to certain threats and the need for risk-reduction management actions to address processes that occur largely outside the boundaries of PCAs.

Risks to ecosystems stemming from outside PCA boundaries usually have social dimensions that interact with ecological functionality (Schultz 2011). In these cases, both human and ecological processes are essential for concurrent understanding of land use and ecosystem changes (Snoo et al. 2013), and hence solutions to ecosystem sustainability. Understanding social drivers and behaviours that underpin human dependence on ecosystems can strengthen conservation management and policy making (Gou et al 2021), however, sociological processes and interactions are yet to be explicitly included in ecosystem risk assessments (Sandbrook et al. 2013).

Socioecological models offer suitable frameworks to develop nature-based solutions supporting human livelihoods while maintaining low risk to the ecosystems (Schulz 2011). A case study underway at Tiwai Island Sanctuary, a tropical rainforest in Sierra Leone, seeks to investigate how livelihood choices and values of human communities interact with risks to the ecosystem. Such approaches should improve conservation outcomes and policies.

All of the African Red List assessments identified climate change as a major driver of ecosystem decline and collapse. Some ecoregional coral reefs in the Western Indian Ocean are at risk from episodic coral beaching related to rising sea surface temperatures and ocean acidification, while Fathala forest is undergoing degradation driven by sustained regional rainfall declines. While local adaptation measures could help to slow the pace of degradation, the most effective risk reduction strategy hinges on sustained implementation of global climate change mitigation policies.

Finally, RLE assessments help to develop ecosystem-specific indicators for monitoring key ecosystem components and processes. Targeted monitoring not only provides sustained data flows for Red List updates and more direct data for reporting than landuse/landcover proxies, but provides insights into the effectiveness of alternative management strategies and the emergence of unexpected trends (Lindenmayer & Likens 2010).

Our review shows that RLEs can contribute to more effective design and management of Protected and Conserved Areas by highlighting where they should be located and how they should be managed to achieve significant reductions in the risk of ecosystem collapse. To realise these outcomes, we recommend continuing expansion of Red List assessments to the full range of African ecosystems, especially across west, east and north Africa, and further integration into conservation policy and management.

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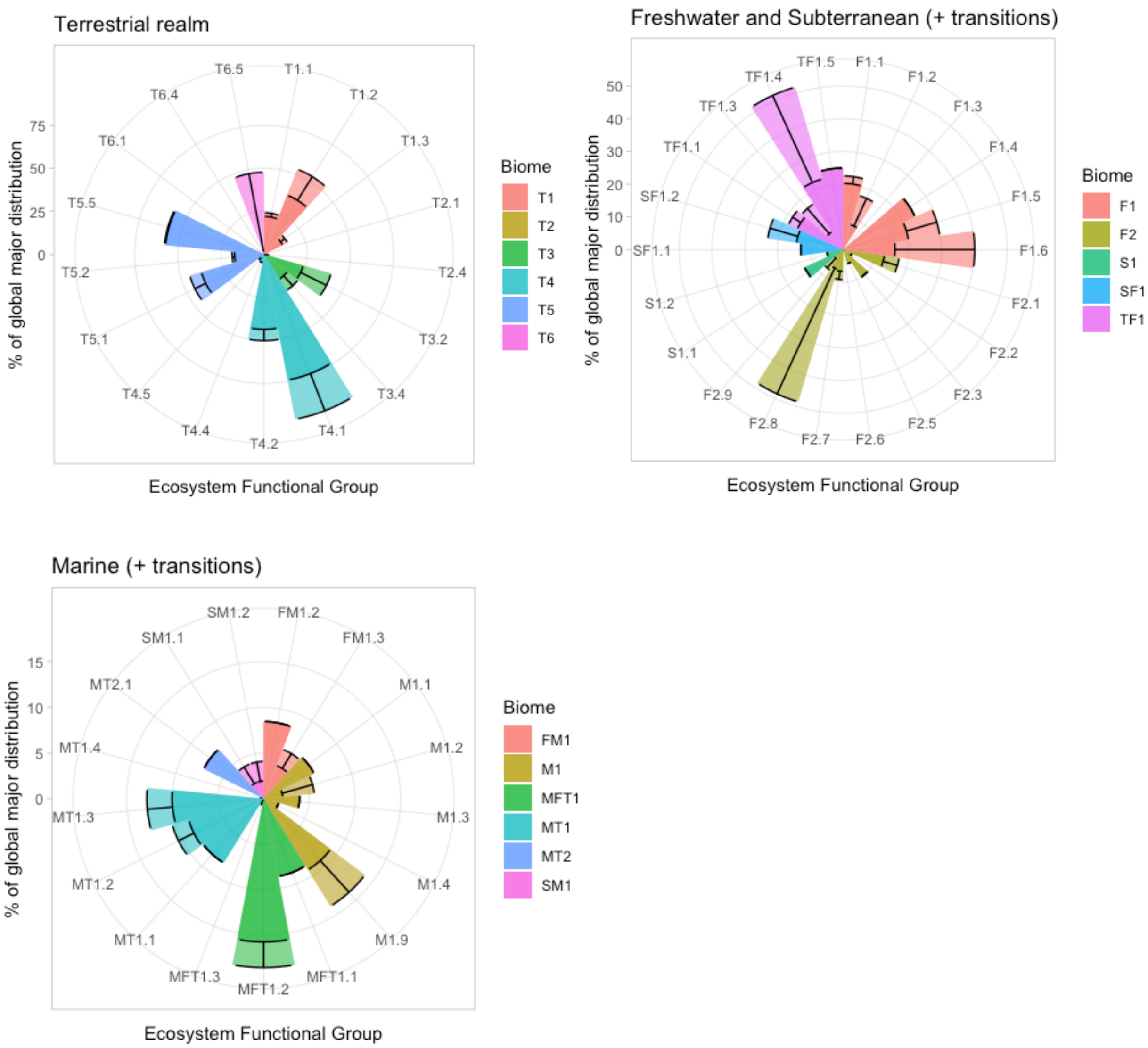

Figure 1. Representation of ecosystem functional groups in Africa as percentage of estimated global extent based on indicative distribution maps (Keith et al. 2022). Error bars represent uncertainty in the estimate when minor occurrences are ignored or included. Scales of percentage values are shown on the left side and are different for each panel.

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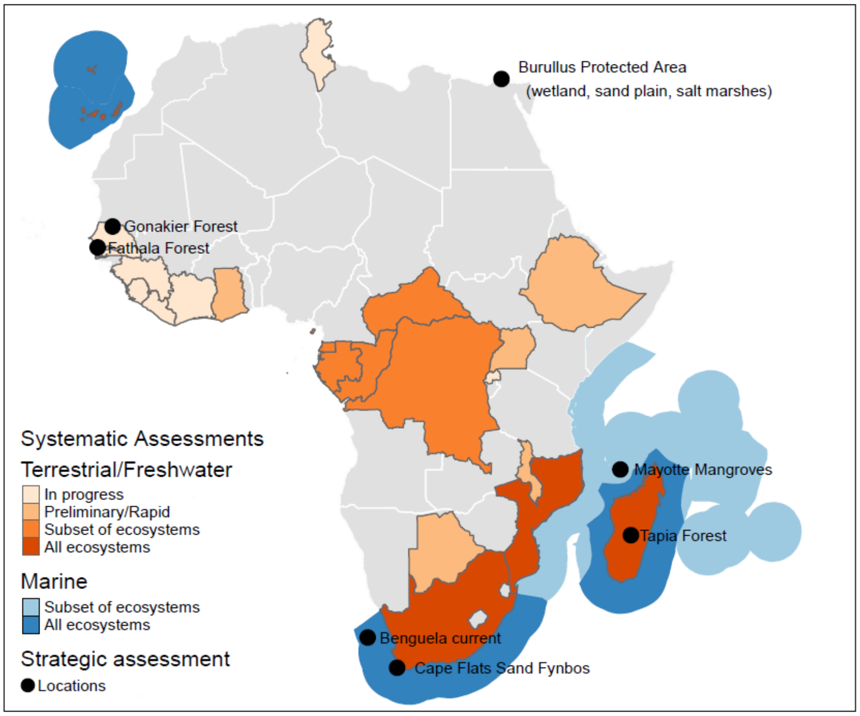

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528 Figure 2. Strategic and systematic Red List of Ecosystems assessments in Africa.

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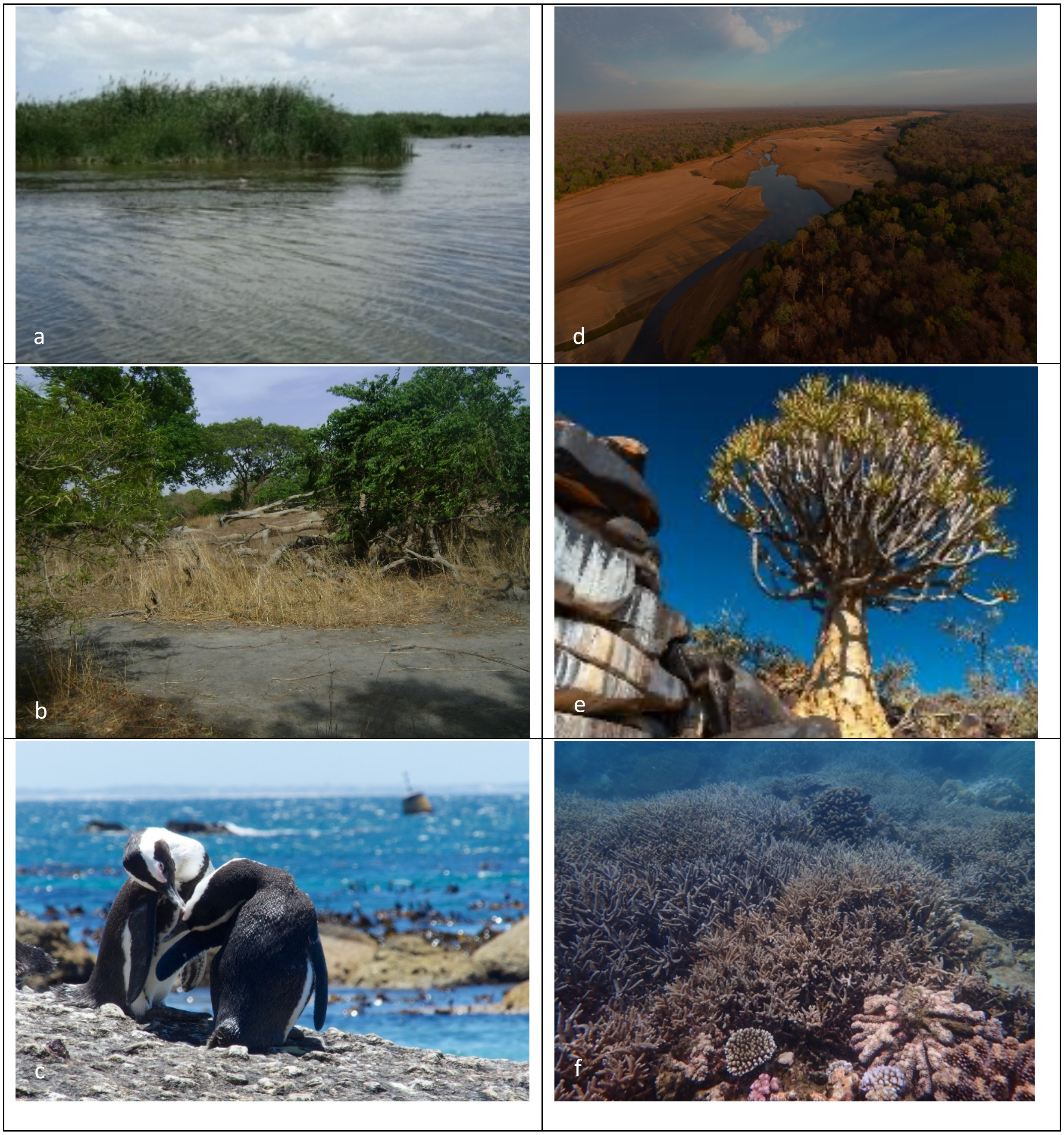

Figure 3. Strategic Red List of Ecosystems assessments for (a) Burullus Ramsar site; (b) Fathala forest protected area; (c) the Southern Benguela upwelling marine system; and systematic Red List assessments for (d) Mozambique; (e) South Africa (photo credit: Emily Weigum); and (f) Western Indian Ocean coral reefs.

Table 1. Extent of ecosystem functional groups with Red List assessments in four areas. Aggregate areas were calculated from available spatial or tabular data for each assessment based on the best estimates of current extent. Assessment units were assigned to one or more ecosystem functional groups by matching their descriptions with those for the functional groups (see Appendix 4 in Keith et al. 2022). Units: number of assessment units aggregated within each functional group one (+), two (++), three or more (+++), not mapped (n/m), uncertain match (?); Area in km^2; RLE cat: status of ecosystems within functional group (CO- Collapsed; CR- Critically Endangered; EN- Endangered; VU- Vulnerable; LC- Least Concern; DD- Data Deficient).

		South Africa			Mozambique			Madagascar			Congo		
Biome	**EFG**	**Units**	**Area**	**RLE cat**	**Units**	**Area**	**RLE cat**	**Units**	**Area**	**RLE cat**	**Units**	**Area**	**RLE cat**
T1	**T1.1**				+++	14798	VU-CR	+++	133975	DD, VU-CR	+++	228070	LC-EN
	T1.2	+++	25455	LC-CR	+++	42517	LC-CR	+++	33133	DD, EN	+++	1298766	LC-CR
	T1.3	++	1161	LC	+++	281	EN	++	33724	LC	+++	2544	LC-CR
T2	**T2.3**	+	37	LC									
	T2.4	+++	1020	LC									
T3	**T3.1**	+	164	LC	++	6536	LC-VU						
	T3.2	+++	80704	LC-CO									
	T3.4							+	5697	NE			
T4	**T4.1**	+++	47059	LC-EN	+++	188096	LC-CR						
	T4.2	+++	311634	LC-CR	+++	474677	LC-CR	++	215076	DD	+++	318962	EN
	T4.4	+	1401	LC									
	T4.5	+++	330764	LC-CO	+++	2430	EN-CR						
T5	**T5.1**	+++	232312	LC-CR									
	T5.2	+++	69908	LC-CR				+++	18333	DD, EN			
	T5.5	+++	5010	LC-EN									
TF1	**TF1.1**				++	14.1	CR				+++	295090	LC-VU
	TF1.2												
	TF1.3							??	5540	DD			
	TF1.4				+++	21627	EN-VU						
FM1	**FM1.2**				+	8.13	CR	?	2625	DD			
F1	**F1.5**				+++	15438	VU-EN	?		DD			
F2	**F2.2**				+	7600	LC	?		DD			
	F2.3				+	3632	LC						
SF1	**SF1.1**							n/m		DD			
M1	**M1.1**							+++		DD, VU			
	M1.3							+++		DD, LC-EN			
MT1	**MT1.3**				++	348	VU-EN						
MT2	**MT2.1**	+++	12819	LC-CR	+++	2734	VU-EN	++	2035	EN			
MFT1	**MFT1.1**							n/m		DD			
	MFT1.2	++	42.6	LC-EN	+	3474	LC	++	2433	VU-EN	+	4041	LC
	MFT1.3				++	3154	LC-EN						