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South Africa's Red List of Terrestrial Ecosystems (RLEs)

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Abstract: Ecosystem level indicators are emerging as important pillars of the post-2020 global biodiversity framework of the Convention on Biological Diversity; at the same time, the IUCN Red List of Ecosystems (RLEs) is experiencing rapid global uptake. We applied a systematic RLE assessment to 456 terrestrial ecosystems in South Africa between 2017 and 2021. What sets South Africa apart in this endeavour is that an independently formulated ecosystem threat status indicator was developed between 2004 and 2008 and the list of threatened ecosystems (effectively a proto RLE) was integrated into the national environmental regulatory framework in 2011. Through this, Critically Endangered and Endangered types were afforded a form of statutory protection through increased regulation of land-use change activities. We describe the transition to the IUCN RLE framework and focus on both the technical steps of incorporating the best available data into a credible assessment, and the unique social and legal processes to ensure that the biodiversity conservation sector in South Africa understood and supported the proposed replacement of the existing list of threatened ecosystems (2011) with the RLE (2021). We discuss the policy development steps required in South Africa, and the pros and cons of maintaining a legislative link for RLE implementation.

Keywords: ecosystem; risk assessment; RLE; South Africa; threatened; vegetation; policy

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1. Introduction

Ecosystem level indicators have emerged as an important element of the post-2020 global biodiversity framework of the Conventional on Biological Diversity [1]. The associated monitoring framework requires parties to report on various aspects of ecosystem extent and integrity. Over this same period, there has been widespread, global uptake of the IUCN Red List of Ecosystems (RLEs) [2–4]. South Africa was one of several countries to independently develop indicators of ecosystem threat prior to the development of IUCN RLE. These indicators met a recognised need for an indicator similar to the IUCN Red List of Species that could identify risk for higher levels of biodiversity organisation, such as ecological communities [2,5–7].

Prior to the development of the IUCN RLE, the South African list of threatened ecosystems was conceptualised as a national indicator of ecosystem conservation status in the early 2000s. From its early applications as a project-based indicator, it progressed into a legislated national listing of threatened terrestrial ecosystems [8,9], which entrenched its use in land-use planning and decision-making (e.g., through the Environmental Impact Assessment processes). The National Environmental Management: Biodiversity Act (Act No. 10 of 2004) of South Africa makes provision for the update of the list of threatened terrestrial ecosystem every five years. Given the improved access to land cover change information [10], updates to the ecosystem type maps in the national vegetation map [11], and the global rollout of the Red List of Ecosystems, a process to update the list of threatened terrestrial ecosystems of South Africa, using the IUCN RLE framework, was initiated in 2017.

The goal of the IUCN RLE is to identify ecosystems that are at risk of losing their constituent biodiversity [2]. The RLE requires consistent and clearly defined units of assessments (ecosystem types) that can be delineated spatially, while at the same time needs to be able to effectively assess risks across widely contrasting ecosystems [2]. Vegetation types, in particular, have been suggested as appropriate and consistent units that represent biodiversity and communities at an appropriate scale for use in the RLE [2,12]. The RLE framework uses the concept of ecosystem collapse as the 'end point' of ecosystem decline. This is equivalent to species extinction in the Red List of Species, and is defined operationally as a 'transformation of identity, loss of defining abiotic or biotic features and characteristic native biota are no longer sustained' [2,13]. The South African ecosystem threat status indicator, which preceded the RLE [9], shared these concepts and as a result, the lists of threatened ecosystems are broadly comparable.

A key factor in South Africa's progress with ecosystem risk assessment is the long history of vegetation mapping that culminated in the publication of Mucina and Rutherford's Vegetation of South Africa, Lesotho, and Swaziland in 2006 [11,14]. The detailed descriptions and maps of potential geographic extent (circa 1750) of each vegetation unit provided the terrestrial ecosystem types assessed in this study.

Here, we present the input data and the assessment approach used in South Africa in the application of the IUCN RLE version 1.1. The study is focussed on South African terrestrial ecosystem types but considers the full geographic extent of those types that occur across the borders between South Africa, Lesotho, and Eswatini; types occurring exclusively in Lesotho or in Eswatini have not yet been assessed. The results are presented per terrestrial biome and the national and global significance of the assessments are discussed. In addition to the technical steps taken and the resulting categorisation of ecosystem types, we outline social and legal steps required to motivate and support the update of a nationally legislated list of terrestrial ecosystems.

2. Materials and Methods

We systematically applied the IUCN RLE framework Criteria A and B (criteria linked to spatial configuration and remaining extent of ecosystems) to 456 terrestrial ecosystem types in South Africa. This assessment, referred to as the 'core' assessment, was then supplemented with additional assessments of selected ecosystem types based on additional data on ecosystem extent and condition, including: habitat loss in certain metropolitan areas and for some selected provinces; degradation in the Albany Thicket biome and the Western Cape Province; and estimates of biotic disruption linked to invasive alien species, disrupted fire regimes, and overgrazing based on data extracted from over 3000 plant red list assessments.

The national habitat loss dataset [10], which was derived from national land cover change data commissioned by the national government [15–17], and the national vegetation map [11,14] were the primary input data to the RLE 2020 analysis. Additional land cover data was sourced for the City of Cape Town, Nelson Mandela Bay Metropolitan Municipality, Mpumalanga, the Western Cape, and KwaZulu-Natal (Table 1); these datasets were used to perform supplementary assessments for Criteria A and B. The threatened species database [18] was used to identify limited range ecosystems (those qualifying for Criterion B) that are experiencing ongoing decline due to disrupted fire regimes, overgrazing, or invasive plant species. Ecosystem integrity data for the Little Karoo, Albany Thicket biome, Nelson Mandela Bay, KwaZulu-Natal, and the Western Cape formed the basis of supplementary assessment of these regions using Criteria D (Table 1).

Table 1. Input data sources for the Red List of South African Terrestrial Ecosystems.

Assessment	Dataset	Description	Reference
All assessments	Terrestrial ecosystem type map	Vegetation map of South Africa, Lesotho and Swaziland 2018 v 22.7. Polygon feature geodatabase developed and curated by South African National Biodiversity Institute.	[11,14,19]
Criteria A3, A2b, B1, B2	National land cover	Land cover change raster based on national land cover products; with modifications for tracking habitat loss and identifying secondary vs. primary natural areas.	[10,16,17]
Supplementary: Criterion A3 using alternative data and Criterion D3 and D1	City of Cape Town natural vegetation remnants map	2018 Vegetation remnants map produced by City of Cape Town based on remote sensing and in-field validation of condition. Provided as a polygon feature geodatabase.	[20]
	Nelson Mandel Bay Metro land cover	Natural areas map from the municipal bioregional planning process, with combination of desk top and field validated ecological condition. Provided as a polygon shapefile.	[21]
	KwaZulu-Natal land cover	2017 provincial raster land cover product (20 m resolution raster) validated by provincial conservation authorities.	[22]
	Mpumalanga land cover	2017 provincial raster land cover product (10 m resolution raster) validated by provincial conservation authorities.	[23]
	Western Cape land cover	2016 provincial raster land cover product (10 m resolution raster) validated by provincial conservation authorities.	[24]
	Albany Thicket biome degradation data	2002 biome-wide Landsat TM 5 based raster ecosystem degradation product (30 m). Developed and field validated as part of the Subtropical Thicket Ecosystem Project (STEP) by the Agricultural Research Council.	[25]
	Eastern Little Karoo degradation mapping	Detailed (1:10,000) ecosystem condition mapping by Cape Nature of the Eastern Little Karoo ecosystem type	(Vlok, A., pers com)
Supplementary assessment: Criteria B1(iii), B2(iii)	Invasive plants, overgrazing and disrupted fire regimes	Evidence of ongoing decline and impaired biotic function for use under Criterion B, extracted from the plant red list database 2020.	[18]

2.1. Core Assessment

2.1.1. Criteria A2b and A3–Historical and Future Reductions in Geographic Range

The ecosystem type data (which represents the geographic extent of potential vegetation circa 1750) and the habitat modification data (1990 and 2018) were cross-tabulated within a geographic information system and the historic reduction in geographic extent between ~1750 and 2018 was computed for each of the 456 ecosystem types (Table 2). This was expressed as a percentage of the potential historical extent (~1750) (Equation (1), allowing for the application of Criterion A3 (historical reduction in geographic extent). The absolute rate of decline in natural habitat between 1990 and 2018 (Equation (2) was used to project spatial change 22 years (2040) into the future to cover a 50-year period starting between 1990 and 2040 (Equation (3). The estimate, expressed as a percentage, allowed for the application of the Criterion A2b (past-present-future reductions in geographic range) (Table 2).

Table 2. IUCN RLE Criteria used in the South African Red List of Terrestrial Ecosystems. Abbreviations used: Critically Endangered (CR), Endangered (EN) and Vulnerable (VU).

Criteria & Sub-Criteria Applied			**CR**	**EN**	**VU**
Criteria A: Reduced geographic distribution					
Sub-criterion A2b–Reductions in extent over a 50 year period including past present and future. The absolute rate of decline in natural habitat between 1990 and 2018 (Equation (2)) was used to estimate the reduction in ecosystem extent between 1990 and 2040 (Equation (3).			≥80%	≥50%	≥30%
Sub-criterion A3–Historical loss of habitat (since ~1750) The historical reduction in geographic extent of each ecosystem type between ~1750 and 2018 was expressed as a percentage of the original (1750) extent (Equation (1)); allowing for the application of the thresholds for Criterion A3 (historical reductions in geographic range). Equivalent supplementary assessments utilised higher resolution land cover products available for KwaZulu-Natal, Mpumalanga, the Western Cape province and two large metropolitan areas.			≥90%	≥70%	≥50%
Criteria B: Restricted distribution and continuing declines in geographic distribution					
Sub-criterion B1 (i) and (iii)–Extent of a minimum convex polygon (km^2) enclosing all occurrences (EOO) & an observed or inferred continuing decline in spatial extent. The percentage rate of decline (Equation (4) was used to identify ecosystems with ongoing decline. A threshold of ≥0.4%/y was used for those ecosystem types that met the various EOO size thresholds for this sub-criterion B1(ii). A supplementary assessment used a comprehensive threatened plant species database to identify ecosystems with very high levels of biotic disruption (from over grazing, invasive species and inappropriate fire management) as evidence of ongoing decline. Those ecosystems below the EOO thresholds and showing ongoing decline qualified under sub-criterion B1(iii).			≤2000 km^2	≤20,000 km^2	≤50,000 km^2
Sub-criterion B2 (i) and (iii)–The number of 10 × 10 km grid cells occupied (AOO) & an observed or inferred continuing decline in spatial extent. The same steps were followed as for B1 in identifying qualifying ecosystem types for this sub-criterion, but using the AOO number thresholds.			≤2	≤20	≤50
Criteria D: Disruption of biotic processes or interactions					
Sub-criterion D1–Disruption of biotic processes, in the last 50 years (circa 1970), based on change in a biotic variable affecting a fraction of the extent of the ecosystem and with relative severity, as indicated by the table. Ecosystem condition data from Cape Nature scientists (Vlok et al., pers com) was used to identify the extent of Eastern Little Karoo where biotic disruption was ≥80% in severity. The extent of this biotic disruption then dictates the risk category.			Relative severity (%)		
			≥80	≥50	≥30
	Extent (%)	≥80	CR	EN	VU
		≥50	EN	VU	
		≥30	VU		
Sub-criterion D3–Disruption of biotic processes, since 1750, based on change in a biotic variable affecting a fraction of the extent of the ecosystem and with relative severity, as indicated by the table. Ecosystem condition data from the Albany Thicket biome, KwaZulu-Natal, Mpumalanga, the Western Cape Province, the City of Cape Town and Nelson Mandela Bay Metro was used to identify the extent of each ecosystem type where biotic disruption was ≥70% in severity. The extent of this biotic disruption then dictates the risk category.			Relative severity (%)		
			≥90	≥70	≥50
	Extent (%)	≥90	CR	EN	VU
		≥70	EN	VU	
		≥50	VU		

Equation (1): Reduction in extent since ~1750:

$$\text{Historical loss (\%)} = (\text{Area}_{1750} - \text{Area}_{2018})/\text{Area}_{1750} \times 100 \quad (1)$$

Equation (2): Absolute rate of Decline:

$$\text{ARD (km}^2/\text{y)} = (\text{Area}_{2018} - \text{Area}_{1990})/(2018 - 1990) \quad (2)$$

Equation (3): Reduction in extent over 50 year period (1990–2040):

$$\text{50y loss (\%)} = (\text{Area}_{1990} - (\text{ARD} \times 50)/(\text{Area}_{1990}) \times 100 \quad (3)$$

2.1.2. Criteria B1(i) and B2(i)–Restricted Geographic Range and Ongoing Decline

The first step for the assessment under this criterion was to combine the habitat modification data for 2018 with the ecosystem type data to produce an 'ecosystem remnants' layer circa 2018. This layer (in geotiff format) was used to compute the Extent of Occurrence (EOO) and Area of Occupancy (AOO) for each ecosystem type with the package [redlistr] within the statistical software R [26,27] (Supplementary Materials 1). Ecosystem types only qualify for consideration under Criteria B1(i) and B2(i) if they are experiencing ongoing declines in extent or condition (observed or inferred). For the core assessment, ARD (Equation (2) was expressed as a percentage of 1990 geographic extent (Equation (4). Ecosystems with a rate of decline greater than or equal to 0.4%/y qualified for consideration under B1(i) and B2(i) (Table 2). Ecosystems with annual rates of decline above this threshold have lost approximately 10% of their natural remaining extent in the last 25 years. This threshold requires further testing, and was chosen at an expert reference group meeting on presentation of a simple sensitivity analysis that compared the number of qualifying ecosystems types at 0.3, 0.4, and 0.5% decline per year (Monyeki, in prep).

Equation (4): Percentage rate of decline:

$$\text{Percentage ARD (\%/y)} = \text{ARD}/\text{Area}_{1990} \times 100 \quad (4)$$

2.2. Supplementary Assessments

To complement the core assessment, several additional datasets were compiled to ensure the ecosystem risk assessments were based on the best available data. These supplementary assessments used Criteria A, B, and D (Table 2).

High-resolution and high-confidence land cover data exist for certain regions within South Africa including the City of Cape Town, Nelson Mandela Bay Metropolitan Municipality, Mpumalanga, the Western Cape Province, and KwaZulu-Natal Province (Table 1). There are also regional data sets that focus on the degree and extent of biotic disruption, such as the Sub Tropical Ecosystem Programmes work. These independent regional datasets were collated into a supplementary ecosystem condition dataset, resampled to a common grid resolution of 30m (all datasets were between 10 and 30 m native resolution) and reclassified to a simple scheme with three classes: (i) natural and near natural habitat (referred to as "natural"), (ii) severely degraded habitat with substantial biotic disruptions (referred to as "degraded"), and (iii) areas with no natural habitat remaining (referred to as "lost"). For "natural" and "lost" classes, the regional land cover products needed no special alignment, but for the "degraded" class, the technical documentation of the source data were consulted. In all cases, the severely degraded classes contained in the regional data sources were composite estimates of overall pixel-level changes to structure, function, and composition of the native plant communities equivalent to the scores $\geq$70% severity. The biotic disruption in the regional datasets mostly reflects the impacts of overutilization by domestic stock, and substantial and persistent losses of plant cover. Other widespread biotic disruptions, such as invasive alien species, are not reliably reflected in these datasets.

Where no supplementary data were available, the national land cover 2018 data was used. This ensured that the full ecosystem extent for each type was evaluated in the supplementary assessment step. The ecosystem type data and supplementary ecosystem condition data were cross-tabulated within a geographic information system. Historical reduction in geographic extent (from ~1750) (Equation (1), and historical extent of degradation (from ~1750) (Equation (5) were computed for each ecosystem type. This allowed for the formulation of a supplementary Criteria A3 assessment (historical reductions in geographic range). A precautionary rule was applied such that the highest resulting threat status of the A3 and A3-supplementary was used.

The calculation of the historical extent of biotic disruption allowed the application of Criterion D3 (in this case vegetation structure, function, and composition are all severely impaired) [25]. The lost habitat was considered to have biotic disruption of 100%, and the severely degraded areas were considered to have biotitic disruption of between 70% and 80%. In addition, high-resolution data were available for one ecosystem type, Eastern Little Karoo, which allowed for the application of Criterion D1—degradation in the past 50 years—using the same equation as for Criterion D3 (Equation (5)).

Equation (5): Extent of historical biotic disruption at $\geq$70% severity:

$$\text{Biotic disruption (\%)} = (\text{Area}_{deg} + \text{Area}_{lost})/(\text{Area}_{natural} + \text{Area}_{deg} + \text{Area}_{lost}) \times 100 \quad (5)$$

Criteria B1(iii)s and B2(iii)s–Restricted Geographic Range and Species Threats

A key challenge in the application of the RLE is the poor availability of spatially explicit ecosystem condition data (biotic disruption and degradation). As a result, the risk of collapse of many ecosystem types may have been underestimated in the core assessment. To address this, a supplementary assessment of Criterion B was undertaken using the threatening processes data from the Threatened Plant Species Database (containing over 3000 species), which has a wealth of information on functional symptoms of biodiversity decline in South Africa. For the supplementary assessment of Criterion B, the qualifying criteria (i.e., evidence of biotic disruption) was a quantitative assessment of threatening processes listed for the threatened species occurring in each ecosystem type. As part of the species assessments, each threatened plant species was already assigned to an ecosystem type(s) using verified location records and descriptions of preferred habitat. We then calculated the number of species per ecosystem type that were threatened by (a) poor rangeland management (e.g., over grazing by domestic stock); (b) invasive alien species; and (c) inappropriate fire management (e.g., changes to natural fire regimes; including both fire suppression and too frequent fires and changes to fire season and intensities). Following a series of tests and iterations, the qualifier for biotic disruption Criteria B1(iii) and B2(iii) in the supplementary assessment was set to: ecosystems that contained $\geq$40 threatened plant species, of which $\geq$60% were threatened due to major biotic disruptions, with the number of threatened species per km^2 $\geq$0.15. This is a preliminary solution while additional data on biotic disruption, severity, and extent are collected.

2.3. National vs. Global Scope of Assessments

This assessment includes all terrestrial ecosystem types (vegetation units after Mucina and Rutherford, 2006) within the borders of mainland South Africa (n = 456). The units can be assigned to Level 5 and in some cases Level 6 on the Global Ecosystem Typology [28]. Alignment with the Level 3 (functional level) types in the GET is generally good, with some challenges in the Albany Thicket biome, a subtropical mixture of spiny and succulent shrubs and low trees without a distinctive canopy to ground layer separation.

An important consideration when conducting RLE assessments is the national vs. global extent of the type. The vegetation map for South Africa [14] also covers the neighbouring countries of Lesotho and Eswatini. As a result, ecosystem types that are distributed across these particular international boundaries and are restricted to these three countries can be considered to have been assessed globally. For Namibia, Botswana, Zimbabwe, and Mozambique, no comparable vegetation maps exist at present (though work is underway in Mozambique) and ecosystem types that likely cross from South Africa and Swaziland into these countries cannot be assessed over their full global extent at present.

For the most part, however, South African terrestrial ecosystem types in the Fynbos, Albany Thicket, Grassland, and Nama-Karoo are endemic to South Africa, Lesotho, and Swaziland (385 out of 456 ecosystem types). The remaining 71 types are members of the Savanna biome (the dominant biome in southern Africa), the Desert and Succulent Karoo biomes (which extends into Namibia), and the Indian Ocean Coastal Belt and Forest biomes (which extend into Mozambique). Further research and mapping are required before the endemism of many of these 71 types can be known with any degree of certainty.

For this assessment, all ecosystem types that occur in South Africa are included in the RLE. Those types for which endemism is not yet resolved are considered to have been assessed nationally and are assigned a "national" RLE status, endemic types are considered to have been globally assessed and are assigned a "global" (and national) RLE status. These globally assessed types will be submitted to the IUCN RLE database.

3. Results

3.1. Overall Results

Of the 456 terrestrial ecosystem types occurring in South Africa, 51 were categorised as Critically Endangered, 55 as Endangered, and 14 as Vulnerable (Table 3, Figure 1). While 11% of the ecosystem types are Critically Endangered, in terms of area, this amounts to less than one percent of the extent of natural remaining habitat in South Africa. Endangered ecosystems make up 12% of ecosystems by type, and by area make up 5% of natural remaining habitat. Vulnerable ecosystems make up 3% of ecosystems by type, amounting to 4% of the natural remaining habitat of South Africa (Table 3, Figure 2).

Table 3. Summary of the assessment outcomes including the number of ecosystem types per category and the proportion of the natural area remaining per category. Supplementary Material 2 contains detailed assessments for each ecosystem type.

Category (IUCN RLE)	Number of Ecosystems	Natural Extent Remaining within South Africa in 2018 (km^2)	Percentage of Total Terrestrial Landmass Extent	Percentage of Total Natural Remaining Ecosystem Extent
Critically Endangered	51	7509	0.62%	0.79%
Endangered	55	50,315	4.13%	5%
Vulnerable	14	35,346	2.90%	3.72%
Least Concern	336	857,576	70.39%	90.20%
Total for South Africa	456	950,745	78%	100.00%

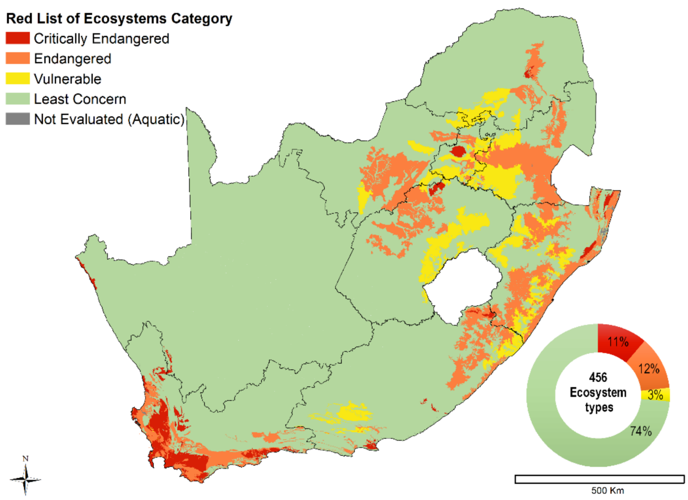

Figure 1. Map showing the distribution of threatened terrestrial ecosystems in South Africa according to the IUCN Red List of Ecosystems. The map shows the historical extent of the ecosystem types (based on Mucina and Rutherford 2006). The inset graph shows the percentage of ecosystem types that falls within each threat category.

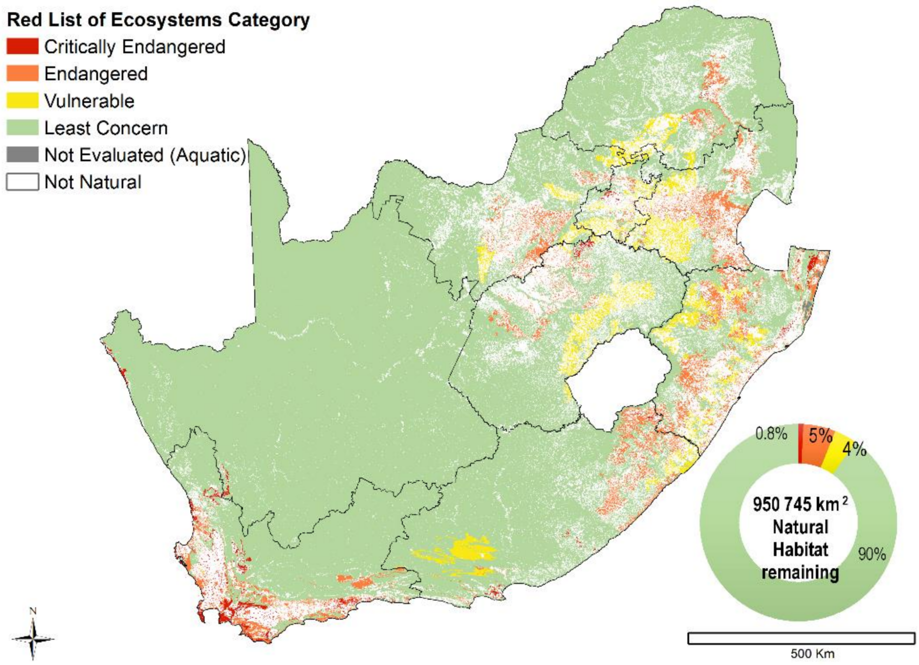

Figure 2. Map showing the current natural remaining extent (circa 2018) of threatened terrestrial ecosystems in South Africa according to the IUCN Red List of Ecosystems. The white areas are croplands, built up areas, mines, and tree plantations. The inset graph shows the percentage of the total natural habitat remaining in South Africa (950,745 km^2) that falls within each threat category.

3.2. Results per Biome

The Fynbos biome (a winter-rainfall, fire-prone shrubland with high plant diversity and endemism) has the highest number of threatened ecosystem types (59), followed by Grassland (which occupies the interior plateau known as the Highveld) with 24 and Savanna (a range of trophic and pyric savanna types covering the north-eastern third of the country) with 13 threatened types. These threatened ecosystem types make up 23%, 29%, and 4% respectively of the natural remaining habitat of each biome (Figures 1 and 2, Table 3). All six ecosystem types making up the Indian Ocean Coastal Belt biome (a unique combination of forest, woodland, and grassy communities situated on the subtropical east coast) are threatened, which means that 100% of the natural habitat remaining in the biome is threatened (Table 4). The arid regions of the country have less threatened ecosystems (by type and by remaining extent); the Succulent Karoo (an exceptionally diverse winter-rainfall arid shrubland) has three threatened ecosystems (amounting to 0.8% of the natural remaining habitat) and the Nama-Karoo (a summer rainfall arid shrubland) has no threatened ecosystems. The Forest biome covers less than 1% of South Africa, and one threatened ecosystem type was identified in this study. This is likely due to a mismatch in the scale of the land cover change data and forest patches; additional research is required to better understand historical and current distribution of this biome. In addition, two forest types, namely Swamp Forest and Mangrove Forest, were not considered terrestrial and were excluded from this study; recent research suggests Swamp Forest may be Critically Endangered [29], while Mangroves have yet to be assessed.

Detailed assessments per ecosystem type can be found in Supplementary Materials Information 2; additional spatial data and information related to this study is available at http://ecosystemstatus.sanbi.org.za (accessed on 29 September 2021).

Table 4. Percentage natural remaining habitat within each IUCN RLE threat category, listed per biome. The number of ecosystem types per threat category, per biome is shown in parenthesis.

Biome	Critically Endangered	Endangered	Vulnerable	All Threatened Ecosystems	Least Concern	Grand Total
Azonal Vegetation	0% (2)	2.6% (3)	0% (0)	2.7% (5)	97.3% (13)	18
Succulent Karoo	0.6% (3)	1.9% (1)	0% (0)	2.4% (4)	97.6% (60)	64
Savanna	0.3% (3)	1.9% (7)	1.7% (3)	3.8% (13)	96.2% (78)	91
Nama-Karoo	0% (0)	0% (0)	0% (0)	0% (0)	100% (13)	13
Indian Ocean Coastal Belt	0% (0)	83.6% (5)	16.4% (1)	100% (6)	0% (0)	6
Grassland	0.5% (4)	16.2% (14)	12.2% (6)	28.9% (24)	71.1% (49)	73
Fynbos	9.3% (33)	13.3% (24)	0.1% (2)	22.7% (59)	77.3% (63)	122
Forests	0% (0)	0% (0)	2.4% (1)	2.3% (1)	97.6% (9)	10
Desert	0.04% (2)	0% (0)	0% (0)	0.04% (2)	100% (13)	15
Albany Thicket	0.9% (4)	1.6% (1)	17.3% (1)	19.8% (6)	80.2% (38)	44
Grand Total	0.8% (51)	5.3% (55)	3.7% (14)	9.8% (120)	90.2% (338)	456

3.3. Triggering Criteria

Of the criteria considered in this assessment, Criterion B emerged as the most influential as a trigger, with 140 ecosystem types listed due to limited distribution and evidence of ongoing spatial decline or biotic disruptions. Declines in geographic extent both historical and recent identified through Criterion A resulted in the listing of 42 ecosystem types. Criterion D only triggered the listing of four ecosystems types. This is unsurprising given the limited data on ecosystem integrity available for this assessment.

3.4. Global vs. National Assessments

There are nine terrestrial ecosystem types that are listed as nationally threatened but are likely to also occur outside of South Africa, Lesotho, and Swaziland. Four of these ecosystem types fall into the Savanna biome, two in the Indian Ocean Coastal Belt, one in the Forest biome, and two in the Desert biome (Figure 3). A further 62 ecosystem types are listed as Least Concern and are also likely to occur outside of South Africa. These 71 (9 + 62) ecosystem types are included in the South African Red List of Terrestrial Ecosystems and continue to form an important part of South Africa’s national biodiversity prioritisation processes; but they will not be submitted to the global IUCN RLE database until vegetation maps across national boundaries have been aligned and global assessments of these types undertaken. The 385 terrestrial ecosystem types judged to be endemic to South Africa have been assessed globally (and nationally) and will be reflected on the global IUCN RLE database.

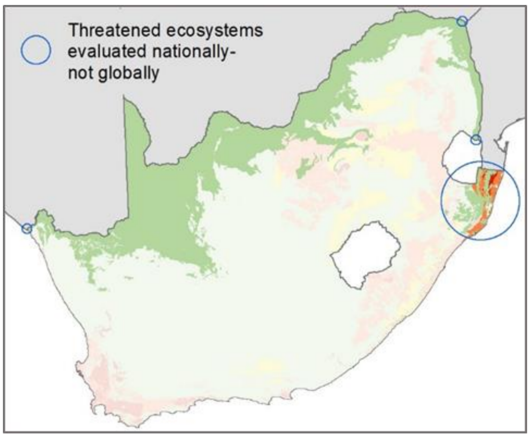

Figure 3. Ecosystem types for which a national assessment (not global) was undertaken. The global extent of these types has yet to be mapped and assessed. Green areas show the Least Concern Ecosystems also assessed nationally not globally. The opaque mask indicates endemic types for which the assessment can be considered global.

4. Discussion

4.1. Threatened Ecosystems in South Africa

In general, the distribution of threatened ecosystems reflects the land cover change and habitat loss patterns across South Africa. The extensive commercial croplands and urban centers of the central Highveld grasslands, the large rural population (and associated settlements and subsistence croplands) along the east coast, and the croplands of the lowlands of the Western Cape [10] have reduced the geographical extent of many ecosystem types, and introduced a range of threatening processes and biotic disruption. Despite the acknowledged lack of detailed spatial data on ecosystem integrity (which, if available, would certainly improve the assessment of the arid interior rangelands), the overall pattern aligns with the findings of previous ecosystem threat assessments' efforts [9].

The unique and exceptionally diverse flora of the Fynbos biome translates into a high number of unique ecosystem types [30]. The Fynbos has also been subject to centuries of commercial farming and as a result, contains the majority of South Africa's Critically Endangered terrestrial ecosystem types by number. In comparison to the Fynbos biome, the ecosystem types of the Grassland and Savanna biome are relatively large; as a result, the 21 Endangered ecosystems of these biomes cover a large proportion of South Africa. The biome most at risk of collapse is the Indian Ocean Coastal Belt where all six ecosystems types are threatened. This is a unique set of ecosystem types that has a large rural population relying on subsistence agriculture, large urban centers, and extensive commercial croplands. While the vegetation map at the heart of this assessment is robust and well accepted, there is scope to improve the representation of the Forest biome, in particular to map or model historical potential distribution. This would allow for a more reliable assessment of the declines in extent for this biome.

The key shortcoming of all of these ecosystem threat status assessments in the terrestrial realm is the lack of comprehensive data on ecosystem integrity and condition. This means that in many regions where out-right habitat loss is not prevalent (e.g., arid rangelands), the baseline risk of collapse reported here will be an underestimate. Improving and broadening degradation and biotic disruption data availability across all biomes in South Africa is a major research priority.

4.2. Moving from a Technical Assessment to a Policy-Relevant Conservation Tool

The process linking the 2021 RLE directly to policy-relevant legislative tools started in 2004 with the publication of the National Environmental Management: Biodiversity Act (NEM:BA), which provides for a national list of ecosystems that are threatened and in need of protection, and proposes the development of bioregional plans (which in South Africa are underpinned by systematic conservation planning) [31] (Figure 4). Both of these provisions were included to provide tools for the conservation of ecosystems and their constituent biota outside of formal protected areas. A set of regulations are followed for planning (Guidelines for the development of bioregional plans, 2009), for reactive decision making (Environmental Impact Assessment Regulations, 2010), and for management (Environmental Management Framework Regulations, 2011). The first list of threatened ecosystems was published in 2011, and the Critically Endangered and Endangered ecosystems on the list started receiving additional protection through the requirement that developments affecting these types required additional and costly specialist studies [9]. The 2011 list included 53 CR and 64 EN types, which is similar to the number identified in 2021 (51 and 55) but with substantial differences in spatial patterns. The differences in assessment criteria [9] make trend analysis impossible, but future updates will use the IUCN RLE, ensuring that trend analysis and the computation of the Red List of Ecosystem Index [32] will be possible. Further links to regulatory tools were established through the inclusion of threatened ecosystems (the remaining extent thereof) in systematic conservation plans, which now cover all regions of the country and which prospective developers are required to consider and adhere to through the use of the national EIA screening tool [31].

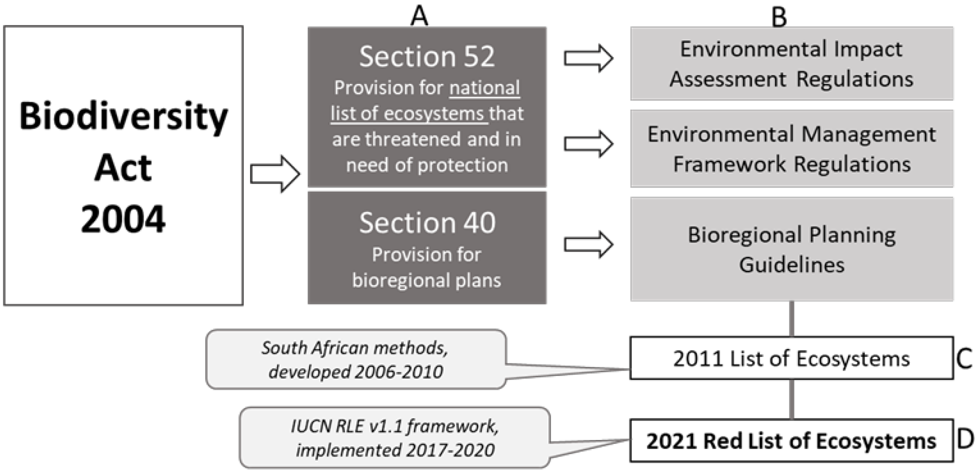

Figure 4. The links between the RLE and legislative tools in South Africa. The Biodiversity Act of 2004 provides for a national list of ecosystems that are threatened and in need of protection, and for the development of bioregional plans (**A**). A set of regulations followed for planning (Guidelines for the development of bioregional plans, 2009), for reactive decision making (Environmental Impact Assessment Regulations, 2010), and for management (Environmental Management Framework Regulations, 2011) (**B**). Over the same period, the first list of ecosystems that are threatened and in need of protection was developed and published (2006–2011) (**C**). A revised list for terrestrial ecosystems based on the IUCN RLE framework was prepared with sector-wide inputs between 2017 and 2021 (**D**).

Updating the legally enacted 2011 list of threatened ecosystems with a new list based on the new IUCN RLE framework was not purely a technical undertaking but involved almost two years of consultation and procedural processes. These started with a presentation of the concept to the Working Group for Biodiversity and Conservation, convened by the National Department of Forestry Fisheries and the Environment (DFFE) and including representatives from conservation authorities from all nine provinces, metropolitan municipal representatives, and from South African National Parks. This working group approved the adoption of the IUCN RLE framework and appointed focal points from each provincial conservation authority to examine the detailed proposal and provide comments on the provisional assessment results. This was the first formal step in updating the legally enacted list, but it was preceded by numerous technical and scientific presentations between 2017 and 2020, where the IUCN RLE framework was explained and discussed. As a consequence, the focal points were well acquainted with the IUCN RLE and provided detailed comments. After the comments and suggestions by the focal points were addressed and the working group members were satisfied, the proposal was passed on high-level government structures (each requiring presentations and questions and answer sessions), eventually culminating in the Minister of Forestry Fisheries and the Environment formally approving that the Red List of Terrestrial Ecosystems be released to the public and published in the Government Gazette for a one-month period. Subsequent to which, and depending on the nature of the comments received, the 2021 Red List will formally replace the 2011 list and come into legal force.

The benefits of a strong policy and regulatory link are clear, but the drawbacks are worth considering. In the setting of the current Biodiversity Act, any changes to the list of ecosystems requires the repeal of the previous list and the publication of the new list in the government gazette, a process that can take up to two years and involves dozens of high-level meetings and workshops. This presents a major challenge, given that the published lists have substantial scope for improvement (e.g., through the inclusion of improved ecosystem condition data) and that regular updates and reassessments are an expected part of the process of curating the national list. It is hoped that in the revision of the Biodiversity Act (currently under consideration), provision will be made for regular updates of the RLE that required technical review but not the lengthy approval process of amendments to legislation.

4.3. Lessons and Future Research

It is worth reflecting on the importance of having suitable ecosystem classification systems and spatial data available, ideally including maps of potential historical distribution of ecosystem types. Having these data readily available in South Africa in the early 2000s certainly contributed to the innovative work of developing an ecosystem threat status indicator and the associated conservation tools. For RLE roll out globally, the emerging Global Ecosystem Typology [28] and range of ecosystem mapping tools [33,34] represents a good opportunity for nations without spatial data on ecosystem types to build the foundational information required for ecosystem risk assessments. In addition to providing a strong platform for conservation action, the RLE process can unlock national level reporting linked to the Convention on Biological Diversity. The Convention's Global Biodiversity Framework includes ecosystem targets, which draw on the same foundational information as the RLE [1,32].

The next phase of RLE-related work in South Africa will center on improving the data on ecosystem integrity for terrestrial and aquatic ecosystems, revising and refining the existing risk assessments to include additional criteria within the IUCN RLE framework, building sector-wide support and understanding of the ecosystem listing process, and adjusting and expanding the existing conservation regulations to better include the RLE for the marine, estuarine, and freshwater realms.

Working across international borders to ensure that ecosystem types are assessed across their full global range is also an increasingly important consideration. As RLE-related efforts are initiated across southern Africa, coordination of efforts and collaborative assessments are essential, especially for cross-border ecosystem types.

5. Conclusions

South Africa's Red List of Terrestrial Ecosystems has effective and well-utilized policy integration that was intentionally developed over a decade through sector-wide, coordinated efforts. It is hoped that the 2021 RLE will influence land-use decision-making and conservation planning in the same way as the 2011 list of ecosystems that are threatened and in need of protection. However, there remains substantial scope for improvement of this RLE, and for its extension to include non-terrestrial realms.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/land10101048/s1, Supplementary Material 1: All the R code and input tables used in the RLE assessment can be accessed at the following address: https://github.com/matlalam/South-Africa-Red-List-of-Terrestrial-Ecosystems (accessed on 29 September 2021). Supplementary Material 2: Detailed assessment reports for each of the 456 ecosystem types can be found at the following address: http://hdl.handle.net/20.500.12143/7664.

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National Terrestrial Ecosystem Data: http://bgis.sanbi.org/SpatialDataset/Detail/1674 (accessed on 29 September 2021). National Habitat Modification Data 1990–2018: https://doi.org/10.15493/SAEON.FYNBOS.10000011.

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