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Cite this article: Akçakaya HR *et al*. 2026 Three decades of classifying threatened species: lessons learned from and about the IUCN Red List criteria for quantifying extinction risk. *Proc. R. Soc. B* **293**: 20260316.
https://doi.org/10.1098/rspb.2026.0316

Received: 4 February 2026
Accepted: 16 April 2026

Subject Category:
Ecology

Subject Area:
ecology

Keywords:
extinction risk, threatened species, endangered species, species conservation

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Special Feature: Science for Conservation: Celebrating 200 Years of the Zoological Society of London (ZSL). Guest Editors: Samuel T. Turvey and Linda DaVolls.

Electronic supplementary material is available online at https://doi.org/10.6084/m9.figshare.c.8496390.

THE ROYAL SOCIETY PUBLISHING

Three decades of classifying threatened species: lessons learned from and about the IUCN Red List criteria for quantifying extinction risk

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The IUCN Red List of Threatened Species, the most widely used global system for assessing species' extinction risk, has become a foundational source of information for conservation management, policy and research. Since the adoption of quantitative extinction risk criteria more than three decades ago, the Red List has expanded substantially in scope and influence, informing decisions ranging from species conservation

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and protected area designation to international agreements, corporate risk assessments and global biodiversity indicators. Given its central role, maintaining scientific rigour, transparency and trust in the Red List system is essential. Feedback from users, emerging from evolving applications and scientific advances, has shaped the Red List throughout. At the same time, the Red List has been subject to recurring critiques, some of which stem from persistent misconceptions about its purpose, design and appropriate use. To address these, we review the history and development of the Red List system, clarify the strengths of its design, delineate the contexts for which the system was and was not intended, and elucidate the circumstances under which it may be modified. Finally, we outline pathways for researchers and users to contribute to ongoing improvements and discuss potential future directions for evolution of the Red List.

1. Introduction

The categories and criteria of the IUCN Red List of Threatened Species (hereafter 'IUCN Red List' or 'Red List') are widely regarded as the most comprehensive, objective and transparent system for categorizing the extinction risk of species [1–9]. The criteria use quantitative thresholds for assigning species to extinction risk categories ranging from Least Concern to Extinct [10]. More than three decades have passed since the first version of these criteria was published [11] and since the first large-scale applications [12,13]. As of 2025, a total of 172 620 species have been assessed globally using this system; of these 48 646 are considered threatened, defined as species categorized as Vulnerable, Endangered or Critically Endangered [14].

The IUCN Red List has been hugely influential in conservation, and is widely used in conservation planning, management, monitoring and decision making [6,15]. Red List data have played a foundational role in helping civil society and other actors prioritize among species for conservation attention (e.g. [16]), identifying key sites for the safeguarding of biodiversity (e.g. 17), and informing appropriate management interventions both *in situ* (e.g. [18,19]) and *ex situ* (e.g. [20]). Red List data are instrumental in numerous policy contexts, from informing proposals to amend the Appendices of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (e.g. [21]), to their implementation in the Red List Index [22], used by the Convention on Biological Diversity (CBD) and other multilateral environmental agreements to track progress towards internationally agreed targets and goals [23,24]. National applications have also grown tremendously: >100 countries have published national Red Lists, often based on IUCN criteria and guidelines for application at regional levels [25], and governments have used these data to inform statutory listing of protected species and the development of National Biodiversity Strategies and Action Plans [26]. The IUCN Red List, including derivatives [27], is now increasingly used by the private sector through tools such as the Integrated Biodiversity Assessment Tool to assess, report and minimize the negative impacts of their operations on biodiversity (e.g. [27,28]). Finally, donors large and small, from multi-lateral agencies and funds (e.g. the Global Environment Facility; the Critical Ecosystem Partnership Fund) to specialist funders (e.g. Mohamed bin Zayed Species Conservation Fund; Fondation Franklinia)—rely on Red List data to inform their funding decisions and resource allocations [15]. Collectively, these diverse applications illustrate how this tool, originally designed to assess extinction risk, has become a key source of biodiversity information that informs conservation policy and decision-making beyond its original scope.

Given the value of the IUCN Red List and the significance of its applications, it is essential that its processes, evaluations and data collection are rigorous and transparent. It is also important that the science underpinning the Red List system is continually evaluated and that its application is adapted in response to new knowledge, approaches and critiques. Processes and tools that do not adapt or learn from critiques can lose trust and thus fall increasingly short of their potential for impact. However, trust can also be eroded if a framework is criticized because of misconceptions about its purpose, underlying data and models, or outputs.

The Red List has been the subject of various critiques and analyses of the bounds of its applicability since its inception (e.g. [29–35]). Some of these critiques have been addressed by making changes to the Red List system, as we detail in §2. Others have been addressed by explaining the history, purpose and basis of the Red List (e.g. [36]) and clarifying common misconceptions (e.g. [37]).

Recent papers critiquing the Red List repeat previously addressed misconceptions but also raise new issues [38–45]. Over the same time frame, the scope of application of the Red List in new contexts has produced a new generation of users, some of whom may be unaware of the foundations and evolution of the Red List. Hence it is timely to revisit the most important aspects of the Red List, and update Collen *et al*. [37]. Rather than correct each specific misconception, we aim to prevent future misconceptions by providing information about the purpose, history and strengths of the system, the limits of its scope and directions for future development. We start with a brief history of the Red List system and follow with three sections on the strengths of the Red List's design: one summarizing the strengths, one focusing on the use of multiple criteria (a frequently misunderstood aspect) and one outlining why the Red List is considered to reflect extinction risks reliably. Building on this analysis, we clarify the circumstances to which the Red List was, and was not, designed to be applied, and consider situations in which the system may be modified. Finally, we outline how researchers and Red List users can contribute to the improvement of specific aspects of the IUCN Red List system, and provide some perspectives on how the IUCN Red List may evolve over the coming years. Our focus is on the Red List system, which includes the Red List Categories and Criteria (the 'standard') and the accompanying guidance documents, not on the Red List process.

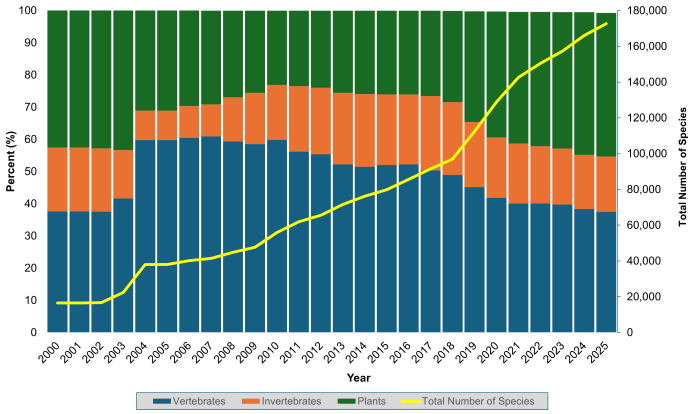

Figure 1. Percentage of vertebrate, invertebrate and plant species (left axis) and the total number of species (right axis) assessed on the IUCN Red List since 2000.

2. The origins and evolution of the Red List system

Some of the criticisms of the Red List are based on assumptions that the categories and criteria were developed by a small and unrepresentative group of experts and for a limited set of taxa. Therefore, a brief historical account is warranted. IUCN first started listing species on the basis of their extinction risk in the early 1960s. These lists of species, which by the 1980s had become exhaustively documented accounts, were termed 'Red Data Books' (the term 'IUCN Red List' was first used in 1986). During the 1980s, the IUCN Species Survival Commission (SSC) recognized the need for a more objective, consistent, transparent and rigorous means to assign species Red List Categories. In 1987, the SSC Steering Committee appointed Dr Georgina Mace (who was then working at the National Zoo Federation and the Zoological Society of London) to take the lead on developing a new system. The initial proposal for a new system was published in 1991 [46], and this formed the basis of extensive review and testing by hundreds of SSC members resulting in updated versions (summarized in [10]) until the IUCN Council formally adopted the new system in 1994 (Decision C/40/22). The first large-scale application of the new Categories and Criteria was published in 1994 [12], in which they were applied to all birds, followed by the Red List of Threatened Animals [13], which included all mammals recognized taxonomically at that time, and the World List of Threatened Trees [47]. Concerns over whether or not the system was working well for commercially exploited marine species were raised at the IUCN World Conservation Congress in 1996, which resulted in a further review of the criteria, culminating in further modifications of the Categories and Criteria being adopted in 2000 (Decision C/51/35) and published in 2001. A fuller summary of the history and the conceptual and scientific basis of the IUCN Red List Categories and Criteria is given by Mace *et al*. [36].

Since 2001, there has been a concerted drive to expand the taxonomic representation of the IUCN Red List (electronic supplementary material). Since the release of the global amphibian assessment in 2004, the proportion of vertebrates in the Red List has gradually decreased, the proportion of plants has increased, and the proportion of invertebrates has remained fairly stable (figure 1). Currently, about 45% of assessed species are plants (76 864 species), 38% are vertebrates (64 754 species) and 17% are invertebrates (29 682 species). While the IUCN Red List remains unbalanced towards certain taxa, with only a tiny fraction of arthropods and fungi represented (electronic supplementary material), trends show substantial progress towards improved taxonomic representation.

While the Red List Categories and Criteria (or 'standard') have remained unchanged since 2001, the accompanying guidelines [48] have undergone 16 updates in response to technological and scientific developments (table 1). Many of the updates have addressed weaknesses or ambiguities in the standard. For example, the guidelines have clarified ambiguities in the criteria regarding what constitutes 'exhaustive surveys' for listing a species as Extinct (EX), what scale is appropriate for measuring area of occupancy (AOO), and when to exclude discontinuities and disjunctions from the extent of occurrence (EOO) (table 1). The guidelines complement the formal categories and criteria, explaining how the criteria should be applied to different taxa and in different circumstances, with examples from different taxonomic groups illustrating appropriate application. The guidelines are now an essential companion document to the Red List standard, reflecting flexible, iterative and evidence-led understanding of how to apply the Red List criteria. The guidelines are accompanied by other guidance documents as needed [69–71].

3. Strengths of the Red List

Some criticisms of the Red List result from a misunderstanding of its primary purpose, which is to categorize species according to their extinction risks. In this and the following two sections, we review how the Red List system assesses extinction risk and how such a system can be validated. The IUCN Red List system is unique among species risk assessment systems in combining three different types of information: threats, biological traits and symptoms of endangerment (table 2). Other systems of assessment focus primarily on either: threats (e.g. the US Endangered Species Act); species-specific traits (e.g. [72,73]); or population-level responses to threats (symptoms of endangerment; e.g. [74]). All three types of information have drawbacks when used in isolation. Threat information may be difficult to obtain (it is often easier to determine that a species is threatened than why); there are only a very small number of traits that can be measured for the majority of species; and the same symptom

Table 1. Examples of changes made in the Red List guidelines to incorporate methodological advances for increased consistency and rigour of Red List assessments, with year of inclusion in the Red List guidelines (expanded from table 1 of [49]).

year[a]	methodological advance	RL category or criterion[b]	references
2001	using fuzzy arithmetic to propagate data uncertainties and identify the range of plausible Red List categories	A–E	[50]
2001	calculating the rate of decline of widely distributed taxa; incorporating uncertainties about the pattern of decline	A2	[51]
2003, 2011	using formulas that approximate generation length based on limited data	A, C1	[52–54]
2003, 2017	measuring the area of occupancy (AOO) at the reference scale of 2×2 km	B2	[55]
2006	measuring the extent of occurrence (EOO) as the area of the minimum convex polygon	B1	[56]
2008	defining (and flagging) species likely to be extinct as 'Critically Endangered (Possibly Extinct)', CR(PE).	EX, CR(PE), EW, CR (PEW)	[57]
2008	differentiating (and flagging) three types of Data Deficient (DD)	DD	[58]
2010, 2024	using ecological niche models and climate model outputs to infer future reductions resulting from climate change	A3	[59–61]
2011	using statistical models fitted to longer time series to calculate past reductions of highly variable species	A2	[51,62]
2014	calculating upper bounds of AOO and EOO based on habitat maps (incl. Area of Habitat)	B	[63]
2019	inferring that a species is extinct, based on threats and on time series of records and surveys	EX, CR(PE), EW, CR (PEW)	[64–67]
2022	discontinuing listing conservation-dependent species as Near Threatened (NT)	NT	[68]

[a]Multiple years indicate stepwise implementation and references related to the issue. The reference may precede the change in guidelines (e.g. if it suggested and provided rationale for such change) or follow it (e.g. if it tested or explained such change).
[b]See IUCN SPC [48] for definitions.

(e.g. reduction in population size or range area) may imply different extinction risks depending on a species's life history. Combining all three types of information allows for a comprehensive evaluation of extinction risk, and makes risk assessment possible even in cases where causes of endangerment cannot be determined, whether due to lack of data or the challenges of linking cause and effect.

An important aspect of the Red List system is its integration of automated and expert-led biodiversity assessments. The system allows for the use of technologies (such as remote-sensing imagery, geospatial analysis tools, species distribution models and the web-based platform sRedList [75]) that facilitate data preparation and automate several aspects of the analysis, but it also relies on the expertise of thousands of human assessors, reviewers and contributors to collate, analyse and interpret the available data in the context of the particular species and regions. Going forward there is a need to use the opportunities of automation, but balance them against the benefits of workshop-intensive expert-led approaches.

Because of the dearth of information for most species that require assessment, the Red List system has a major focus on the handling of missing and uncertain information. It offers three explicit pathways to incorporate and account for data uncertainties. The first is through providing multiple criteria and decision rules that allow assessments to be completed, even when data are lacking for one or more aspects of the species's status—the category depends only on the criteria that can be applied with the data available (detailed in §4 below). The second is to allow assessors to specify a best estimate within a range of plausible values for uncertain quantitative parameters in the criteria. These values can be based on confidence or credible intervals, or the opinion(s) of experts [48]. Treating uncertainty in this way results in a range of plausible Red List categories, with a single category within this range selected on the basis of the assessors' risk tolerance and the range of categories reported in the documentation [50]. The third mechanism for dealing with uncertainty is through use of the Data Deficient (DD) category, which is applied when missing data (including contextual information on trends in habitat extent and condition) preclude all inference of relative extinction risk levels. After an initial increase, the proportion of species assessed as DD has been declining for the last decade (figure 2), likely resulting from improvements in biodiversity data availability and improved guidance on using the DD category.

Finally, an often under-appreciated strength of the Red List criteria is that species with very different life histories can be assessed against a single set of thresholds through the use of parameters scaled to the species's life history. Parameters such as 'mature individual' (in criteria A, B, C and D), 'population reduction' (A), 'decline' (C), 'location' (B and D) and 'severe fragmentation' (B) are critical for the criteria and provide the Red List with consistency across all taxa. However, for comparable risk assessment of taxa with diverse life histories, the definition of these parameters requires transparent taxon-specific customization that ensures consistent application. For instance, the definition of 'mature individual' directs assessors to consider broad taxon-specific traits, such as age or stage at sexual maturity, mature individuals that never breed, biased sex ratios, fluctuating populations, clonality, etc. The time frames for 'population reduction' are based on the species's generation length, which reflects the turnover rate of breeding individuals. Population growth has a biological limit based on life history. Species of any generation length can decline similarly rapidly in response to threats such as habitat loss and exploitation, but long-generation species are constrained to recover much more slowly. For the purpose of assessing extinction risk, measuring

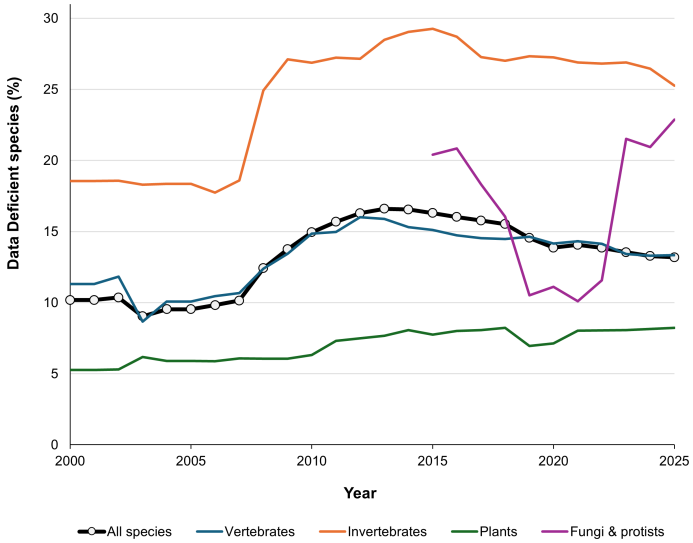

Figure 2. Percentage of species on the IUCN Red List that are assessed as Data Deficient.

Table 2. How information on symptoms, traits and threats are used in the five IUCN Red List criteria A–E for determining the extinction risk of species.

criterion	symptoms	traits	threats
A	• population trends	• generation length	• for identifying the basis of population reductions (a–e) • for projection of future reductions (A3 and A4) • for determining whether the causes of declines are reversible, understood and ceased (A1)
B	• range area (AOO and EOO) • population trends • population fluctuations • population subdivisions	• dispersal (for defining 'severely fragmented' and calculating 'extreme fluctuations') • habitat preferences (for B(b)(iii))	• for defining 'location' • for projection of future declines • AOO thresholds consistent with threat footprints [55]
C	• population size • population trends • population fluctuations • population subdivisions	• life cycle, breeding system and social structure (for defining 'mature individual') • generation length • dispersal (for calculating 'extreme fluctuations')	• for projection of future declines
D	• population size (for D1) • range area (AOO for D2)	• life cycle, breeding system and social structure (for defining 'mature individual' for D1)	• for defining 'location' (D2) • for defining 'restricted' (D2)
E	probability of extinction calculated with quantitative methods that incorporate species-specific traits and threats, and fit observed trends and abundance		

AOO, area of occupancy; EOO, extent of occurrence.

all population reductions over a fixed time period (as suggested by, for example, [44]) would result in underestimated risks for long-lived species relative to shorter-lived species. Scaling population reductions by generation length prevents this bias [36,48].

'Severely fragmented' is also customized for a species's life history, in this case in terms of dispersal distances in relation to spatial configuration and minimum viable population sizes. Together, these attributes and the quantitative nature of the criteria have underpinned the widespread adoption of the Red List Categories and Criteria system and have motivated efforts to evaluate and validate extinction risk assessments across taxonomic groups (see §5), contributing to the compilation of the world's most comprehensive database of species' extinction risk.

4. The use of multiple criteria in assessments

For many species, particularly fishes, invertebrates and plants, data on population sizes and trends are often unavailable. This has raised concerns about the applicability of the five IUCN Red List criteria (A to E) to these taxa [32,39,44]. However, by design, population data are not required for the application of all Red List criteria. Although Red List assessments evaluate species against as many criteria as the available data allow, it is sufficient for a species to meet just one criterion to be assigned to a category. The IUCN Red List framework is not structured to ensure that all criteria are applicable to all taxa; there are seldom data to apply every criterion to a taxon. More importantly, multiple criteria act as an ensemble to detect different symptoms of extinction risk born from different mechanisms of threat and different life histories and habitat dependencies [76]. Every taxon should therefore be assessable under at least one criterion given the available information (or be assessed as Data Deficient).

For example, criterion B (restricted distribution, decline, fluctuations and fragmentation) does not require population size estimates, being based on a taxon's distribution and habitat trends. Criterion B is the most widely used criterion, and its use has been increasing (figure 3). Similarly, criterion D2 (very restricted distribution) only requires information on the distribution of a species and the occurrence and plausibility of major threats capable of driving it extinct in a short time period. For species that are not directly monitored, assessment against criterion A (population reduction) is possible using sources of information other than trends in numbers of mature individuals, such as changes in habitat availability or expansion of threats (e.g. invasive alien species, catch or trade, agricultural expansion and mining). For example, analysis of deforestation data from the Global Forest Watch platform [77] was used to infer the rate of reduction (criterion A) and continuing decline of many forest species (e.g. [78]).

If data allow evaluation against more than one criterion, the species is listed under the criterion that gives the highest extinction risk category. This method emphasizes the most critical factors affecting a taxon's survival and is analogous to how emergency room doctors prioritize the most severe symptoms in a patient, rather than averaging all symptoms [37]. It supports the precautionary but realistic approach espoused in the Red List [79], especially when decisions must be made with limited information.

5. The Red List as a robust indicator of extinction risk

Like any system that predicts extinction risk, the Red List cannot be tested empirically by monitoring the change in the status of species after they are assessed. In some cases, this may be because the documentation of the Red List category (prediction of extinction) triggers mitigation actions and thus changes the course of the species's trajectory [80], so a threatened species not going extinct cannot falsify the prediction [81,82]. Despite this, there are five lines of evidence that support the view that the Red List robustly reflects species' extinction risks at the time of the assessment.

The foundation in expert knowledge and real-world application: As described in §2, the Red List criteria were developed, applied and revised over a decade (1991 to 2001) through the contribution of hundreds of scientists spending many thousands of person-hours in workshops, discussions and data analysis. This was an open, intense and robust process, with all ideas freely exchanged, discussed and dissected. The end product (the current Red List criteria) reflects the consensus of the contributing scientists and species experts. Moreover, the extensive guidelines for application of the criteria continue to be regularly updated to reflect new developments (table 1).

The theoretical basis of the criteria: The Red List criteria are firmly based on ecological principles rooted in population and metapopulation dynamics. The scientific basis of the criteria has been peer-reviewed and published in several scientific papers and IUCN publications. These include Mace & Lande [46] and Mace *et al*. [36], as well as many of the 160 or so references cited in IUCN [10,83] and IUCN SPC [48].

Tests with retrospetive assessments: An assessment system can be tested by applying it retrospectively to cases with a known outcome, as long as the cases do not include species that were publicly declared to be threatened during the assessment period. For example, Keith *et al*. [84] applied the Red List criteria to extinct-extant pairs of related species. Using data from before the extinction (and before any Red List existed), assessors correctly classified the extinct species in high-threat categories and the extant species in low-threat categories. However, there was high variation in outcomes resulting from differences in how assessors interpreted the same evidence when estimating parameter values, underscoring the importance of guidelines and training for assessors. In another type of retrospective study, Stanton [7] demonstrated that, had the Red List criteria been available, the Passenger Pigeon would have been classified as a threatened species long before its extinction in the wild at the end of the nineteenth century. These studies suggest that the Red List criteria correctly identify species at high risk of extinction.

Tests with simulated species: In this approach, the population dynamics of species are simulated using realistic models. During the simulation, the Red List category of the species is calculated based on the state of the population (such as size, recent declines, number of subpopulations, etc.). At a point in time early in the simulation the Red List status is compared with the simulation outcome (e.g. whether the species is extinct by the end of the simulation). Using this approach, Keith *et al*. [8] and Stanton *et al*. [9] showed that the Red List criteria were able to identify as threatened the species that would eventually go extinct, long before they did so. Other studies used a similar approach to show that IUCN Red List classifications under criterion A were robust to high levels of uncertainty [85–87].

Tests through inter-model comparison: Relatively high levels of agreement have been found between Red List status and the results of other approaches, including other extinction risk protocols [2,4,5] and fisheries population assessments [62,88–90]. While not conclusive validation, this is indicative of the robustness of the Red List process.

To the best of our knowledge, no other method or approach for categorizing species according to their extinction risk is as well supported scientifically, or is applicable to as many different types of species, as the IUCN Red List system.

6. Genetic diversity and the Red List

As genetic diversity is increasingly incorporated into biodiversity monitoring and assessment schemes, there have been proposals to add genetically based criteria [91–94]. However, the Red List is not designed to measure loss of genetic diversity; it measures extinction risk, a metric of biodiversity loss at the species level. While a loss of genetic diversity may increase extinction risk, many mechanisms that link genetic diversity with extinction risk are ultimately expressed in demographic indicators such as vital rates, population size and spatial parameters, which are embedded in the Red List criteria.

Various aspects of the genetics of a population (e.g. structure, isolation and inbreeding) that affect its extinction risk can be considered in a Red List assessment in several ways. Most directly, extinction probability models (criterion E) can be used to

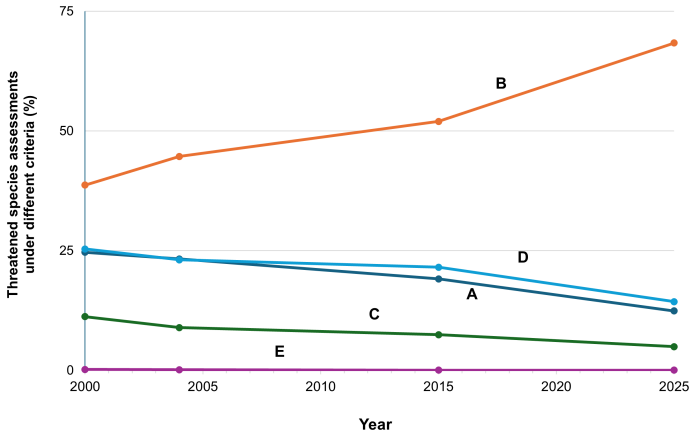

Figure 3. Percentage of threatened species assessments on the IUCN Red List under criteria A–E since 2000.

incorporate genetic effects on demography, and hence extinction risk (e.g. [95]). More indirectly, genetic effects are incorporated through the main metric of abundance used in the Red List, namely the number of mature individuals (Nm), which is assessed not only for the total population size of the taxon (criterion D) but also for each subpopulation (criterion C2). There is strong indication that neutral genetic diversity (as genetic diversity is often measured) correlates with extinction risk mainly at low population sizes [96] approximately corresponding to criterion D thresholds of Nm. In addition, Nm takes values between those of effective population size (Ne; a common metric of genetic diversity) and census population size (Nc), and can be closer to the former than the latter. This is because Nm captures some of the difference between Ne and Nc (e.g. Nm excludes pre-reproductive, senescent and suppressed individuals and takes sex ratio into account [48]).

Another indirect way in which a Red List assessment accounts for genetic information is via the threats posed by genetic (as well as demographic) processes such as fragmentation (criteria B1a, B2a) and hybridization (A1e, A2e, etc.), as well as declines in distribution (e.g. A2c, B1b(i),(ii),(iii)), and in the number of subpopulations (B1b(iv), B2b(iv)). These processes and declines can both correlate with and be proxies for loss of genetic diversity [97]. Other metrics of genetic diversity may also correlate with extinction risk, or reveal extinction risk and future evolutionary potential at time scales longer than those in the Red List criteria. However, new metrics of any kind (genetic, spatial, ecological, life history, etc.) proposed for the Red List must meet the conditions expected of any proposed major change to the Red List system (see below).

7. What the Red List categories and criteria are not designed for

Many misconceptions about, and disagreements with, the Red List stem from misunderstanding the Red List's primary purpose (measuring current extinction risk), and from the fact that extinction risk, while of fundamental importance, is not the only conservation-relevant metric. The extinction risk category of Least Concern, for instance, does not mean that there is no conservation concern (only that there is little concern regarding extinction in the near future). In particular, the Red List was not designed to measure the long-term impact of past threats on a species, or the degree to which it has recovered. Controversies have arisen when species have a low risk of extinction (therefore are listed as Least Concern) despite being now severely depleted relative to a historical, more abundant (or more widespread) baseline that precedes the three generations time period used in the criteria. However, the recently developed IUCN Green Status of Species (GSS) provides a credible and complementary means for reflecting how far species might be from full recovery relative to a previous baseline, as well as the impact of past conservation on current status [98]. This means, for example, that species currently listed as Least Concern which have been extirpated from large parts of their historical range would have a Green Status of 'depleted'. After extensive testing, the GSS is now being rolled out as an integral component of the Red List process, providing a complementary lens through which to view species status [99].

Controversies have also arisen when a decrease in a species's extinction risk, reflected as an improvement in its Red List category, has been viewed as detrimental to the continuation of conservation measures directed at the species [100,101]. However, the Red List was not intended to be used as the sole means of setting priorities for conservation measures, including making funding decisions ([10], pp. 1, 8). The Red List was also not designed to measure conservation dependence. Until 2022, the Red List guidance allowed species with lower extinction risk to be designated as Near Threatened (NT) based on their dependence on conservation. However, this was discontinued (see table 1) because species at any category of extinction risk may depend on conservation measures, so that interpretation of the NT category was not aligned with the aim of assessing extinction risk [48]. The need to determine the degree to which a species is dependent on ongoing conservation (or has benefited from past conservation) is now met by the conservation impact metrics of the GSS [102].

The Red List criteria were designed to assess species' global extinction risk, but a single conservation status for widely distributed species can sometimes obscure highly divergent regional trajectories or heterogeneous conservation concerns (e.g. [103]). These may be captured in Red List assessments at the national, regional or population scales (e.g. [104]). Regional guidelines [83] have been developed to ensure that assessments are robust at sub-global scales. Again, the GSS complements Red List sub-global assessments by explicitly delineating range, including historical range, into discrete spatial units that allow assessors to articulate the differing states of a species across a wide distribution, but with the advantage of placing this sub-global status into a longer-term and larger-scale context.

8. Considerations for modifying the Red List categories and criteria

Although the guidance on how to apply the Red List in different circumstances has evolved based on real-world experience and stakeholder needs, the foundational categories, criteria, metrics and thresholds have remained unchanged since they were launched in 2001. This long-standing stability reflects an explicit recognition that changes to the Red List categories and criteria could have major ramifications including possible loss of comparability with historical assessments and downstream effects on all global, regional, national and local systems that use or adapt the current Red List system.

At the same time, the Red List categories and criteria are not immutable, and modification may become necessary under certain circumstances. The IUCN has an established procedure for this (see [105]), and is currently refining a process that might allow some changes to be implemented relatively easily and quickly. Examples of such changes include expanding the definition of 'threatened' to include Extinct in the Wild (EW), and better aligning the definitions of some of the metrics such as EOO and AOO with the current practice and guidelines (e.g. discouraging exclusion of discontinuities and disjunctions for EOO and requiring application of a standard grid size for AOO).

By contrast, major changes—such as the introduction of new metrics (parameters) or criteria (rules that compare parameters to thresholds), modification of quantitative thresholds, or substantive change to definitions—would be subject to the same general process, but would be expected to meet higher evidentiary standards and conditions, such as the following:

(1) There must be a theoretical basis (i.e. a causal relationship) and an empirical association (i.e. a statistical relationship) between the proposed or modified metric or criterion and the probability of extinction of species in the time frames relevant to the Red List (10–100 years).
(2) When demonstrating a statistical association between extinction probability and the proposed modification to the Red List, the association must be measured independently of the Red List category of the species. This is in part because of the unfalsifiability issue discussed above, but mainly because a lack of correlation between a proposed metric and Red List categories cannot prove or disprove the predictive ability of the proposed metric, whereas a strong correlation demonstrates that the proposed metric is largely redundant with the current Red List criteria, and therefore not needed, unless intended as a more practical replacement for an existing metric.
(3) Both false positives and false negatives must be considered when interpreting the results of the statistical relationship between any proposed metric and extinction probability. This is because, given inherent uncertainties, a modification to ensure that 100% of species that are at risk of extinction are listed in a threatened category may also list as threatened a large number of species with negligible risk. The trade-off between the two types of errors must be considered.
(4) It must be demonstrated (e.g. through retrospective and simulation-based tests; see discussion of validation above) that the proposed new metric or criterion either reduces uncertainty or shifts some species to a higher category of extinction than the one they are assigned to with the current Red List criteria (otherwise, there is no information gained from the modification, because of the precautionary approach to listing at the highest category of threat that is met).
(5) The proposed metric or criterion must be applicable to most taxa (except micro-organisms) *in principle*, and must be practical to assess for multiple taxonomic groups.
(6) In order to maintain the same standard extinction risk benchmark over time (so that it is possible to follow the trend in the status of biodiversity), the overall risk levels implied by the threat categories must remain approximately constant (but obviously not exactly for all species; see (4) above). Thus, changes that would result in a large number of Red List category changes would need to be carefully evaluated.

As far as we are aware, no major change or addition to the Red List criteria has been proposed in the scientific literature that satisfies these conditions.

9. Improving the Red List: a call to all researchers and users to engage

Cazalis *et al*. [49] reflected on the research-implementation gap between the numerous scientific papers proposing changes to, or critiquing, Red List methods or processes and the assessment practice that has integrated very few such proposals. We echo their calls for improved communication and collaboration between academic researchers and Red List practitioners. The Red List depends greatly on the contributions and time of all scientists and conservationists, and the best way to help improve the system is to engage directly. We particularly see potential in the following areas.

Species data: Better data on all aspects of the biology of species (including distribution, life history, habitat, population estimates and trends) are needed, especially for marine species, invertebrates, fungi and non-vascular plants. In addition, analytical summaries of distribution and trend data in terms of calculated range shifts and population reductions, and analyses of demographic data in terms of generation length for large taxonomic groups would greatly speed up assessments. For maximum impact, these data and analytical results need to be open-access and easily found by a web-search. We also highlight the need to overcome fundamental biases in data collection because the geography of biodiversity science is shaped by social and political inequity [106].

Threats data and methods: Global databases related to specific threats (such as forest loss) can be immensely useful for Red List assessments, so long as the spatial data are a defensible representation of the extent and quality of the species's habitat, and the time series accurately reflects change in habitat extent or quality. Similarly, globally applicable databases with a suitable level of spatial resolution are needed for other threats, especially on diseases, invasive species and direct exploitation [107]. In

addition, new methods are needed for better identification of direct threats and for quantifying their impact on extinction risk [108].

Fundamental science: Red List criteria are based on a theory of population dynamics that was developed mainly for unitary macro-organisms. Theoretical developments in extinction dynamics of clonal and colonial organisms and of micro-organisms in nature need to be refined so that they can be incorporated into practical guidelines. Past advances in inferring extinctions have been incorporated into the Red List guidelines to list species as Extinct or Critically Endangered (Possibly Extinct) (table 1), but improvements to these methods are needed to make them applicable to a wider range of taxa. Similarly, some practical methods have been developed to assess extinction risks of species impacted by infectious diseases based on criterion E (e.g. [109]), but more advanced methods are needed. Also needed are new methods for applying criterion E to assess other threats and stresses, such as loss of genetic diversity, hybridization and invasive species.

Tools implementing scientific advances: Practical methods are needed for the robust estimation of Red List parameters. Red List assessments are benefiting from practical tools that implement advanced methods, especially methods of spatial analysis (e.g. sRedList [62,75]). Similar tools are needed for determining the appropriate pattern of decline for fitting curves to population trajectories, for predicting population declines based on climate projections from regional, high-resolution models and for calculating spatial metrics (AOO and EOO) when there are sampling gaps (e.g. [110]).

Investment in capacity: The Red List is a communal endeavour, which relies on the expertise of thousands of scientists around the world, largely unpaid and supported by a small and overstretched central Red List Unit. The credibility and rigour of the Red List is founded largely on the diversity and expertise of its assessors. Everybody with knowledge of a species and requisite online training [111] can submit or contribute to Red List assessments, but language, time and informational barriers can preclude engagement. The IUCN SSC is the vehicle for engagement, and researchers who are interested in becoming members are encouraged to contact the relevant SSC group [112]. Investment is needed in training and supporting the next generation of assessors, preferably based in the countries where the species occur, and in enabling the Red List Unit to provide the infrastructure required for efficient, effective and timely updates to the Red List system. This is something that beneficiaries of the Red List could consider engaging with.

10. Conclusions

The Red List has a decades-long history of supporting conservation action through informing governments, non-governmental organizations and, increasingly, businesses, of the extinction risks facing species, the threats underlying these risks and the ways in which these risks manifest themselves. In this way, it has had direct and indirect conservation impacts through several pathways [15]. The challenge is to keep up to date with new developments in technologies, experience and data, while also maintaining the stability that fosters confidence in the framework and associated processes. Here, we have outlined the principles, processes and structures that underpin the Red List, their strengths and constraints and addressed some of the concerns that have been expressed in the recent literature. We find that most of these concerns generally either relate to the specifics of particular species assessments, or are based on misconceptions of how the Red List works and what its aims are. There are areas where new approaches and guidance are needed, such as the treatment of clonal species, and other areas in which there is an exciting prospect of more efficient and insightful ways to generate a Red List assessment and ensure that the Red List and its products are as aligned as possible with the broader landscape of biodiversity indicators. With transparency and continued engagement from the wider research and end-user community, we expect that the Red List will continue to provide a relevant and robust framework for the assessment of extinction risk for a range of purposes and users in the decades ahead.

Ethics. This work did not require ethical approval from a human subject or animal welfare committee.

Data accessibility. Supplementary material is available online [113].

Declaration of AI use. We have not used AI-assisted technologies in creating this article.

Authors' contributions. H.R.A.: conceptualization, writing—original draft, writing—review and editing; E.J.M.-G.: writing—original draft, writing—review and editing; M.H.: writing—original draft, writing—review and editing; H.M.R.: writing—original draft, writing—review and editing; I.N.: writing—original draft, writing—review and editing; A.E.P.: writing—original draft, writing—review and editing; K.J.G.: writing—original draft, writing—review and editing; D.A.K.: writing—original draft, writing—review and editing; S.H.M.B.: writing—original draft, writing—review and editing; S.N.S.: writing—original draft, writing—review and editing; N.J.C.: writing—original draft, writing—review and editing; M.D.M.: writing—original draft, writing—review and editing; M.B.: writing—original draft, writing—review and editing; A.J.B.: writing—original draft, writing—review and editing; D.P.M.: writing—original draft, writing—review and editing; A.H.: writing—original draft, writing—review and editing; N.K.D.: writing—original draft, writing—review and editing; M.R.: writing—original draft, writing—review and editing; T.B.: writing—original draft, writing—review and editing; J.R.S.W.: writing—original draft, writing—review and editing; J.P.R.: writing—original draft, writing—review and editing; C.H.-T.: data curation, writing—review and editing; J.S.: data curation, writing—review and editing; S.T.: data curation, writing—review and editing; S.H.L.: data curation, writing—review and editing; C.L.: writing—original draft, writing—review and editing.

All authors gave final approval for publication and agreed to be held accountable for the work performed therein.

Conflict of interest declaration. We declare we have no competing interests.

Funding. We thank the Environment Agency–Abu Dhabi and the Rufford Foundation for their long-term financial support of the Red List.

Acknowledgements. We thank the hundreds of experts who contributed to the development and testing of the IUCN Red List categories and criteria, begun under the leadership of the late Georgina Mace, and the many thousands of experts who have engaged with the Red List since, including contributing to the Red List assessments of 172 620 species to date.

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