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A practical guide to the application of the IUCN Red List of Ecosystems criteria

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The newly developed IUCN Red List of Ecosystems is part of a growing toolbox for assessing risks to biodiversity, which addresses ecosystems and their functioning. The Red List of Ecosystems standard allows systematic assessment of all freshwater, marine, terrestrial and subterranean ecosystem types in terms of their global risk of collapse. In addition, the Red List of Ecosystems categories and criteria provide a technical base for assessments of ecosystem status at the regional, national, or subnational level. While the Red List of Ecosystems criteria were designed to be widely applicable by scientists and practitioners, guidelines are needed to ensure they are implemented in a standardized manner to reduce epistemic uncertainties and allow robust comparisons among ecosystems and over time. We review the intended application of the Red List of Ecosystems assessment process, summarize 'best-practice' methods for ecosystem assessments and outline approaches to ensure operational rigour of assessments. The Red List of Ecosystems will inform priority setting for ecosystem types worldwide, and strengthen capacity to report on progress towards the Aichi Targets of the Convention on Biological Diversity. When integrated with other IUCN knowledge products, such as the World Database of Protected Areas/Protected Planet, Key Biodiversity Areas and the IUCN Red List of Threatened Species, the Red List of Ecosystems will contribute to providing the most complete global measure of the status of biodiversity yet achieved.

1. Introduction

Human activities have caused widespread alteration of natural ecosystems over the past few centuries and continue to severely threaten biodiversity worldwide [1,2]. The recently launched International Union for the Conservation of Nature (IUCN) Red List of Ecosystems (www.iucnredlistofecosystems.org) was developed to help assess risks to ecosystems by evaluating their characteristic biota and ecological processes [3–5]. The IUCN Red List of Threatened Species [6] and IUCN Red List of Ecosystems are designed to reflect complementary aspects of biodiversity loss and recovery. For instance, ecosystems may collapse, while their component species persist elsewhere or within novel ecosystems; species may go extinct locally and globally even though the ecosystems in which they

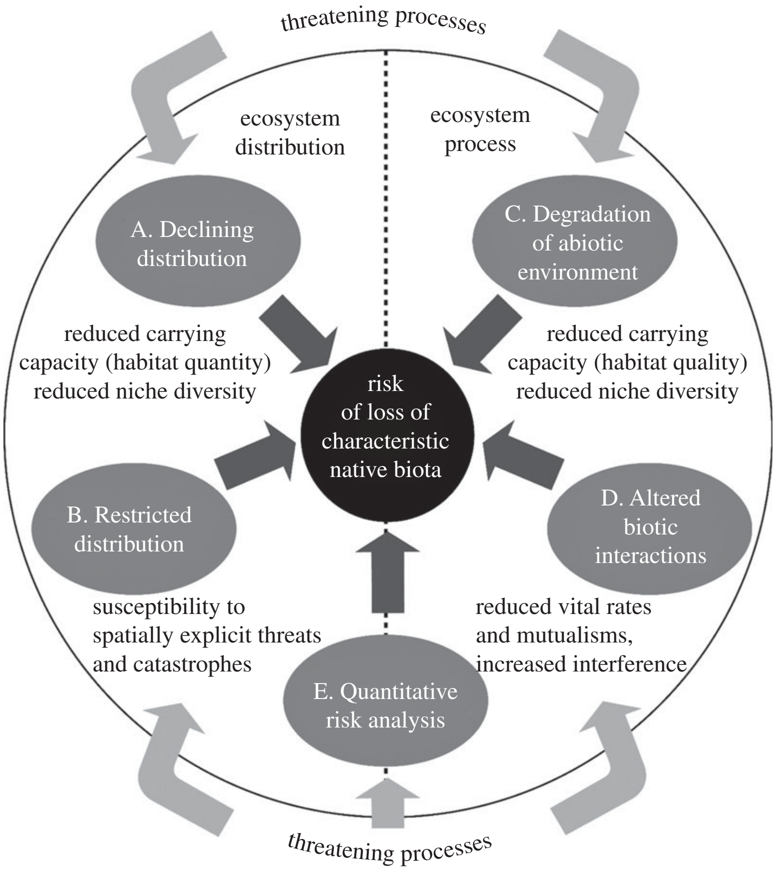

Figure 1. Mechanisms of ecosystem collapse, and symptoms of the risk of collapse. From Keith *et al*. [4].

occurred remain functional [3,4,7]. Likewise, the prevention of a species' extinction may theoretically be achievable despite collapse of the ecosystems in which it originally occurred, while reestablishment of ecosystem functionality may be possible through successional paths involving different sets of species than the original. Monitoring the status of both species and ecosystems provides a more complete picture of the state of biodiversity, and allows us to manage and conserve biodiversity most effectively [8].

The IUCN Red List of Ecosystems aims to systematically assess all freshwater, marine, terrestrial and subterranean ecosystem types of the world at a global level by 2025. Thereafter, the Red List of Ecosystems will be updated periodically to monitor progress towards international targets, such as the Aichi Targets [9] or Sustainable Development Goals [10]. The Red List of Ecosystems could also be updated following catastrophic events that dramatically alter ecosystem states, such as severe biological invasions. The Red List of Ecosystems standard provides a technical base for the development of threatened ecosystem lists at the regional, national and subnational levels through the provision of training, guidelines, peer-review and support. The Red List of Ecosystems standard thus has two primary applications: to produce and periodically update the global-level Red List of Ecosystems, and to support others in the development of subglobal assessments. Achieving these aims requires clear and easily accessible guidelines to help assessors carry out robust and repeatable assessments following the Red List of Ecosystems methods. In a previous article, the scientific foundations of the Red List of Ecosystems were developed, summarizing the science and the logic underlying the categories and criteria [4]. That article, 'version 2.0' of the Red List of Ecosystems Categories and Criteria, is a substantial expansion of 'version 1.0' [11], and combines a detailed review of the literature with feedback received through extensive consultation of the scientific community [3]. In May 2014, the IUCN Council adopted version 2.0 as an official global standard for assessing the risks to ecosystems. Here, our audience are the practitioners who will now begin to implement the protocol widely. We provide guidance to the application of the Red List of Ecosystems Categories and Criteria, to ensure conceptual and operational rigour of the resulting assessments. Accurate and consistent implementation of the method is essential if Red List of Ecosystems assessments are to achieve their potential as powerful tools that can monitor global biodiversity change, inform conservation actions and promote effective communication with decision-makers across sectors.

2. Ecosystem risk assessment model

The Red List of Ecosystems risk assessment model provides a unified standard for assessing the status of all ecosystems, applicable at subnational, national, regional and global levels (figure 1). It is based on transparent and repeatable decision-making criteria for performing evidence-based assessments of the risk of ecosystem collapse [4].

Collapse is the endpoint of ecosystem decline, and occurs when all occurrences of an ecosystem have moved outside the natural range of spatial and temporal variability in composition, structure and/or function. This natural range of variation must be explicitly defined in the description of each ecosystem type. Collapse is thus a transformation of identity, a loss of defining features and a replacement by another and essentially different ecosystem type [4,5]. In contrast to the analogous concept of species extinction, the method makes

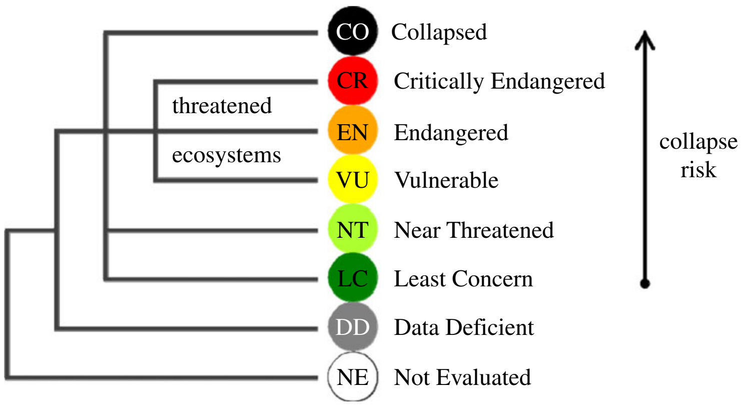

Figure 2. Structure of the IUCN Red List of Ecosystems categories (thresholds are summarized in the electronic supplementary material, appendix S1). (Online version in colour.)

no assumption about whether collapse may be reversible. If all the components of a collapsed ecosystem type still exist in other ecosystems, restoration is at least theoretically possible though it may be difficult or costly to achieve.

Risk of collapse is evaluated using five criteria based on one or more proxy variables, which may be specific to particular ecosystem types with appropriate standardization procedures [4]. Ecosystems should be evaluated using all criteria where data permit; if data for all criteria are unavailable, the ecosystem type is Data Deficient (DD; figure 2). The overall Red List of Ecosystems status is the highest level of risk identified by any of the criteria. The criteria and thresholds assign each ecosystem type to one of eight categories: two categories of non-threat (LC, NT), three categories of threat (CR, EN and VU), one category for collapsed ecosystems (CO), one category reflecting lack of information (DD) and one category for ecosystem types which have not yet been assessed (NE). These categories are analogous to those of the IUCN Red List of Threatened Species [12] (figure 2).

The Red List of Ecosystems criteria focus on four ecological symptoms to estimate the risk that an ecosystem type will lose its defining features (characteristic native biota and/or ecological processes; figure 1). These include two distributional symptoms: (A) ongoing declines in distribution, indicating ongoing incidence of threatening processes that result in ecosystem loss; and (B) restricted distribution, which predisposes the system to spatially explicit threats, along with manifested decline, threat or fragmentation. Two other mechanisms identify functional symptoms of collapse: (C) degradation of the abiotic environment, reducing habitat quality or abiotic niche diversity for component biota, for example ocean acidification or soil fertility loss; and (D) disruption of biotic processes and interactions, which can result in the loss of mutualisms, biotic niche diversity or exclusion of component biota. Interactions between two or more of these four mechanisms may produce additional symptoms of transition towards ecosystem collapse. Multiple mechanisms and their interactions may be integrated into a simulation model of ecosystem dynamics to produce (E) quantitative estimates of the risk of collapse. These four groups of symptoms and their integration into ecosystem models form the basis of the Red List of Ecosystems criteria.

3. Risk assessment process

The term ‘ecosystem type’ refers to the unit of assessment evaluated under the Red List of Ecosystems methodology [4,5]. Other typologies of ‘vegetation types’, ‘ecological communities’, ‘habitats’ and ‘biotopes’ may be suitable ecosystem types so long as they are typologies that represent biological diversity and meet the requirements of ecosystem description outlined below.

Initially, all ecosystem types are considered Not Evaluated (NE) for all criteria (figure 3). The next step is to determine whether adequate data exist for the application of the Red List of Ecosystems criteria (figure 3). These may include information from the scientific literature, unpublished reports, expert opinion, historical accounts, past and present maps, satellite imagery or other relevant data sources. If adequate data are unavailable to inform any criteria and reliably assign a category of risk, an ecosystem type is assessed as DD (figure 2).

Given the dynamic nature of life on earth, all species and ecosystem types will eventually be replaced by others over million-year timescales [13]. Thus, no ecosystem type can ever be considered completely free of the risk of collapse [4]. The language of the Red List of Ecosystems Categories and Criteria acknowledges this by naming its lowest risk category Least Concern (LC), emphasizing that under current scientific knowledge the likelihood of collapse is low but not null.

(a) Describing and delimiting the unit(s) of assessment

Describing the unit(s) of assessment begins with a compilation of all available information about the ecosystem types within the scope of the assessment (figure 3). The description of ecosystem types for a risk assessment process must include [4,5]: (i) their characteristic native biota, (ii) physical environment, (iii) salient processes and interactions and (iv) spatial distribution. It is fundamental to include a diagram of a conceptual model of the ecosystem highlighting the cause and effect links between ecosystem processes and components. When compiling this information, assessors must justify why the unit(s) selected for assessment can be recognized as a separate ecosystem. In other words, what are the key features that distinguish one ecosystem type from other ecosystem types?

Red Lists of Ecosystems for the global and subglobal domains should be based on a systematic ecosystem typology. But until such a system is available at the global level, application of the IUCN Red List of Ecosystems Categories and Criteria at national and regional levels is necessarily based on locally developed and internally consistent classifications of ecosystems. Subglobal red lists have been based on

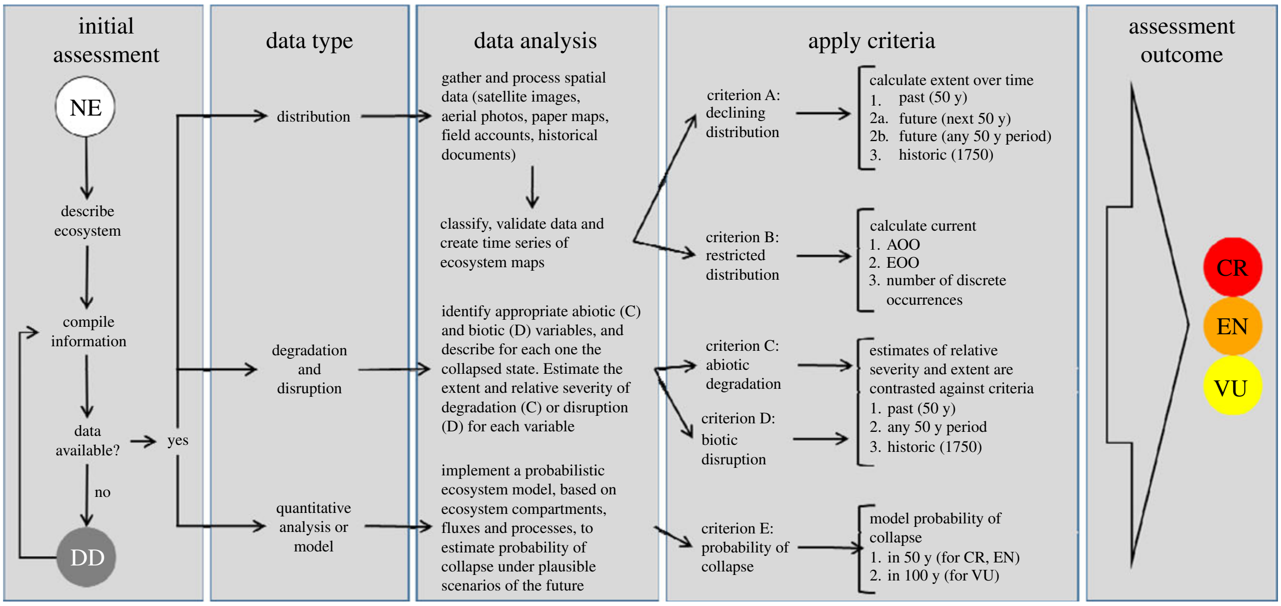

Figure 3. Steps followed for the application of the IUCN Red List of Ecosystems Categories and Criteria. For risk status symbols, follow figure 2. AOO, area of occupancy, EOO, extent of occurrence. (Online version in colour.)

maps of biotopes, vegetation types, ecological communities, habitat types and remotely sensed land cover types [14–17].

Numerous examples of such subglobal ecosystem red lists exist [14–19]. However, the Red List of Ecosystems Categories and Criteria may also be applied to assess single or selected ecosystem types across their distribution. Such assessments provide baselines for monitoring the future status of individual ecosystems, produce useful insights to support ecosystem management, and also serve as demonstrations of how the criteria may be interpreted in functionally contrasting types of ecosystem. For example, version 2.0 was applied to 20 case studies located in 12 countries or regions worldwide [4], providing specific guidance on the application of the criteria to a range of freshwater, marine and coastal, and terrestrial ecosystem types. More recently, assessments of selected ecosystem types [20–22] have identified key threats and suitable variables for monitoring, and have provided a strong basis for developing conservation strategies to reduce or at least stabilize the risks of collapse. Previously, version 1.0 of the of the Red List of Ecosystems criteria was applied to assess the relative status of 10 Venezuelan ecosystem types [11] and 72 naturally uncommon ecosystems of New Zealand [23].

(b) Evaluating criterion A: declining distribution

Criterion A seeks to identify ecosystem types that are currently declining in extent or may decline in the near future. The minimum data required for application of criterion A are two measures of the distribution of an ecosystem type, taken at different points in time and calibrated to the time scales of Red List of Ecosystems assessments [4,5]. To maximize repeatability of assessments of decline in distribution, assessors should be explicit and clear about what constitutes absence (i.e. local collapse) of the ecosystem type. In other words, how it was decided which areas were no longer occupied by the ecosystem type (e.g. replaced by agriculture, urban expansion or another ecosystem type) should be explicit.

Change in geographical distribution may be inferred from a time series of maps, written accounts or any other reliable data source that provides information on the distribution of an ecosystem type through time (figure 3). Assessors should include relevant maps in their account or provide full bibliographic references, and justify why the selected dataset is appropriate for assessing distributional change. Typically, estimates of change will be uncertain, and the uncertainty should be quantified and incorporated into calculations. In some cases, for example, there may be more than one credible source of data available (e.g. different vegetation maps or estimates produced with different methods) and it may be uncertain which is the most appropriate. In such cases, estimates of change should be calculated from each data source to document the sensitivity of ecosystem status to data uncertainty. The net change will thus be expressed as a best value bounded by an interval spanning the estimates generated from each data source. We recommend the assessors estimate the category for each endpoint of the interval, and report the range of plausible categories as well as the best estimate.

In many cases, raw data may be unavailable for the specific time scales required for Red List of Ecosystems assessments (electronic supplementary material, appendix S1). Assessors must therefore explain how the raw data were used to calculate estimates of distribution change over the past 50 years (criterion A1), the next 50 years or any 50 year period including the present and future (criterion A2), and/or since 1750 (criterion A3). This will typically involve assumptions about the nature or pattern of change (e.g. increasing, constant or decreasing), and interpolation or extrapolation of change rates to a 50-year period or since 1750.

Assessors often rely on time series of satellite images to quantify the change in distribution of ecosystem types. To apply criterion A, at least two measures of the distribution of the ecosystem type at different points in time are required, although three or more are desirable. These measurements should generally span at least 20 years apart, though a longer interval is preferred to support robust estimates of change over the timeframes specified in criterion A. Past and future risk assessments are based on a 50-year time frame (electronic supplementary material, appendix S1), but

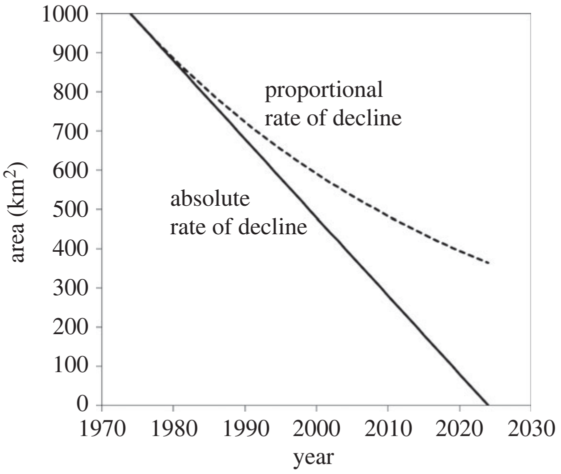

Figure 4. Proportional versus absolute rate of decline [24]. The figure shows an ecosystem type whose initial area in 1974 was 1000 km^2. It declined at a rate of 2% per year during the following few years, but the outcome over a longer period (50 years) was substantially different depending on whether the decline was considered proportional or absolute. If decline is proportional, the decline is a fraction of the previous year's remaining area (0.02 $\times$ last year's area), whereas in an absolute rate of decline, the area subtracted each year is a constant fraction of the area of the ecosystem at the beginning of the decline ($0.02 \times 1000 = 20$ km^2 per year). If the ecosystem type is assessed in 2014, under a proportional decline scenario this ecosystem type would be considered Endangered under criterion A2b (50–80% decline over any 50 year period including the present and future, electronic supplementary material, appendix S1), whereas under an absolute decline scenario, it is projected to disappear by 2024, and is thus considered Critically Endangered under criterion A2b (>80% decline). If the ecological evidence on patterns and mechanisms of decline suggests that both of these models are plausible, then the status of the ecosystem type is EN-CR, reflecting the uncertainty in projecting rates of distribution decline.

can be based on extrapolated data if the measurement interval is shorter. Whether inferences are made from time series of satellite images or from other data sources, two important additional aspects will fundamentally influence assessments under criterion A: (i) assumptions about the rate of decline and (ii) the number of points in the time series.

When the rate of decline is estimated from two images (or maps) separated by a certain number of years, assessors should explore all plausible scenarios of decline based on direct and indirect evidence about the shape of the decline trajectory and its underlying causes. If a decline is proportional, the absolute reduction in area dampens over time, leading to a convex curve (figure 4). If a decline is linear, the reduction in area occurs more rapidly as a constant area is subtracted at each time interval [24]. Different risk assessment outcomes may be obtained if two or more models of decline are plausible based on ecological evidence (figure 4). Investigating different decline shapes (e.g. proportional, absolute or diminishing) allows the assessor to examine ecosystem status under relatively optimistic and pessimistic scenarios.

The distribution of an ecosystem may follow many trajectories within the interval being examined, and those trajectories will only be visible when intermediate dates are considered (figure 5). A causal understanding of such trajectories is key for projecting future change, as levels of risk may vary depending on whether ecosystem decline is accelerating, decelerating or fluctuating. Adding even a single intermediate observation can help assessors identify trends in ecosystem decline that will inform future projections. Although criterion A can be applied correctly with only two data points, a deeper understanding of the processes of decline will lead to a more accurate assessment.

(c) Evaluating criterion B: restricted distribution

Criterion B focuses on risks posed by threatening processes that are spatially extensive relative to the distribution of an ecosystem type. Criterion B evaluates the risk of loss of all occurrences of an ecosystem type, by taking into account the interaction between the spatial extent of threats and the spatial distribution of ecosystem occurrences. To be listed as threatened under criterion B, an ecosystem type must satisfy two conditions: (1) evidence of a restricted distribution and (2) evidence of ongoing or future decline, threat or few locations.

To apply criterion B, assessors must calculate metrics from a suitable distribution map of the ecosystem type (figure 3). These include the extent of occurrence (EOO), area of occupancy (AOO) and number of locations. EOO is the area contained within the smallest polygon encompassing all the known, inferred or projected sites of present occurrence of an ecosystem type; AOO is the area within EOO occupied by an ecosystem type, measured with 10 $\times$ 10 km grid squares to allow consistent comparison with risk assessment thresholds [5,25,26]. For an ecosystem type that exists as a single occurrence or a few closely located occurrences, EOO and AOO will be of similar magnitude. In contrast, an ecosystem type with occurrences spread over a large area will have a substantially larger EOO than AOO (figure 6). Because ecosystems and their threats differ in spatial distribution patterns, EOO and AOO provide a complementary picture of ecosystem risk. The number of locations is a general measure of ecosystem distribution, defined relative to the spatial extent of threats. One location is a portion of the ecosystem distribution that could simultaneously be affected by the most serious plausible threat. This metric does not simply refer to the number of sites or localities, but rather reflects the number of spatially independent events that could seriously affect the persistence of the ecosystem type [3].

The second group of conditions to be assessed under criterion B (subcriteria a, b and c) distinguishes restricted ecosystem types exposed to an appreciable risk of collapse from those that are essentially stable and not exposed to identifiable threats, despite their currently restricted distributions [3,4]. This condition contrasts with criterion A, which requires quantitative estimates of decline over explicit time frames. After estimating EOO and AOO, assessors must compile all the evidence required to evaluate the subcriteria within B1 and B2: (i) ongoing continuing decline in distribution, environmental degradation and/or ongoing disruption to biotic interactions, (ii) threats that may in the next 20 years cause continuing declines in distribution, environmental degradation and/or ongoing disruption to biotic interactions, and (iii) number of locations [4,5].

Criterion B3 does not require quantitative calculations of spatial metrics (electronic supplementary material, appendix S1), but does require assessors to estimate the number of locations as outlined above. Two features of criterion B3 compensate for this lower standard of evidence required. First, it requires stronger evidence of ongoing decline or stochastic events that could cause an ecosystem type to collapse in the near future (*ca* 20 years). Second, ecosystem types are only eligible for listing as vulnerable under

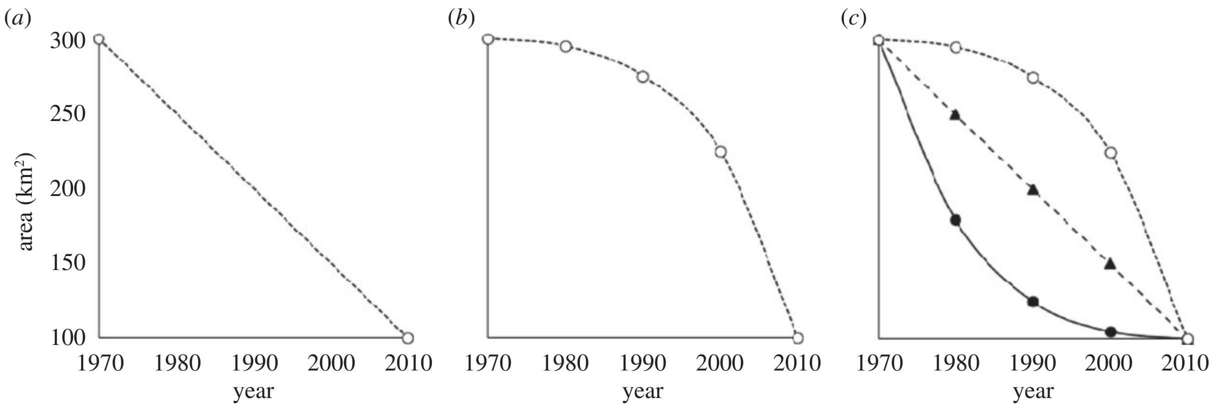

Figure 5. All trajectories for distribution size in this figure have the same endpoints over a 40-year time frame: 300 km^2 in 1970 and 100 km^2 in 2010. A simple interpolation between the two extremes assumes linear decline (*a*). Addition of intermediate distribution size estimates could reveal that the decline is not linear (*b*). Different ecosystem types could also exhibit contrasting trajectories with identical endpoints: future projections of distribution considering these trajectories would clearly differ (*c*).

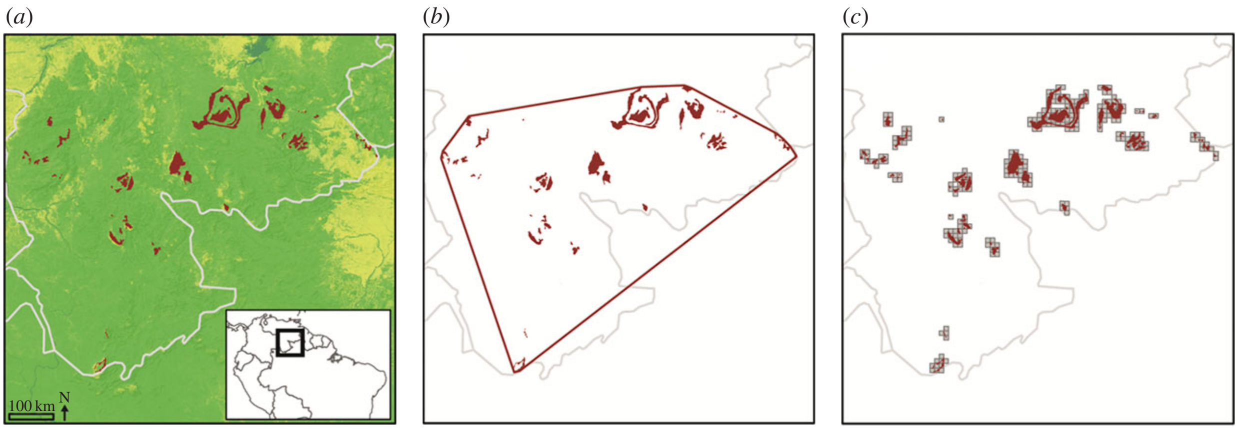

Figure 6. Distribution of Tepui shrublands, southern Venezuela. The ecosystem is mapped using remote sensing and field data (*a*) to determine present extent (8548 km^2). The extent of occurrence (*b*) is calculated as the area within a minimum convex hull around the ecosystem (266 218 km^2), and the area of occupancy (*c*) determined by determining the number of 10 × 10 km grid cells that contain more than 1 ha of the ecosystem (276 grid cells). Based on data from reference [4]. (Online version in colour.)

criterion B3. Listing in higher categories requires evidence based on at least one other subcriterion.

(d) Evaluating criterion C: degradation of the abiotic environment

Criterion C evaluates the risk of collapse posed by degradation of the abiotic environment, thus to apply criterion C one must first select a variable to estimate environmental degradation. Process models can play a key role in identifying ecosystem processes and abiotic variables for assessment under criterion C [3]. Alternative abiotic variables representing distinct trajectories of environmental degradation should be examined independently. The variable producing the greatest rate of decline should be used to assess status [4,5].

Assessors must justify the suitability of the selected variable for representing ecosystem processes, and explicitly relate the variable to the capacity of the ecosystem to sustain its identity (characteristic native biota, abiotic environment, ecological processes and interactions, distribution). The development of a conceptual model summarizing cause–effect dependencies among ecosystem components and processes is a useful tool to justify the choice of variables for risk assessment. Temporal variation in degradation is best shown with time series of the variable(s). Any interpolation or extrapolation made within the relevant time frames should be explicitly justified (electronic supplementary material, appendix S1).

To standardize estimates of environmental degradation among variables and ecosystem types, estimated declines must be scaled relative to the amount of change necessary for ecosystem collapse (figure 3). This requires the value of the collapse threshold to be estimated for the degradation variable [4,5]. When this value is uncertain, the uncertainty should be quantified (e.g. as bounded estimates) and propagated through the assessment [4,22]. In the simplest case, where progression towards collapse is linearly related to the degradation variable, range standardization enables the numeric values of degradation to be converted to % *relative severity* (electronic supplementary material, appendix S1). Other mathematical functions are required to estimate relative severity when the relationships are more complex. Estimating relative severity using range standardization requires estimates of: (i) the expected value of the collapse threshold, (ii) the observed value for the initial state (e.g. 50 years ago) and (iii) the observed value of the variable for the later state (e.g. present day). The degradation variable is rescaled as a proportional change (i.e. 0–100%) with the following expression:

$$\text{relative severity (\%)} = 100 \times \frac{\text{observed or predicted decline}}{\text{decline to collapse}},$$

where

$$\text{observed or predicted decline} = (\text{present or future state}) - (\text{initial state}),$$

and

$$\text{decline to collapse} = \text{collapse threshold} - \text{initial state}.$$

Next, assessors must determine the extent of the degradation (as a fraction of the total distribution of the ecosystem type affected by the decline) and document the quantitative evidence supporting the estimate. In many cases, it may be appropriate to estimate relative severity of a decline averaged across 100% of the extent of the ecosystem type. With these two quantities, relative severity and extent, assessors proceed to assign a risk category using the thresholds described in the electronic supplementary material, appendix S1.

(e) Evaluating criterion D: altered biotic interactions

The evaluation of criterion D follows the same procedure as for criterion C (figure 3), but focuses on biotic variables (electronic supplementary material, appendix S3): (i) select a suitable biotic variable or variables to measure, with justification of its relationship(s) to salient drivers of ecosystem dynamics (e.g. with reference to a process model specific to the ecosystem type being assessed); (ii) estimate a threshold of collapse; (iii) estimate the value of the variable across the distribution of the ecosystem at the beginnings and ends of the assessment periods (50 years ago and present day for D1, present day and 50 years into the future and/or at two time periods separated by 50 years between 50 years in the past and 50 years in the future for D2, 1750 and present day for D3); (iv) calculate the relative severity of declines as described above (this may require temporal interpolation or extrapolation and justification of associated assumptions); (v) estimate the extent (as a percentage of the ecosystem distribution) over which the change has occurred; and finally (vi) compare the estimates of relative severity and extent to the assessment thresholds under criterion D (electronic supplementary material, appendix S1).

(f) Evaluating criterion E: quantitative estimates of risk of ecosystem collapse

The application of criterion E depends upon the development or adaptation of a process-based ecosystem simulation model for the ecosystem type under assessment (figure 3), to allow the risk of ecosystem collapse to be estimated over a 50 or 100 year timeframe (electronic supplementary material, appendix S1). Examples of suitable model structures for assessing criterion E include an empirically derived state-and-transition model [27,28] for the Coorong Lagoons and Murray Mouth Inverse Estuary, South Australia [4], and for the mountain ash forests of southeastern Australia [20].

The explicit definition of collapse in the ecosystem model is a critical component of assessment under criterion E. For example, Lester and Fairweather [4] defined a number of different ecosystem states for the Coorong lagoon and explicitly identified those that were 'healthy' and 'degraded'. They assumed collapse would occur in the Coorong 'when half of the modelled years occur either in degraded ecosystem states or are in a period of recovery following the occurrence of degraded ecosystem states'. The process most likely to cause ecosystem collapse was a decline of freshwater flows to the lagoon that would increase salinity, and decrease water levels and marine connectivity. They used a stochastic state-and-transition model [27,28] to assess risk of collapse under plausible scenarios of climate change and water extraction, and assessed the Coorong ecosystem as critically endangered.

Developing methods for risk assessment under criterion E is an area of ongoing research, including suitable modelling methods and procedures for their use in risk assessment. The key steps in Lester and Fairweather's [27,28] and Burn *et al.*'s [20] analyses were: (i) explicit definition of the collapsed ecosystem state(s); (ii) application of a stochastic model of ecosystem dynamics that includes salient processes influencing ecosystem collapse; (iii) estimation of model parameters from empirical data; (iv) simulations representing a range of plausible future scenarios; and (v) quantitative estimation of risk of collapse over time scales specified under criterion E. Further examples and guidelines for the application of criterion E are in preparation.

(g) Assessment synthesis: overall risk of collapse

After the ecosystem type has been assessed against all the criteria, a final overall category is assigned; a summary table is used to report the outcome of the assessment. Criteria A–D have three subcriteria, whereas E has only one (electronic supplementary material, appendix S1). There are therefore 13 possible combinations of listing criteria and subcriteria under which one of the eight Red List of Ecosystems categories can be assigned (figure 2). Some ecosystems may be assessed as Data Deficient under one or more criteria, but available information must be included in the assessment documentation (examples can be found in reference [4], and at http://www.iucnredlistofecosystems.org/case-studies/). Following the precautionary principle [29], the highest category obtained by any of the assessed criteria will be the overall status of the ecosystem.

4. Documentation

(a) General requirements

The documentation standards of the IUCN Red List of Ecosystems are expected to include seven main sections [4,5] summary, classification, description, distribution, pressures and threats, assessment, and references (also see http://www.iucnredlistofecosystems.org/case-studies/).

(b) Subglobal assessments

Systematic application of the Red List of Ecosystems Categories and Criteria at regional, national and subnational levels [3] is a priority. IUCN will provide support for these assessments in the form of capacity building, development of guidance, tools and resources, peer-review and advice to local assessment teams, as well as assisting with testing integration with other conservation tools, and testing application.

Fundamental pieces of information in the documentation of subglobal assessments include the classification of ecosystem types and the global context of each ecosystem type. For global ecosystem types that are completely contained within the boundary of a subglobal assessment, risk categories will be identical at the subglobal and global levels. Assessment of such ecosystem types may thus be directly incorporated into the global Red List of Ecosystems.

In contrast, if other occurrences of an ecosystem type are found outside the boundary of a subglobal assessment, the assessment outcome will reflect the subglobal risk of ecosystem collapse and may not match the categorization of the same ecosystem in the global Red List of Ecosystems. In these cases, assessors must indicate the proportion of the global ecosystem included within the region and describe the spatial relationship between its subglobal and global extents. A discussion of the problems raised by cross-jurisdictional assessments and some potential solutions can be found in Nicholson *et al.* [26]. The significance of collapse in one country (in terms of opportunities for restoration) will be very different between ecosystem types distributed contiguously across political boundaries, and ecosystem types with disjoint occurrences.

(c) Risk assessment and priority setting

Objective, transparent and repeatable ecosystem risk assessments are necessary for effective global monitoring and conservation priority setting [4,5]. The risk of ecosystem collapse is only part of the information required for efficient resource allocation. Prioritization schemes could include the availability of financial resources, legislation, logistical factors, social values and the contribution to ecosystem services [30,31].

In practice, the most threatened ecosystem(s) might not be considered the highest priority by society. We believe Red List of Ecosystems assessments can and should inform evidence-based prioritization schemes, land/water use policies (especially related to broad-scale issues such as agriculture, forestry, fisheries and river basin management) and restoration efforts. This is an active area of research [32] that we do not aim to explore here.

There is no single way to approach priority setting for threatened ecosystems; the most appropriate approach will depend on the ecosystem type concerned, the conservation objective and the context (e.g. political, societal, economic and financial) in which priorities are being set. One recent proposal focused on four variables: risk of collapse, proportion protected, biological singularity and societal values [33].

5. Peer-review and publication of assessments and case studies

To enhance objectivity, transparency, repeatability and comparability, all assessments should undergo peer-review. For global assessments undertaken as contributions to the IUCN Red List of Ecosystems knowledge product, the peer-review process is coordinated by the Red List of Ecosystems Committee for Scientific Standards (CSS). The committee includes experts in risk assessment, ecological modelling, remote sensing, ecosystem mapping, decision theory and ecology of terrestrial, freshwater, marine and subterranean ecosystems. The expertise of the committee spans the full diversity of ecosystem types, biological realms and geographical regions [5]. The minimum requirement for peer-review stipulates that two experts examine each assessment: one expert on the ecosystem type being evaluated, and one expert familiar with the IUCN Red List of Ecosystems Categories and Criteria.

Subglobal assessments and case studies are set to the same standards of global assessments, but the responsibility for assuring effective peer-review lies in the hands of the coordinating organizations, with technical support from the IUCN Red List of Ecosystems development team as appropriate.

6. Conclusion

The IUCN Red List of Ecosystems is a tool in the portfolio of knowledge products mobilized by IUCN [34] to assess biodiversity change at a level of organization above that of species. By tracking the status of ecosystems, it identifies ongoing ecosystem declines and positive impacts of conservation action. The Red List of Ecosystems informs decision-making and planning in a multitude of sectors (e.g. conservation, natural resource management, macroeconomic planning and improvement of livelihood security). However, the Red List of Ecosystems' greatest strength will emerge from integration with other biodiversity and conservation knowledge products. We envision an easily accessible online tool that will allow stakeholders around the world to outline an area on a map and retrieve up-to-date conservation information, building from existing systems such as IBAT (https://www.ibat-alliance.org/ibat-conservation/login). Species- and ecosystem-level data could include risk status and threats, degree of protection, contribution to global biodiversity and role in supporting society and human well-being. These could be supplemented by site level data, on existing protected areas (protected planet) and sites contributing significantly to the global persistence of biodiversity (key biodiversity areas) [34]. When used together and made widely available through such a tool, data from multiple sources will provide the most informative picture of the status of biological diversity to date.

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