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Rates and patterns of habitat loss across South Africa's vegetation biomes

The loss of natural habitat resulting from human activities is the principal driver of biodiversity loss in terrestrial ecosystems globally. Metrics of habitat loss are monitored at national and global scales using various remote sensing based land-cover change products. The metrics go on to inform reporting processes, biodiversity assessments, land-use decision-making and strategic planning in the environmental and conservation sector. We present key metrics of habitat loss across South Africa at national and biome levels for the first time. We discuss the spatial patterns and trends, and the implications and limitations of the metrics. Approximately 22% of the natural habitat of South Africa has been lost since the arrival of European settlers. The extent and the rate of habitat loss are not uniform across South Africa. The relatively mesic Grassland, Fynbos and Indian Ocean Coastal Belt biomes have lost the most habitat, while the arid Nama-Karoo, Succulent Karoo and Desert have lost the least. Rates of loss increased across all biomes in recent years (2014–2018), indicating that the historical drivers of change (i.e. expansion of croplands, human settlements, plantation forestry and mining) are intensifying overall. We should caution that the losses we report are conservative, because the land-cover change products do not capture degradation within natural ecosystems. Preventing widespread biodiversity losses and securing the benefits we derive from biodiversity requires slowing and preventing further habitat degradation and loss by using existing land-use planning and regulatory tools to their full potential.

Significance:

- The loss of natural habitat resulting from human activities is the principal driver of biodiversity loss in terrestrial ecosystems in South Africa.

- Monitoring trends and patterns of habitat loss at a national scale provides a basis for informed environmental decision-making and planning, thus equipping civil society and government to address habitat loss and protect biodiversity while also meeting key development and socio-economic needs.

Introduction

The loss of natural habitat caused by human activities such as crop farming and infrastructure development is the principal driver of biodiversity loss in terrestrial ecosystems, globally and in South Africa.[1,2] These changes are increasingly reliably detected through the use of satellite remote sensing platforms[3], and there is a growing focus on developing tools to automatically detect change in near-real time[4,5]. The land-cover change products that result are now widely used as the basis for species and ecosystem risk assessments[3,6], land-use decision-making and strategic planning in the environmental and conservation sector[7,8]. The utility of these products stretches well beyond the environmental sector and forms a key source of intelligence for planning and management across multiple sectors including infrastructure development, agricultural planning, defence, health, mining and energy.[9]

In this study, we used recently released, high-resolution, national land-cover data from three time points (1990, 2014 and 2018)[10-12], and a baseline of 1750 before widespread anthropogenic land-cover change[13,14], to estimate rates of habitat loss across the whole of South Africa's land mass. Although a comprehensive land-cover change study has been undertaken at a provincial scale for KwaZulu-Natal[15], this is the first national-scale analysis for South Africa. We define habitat loss as the persistent loss of natural or near natural vegetation cover through anthropogenic activities and focus on the extent and rates of loss of natural terrestrial habitat as described in the *Vegetation of South Africa, Lesotho and Swaziland*[13,16]; including 458 distinct vegetation types, grouped into nine biomes plus azonal types. The Biodiversity Intactness Index[17] and South Africa's national biodiversity assessments[2] used vegetation types as the unit of assessment and clearly illustrated the wide application to biodiversity conservation efforts of land-cover change analysis.

Habitat loss is a key indicator in the Global Biodiversity Framework 2050, proposed by the Convention on Biological Diversity as the replacement of the Aichi Targets. To aid in reporting against the new Global Biodiversity Framework and the Sustainable Development Goals, we applied the recently described Ecosystem Area Index (EAI)[18] to our data as an overall indicator of the state of South Africa's terrestrial ecosystems. We then disaggregated the EAI to the biome level and explored the spatial patterns of habitat loss and the rates of change in different regions of the country. The implications of the observed changes for the country's unique and globally significant biodiversity are discussed.

Methods

Land-cover data sets for 1990, 2014 and 2018[10-12] were modified to improve the representation of abandoned croplands and artificial water bodies and combined onto a common reference grid to allow for pixel-level comparisons (see supplementary material). The data sets were reclassified to a simplified scheme with seven land-cover classes (Supplementary table 1), including one class for natural/near natural vegetation and six anthropogenic classes: (1) croplands, including all field and horticultural crops, irrigated and dryland; (2) built-

up areas, including infrastructure and human settlements; (3) plantation forestry areas; (4) mining areas; (5) artificial water bodies and (6) secondary natural areas (previously ploughed, mined or developed areas, which have recovered some semblance of natural vegetation cover since abandonment).
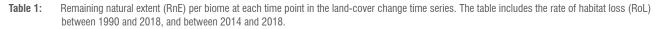
The extent and rates of loss of natural vegetation cover were calculated for each of the 458 vegetation types delineated and described in the *Vegetation of South Africa, Lesotho and Swaziland*.[13,16] The total extent of habitat loss caused by the expansion of each of the six anthropogenic land-cover classes since European settlement was evident from the 2018 data set, while recent change was calculated by cross tabulating the 1990 and 2018 data sets. The remaining natural extent (*RnE*) of each vegetation type in 1990, 2014 and 2018 was calculated and expressed as a proportion of the original historical extent of the type prior to major land-cover changes in South Africa (i.e. circa 1750). The rate of recent habitat loss (*RoL*), between 1990 and 2018, was calculated and expressed as a proportion of the 1990 extent, divided by the difference in years between the time points. We then calculated the Ecosystem Area Index[18] for South Africa by calculating the geometric mean of the *RnE*

values for all 458 vegetation types in the country, and did the same for each biome, based on the equation $EAI = \sqrt[n]{a_1 \cdot a_2 \cdots a_n}$, where *n* is the number of vegetation (ecosystem) types (458) and *a* is the proportion of natural habitat remaining for each ecosystem type at each time point.
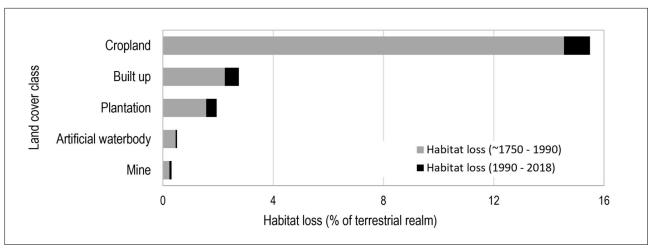
Results

Extent of loss

In 1990, natural vegetation covered just over 80% of South Africa (1 019 005 km²; Table 1). Between 1990 and 2018, a further 33 849 km² was cleared for various human activities, leaving just over 78% (951 831 km²) of the original natural vegetation – a 3% decline over the 28-year period. Biome-level statistics revealed that the loss was not uniform, with the relatively mesic Indian Ocean Coastal Belt, Grassland and Fynbos biomes losing more of their original extent than others (Table 1, Supplementary tables 2 and 3). The establishment of crop fields, human settlements and plantation forestry are the dominant drivers of change in these regions (Figure 1, Supplementary tables 2 and 3).

Table 1: Remaining natural extent (RnE) per biome at each time point in the land-cover change time series. The table includes the rate of habitat loss (RoL) between 1990 and 2018, and between 2014 and 2018.

Biome	†1750 (km²)	1990 (km²)	%remaining 1990	2014 (km²)	%remaining 2014	2018 (km²)	%remaining 2018	Rate of loss (1990–2018)	Rate of loss (2014–2018)
Albany Thicket	35 307	32 486	92%	32 159	91%	31 988	91%	0.05	0.13
Desert	6262	6181	99%	6168	98%	6142	98%	0.02	0.10
Forests	4711	3987	85%	3896	83%	3882	82%	0.09	0.09
Fynbos	81 645	57 993	71%	55 958	69%	54 918	67%	0.19	0.46
Grassland	330 848	209 225	63%	198 044	60%	193 631	59%	0.27	0.56
Indian Ocean Coastal Belt	11 692	4882	42%	4195	36%	3945	34%	0.69	1.49
Nama-Karoo	249 354	245 220	98%	244 526	98%	244 192	98%	0.01	0.03
Savanna	394 102	327 806	83%	319 048	81%	316 490	80%	0.12	0.20
Succulent Karoo	78 208	74 910	96%	74 610	95%	74 386	95%	0.02	0.07
Azonal Vegetation	26 428	22 055	83%	21 564	82%	21 339	81%	0.12	0.26
Total	**1 218 557**	**984 743**	**80.8%**	**960 169**	**78.8%**	**950 913**	**78.0%**	**0.12**	**0.24**

†1750 is considered the historical baseline date, before widespread habitat loss began.

Figure 1: Habitat loss per major land-cover class (shown as a percentage of the terrestrial realm). Historical loss (between ~1750 and 1990) is shown in grey and recent loss (1990–2018) is shown in black. The clearing of natural habitat for the establishment of field and horticultural crops is the single largest historical driver of biodiversity loss in South Africa.
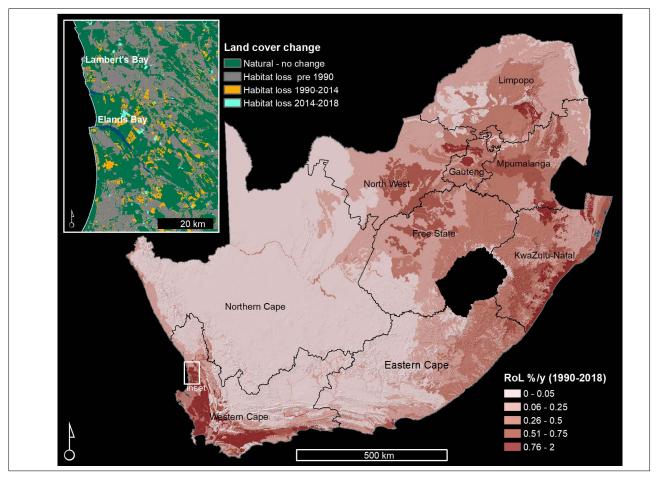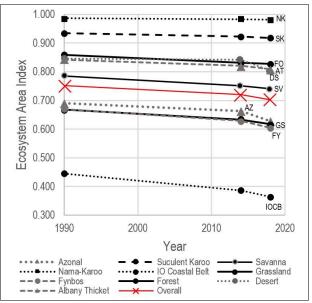
Figure 2: Rate of habitat loss indicator (RoL) for the period 1990–2018, calculated per terrestrial ecosystem type (vegetation types as defined by Mucina and Rutherford[13]). The Cape lowlands, Mpumalanga Highveld grasslands and KwaZulu-Natal coast and adjacent interior had the highest rates of habitat loss between 1990 and 2018, with expanding croplands and human settlements being the key drivers. The inset map shows the land-cover change for a coastal portion of the Western Cape (known as the 'Sandveld') where cropland expansion has occurred during each time period.

Rates of loss

Overall, South Africa lost 0.12% of its natural vegetation per year between 1990 and 2018, but this rate has been much faster in recent times – 0.24% per year between 2014 and 2018 (Table 1). As for the extent of loss, there are major differences in the rates of loss between biomes and between vegetation types (Figure 2). Rates of loss are highest in the southern and eastern coastal regions, in the interior Highveld grasslands and in the savannas of Limpopo and Mpumalanga. The arid interior had the lowest rates of loss. The key drivers of change are clearing for new croplands in the grasslands and expanding rural/peri-urban human settlements in the savannas in the northern parts of the country (Table 2, Supplementary tables 2 and 3). Loss of vegetation cover in coastal regions was linked to expansion of cultivation and human settlements.

Ecosystem Area Index

The Ecosystem Areas Index (EAI) for South Africa showed a 7% decline between 1990 and 2018, from 0.752 to 0.702 (Figure 3). In the Indian Ocean Coastal Belt biome there has been an 18% decline in the EAI between 1990 and 2018, despite already having less than 50% of its original extent by 1990. The arid Nama Karoo and Succulent Karoo biomes show less decline than more mesic biomes. The EAI for the Desert biome declined by 5% due to the high rate of habitat loss (due to coastal mining) in two small ecosystem types (Namib Lichen Fields and Alexander Bay Coastal Duneveld), despite the overall extent of natural habitat in the biome remaining relatively high (Table 1 and Supplementary table 3).

Figure 3: Ecosystem Area Index (EAI) for terrestrial ecosystems of South Africa: 1990, 2014 and 2018. There has been an overall decline of 7% across the whole of South Africa (1990–2018). For Fynbos, Grassland, Azonal vegetation and the Indian Ocean Coastal Belt, relative decline in EAI is most severe over the period from 2014 to 2018.

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Discussion

The habitat extent and rate of loss metrics indicate that recent land-cover changes are impacting the same terrestrial ecosystems which suffered historical impacts, likely because the major drivers remain largely the same (i.e. croplands, human settlements, plantation forestry and mining). The increased rate of habitat loss in recent years (2014–2018) indicates that these drivers are intensifying. Variation in drivers between biomes has led to stark differences in habitat loss, such as between the relatively mesic Grassland, Savanna, Indian Ocean Coastal Belt and Fynbos biomes, and the arid Nama-Karoo, Succulent Karoo and Desert biomes. The Indian Ocean Coastal Belt, a narrow biome (~20 km wide) stretching from the Eastern Cape through KwaZulu-Natal into Mozambique, stands out in terms of high overall habitat loss and rate of loss. In this region in particular, it is crucial that the bioregional plans and biodiversity sector plans (which now cover the whole of South Africa's mainland) are fully considered in land-use and development planning.[19-21] These plans clearly identify a network of Critical Biodiversity Areas and Ecological Support Areas in which further habitat loss needs to be prevented, in order to secure crucial ecosystem services and allow biodiversity to persist. The focus of impacts on the relatively mesic regions may change in coming years, with emerging pressures such as renewable energy facilities (solar photovoltaic and wind in particular) and intensive wildlife breeding operations threatening arid biomes.[2,7] Forests remain relatively unchanged, likely due to a long history of legislated and cultural protections.[22,23]

Compared to direct habitat loss, the impacts of overgrazing, disrupted fire regimes and invasive species on biodiversity and ecosystem function are far more difficult to quantify.[1,24] A large portion of South Africa is subject to these pressures, but these changes were not detected or included in the national land-cover data set used in our analysis, and information on the overall condition of ecosystems that incorporates these elements is still lacking.[2] As such, the results presented here should be seen as a conservative estimate of the threats to South Africa's biodiversity. In particular, overgrazing is likely to alter the current estimates of >95% natural extent remaining for the arid biomes (Desert, Nama and Succulent Karoo), as much of this area is used for rangelands, while altered fire regimes and invasive species are likely to impact the more productive and flammable biomes (Fynbos, Grasslands, Savanna and some Azonal vegetation types).[25] As this information is collated, the assessment of habitat loss should be expanded to include aspects of ecosystem condition/degradation using similar indices.[18]

The Ecosystem Area Index is a more sensitive indicator of habitat loss at the biome and national scales than the 'remaining extent' and 'rate of loss' metrics. This is illustrated in the Desert biome where, overall, the rate of loss was only 0.02% per year between 1990 and 2018, but nearly all of the habitat loss was focused in a single small vegetation type – Alexander Bay Coastal Duneveld. As each vegetation type contributes equally to the Index for the Desert Biome, this indicator reflected a 0.15% per year decline over the same period, highlighting the threat to this vegetation type.

The extent and rate of habitat loss, and EAI are simple and powerful indicators of the state of biodiversity for national and international reporting processes.[2,18] However well-intentioned and ambitious the national or global targets are, the consequences of not meeting such targets are minimal. For example, our results indicate that South Africa failed to halve the rate of habitat loss between 2010 and 2020, which was the goal of Aichi Biodiversity Target 5. While the post-2020 successors to the Aichi targets are currently being debated by the Convention on Biological Diversity, it is clear that existing land-use planning and regulatory tools need to be strongly enforced and improved in order to change the trajectory of continued habitat loss. For example, the habitat loss metrics discussed above provide the basis for ecosystem risk assessment such as the IUCN Red List of Ecosystems[14], which allows for the identification of threatened ecosystems. These ecosystems are then prioritised in systematic biodiversity plans that underpin bioregional planning processes.[26] Threatened ecosystems are also directly referred to in South African environmental authorisation regulations[8,27], although

their influence on land-use decision-making processes, especially at the local government level, needs to be strengthened.

While national and provincial authorities have taken steps recently to develop online environmental screening tools (which include key biodiversity information) and publish regulations making the use of the tools mandatory for all environmental authorisation processes, the efficacy of the interventions are difficult to gauge.[28] Monitoring the status of species and ecosystems with appropriate and up-to-date indicators improves biodiversity assessments and plans, and provides an avenue through which we can test the impact of policy interventions and regulations.[2]

Using land-cover change data to monitor ecosystems and biodiversity has its limitations, but the simplicity of the approach is also a great strength. Habitat loss related indicators are relatively easy to update (i.e. land-cover products from semi-automatic remote-sensing platforms are becoming a reality globally[9]), and the trends observed are relatively simple to interpret and are clearly attributable to drivers of change. The suite of conservation tools that use these metrics are impressive, although they do require consistent and strong implementation programmes. As we enter the UN Decade of ecosystem restoration (2021–2031) we need to complement the habitat loss indicators with analogous tools that allow semi-automated tracking of the more subtle elements of ecosystem degradation, including invasive species, overgrazing and altered fire regimes.[5]

Competing interests

We declare that there are no competing interests.

Authors' contributions

A.L.S.: Conceptualised the study; developed the methods; curated the data; undertook the analyses; produced the figures and maps; wrote the article; and edited the article. D.J.: Conceptualised the study and edited the article. J.A.S.: Conceptualised the study; wrote the article; revised the article; and edited the article.

References

1. Barger NN, Gardner TA, Sankaran M, Belnap J, Broadhurst L, Brochier V, et al. Chapter 3: Direct and indirect drivers of land degradation and restoration. In: Montanarella L, Scholes R, Brainich A, editors. The IPBES assessment report on land degradation and restoration. Bonn: Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services; 2018. p. 198–314. Available from: https://www.ipbes.net/system/tdf/ipbes_6_inf_1_rev.1_2.pdf?file=1&type=node&id=16514

2. Skowno AL, Poole CJ, Raimondo DC, Sink KJ, Van Deventer H, Van Niekerk L, et al. National Biodiversity Assessment 2018: The status of South Africa's ecosystems and biodiversity – synthesis report. Pretoria: South African Naitonal Biodiversity Institute; 2019. http://opus.sanbi.org/handle/20.500.12143/6362

3. Murray NJ, Keith DA, Bland LM, Ferrari R, Lyons MB, Lucas R, et al. The role of satellite remote sensing in structured ecosystem risk assessments. Sci Total Environ. 2018;619–620:249–257. https://doi.org/10.1016/j.scitotenv.2017.11.034

4. Jantz SM, Pintea L, Nackoney J, Hansen MC. Landsat ETM+ and SRTM data provide near real-time monitoring of Chimpanzee (*Pan troglodytes*) habitats in Africa. Remote Sens. 2016;8(5), Art. #427. https://doi.org/10.3390/rs8050427

5. Slingsby JA, Moncrieff GR, Wilson AM. Near-real time forecasting and change detection for an open ecosystem with complex natural dynamics. ISPRS J Photogramm Remote Sens. 2020;166(May):15–25. https://doi.org/10.1016/j.isprsjprs.2020.05.017

6. Li BV, Hughes AC, Jenkins CN, Ocampo-Peñuela N, Pimm SL. Remotely sensed data informs Red List evaluations and conservation priorities in Southeast Asia. PLoS ONE. 2016;11(8):1–18. https://doi.org/10.1371/journal.pone.0160566

7. Skowno AL, Raimondo DC, Poole CJ, Fizzotti B, Slingsby JA, editors. National Biodiversity Assessment 2018 technical report volume 1: Terrestrial realm. Pretoria: South African National Biodiversity Institute; 2019. http://opus.sanbi.org/handle/20.500.12143/6370

8. Botts E, Skowno A, Driver A, Holness S, Maze K, Smith T, et al. More than just a (red) list: Over a decade of using South Africa's threatened ecosystems in policy and practice. Biol Conserv. 2020;246, Art. #108559. https://doi.org/10.1016/j.biocon.2020.108559

9. Gómez C, White JC, Wulder MA. Optical remotely sensed time series data for land cover classification: A review. ISPRS J Photogramm Remote Sens. 2016;116:55–72. https://doi.org/10.1016/j.isprsjprs.2016.03.008

10. GeoTerraImage. Technical report: 1990 South African national land cover dataset version 5.2. Pretoria: South African Department of Environmental Affairs; 2015. Available from: http://egis.environment.gov.za

11. GeoTerraImage. Technical report: 2013/2014 South African national land cover dataset version 5. Pretoria: South African Department of Environmental Affairs; 2015. Available from: http://egis.environment.gov.za

12. GeoTerraImage. Technical report: 2018 South African national land cover dataset version 4. Pretoria: South African Department of Environment Forestry and Fisheries; 2019. Available from: http://egis.environment.gov.za

13. Mucina L, Rutherford MC, editors. The vegetation of South Africa, Lesotho and Swaziland. Pretoria: South African Naitonal Biodiversity Institute; 2006.

14. Keith DA, Rodríguez JP, Rodríguez-Clark KM, Nicholson E, Aapala K, Alonso A, et al. Scientific foundations for an IUCN Red List of ecosystems. PLoS ONE. 2013;8(5), e62111. https://doi.org/10.1371/journal.pone.0062111

15. Jewitt D, Goodman PS, Erasmus BFN, O'Connor TG, Witkowski ETF. Systematic land-cover change in KwaZulu-Natal, South Africa: Implications for biodiversity. S Afr J Sci. 2015;111(9–10), Art. #2015-0019. https://doi.org/10.17159/sajs.2015/20150019

16. Dayaram A, Harris LR, Grobler BA, Van der Merwe S, Rebelo AG, Powrie LW, et al. Vegetation map of South Africa, Lesotho and Swaziland 2018: A description of changes since 2006. Bothalia. 2019;49(1), Art. #2452. https://doi.org/10.4102/abc.v49i1.2452

17. Scholes RJ, Biggs R. A biodiversity intactness index. Nature. 2005;434(7029):45–49. https://doi.org/10.1038/nature03289

18. Rowland JA, Bland LM, Keith DA, Juffe-Bignoli D, Burgman MA, Ferrer-Paris JR, et al. Ecosystem indices to support global biodiversity conservation. Conserv Lett. 2020;13(1), e12680. https://doi.org/10.1111/conl.12680

19. Berliner D, Desmet P. Eastern Cape biodiversity conservation plan technical report. Pretoria: Department of Water Affairs; 2007. Available from: http://dev.biodiversityadvisor.sanbi.org/ECBCP/ECBCP_technicalreport2007.pdf

20. McLean CT, Ground LE, Boon RGC, Roberts DC, Govender N, McInnes A. Durban's Systematic Conservation Assessment. Durban: eThekweni Municipality; 2016. Available from: http://www.durban.gov.za/City_Services/development_planning_management/environmental_planning_climate_protection/Publications/Documents/DurbansSystematicConservation.pdf

21. Escott B, Elliot F, Livingstone T. Draft KwaZulu-Natal biodiversity spatial planning terms and processes: Version 3.3. Pietermatizburg: Ezemvelo KZN Wildlife; 2016.

22. Pooley S. Burning Table Mountain: An environmental history of fire on the Cape peninsula. New York: Palgrave Macmillan; 2014. https://doi.org/10.1057/9781137415448

23. National Forests Act of South Africa . Notice No. 1388 South Africa: Government Gazette 19408; 1998. Available from: www.gov.za/sites/default/files/gcis_document/201409/a84-98.pdf

24. Prince S, Von Maltiz G, Zhang F, Byrne K, Driscoll C, Eshel G, et al. Chapter 4: Status and trends of land degradation and restoration and associated changes in biodiversity and ecosystem fundtions. In: Montanarella L, Scholes R, Brainich A, editors. The IPBES assessment report on land degradation and restoration. Bonn: Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem services; 2018. p. 315–426. Available from: https://www.ipbes.net/system/tdf/ipbes_6_inf_1_rev.1_2.pdf?file=1&type=node&id=16514

25. Slingsby JA, Moncrieff GR, Rogers AJ, February EC. Altered ignition catchments threaten a hyperdiverse fire-dependent ecosystem. Glob Chang Biol. 2020;26(2):616–628. https://doi.org/10.1111/gcb.14861

26. Botts EA, Pence G, Holness S, Sink K, Skowno A, Driver A, et al. Practical actions for applied systematic conservation planning. Conserv Biol. 2019;33(6):1235–1246. https://doi.org/10.1111/cobi.13321

27. Bland LM, Nicholson E, Miller RM, Andrade A, Carré A, Etter A, et al. Impacts of the IUCN Red List of Ecosystems on conservation policy and practice. Conserv Lett. 2019;12(5), e12666. https://doi.org/10.1111/conl.12666

28. South African Department of Environment, Forestry and Fisheries. National Environmental Screening Tool [webpage on the Internet]. No date [cited 2020 Aug 04]. Available from: https://screening.environment.gov.za