Accelerating and standardising IUCN Red List assessments with sRedList

Article

Published Version

Cazalis, V., Di Marco, M., Zizka, A., Butchart, S. H. M., Gonzalez-Suarez, M. ORCID: https://orcid.org/0000-0001-5069-8900, Böhm, M., Bachman, S. P., Hoffmann, M., Rosati, I., De Leo, F., Jung, M., Benítez-López, A., Clausnitzer, V., Cardoso, P., Brooks, T. M., Mancini, G., Lucas, P. M., Young, B. E., Reşit Akçakaya, H., Schipper, A. M., Hilton-Taylor, C., Pacifici, M., Meyer, C. and Santini, L. (2024) Accelerating and standardising IUCN Red List assessments with sRedList. Biological Conservation, 298. 110761. ISSN 1873-2917 doi: 10.1016/j.biocon.2024.110761 Available at https://centaur.reading.ac.uk/117944/

To link to this article DOI: http://dx.doi.org/10.1016/j.biocon.2024.110761

Publisher: Elsevier

Biological Conservation 298 (2024) 110761

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Accelerating and standardising IUCN Red List assessments with sRedList

Victor Cazalis[a,b,c,*], Moreno Di Marco[d], Alexander Zizka[e], Stuart H.M. Butchart[f,g], Manuela González-Suárez[h], Monika Böhm[i], Steven P. Bachman[j], Michael Hoffmann[k], Ilaria Rosati[l], Francesco De Leo[l], Martin Jung[m], Ana Benítez-López[n], Viola Clausnitzer[o], Pedro Cardoso[p,q], Thomas M. Brooks[r,s,t], Giordano Mancini[d], Pablo M. Lucas[d,u], Bruce E. Young[v], H. Reşit Akçakaya[w,x], Aafke M. Schipper[y,z], Craig Hilton-Taylor[aa], Michela Pacifici[ab], Carsten Meyer[a,ac,ad], Luca Santini[d]

[a] German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Puschstr 4, D-04103 Leipzig, Germany
[b] Leipzig University, Ritterstraße 26, 04109 Leipzig, Germany
[c] Conservara, Moulis, France
[d] Department of Biology and Biotechnologies "Charles Darwin", Sapienza Università di Roma, Rome, Italy
[e] Department of Biology, Philipps-University Marburg, Karl-von-Frisch-Str. 8, D-35043 Marburg, Germany
[f] BirdLife International, David Attenborough Building, Pembroke Street, Cambridge CB2 3QZ, UK
[g] Department of Zoology, University of Cambridge, Downing Street, Cambridge CB2 3EJ, UK
[h] Ecology and Evolutionary Biology, School of Biological Sciences, University of Reading, Whiteknights, Reading RG6 6EX, UK
[i] Global Center for Species Survival, Indianapolis Zoological Society, Indianapolis, USA
[j] Conservation Assessment and Analysis, Royal Botanic Gardens, Kew, Richmond, UK
[k] Zoological Society of London, Regents Park, London NW1 4RY, UK
[l] National Research Council, Research Institute on Terrestrial Ecosystems, Lecce, Italy
[m] Biodiversity, Ecology and Conservation Group, Biodiversity and Natural Resources Management Programme, International Institute for Applied Systems Analysis, Laxenburg, Austria
[n] Department of Biogeography and Global Change, Museo Nacional de Ciencias Naturales (MNCN-CSIC), Madrid, Spain
[o] Senckenberg Research Institute, Goerlitz, Germany
[p] Centre for Ecology, Evolution and Environmental Changes (cE3c), Global Change and Sustainability Institute (CHANGE), Faculdade de Ciências, Universidade de Lisboa, 1749-016 Lisboa, Portugal
[q] Laboratory for Integrative Biodiversity Research, Finnish Museum of Natural History, Luomus, University of Helsinki, Helsinki, Finland
[r] IUCN, Gland, Switzerland
[s] World Agroforestry Center (ICRAF), University of The Philippines Los Baños, Los Baños, Laguna, Philippines
[t] Institute for Marine and Antarctic Studies, University of Tasmania, Hobart, Tasmania, Australia
[u] Departamento de Biología Vegetal y Ecología, Universidad de Sevilla, Sevilla, Spain
[v] NatureServe, Arlington, VA, USA
[w] Department of Ecology and Evolution, Stony Brook University, New York, USA
[x] IUCN Species Survival Commission (SSC), Gland, Switzerland
[y] Department of Environmental Science, Radboud Institute for Biological and Environmental Sciences (RIBES), Radboud University, Nijmegen, the Netherlands
[z] PBL Netherlands Environmental Assessment Agency, The Hague, the Netherlands
[aa] IUCN, Cambridge, United Kingdom
[ab] Global Mammal Assessment Programme, Department of Biology and Biotechnologies "Charles Darwin", Sapienza Università di Roma, Rome, Italy
[ac] Institute of Geosciences and Geography, Martin Luther University Halle-Wittenberg, Halle (Saale), Germany
[ad] Institute of Biology, Leipzig University, Leipzig, Germany

ARTICLE INFO

Keywords:
Species range map
Red List
National Red List
Biodiversity conservation
Extinction risk

ABSTRACT

The IUCN Red List of Threatened Species underpins much decision-making in conservation and plays a key role in monitoring the status and trends of biodiversity. However, the shortage of funds and assessor capacity slows the uptake of novel data and techniques, hampering its currency, applicability, consistency and long-term viability. To help address this, we developed sRedList, a user-friendly online platform that assists Red List assessors through a step-by-step process to estimate key parameters in a standardised and reproducible fashion. Through the platform, assessors can swiftly generate outputs including species' range maps, lists of countries of

* Corresponding author at: German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Puschstr 4, D-04103 Leipzig, Germany.
E-mail address: victor.cazalis@conservara.fr (V. Cazalis).

https://doi.org/10.1016/j.biocon.2024.110761
Received 10 May 2024; Received in revised form 12 July 2024; Accepted 9 August 2024
Available online 23 August 2024

Web application
GBIF
Decision support

occurrence, lower and upper bounds of area of occupancy, habitat preferences, trends in area of habitat, and levels of fragmentation. sRedList is compliant with the IUCN Red List guidelines and outputs are interoperable with the Species Information Service (SIS; the IUCN Red List database) in support of global, regional and national assessments and reassessments. sRedList can also help assessors prioritise species for reassessment. sRedList was released in October 2023, with a complete documentation package (including text documentation, 'cheatsheets', and 15 video tutorials), and will soon be highlighted in the official Red List online training course. sRedList will help to bridge the gap between extinction risk research and Red List assessment practice, increase the taxonomic coverage and consistency of assessments, and ensure the IUCN Red List is up-to-date to best support conservation policy and practice across the world.

1. Introduction

The IUCN Red List of Threatened Species™ (hereafter, Red List) is the most authoritative source of information on the extinction risk of species (Rodrigues et al., 2006) and has been a key tool in biodiversity conservation for many decades (Betts et al., 2020). For example, it is central in guiding and monitoring several goals and targets adopted by the Parties to the Convention on Biological Diversity (SCBD, 2010, 2022a, 2022b). Currently >163,000 species of animals, fungi and plants have been assessed, of which >45,000 are considered threatened with extinction globally (IUCN, 2024). Thousands of regional and national Red List assessments have also been undertaken (Zamin et al., 2010; Hochkirch et al., 2023). However, the Red List is currently taxonomically biased towards well-known groups, and faces the dual challenge of expanding the number of assessments to invertebrates, fungi, and some plant groups (IUCN, 2021b; Cardoso et al., 2011; Nic Lughadha et al., 2020; Stuart et al., 2010), while updating existing assessments (Juffe-Bignoli et al., 2016; Rondinini et al., 2014). Furthermore, the Red List must ensure the highest possible levels of consistency and accuracy are maintained in line with new data and methods (Cazalis et al., 2022).

To address these challenges, various technological solutions have been proposed to enable assessments and reassessments to be undertaken more rapidly and accurately, or to prioritise assessments and reassessments (Zizka et al., 2022; Lucas et al., 2024; Cazalis et al., 2023; Henry et al., 2024). For instance, available occurrence records can serve as a basis to calculate distribution parameters (Zizka et al., 2021; Pelletier et al., 2018) and automated procedures can potentially improve the accuracy of range maps (Ficetola et al., 2014; Huang et al., 2021; Hughes et al., 2021). Furthermore, novel methods based on remote-sensing products can help to monitor changes in habitat suitability, or to estimate population size and severe fragmentation (Santini et al., 2019; Tracewski et al., 2016; Brooks et al., 2019; Lumbierres et al., 2022). In addition, the development of new databases on ecological traits (Pacifici et al., 2013; Soria et al., 2021; Tobias et al., 2022; Pekár et al., 2021; Bird et al., 2020) and species' population density (Santini et al., 2022, 2023) can bring further quantitative information to Red List assessments.

Yet, while many of these approaches have shown potential to support IUCN Red List assessments, their uptake has been somewhat limited so far (Cardillo and Meijaard, 2012; Cazalis et al., 2022). A major reason for this lack of implementation is the challenge to deliver a system that meets the practical needs of Red List assessors and is compatible with the existing Red List infrastructure, while simultaneously being easy to learn for a broad group of users with very diverse technical capacities. Due to time constraints and/or limited GIS and programming skills, assessors have struggled to map species ranges and quantify the species' extent of occurrence (EOO), identify suitable habitats and elevations, or estimate population sizes, trends and fragmentation, among other required tasks. Furthermore, many assessments could be improved by making better use of the available data and methods, and by strengthening the consistency of calculation methods while applying Red List criteria. The widespread uptake of the GeoCAT tool (https://geocat.iucnredlist.org), which helps assessors gather occurrence records and calculate criterion B parameters (EOO and potential area of occupancy AOO; Bachman et al., 2011), suggests that Red List assessors hugely benefit from user-friendly and openly available tools supporting their assessments. Similar tools providing a wider range of Red List parameters and outputs could thus provide key support to Red List assessors.

2. Introducing sRedList

To help address these challenges, we developed sRedList (https://sredlist.eu), a user-friendly online platform to support Red List assessors in deriving key parameters and outputs for Red List assessments in a standardised way. sRedList guides assessors through a step-by-step procedure to assess species' extinction risk, based on the latest data and modelling approaches, and covering multiple Red List criteria. Building on decades of scientific developments, sRedList facilitates: the creation of range maps from different input data sources, the extraction of potential countries of occurrence and species' habitat preferences (which are required information for Red List assessments), and the estimation of various parameters linked directly or indirectly to assessment criteria (Table 1). These include the extent of occurrence (EOO), area of habitat (AOH), upper and lower bounds of area of occupancy (AOO), number of mature individuals, population trends and fragmentation, and trends in threatening processes as estimated based on multiple remotely sensed products. It also facilitates prioritising species for reassessment using comparative statistical modelling (currently limited to prioritising reassessment of Data Deficient species).

sRedList has been developed through cooperation among researchers in conservation and modelling, software developers, relevant Red List bodies and assessors. Its purpose is to support Red List assessors with mapping tools, auxiliary information, and prioritisation tools to best inform their assessments and enhance their consistency. We followed five rules in the development:

1) Science-based. The implemented features are based on established methods documented in the scientific literature.
2) Red List compliant. All steps adhere to the Red List Categories and Criteria (IUCN, 2012b) and the Red List user guidelines (IUCN Standards and Petitions Committee, 2024).
3) User-friendly. Using sRedList does not require any programming skills; an understanding of the Red List Categories and Criteria, user guidelines and assessment process are sufficient to interpret all outputs.
4) Non-prescriptive. The outputs do not impose any extinction risk categorisation, but provide data related to key Red List parameters, which users can modify as appropriate based on other available data and their expert knowledge on the species, and help to determine the appropriate Red List category for each species. Guidance to interpret all available data is also provided to make the best-informed choices.
5) SIS-ready. The outputs can be directly uploaded into the Species Information Service (SIS), the Red List database, through the 'SIS Connect' tool, and include additional information (e.g. maps) for further evaluation that can easily be shared between assessors and reviewers.

sRedList is available through a web platform designed using Angular

Table 1
Assessment elements informed by sRedList steps, and role in the assessment process (either as parameters to apply Red List criteria (IUCN, 2012b), or as supporting assessment information).

Step	Assessment element	Role	Before sRedList	With sRedList
1	Occurrence record points	Supporting (Required)	Gathered manually or via GeoCAT (from GBIF, iNaturalist, Flickr, etc.). Filtered manually.	Points automatically gathered (from GBIF, OBIS, existing Red List assessments, or uploaded by the user), and filtered.
1	Polygon range map	Supporting (Required)	In most cases, drawn manually using GIS software.	Automatically drawn with multiple options (alpha hulls, kernels, hydrobasins, etc.).
1	Hydrobasin range map (freshwater species only)	Supporting (Required)	Gathered from occurrence records through IUCN Freshwater Mapping Application.	Mapped from occurrence records with multiple options (level 8, 10, 12, or within Minimum Convex Polygon).
2	Countries of occurrence	Supporting (Required)	Manually selected from a list.	Automatically extracted from the range map.
2	Realms	Supporting (Recommended)	Manually selected from a list.	Automatically extracted from the range map.
3	Extent of occurrence	Criterion B1	Calculated as minimum convex polygon or alpha hull using GeoCAT or GIS software.	Automatically calculated as minimum convex polygon from the range map.
4	Habitat preferences	Supporting (Required)	Manually selected from a list.	Suggested from habitats at locations of occurrence records.
4	Elevational preferences	Supporting (Recommended)	Manually imputed value.	Suggested from elevation of occurrence records.
4	Area of occupancy	Criteria B2, D2	Lower bound calculated and mapped from occurrence records in GeoCAT or any GIS software. Upper bound might be derived individually from AOH maps.	Lower bound calculated and mapped from occurrence records. Upper bound automatically calculated and mapped from area of habitat derived from remotely sensed land cover products.
4	Population size	Criteria C1, C2, D1	Obtained from a species-specific literature search, statistical analyses, or expert consultation.	Inferred or estimated from area of habitat and population density parameter (suggested by sRedList for available taxa, user-defined otherwise).
5, 7	Past population trends	Criteria A1, A2	Obtained from a species-specific literature search, statistical analyses, analysis of habitat maps, or expert consultation.	Inferred or estimated and mapped from trends in area of habitat or tree-cover automatically extracted from time series of remotely sensed land cover products.
6	Population severe fragmentation	Criteria B1, B2	Expert opinion, more rarely GIS analyses.	Inferred or estimated from area of habitat derived from remotely sensed land cover products.

(Jain et al., 2014), providing users with a seamless and intuitive experience. This interface is underpinned by R programming (R Core Team, 2024), using the ‘plumber’ package (Schloerke and Allen, 2024) and the ‘future’ framework (Bengtsson, 2021). This architecture makes the platform scalable and efficient in handling the complex computations involved. The R-code for the analyses provided by sRedList is publicly available at https://github.com/LifeWatch-Italy/sredlist-server.

sRedList is accompanied by a comprehensive documentation package (see links in sRedList home page). This includes a detailed manual that guides users through each step of the assessment process, elucidating relevant parameters to enhance transparency and reproducibility. The same information is also available through tooltips directly embedded into the various components of the web interface to provide information at the user’s fingertips. Further, a concise ‘cheatsheet’ is provided as a quick reference for users to familiarise themselves with the different features. Additionally, 15 video tutorials and 2 recorded webinars offer a dynamic exploration of all functionalities. sRedList will be highlighted in the official Red List training course that any new Red List assessor follows.

The target audience of sRedList includes both new and experienced Red List assessors and is equally relevant for first assessments and reassessments. It can be useful for assessors running hundreds of assessments (who thus need to fast-track some steps) and for assessors running a few assessments (who will benefit from the step-by-step guidance provided by sRedList). It was tested at multiple development stages by Red List assessors for a wide range of taxonomic groups, and continues to be improved through user feedback.

3. sRedList assessment workflow

The sRedList assessment workflow is designed for use early in the assessment process, as a way to gather important data and calculate parameters used in the assessment in a consistent and standardised way. It starts with users defining the current range map of the species to be assessed, followed by optional steps performing spatial analyses, and a final step summarising the results (Fig. 1, examples in Boxes 1–2). Each of these steps offers functionalities and outputs that assessors cannot readily access without sRedList (Table 1). sRedList covers most of the parameters that can be extracted from spatial data and is the most comprehensive tool to document Red List parameters in a single workflow to date. Currently, it does not inform parameters that need other, context-specific information (e.g., population reduction caused by factors other than habitat loss, magnitude of threats impacting the species, or the highest priority conservation actions) but has been designed to incorporate additional parameters as methods develop. Running steps 1–8 takes on average between 5 and 15 min depending on the species group and on the choices made by the assessor. In the following paragraphs we describe the individual steps in sRedList; more details can be found in the sRedList documentation: https://sredlist.eu/assets/documentation/sRedList_documentation.pdf. All spatial analyses and calculations are based on the World Mollweide projection (https://epsg.io/54009).

3.1. Step 1: range map

A user performing an assessment for a species starts by either uploading a GIS shapefile depicting the geographic range limits, or creating a range map directly on sRedList from occurrence records. For reassessments, assessors can also use the range map provided in the previously published Red List assessment, which can be accessed directly via sRedList, and filtered by presence, origin and seasonality attributes. Existing range maps can also be updated by combining them with new polygons. Soon, users will also be able to manually edit the range map and complete some map attributes directly through an interactive tool with no GIS skills required. At this step, in the case of national or regional Red List assessments, users can also choose to restrict the assessment to a single country or region.

If users choose to create a new range map from occurrence records, they are guided through a four-step process. First, users select the source of the occurrence records they wish to use, if available (currently: Global

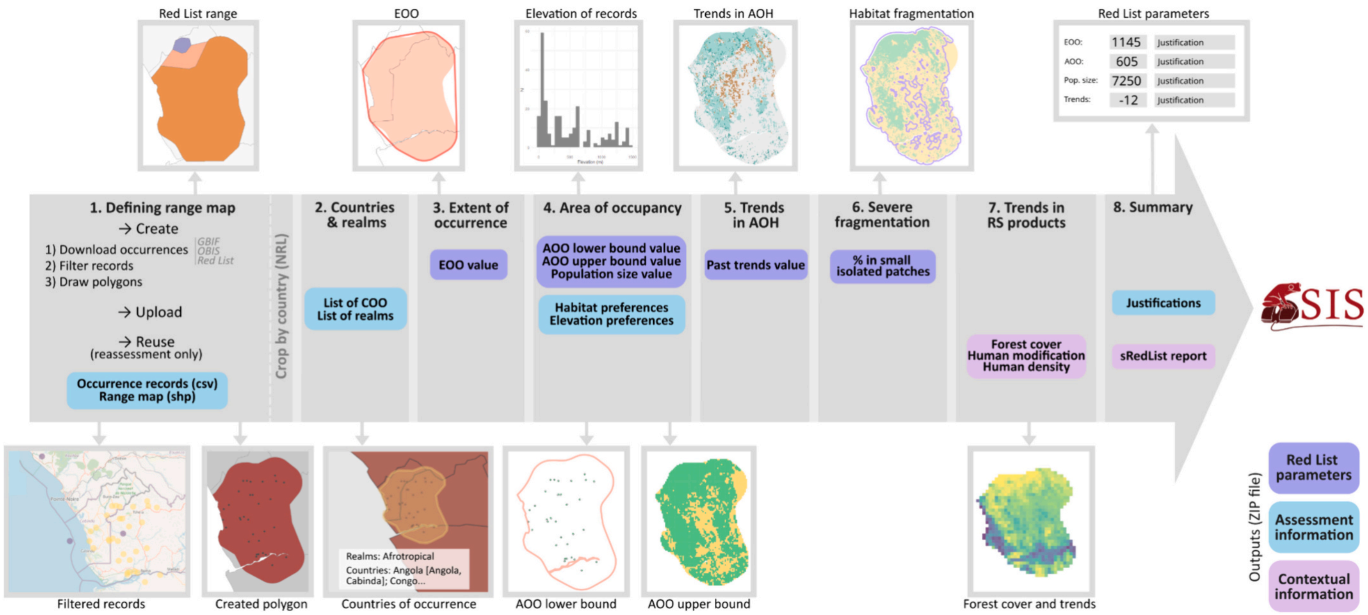


Fig. 1. The sRedList workflow for species assessments. The insets in the upper and lower rows show the graphical results for each step. Coloured boxes indicate the output of each step for assessments (purple: parameters to apply Red List criteria, light blue: supporting information or data required in Red List assessments, pink: contextual information for assessors). GBIF "Global Biodiversity Information Facility"; OBIS "Ocean Biodiversity Information System"; NRL "National and Regional Red Listing"; COO "countries of occurrence"; EOO "extent of occurrence"; AOO "area of occupancy"; AOH "area of habitat"; RS "Remote-sensed". (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Biodiversity Information Facility (GBIF), Ocean Biodiversity Information System (OBIS), Red List point records from last assessment, or data uploaded by the user). sRedList downloads and merges those records, with the possibility to also use records from taxa regarded as synonyms by the user. If there are >2000 records from a single selected source, sRedList keeps a subset of 2000 records in order to minimise computing time (in the case of GBIF records, it downloads a geographically representative sample of records; see sRedList documentation for details). Second, sRedList applies filters to exclude occurrence records that are likely less reliable, such as records made before a user-defined observation year, records with a localisation uncertainty higher than a user-defined value, records outside a user-defined geographic extent, records that are in the wrong domain (land or sea) given the species of concern, and any records identified by functions in the 'CoordinateCleaner' package in R (Zizka et al., 2019). Users can also add, remove, or move occurrence records manually. Third, users specify how sRedList should approximate the species range boundary using the point records with options including: alpha hulls, kernels, minimum convex polygon, or buffers around each point record or around coastline for coastal species. The resulting polygonal range can then be buffered based on a user-defined distance, cropped by land or sea, cropped by elevation (e.g. to exclude mountainous areas), or merged with the Red List range map of the most recent assessment. For freshwater species, the range can be constructed using hydrobasin maps (IUCN, 2021a; Lehner and Grill, 2013) following the Red List mapping standards (IUCN SSC Red List Technical Working Group, 2021). Finally, the range polygons generated can be further smoothed if desired. At the end of this process, the system outputs a spreadsheet of the occurrence records used and a shapefile of the polygon range map; both match the format required by the Red List for range map submission.

3.2. Step 2: countries of occurrence and biogeographical realms

Once the range map is defined, sRedList derives a list of countries of occurrence (including the subnational divisions listed by the Red List; e.g. if a species occurs in the United States, sRedList will extract the US states overlapping the range map) and biogeographical realms, required and recommended supporting information in assessments, respectively. The species' range map generated in step 1 is intersected with country and biogeographical realm base maps following the classifications used in the IUCN Red List (Cazalis, 2023a, 2023b, 2023c). To generate countries of occurrence, we automatically differentiate those with confirmed occurrence records (presence code "Extant") from those overlapping with the range map but without occurrence records in the input datasets (presence code "Possibly Extant"). Users can manually edit the list of countries of occurrence and their presence, origin, or seasonal attributes.

3.3. Step 3: extent of occurrence

Based on the range map, sRedList estimates the extent of occurrence (EOO), which is used mainly in criterion B1 (but may inform other criteria by looking at trends in EOO). Following the Red List guidelines and previous publications (Joppa et al., 2015; IUCN Standards and Petitions Committee, 2024), EOO is calculated as the area of the Minimum Convex Polygon around the mapped range determined in step 1. Users are reminded that EOO is based not only on confirmed occurrences, but also on occurrences projected or inferred by the assessor. For this reason, it is important that both projected or inferred occurrences are accounted for in step 1 when determining the range (either by adding inferred or projected occurrence records, or by adequately buffering the range map).

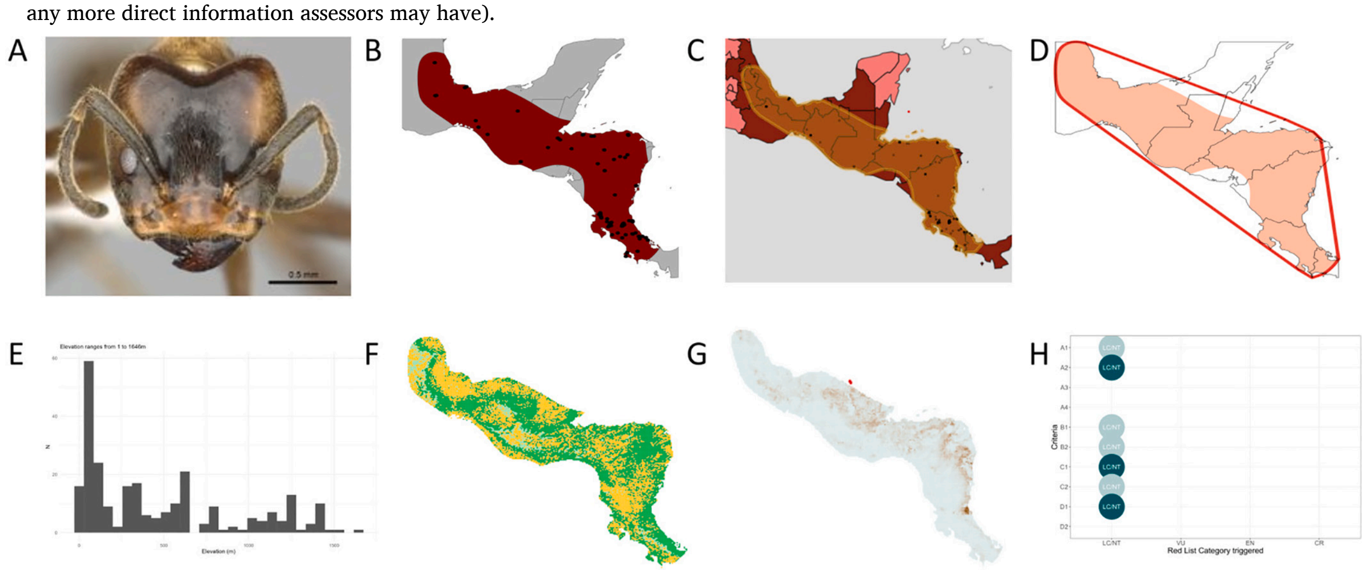
3.4. Step 4: area of occupancy and population size

The area of occupancy (AOO) is required to apply criterion B2 (and informs D2, as well as other criteria by considering trends in AOO). It is calculated as the area of 2 × 2km grid cells that intersect localities occupied by the species (Bachman et al., 2011; IUCN Standards and Petitions Committee, 2024). sRedList estimates the minimum AOO by considering only those 2 × 2 km cells containing occurrence records. This typically underestimates AOO (often substantially) because of

Box 1

Example of a new global assessment of *Azteca xanthochroa* (Formicidae, ants) completed with sRedList, summarising steps performed. All maps and plots are direct screenshots from sRedList. All options are for illustration only, as users should justify any choices for real assessments. More details can be found in Supplementary information S1. Picture by Ryan Perry accessed from www.antweb.org under licence CC-BY-SA-3.0.

1 (range map) - We combined online available occurrence records from GBIF ($N = 262$) and occurrence records we gathered from the literature and personal observations ($N = 8$) of *Azteca xanthochroa* (Fig. A). We filtered out 12 records that were flagged because they dated from before 1900, had localisation uncertainty of >100 km, fell into the sea (as the species is terrestrial), were extreme outliers (e.g., one observation from the Netherlands, but the species is restricted to Central America), or because they were flagged by the CoordinateCleaner R package. An alpha hull of the records was calculated (we defined an alpha parameter of 0.7/10, which the sRedList transformed into an alpha value of 226,847; more detail in Supplementary Information S1), buffered (by 100 km), cropped to keep only the terrestrial area, and finally smoothed (smoothing parameter = 50 %) to obtain a polygon range map used in the subsequent analyses (Fig. B).
2 (countries and realms) - The species was coded up as occurring in the Neotropical realm and in 7 countries (including 2 where it is only "Possibly Extant" since the range map overlapped with countries but no occurrence records were known within the country): Belize, Costa Rica (mainland), El Salvador, Guatemala, Honduras (2 subnational entities), Mexico (8 subnational entities), Nicaragua (mainland), and Panama (Fig. C).
3 (extent of occurrence) - The extent of occurrence was estimated as 929,710 km^2, which the user may later decide to round (Fig. D).
4 (area of occupancy) - Based on the distribution of occurrence records in relation to the habitat map that follows IUCN classification (Jung et al., 2020), we considered habitats 1.6 (Forest - Subtropical/Tropical Moist Lowland) and 1.9 (Forest - Subtropical/Tropical Moist Montane) as suitable, and 14.1 (Artificial/Terrestrial - Arable Land) as possibly suitable. Occurrence records ranged in elevation from 1 to 1646 m (Fig. E), so we set the minimum elevation to 0 and the maximum elevation to 1700–2500 m (the true maximum limit being uncertain). Based on these parameters, we estimated the lower bound of area of occupancy at 344 km^2, which is likely to be a considerable underestimate as it was based on few occurrence records, and the upper bound, based on the area of habitat, at between 5.0 and 5.6×10^5 km^2 (Fig. F)
5 (trends in AOH) - Not relevant for this species since we use trends in tree cover (step 7) for habitat trends.
6 (fragmentation) - Not relevant for the species, which has a quite continuous habitat.
7 (trends in RS products) - As the species is a forest specialist, we used trends in tree cover to estimate trends in suitable habitat. Assuming that 3 generations were <10 years, we mapped trends in tree cover between 2012 and 2022 and found a decline of 9 %, which can be used to inform criterion A2 (Fig. G).
8 (summary) - None of the spatial information compiled or estimated through sRedList suggested the species was threatened or Near Threatened (Fig. H). We thus suggested the species is Least Concern based on the available information (which should be complemented with any more direct information assessors may have).

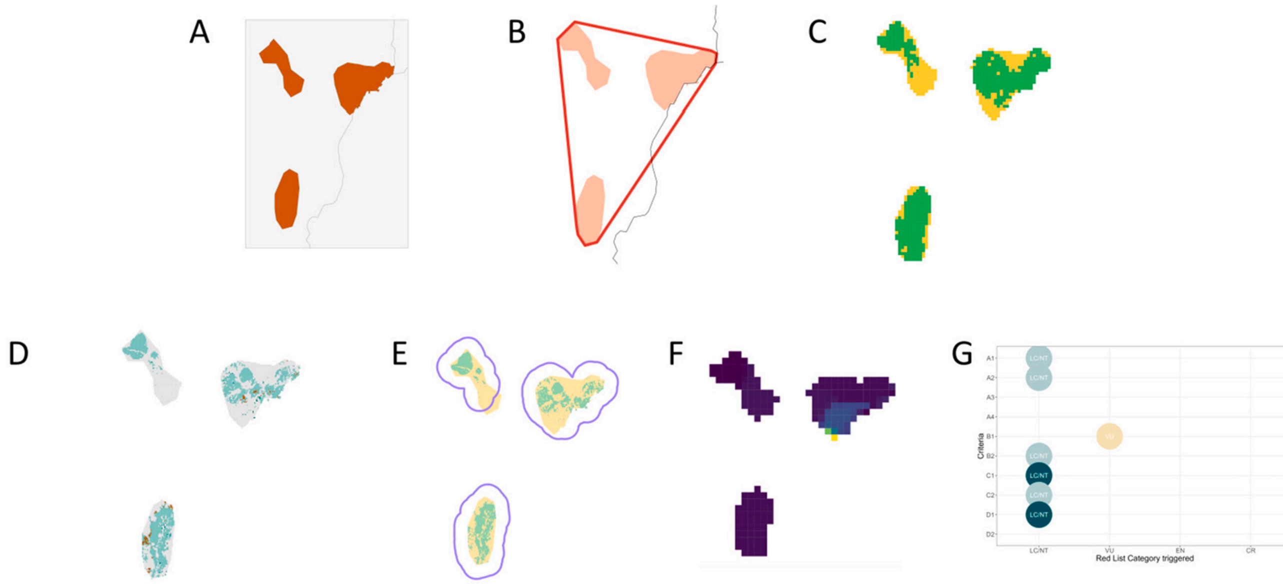


incomplete surveying/sampling and limited data availability (Brooks et al., 2019; IUCN Standards and Petitions Committee, 2024). The upper bound to AOO is estimated as the intersection of 2×2 km grid cells with the area of habitat (AOH). This approach tends to overestimate true occupancy (Brooks et al., 2019).

To map the AOH, sRedList uses data on habitat preferences (following the IUCN Habitat Classification Scheme: https://www.iucnredlist.org/resources/habitat-classification-scheme) and elevation bounds of the species combined with land cover and elevation maps. Habitat and elevation preferences of the species are pre-filled with data from the most recent published assessment if available, or can be inferred from the distribution of occurrence records over the global habitat map from Jung et al. (2020), which follows the IUCN Habitat classification scheme, and the MERIT Digital Elevation Model (Yamazaki et al., 2017). sRedList then calculates AOH as the area with suitable habitat and elevation, using the ESA-CCI land cover product (ESA, 2022), an empirically derived crosswalk between ESA-CCI and IUCN habitat classes (Lumbierres et al., 2022) and the MERIT DEM global elevation

Box 2
Example of a reassessment of *Thamnomys kempi* (Kemp's thicket rat, Muridae) for a national Red List assessment of Democratic Republic of the Congo completed with sRedList, summarising the steps performed. All maps and plots are direct screenshots from sRedList. All options taken here are for illustrative purposes only, as users should justify any choices for real assessments. More details can be found in Supplementary information S2.

1 (range map) - We used the range map published with the last global assessment of the species and cropped it to keep only the part in the Democratic Republic of the Congo (the species also occurs in other countries in the Albertine Rift; Fig. A).
2 (countries) - Not applicable for national Red Listing.
3 (extent of occurrence) - The extent of occurrence measured was 10,354 km^2 (Fig. B).
4 (area of occupancy) - We used habitat and elevation preferences from the most recent published global assessment, and a density of 41–83 mature individuals/km^2 of suitable habitat calculated on sRedList (a total density of 173 individuals/km^2 was suggested by sRedList from Santini et al. (2022), which we multiplied by 60–80 % of mature individuals in the population, and 40–60 of the suitable habitat being occupied). We found an upper bound of area of occupancy of 2296 km^2 (Fig. C) and a potential population size estimated at 43,468–86,935 individuals. As the users started from known distribution rather than occurrence records, the lower bound of AOO was not calculated.
5 (trends in AOH) - Using the generation length from the past assessment, we mapped trends in AOH in the last 10 years (as the generation time is 1.7 years), suggesting a decline of 3 % (Fig. D).
6 (fragmentation) - We entered an isolation distance of 20 km (i.e. subpopulations distant by >20 km are assumed to be isolated) based on our expert knowledge. sRedList identified 3 subpopulations and estimated number of mature individuals for each subpopulation, concluding that at least 50 % of the population lives in subpopulations with <17,054–34,108 mature individuals (the uncertainty is due to uncertainty in density estimate; Fig. E). Hence we could consider the population as "severely fragmented" only if we consider that a subpopulation of 17,054–34,108 individuals is "small" in the sense of the Red List guidelines; we thus considered the population was not severely fragmented.
7 (trends in RS products) - The human population density within the range has increased by 31 % since 2010 (especially in the Eastern part of the range), reaching a median of 268 inds/km^2 (Fig. F). This may indicate that this species faces increased human disturbance.
8 (summary) - We entered some parameters manually (e.g., that there is a continuing decline in habitat extent and quality, and that the number of locations is <10). Based on the information gathered on sRedList, the species appeared to qualify as Vulnerable in the Democratic Republic of the Congo based on criterion B1 (Fig. G). To confirm this category, assessors are then required to investigate whether the existence and status of any conspecific populations outside the assessment country may affect the risk of extinction within the country (IUCN, 2012a).



map (Yamazaki et al., 2017). The ESA-CCI layer was chosen over other global land-cover products for its large temporal scope (1992-onwards) allowing calculation of trends in AOH (step 5). For species with a small range (<500,000 km^2), sRedList uses the 'aoh' R package (Hanson, 2022). For species with a larger range (≥500,000 km^2), it uses an aggregated version at a 10 km resolution of the ESA-CCI and elevation rasters to enable fast calculation (ESA-CCI was aggregated reporting the proportion of each land cover class in raster cells; elevation raster was aggregated reporting the median elevation in raster cells).

Users can assign uncertainty in the habitat and elevation preferences. For example, the suitability of a given habitat can be defined as unknown, while minimum and maximum values can be provided for both lower and upper elevation limits. sRedList then generates minimum (using the strictest habitat and elevation preferences) and maximum (using the broadest habitat and elevation preferences) AOH maps and estimates. Currently, there is no step of validating the AOH maps, for example, using independent data on occurrence, but this is a potential candidate for future development.

AOH can also be used to obtain an estimate of the number of mature individuals (relevant to criteria C and D) if a mean density of mature individuals within suitable habitat is provided by assessors (Santini et al., 2019). By default, for birds and mammals, a statistical prediction of population density per species is provided based on thousands of empirical records compiled from published sources (Santini et al., 2022, 2023). This value is then multiplied first by a user-entered hypothesised proportion of mature individuals in the population, by the proportion of suitable habitat that is occupied by the species, and by the AOH to produce a crude estimate of the number of mature individuals to inform criteria C and D. Otherwise, if available, the user can directly input the density of mature individuals. Since the AOH is unlikely to be fully occupied, this approach tends to overestimate abundance. To address this simplification, sRedList allows users to specify the likely percentage of available habitat that is occupied. Users can also provide upper and lower estimates for population density to estimate the uncertainty around the population size estimate. Finally, users can overwrite the population size estimate with their own if they have more appropriate information available.

3.5. Step 5: trends in area of habitat

Trends in AOH can inform an estimate of the rate of population reduction for application of criterion A2 (and can inform whether continuing declines are ongoing for criterion B). Following the same method for mapping AOH, sRedList also calculates trends in AOH by comparing the current AOH (based on the most recent ESA-CCI layer) with the AOH 10 years or 3 generations before (whichever is longer (IUCN, 2012b)), following Santini et al. (2019). If this brings back before 1992 (the first year with ESA-CCI data), trends are extrapolated from the calculated trends between 1992 and current times. Generation length is taken from the previous Red List assessment if available, otherwise it can be extracted from published data (Pacifici et al., 2013; Mancini et al., 2024) or provided by the user, who can also edit any extracted values.

3.6. Step 6: severe fragmentation of the population

For the population to be considered "severely fragmented" (a condition considered under criteria B1 and B2), the Red List guidelines state that at least 50 % of the total population should be in small isolated patches, and therefore may not be viable (IUCN Standards and Petitions Committee, 2024). To assess fragmentation, users have to define the isolation distance (i.e. a distance above which two subpopulations are considered isolated) and the average population density; both estimates can accommodate uncertainty bounds. Using the AOH map from Step 4, sRedList then identifies clusters of habitat patches that can be assumed to be connected (based on the isolation distance), with each cluster containing an isolated subpopulation. The density of mature individuals within suitable habitat is then used to estimate the size of each subpopulation, which in turn is used to calculate the maximum number of mature individuals per subpopulation (subcriterion C2(a)(i); Santini et al., 2019), and the percentage of mature individuals in one subpopulation (subcriterion C2(a)(ii)). sRedList then displays a plot that guides assessors in determining whether the population is severely fragmented or not (based on what they consider a "small" subpopulation) for application of criterion B.

3.7. Step 7: trends in remotely sensed products

To provide contextual information to assessors, sRedList also calculates trends in various parameters within the mapped range derived from several remotely sensed products: % tree-cover (using Global Forest Change tree-cover maps from 2000 to 2022; (Hansen et al., 2013)), human modification index (using Theobald et al., 2020), and human population density (using Global Human Settlement dataset; (Florczyk et al., 2019)). All these products were aggregated to a ~ 5 km resolution (using the mean) to enable fast analyses, thus this step is more relevant for species with medium to large range sizes (e.g., >100km^2). For each product, sRedList calculates and maps the current mean value within the range, as well as absolute and relative trends over the last 10 years or 3 generations (if the product temporal depth is sufficient), whichever is longer (consistent with the period considered under criterion A2).

Forest loss has been widely used to inform estimates of population decline in forest-dependent species for application of criterion A2 in Red List assessments (Tracewski et al., 2016). Statistics on human modification and human population density do not feed directly into Red List criteria, but may help assessors to justify choices and application of subcriteria (e.g., continuing decline), as well as an understanding of the potential intensity of threats to the species.

3.8. Step 8: summarising results

In the last step, sRedList summarises all estimated parameters and provides short justification for parameter estimates, and the corresponding Red List category and criteria under which the species qualifies seems to qualify. The user has the option to modify any parameter or justification compiled by the platform, or to enter any other parameters required for criteria A, B, C, and D, including number of locations and subpopulations, population trend data (generated from an external source), and to specify whether continuing decline or extreme fluctuations are occurring. sRedList then applies these parameters to the Red List criteria and proposes a Red List category for each criterion, and indicates the highest extinction risk category triggered for the species. Considering the uncertainty in the parameter estimates, a range of Red List categories triggered for each criterion is presented.

Finally, the user can export a ZIP file that includes all outputs from sRedList. First, csv tables including all parameters and justifications used to calculate parameters, potential countries of occurrence, habitat preferences, and references to cite in the assessment (related to the tools and the data accessed via sRedList). These csv tables can be uploaded into a draft assessment in SIS through the 'SIS Connect' tool (https://connect.iucnredlist.org), to which assessors must add additional required and recommended information (e.g., description of and list of threats or conservation actions), complete the narratives and rationale, and finally complete the assessment review process. Second, if users created or edited a range map on sRedList, the outputs include a table of occurrence records used and a shapefile with the polygon range map, both in a format that can be directly published with the assessment, or can be manually edited before publication if needed. Third, the outputs include a report detailing the analyses and decisions taken in sRedList (e.g., every parameter that was selected by users) and all results (e.g., all maps, plots, and tables). This file enables users to document how results were obtained, explore them in more depth, and share them with other assessors and reviewers.

4. Prioritising reassessments with sRedList

While in theory every species on the Red List should be reassessed at least every 10 years (IUCN Standards and Petitions Committee, 2024), in practice 21 % of assessments on the global IUCN Red List are currently considered outdated (IUCN, 2024). In addition, some species should ideally be reassessed more regularly than 10 years because their status can rapidly worsen (IUCN, 2020) or quickly improve (e.g., IUCN, 2013) because of dynamic threatening processes. A possible solution is to help Red List assessors to prioritise species reassessments based on correlative approaches (Di Marco et al., 2014; Henry et al., 2024; Lucas et al., 2024; Zizka et al., 2021). Thus, in addition to its role in supporting the assessment process, sRedList is also designed to help prioritise assessments and reassessments. Assessor groups can use sRedList prioritisation tools to decide which species they will assess or reassess, for instance when preparing an assessment workshop.

In its current version 1.2, sRedList includes a tool to help assessors prioritise the reassessment of Data Deficient species for four groups (odonata, amphibians, reptiles, and mammals; Box 3) based on the methodology presented in Cazalis et al. (2023). This approach identifies which Data Deficient species are the most likely to qualify in a data sufficient category if they were reassessed today (e.g., because the number of GBIF records has increased significantly since the last assessment) and offers additional information to assessors to guide their assessment (e.g., why the species is considered a priority for reassessment, a list of recently published articles on the species, an interactive map of occurrence records and habitat loss).

For each group, users can visualise the priority list of Data Deficient species to reassess in a table and a scatterplot. The plot shows, for each species, the probability of qualifying as data sufficient. Assessors can filter this list (e.g., select species from a given family or those that were last assessed at a given time) and order it based on particular variables (i.e., the value for the priority index developed by Cazalis et al., 2023, or an individual variable used to calculate that index). When selecting a species, they can access and visualise the additional information for the species, which can help them identify priorities and start informing their reassessment. They can then create their own priority list by clicking on the species they want to reassess and download this list as a csv file (Box 3).

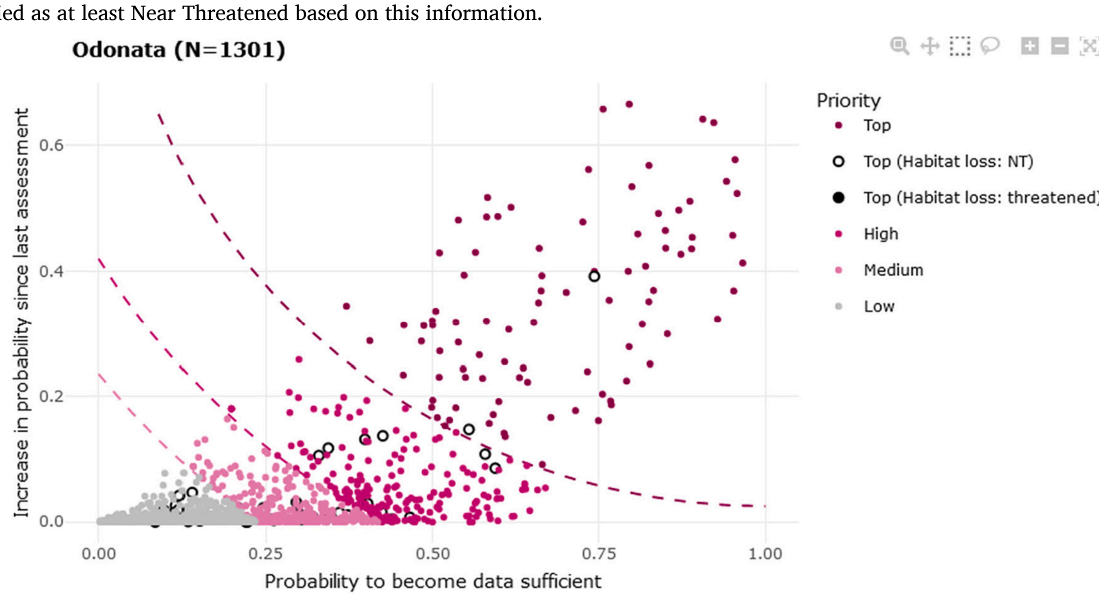
If fundings is sufficient, this approach could be replicated regularly or extended to other groups in order to help reduce the proportion of Data Deficient species. We also plan to add other tools to prioritise the (re)-assessment of species, based on methods presented by recently published studies (e.g., Bachman et al., 2024; Lucas et al., 2024).

5. Discussion

Over the last 20 years, considerable progress has been made in extinction risk research, while over 100,000 new extinction risk assessments have been added to the Red List. Yet, for the most part, these two advances have been disconnected from each other (Cazalis et al., 2022). sRedList is a new tool co-developed by extinction risk scientists and Red List practitioners, aimed to bridge this research-implementation gap. We developed sRedList to help Red List assessors to conduct more rapid, more cost-efficient, more consistent, and better-informed assessments (Table 1). Its ability to support global, regional and national Red List assessments makes it a key tool for enhancing the ability of countries to implement actions needed to meet the goals and targets of the Global

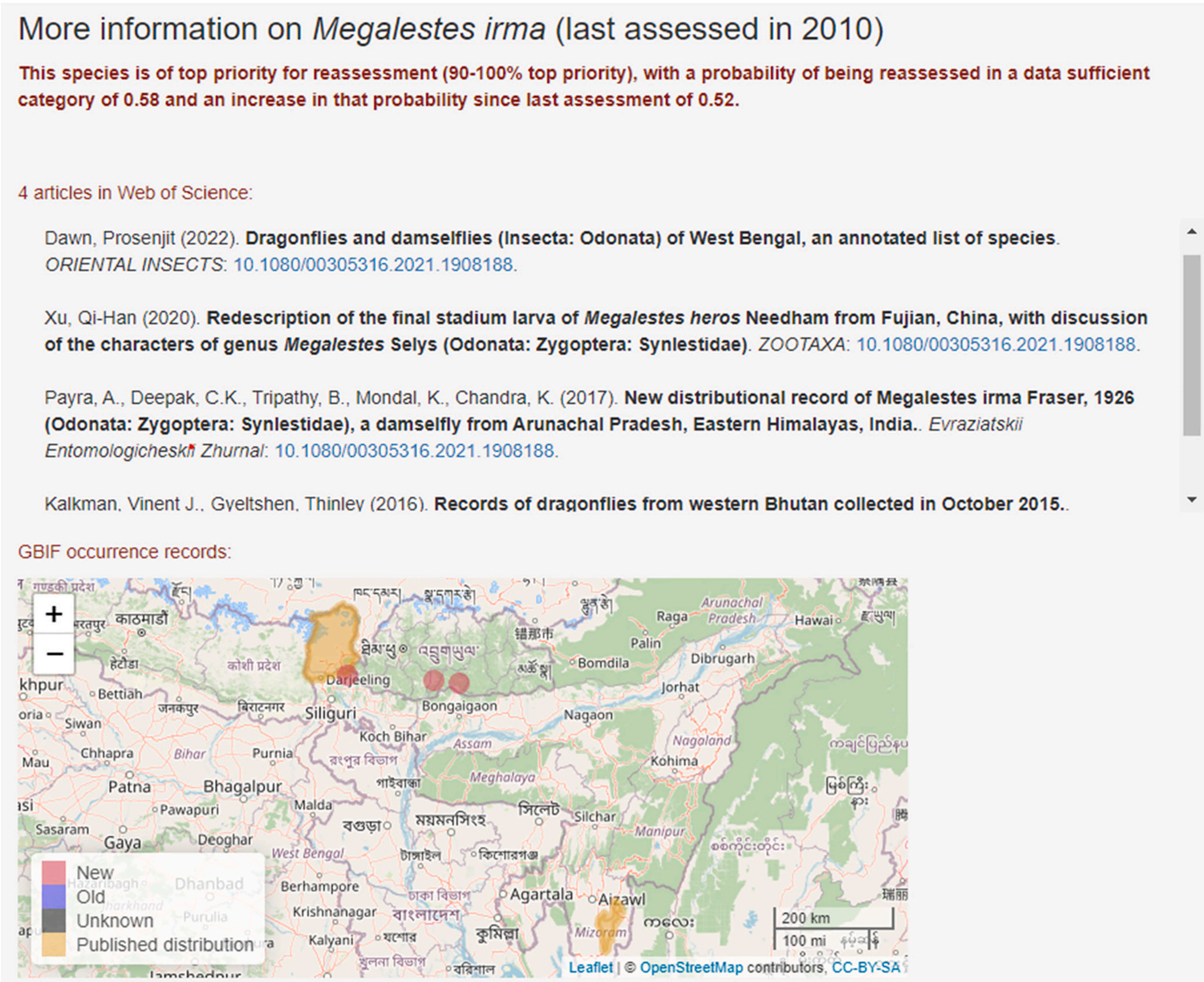
Box 3
Example of using the sRedList Data Deficient reassessment prioritisation tool. The interactivity of such tools can help the uptake of published methods by assessors (demonstrated here with an example on DD species but this can be extended to other groups and categories; see details in the Discussion).

1. **Select taxonomic group**
   Users first choose a taxonomic group (in this example Odonata). For the Data Deficient species in the selected group, an interactive scatterplot shows the modelled probability to become data sufficient if reassessed today (pDS; x-axis) and the increase in this probability since last assessment (dpDS; y-axis; Cazalis et al., 2023). The closer a species is to the right end of the plot, the more likely it is to be currently data sufficient, while the higher it is on the plot, the more data have become available since the last assessment. This plot also highlights species that lost >20 % of habitat in the last 10 years/3 generations (as calculated in Cazalis et al., 2023), which could therefore potentially be reclassified as at least Near Threatened based on this information.



2. **Filter species and identify species priority**
   Users can select species falling within their expertise. Here, we selected species from two odonata families (Synlestidae and Aeshnidae) from the Indomalayan realm that were last reassessed before 2018 ($N = 21$).
   In this example, the tool identifies the six species with the highest reassessment priority (PrioDS>90 %) following the approach described by Cazalis et al. (2023).

(*continued on next page*)



Biodiversity Framework, and to track progress towards achieving these (SCBD, 2022a, 2022b). For example, Red Lists help countries to identify threatened species and the urgent management actions they require (relevant to Target 4), including the actions needed to prevent human-induced extinctions (relevant to Goal A and Target 4). Threatened species are also the focus of some of the criteria for identifying Key Biodiversity Areas (IUCN, 2016), which are used to ensure that protected areas are targeted to 'areas of particular importance for biodiversity' (under Target 3). Finally, Red Lists form the basis of the Red List Index, which has been adopted by the CBD as a 'headline indicator' for assessing progress towards Goal A and Target 4 (SCBD, 2022a, 2022b).

The rigorous alignment of all methods and outputs produced by sRedList with the Red List protocols and procedures and SIS formats, in combination with a user-friendly, interactive, and flexible interface, should facilitate adoption of this tool by Red List assessors. We believe that the thorough documentation (including manuals, cheatsheets, and 15 video tutorials) allows assessors to quickly and autonomously learn how to use sRedList. By providing easy access to data and tools for estimating all key Red List parameters, while compiling all information in a format that can be directly uploaded to SIS, sRedList is expected to substantially reduce the time needed to complete an assessment, while improving consistency and completeness. Currently, >200 assessors have registered to the platform and have started using it for global and national Red List assessments. By tracking sRedList usage and citations in published assessments, as well as circulating a survey to Red List assessors, in a few years from now we will be able to quantify its contribution to assessments' consistency, velocity and completeness. sRedList could also be useful to a wider community, for instance to create species range maps (for purposes other than the Red List) or for students to learn about extinction risk and species distribution.

sRedList can be used for all taxonomic groups, although not all steps will necessarily be useful to all species. For birds, for instance, which have been assessed comprehensively several times and are one of the most data-rich groups in the Red List, extracting countries of occurrence or creating range maps will be less important, but updating estimates of deforestation within the range or mapping fragmentation will expedite and augment reassessments. Similarly, mapping the area of habitat of a widespread, common plant species is unlikely to provide key information for Red List assessment, but the possibility to extract the list of countries of occurrence and elevation limits will help assessors and save time. sRedList currently offers more value to assessors of terrestrial species than those assessing freshwater or marine species, reflecting a higher research attention to Red Listing of the former in recent decades (Cazalis et al., 2022). However, assessors of marine and freshwater species can benefit from the range map creation, extraction of countries of occurrence, calculation of the extent of occurrence, and - in the case of semi-aquatic freshwater species - most of the habitat analyses.

In the future, we intend to integrate new functionalities and modules, furthering sRedList's coverage of assessor needs and its applicability across a wide range of taxonomic groups. Updates could include, for example, incorporation of additional remotely sensed data products (e.g., different land-cover maps for Step 4–5, Normalised Difference Vegetation Index or additional pressure data from Branco et al. (2023) in Step 7), and data uncertainty in remotely sensed and land-cover products. We also expect additional prioritisation tools to be added (e.g., Lucas et al., 2024; Borgelt et al., 2022; Caetano et al., 2022; Bachman et al., 2024), which will help assessors make the best use of their limited assessment time. Such tools should ideally not only assign the most likely Red List category, but also indicate which criteria may be triggered, in order to be useful for assessors (Henry et al., 2024). A high priority for further development is to integrate functionality to run the tool on batches of species (e.g. running all species from a given taxon at once) in order to swiftly identify species that could benefit from a reassessment or to rapidly assess many species.

There is also the potential to integrate new scientific methods to support individual assessments. For example, extinction risk due to projected climate change is difficult for assessors to estimate, but a recent paper presents a simple, widely applicable methodology, which could be integrated to support assessors in applying criteria A3 and A4 based on expected range shifts from climate change (Mancini et al., 2023). Similarly, spatial methods to project expected range changes because of changing land-use patterns (Visconti et al., 2016) and spreading infectious diseases (Akçakaya et al., 2023) could be integrated. Additionally, the use of area of habitat could be further developed, for instance by refining area of habitat by accounting for other mapped threats (e.g., hunting; Benítez-López et al. (2019)). The use of area of habitat could also be extended to marine and freshwater species, as methodologies are currently being developed (Turner et al., 2024; Ridley et al., in prep) and could be integrated once fully elaborated. Third, sRedList in the future may support features to guide assessors in selecting the threats faced by each species (based on the IUCN Red List Threats Classification Scheme), for instance by crossing distribution with global threat map products (Branco et al., 2023; Jung et al., 2022). Finally, tools to estimate past population trends using more than trends in area of habitat would be useful, for instance using trends in occurrence records (Boyd et al., 2023) or non-spatial survey and monitoring records (Akçakaya et al., 2021).

Several tools like GeoCAT or the Freshwater Mapping Application have been built in the past to support Red Listing, however, it is challenging to actively maintain these. A key challenge of sRedList will thus be to ensure that it is kept functioning in the medium and long-term: fixing bugs that may appear (e.g., with R packages updates), updating the input data regularly, updating the output format if changes are made in SIS, or adapting it based on assessors' feedback. Eventually, the sRedList functionalities are planned to be directly accessible within SIS and other national Red List portals, to simplify the assessment process. As sRedList was built with APIs, it could easily and advantageously become accessible from multiple portals while the analyses keep running on a single server. It will also be important to keep the documentation up-to-date (and ideally translated into common languages), so that assessors can always be adequately guided. In overcoming these maintenance challenges, LifeWatch Italy, the Italian node of the European Research Infrastructure LifeWatch ERIC, currently supports the operation and maintenance of the IT facilities and optimisation of the online platform, with no predetermined end date.

6. Conclusion

The multiple methods proposed by the scientific community to support and standardise the Red List over the past two decades have mostly remained academic exercises. This was due to a lack of communication and collaboration between Red List stakeholders and ecological modellers in their development, and a lack of resources to implement these methods in a user-friendly way at scale to promote their uptake. sRedList acts as a bridge between both communities, aiming to provide the most relevant scientific methods and data to all Red List assessors in a user-friendly way. Helping Red List assessors to evaluate species' risk in a fast and standardised way will ensure that the global Red List can expand and keep up-to-date, and also support national and regional Red Lists. This is essential to inform actions to halt biodiversity loss, and to monitor their outcomes.

CRediT authorship contribution statement

Victor Cazalis: Writing – original draft, Formal analysis, Conceptualization. **Moreno Di Marco:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization. **Alexander Zizka:** Writing – review & editing, Methodology. **Stuart H.M. Butchart:** Writing – review & editing, Methodology. **Manuela González-Suárez:** Writing – review & editing, Methodology. **Monika Böhm:** Writing – review & editing, Methodology. **Steven P. Bachman:** Writing – review & editing, Methodology. **Michael Hoffmann:** Writing – review & editing, Methodology. **Ilaria Rosati:** Writing – review & editing, Methodology. **Francesco De Leo:** Writing – review & editing, Methodology. **Martin Jung:** Writing – review & editing, Methodology. **Ana Benítez-López:** Writing – review & editing, Methodology. **Viola Clausnitzer:** Writing – review & editing, Methodology. **Pedro Cardoso:** Writing – review & editing, Methodology. **Thomas M. Brooks:** Writing – review & editing, Methodology. **Giordano Mancini:** Writing – review & editing, Methodology. **Pablo M. Lucas:** Writing – review & editing, Methodology. **Bruce E. Young:** Writing – review & editing, Methodology. **H. Reşit Akçakaya:** Writing – review & editing, Methodology. **Aafke M. Schipper:** Writing – review & editing, Methodology. **Craig Hilton-Taylor:** Writing – review & editing, Methodology. **Michela Pacifici:** Writing – review & editing, Methodology. **Carsten Meyer:** Writing – review & editing, Methodology. **Luca Santini:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Acknowledgements

This paper is a joint effort of the working group sRedList kindly supported by sDiv, the Synthesis Centre of the German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, funded by the German Research Foundation (FZT 118, 202548816), which also funded a position for V.Ca. V.Ca. was also partly funded by the Global Environment Facility grant to IUCN "Knowledge for Nature" (GEF ID10897), and we would like to thank the IUCN GEF Project Agency for their support. M.D.M. and L.S. acknowledge support from the MUR Rita Levi Montalcini program. C.M. acknowledges funding by the Volkswagen Foundation through a Freigeist Fellowship (A118199), and additional support by iDiv, funded by the German Research Foundation (DFG–FZT 118, 202548816). A.B.L. was supported by an EMERGIA grant (EMERGIA20_00252) from the Junta de Andalucía and by a Ramón y Cajal grant (RYC2021-031737-I) funded by MCIN/AEI/10.13039/501100011033 and the EU ("NextGenerationEU"/PRTR). P.C. is supported by Kone Foundation. B.E.Y. acknowledges Chevron, Inc. P.M.L. was supported by Re:wild and Microsoft Corporation (Grant number: 5313.006-AI4E), the Emergia grant (EMERGIA20_00135) funded by the Junta de Andalucía, the grant CNS2022-136018 funded by MICIU/AEI/

10.13039/501100011033 and by European Union NextGenerationEU/PRTR, and by the Sapienza University of Rome (AR22117A859F7D58). G.M. acknowledges support from the Italian Ministry of the University and Research, Programma Operativo Nazionale (CUP B85F21005360001). M.P. acknowledges financial support from Azione IV.6 'Dottorati e contratti di ricerca su tematiche green'. The views expressed in this publication do not necessarily reflect those of IUCN.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2024.110761.

References

Akçakaya, H.R., Hochkirch, A., Bried, J.T., van Grunsven, R.H.A., Simaika, J.P., De Knijf, G., Henriques, S., 2021. Calculating population reductions of invertebrate species for IUCN Red List assessments. J. Insect Conserv. 25 (2), 2 https://doi.org/10.1007/s10841-021-00303-0.

Akçakaya, H.R., Neam, K., Hobin, L., Lötters, S., Martel, A., Pasmans, F., 2023. Assessing the extinction risks of amphibians impacted by infectious diseases. Biol. Conserv. 284, 110205 https://doi.org/10.1016/j.biocon.2023.110205.

Bachman, S., Moat, J., Hill, A., de la Torre, J., Scott, B., 2011. Supporting Red List threat assessments with GeoCAT: geospatial conservation assessment tool. ZooKeys 150, 117–126. https://doi.org/10.3897/zookeys.150.2109.

Bachman, S.P., Brown, M.J.M., Leão, T.C.C., Nic Lughadha, E., Walker, B.E., 2024. Extinction risk predictions for the world's flowering plants to support their conservation. New Phytol. 242 (2), 797–808. https://doi.org/10.1111/nph.19592.

Bengtsson, H., 2021. A Unifying Framework for Parallel and Distributed Processing in R using Futures. The R Journal 13 (2), 208–227. https://doi.org/10.32614/RJ-2021-048.

Benítez-López, A., Santini, L., Schipper, A.M., Busana, M., Huijbregts, M.A.J., 2019. Intact but empty forests? Patterns of hunting-induced mammal defaunation in the tropics. PLoS Biol. 17 (5), 5 https://doi.org/10.1371/journal.pbio.3000247.

Betts, J., Young, R.P., Hilton-Taylor, C., Hoffmann, M., Rodríguez, J.P., Stuart, S.N., Milner-Gulland, E.J., 2020. A framework for evaluating the impact of the IUCN Red List of threatened species. Conserv. Biol. 34 (3), 3 https://doi.org/10.1111/cobi.13454.

Bird, J.P., Martin, R., Akçakaya, H.R., Gilroy, J., Burfield, I.J., Garnett, S.T., Symes, A., Taylor, J., Şekercioğlu, Ç.H., Butchart, S.H.M., 2020. Generation lengths of the world's birds and their implications for extinction risk. Conserv. Biol. 34 (5), 5 https://doi.org/10.1111/cobi.13486.

Borgelt, J., Dorber, M., Høiberg, M.A., Verones, F., 2022. More than half of data deficient species predicted to be threatened by extinction. Communications Biology 5 (1), 1. https://doi.org/10.1038/s42003-022-03638-9.

Boyd, R.J., August, T.A., Cooke, R., Logie, M., Mancini, F., Powney, G.D., Roy, D.B., Turvey, K., Isaac, N.J.B., 2023. An operational workflow for producing periodic estimates of species occupancy at national scales. Biol. Rev. 98 (5), 1492–1508. https://doi.org/10.1111/brv.12961.

Branco, V.V., Correia, L., Cardoso, P., 2023. SPECTR : standardized global spatial data on terrestrial SPECies ThREats (p. 2023.11.26.568516). bioRxiv. https://doi.org/10.1101/2023.11.26.568516.

Brooks, T.M., Pimm, S.L., Akçakaya, H.R., Buchanan, G.M., Butchart, S.H.M., Foden, W., Hilton-Taylor, C., Hoffmann, M., Jenkins, C.N., Joppa, L., Li, B.V., Menon, V., Ocampo-Peñuela, N., Rondinini, C., 2019. Measuring terrestrial area of habitat (AOH) and its utility for the IUCN Red List. Trends Ecol. Evol. 34 (11), 11 https://doi.org/10.1016/j.tree.2019.06.009.

Caetano, G.H. de O., Chapple, D.G., Grenyer, R., Raz, T., Rosenblatt, J., Tingley, R., Böhm, M., Meiri, S., Roll, U., 2022. Automated assessment reveals that the extinction risk of reptiles is widely underestimated across space and phylogeny. PLoS Biol. 20 (5), 5 https://doi.org/10.1371/journal.pbio.3001544.

Cardillo, M., Meijaard, E., 2012. Are comparative studies of extinction risk useful for conservation? Trends Ecol. Evol. 27 (3), 3 https://doi.org/10.1016/j.tree.2011.09.013.

Cardoso, P., Borges, P.A.V., Triantis, K.A., Ferrández, M.A., Martín, J.L., 2011. Adapting the IUCN Red List criteria for invertebrates. Biol. Conserv. 144 (10), 10 https://doi.org/10.1016/j.biocon.2011.06.020.

Cazalis, V., 2023a. Global map of realms fitting Red List SIS classification. GitHub repository, version 2023_1. Available at: https://github.com/victorcazalis/RedList_realms/releases/tag/v2023.1 (jeu de données).

Cazalis, V. (2023b). Global shapefile of countries/subnational entities matching Red List (SIS) list of Countries of Occurrence. GitHub repository, version 2023_1. Available at: https://github.com/victorcazalis/RedList_countries/releases/tag/v2023.1. (jeu de données).

Cazalis, V., 2023c. Shapefile of the marine Exclusive Economic Zones matching Red List countries. GitHub repository, version 2023_2. Available at: https://github.com/victorcazalis/RedList_EEZs/releases/tag/v_2023.2 (jeu de données).

Cazalis, V., Di Marco, M., Butchart, S.H.M., Akçakaya, H.R., González-Suárez, M., Meyer, C., Clausnitzer, V., Böhm, M., Zizka, A., Cardoso, P., Schipper, A.M., Bachman, S.P., Young, B.E., Hoffmann, M., Benítez-López, A., Lucas, P.M., Pettorelli, N., Patoine, G., Pacifici, M., Santini, L., 2022. Bridging the research-implementation gap in IUCN Red List assessments. Trends Ecol. Evol. https://doi.org/10.1016/j.tree.2021.12.002.

Cazalis, V., Santini, L., Lucas, P.M., González-Suárez, M., Hoffmann, M., Benítez-López, A., Pacifici, M., Schipper, A.M., Böhm, M., Zizka, A., Clausnitzer, V., Meyer, C., Jung, M., Butchart, S.H.M., Cardoso, P., Mancini, G., Akçakaya, H.R., Young, B.E., Patoine, G., Di Marco, M., 2023. Prioritizing the reassessment of data-deficient species on the IUCN Red List. Conservation Biology, e14139. https://doi.org/10.1111/cobi.14139.

Di Marco, M., Buchanan, G.M., Szantoi, Z., Holmgren, M., Grottolo Marasini, G., Gross, D., Tranquilli, S., Boitani, L., Rondinini, C., 2014. Drivers of extinction risk in African mammals: the interplay of distribution state, human pressure, conservation response and species biology. Philosophical Transactions of the Royal Society B: Biological Sciences 369 (1643), 1643. https://doi.org/10.1098/rstb.2013.0198.

ESA, 2022. Climate Change Initiative—land cover project map v2.1.1. Data from year 1992 to 2020. http://maps.elie.ucl.ac.be/CCI/viewer/index.php. (Accessed August 2022).

Ficetola, G.F., Rondinini, C., Bonardi, A., Katariya, V., Padoa-Schioppa, E., Angulo, A., 2014. An evaluation of the robustness of global amphibian range maps. J. Biogeogr. 41 (2), 2 https://doi.org/10.1111/jbi.12206.

Florczyk, A.J., Corbane, C., Ehrlich, D., Freire, S., Kemper, T., Maffenini, L., Melchiorri, M., Pesaresi, M., Politis, P., Schiavina, M., Sabo, F., Zanchetta, L., 2019. GHSL data package 2019 : Public release GHS P2019, Publications Office. https://data.europa.eu/doi/10.2760/290498. (Accessed 31 January 2022).

Hansen, M.C., Potapov, P.V., Moore, R., Hancher, M., Turubanova, S.A., Tyukavina, A., Thau, D., Stehman, S.V., Goetz, S.J., Loveland, T.R., Kommareddy, A., Egorov, A., Chini, L., Justice, C.O., Townshend, J.R.G., 2013. High-resolution global maps of 21st-century forest cover change. Science 342 (6160), 6160. https://doi.org/10.1126/science.1244693.

Hanson, J.O., 2022. Aoh: create area of habitat data. R package version 1.0.0. Available at. https://github.com/prioritizr/aoh.

Henry, E.G., Santini, L., Butchart, S.H.M., González-Suárez, M., Lucas, P.M., Benítez-López, A., Mancini, G., Jung, M., Cardoso, P., Zizka, A., Meyer, C., Akçakaya, H.R., Berryman, A.J., Cazalis, V., Di Marco, M., 2024. Modelling the probability of meeting IUCN Red List criteria to support reassessments. Glob. Chang. Biol. 30 (1), e17119 https://doi.org/10.1111/gcb.17119.

Hochkirch, A., Bilz, M., Ferreira, C.C., Danielczak, A., Allen, D., Nieto, A., Rondinini, C., Harding, K., Hilton-Taylor, C., Pollock, C.M., Seddon, M., Vié, J.-C., Alexander, K.N. A., Beech, E., Biscoito, M., Braud, Y., Burfield, I.J., Buzzetti, F.M., Cálix, M., Zuna-Kratky, T., 2023. A multi-taxon analysis of European Red Lists reveals major threats to biodiversity. PLoS One 18 (11), e0293083. https://doi.org/10.1371/journal.pone.0293083.

Huang, R.M., Medina, W., Brooks, T.M., Butchart, S.H.M., Fitzpatrick, J.W., Hermes, C., Jenkins, C.N., Johnston, A., Lebbin, D.J., Li, B.V., Ocampo-Peñuela, N., Parr, M., Wheatley, H., Wiedenfeld, D.A., Wood, C., Pimm, S.L., 2021. Batch-produced, GIS-informed range maps for birds based on provenanced, crowd-sourced data inform conservation assessments. PLoS One 16 (11), e0259299. https://doi.org/10.1371/journal.pone.0259299.

Hughes, A.C., Orr, M.C., Yang, Q., Qiao, H., 2021. Effectively and accurately mapping global biodiversity patterns for different regions and taxa. Glob. Ecol. Biogeogr. 30 (7), 7 https://doi.org/10.1111/geb.13304.

IUCN, 2012a. Guidelines for Application of IUCN Red List Criteria at Regional and National Levels: Version 4.0. IUCN (p. iii + 41pp).

IUCN, 2012b. IUCN Red List Categories and Criteria: Version 3.1, second edition. IUCN (p. iv + 32pp).

IUCN, 2013. Urocyon littoralis: Coonan, T., Ralls, K., Hudgens, B., Cypher, B. & Boser, C.: The IUCN Red List of Threatened Species 2013: e.T22781A13985603 [jeu de données]. https://doi.org/10.2305/IUCN.UK.2013-2.RLTS.T22781A13985603.en.

IUCN, 2016. A Global Standard for the Identification of Key Biodiversity Areas, Version 1.0. IUCN, Gland, Switzerland.

IUCN, 2020. Rhinoplax vigil: BirdLife International: The IUCN Red List of Threatened Species 2020: e.T22682464A184587039 [jeu de données]. https://doi.org/10.2305/IUCN.UK.2020-3.RLTS.T22682464A184587039.en.

IUCN, 2021a. HydroBASINS (level 8). Version May-2021. Downloaded on the 7th of April 2022 at. https://www.iucnredlist.org/resources/spatialtoolsanddata.

IUCN, 2021b. The IUCN Red List 2021-2030 Strategic Plan. Preventing Extinction and Advancing the Recovery of Species Using the IUCN Red List of Threatened Species, p. 29 (Gland, Switzerland).

IUCN. (2024). The IUCN Red List of Threatened Species. Version 2024-1. https://www.iucnredlist.org. accessed July 5, 2024. IUCN.

IUCN SSC Red List Technical Working Group, 2021. Mapping Standards and Data Quality for the IUCN Red List Spatial Data. Version 1.19 (May 2021). IUCN, p. 28.

IUCN Standards and Petitions Committee, 2024. Guidelines for using the IUCN Red List categories and criteria. Version 16. Prepared by the Standards and Petitions Committee. Downloadable from. http://www.iucnredlist.org/documents/RedListGuidelines.pdf.

Jain, N., Mangal, P., Mehta, D., 2014. AngularJS: A modern MVC framework in JavaScript. J. Global Res. Comput. Sci. 5 (12), 17–23.

Joppa, L.N., Butchart, S.H.M., Hoffmann, M., Bachman, S.P., Akçakaya, H.R., Moat, J.F., Böhm, M., Holland, R.A., Newton, A., Polidoro, B., Hughes, A., 2015. Impact of alternative metrics on estimates of extent of occurrence for extinction risk assessment: extent of occurrence and extinction risk. Conserv. Biol. 30 (2), 2 https://doi.org/10.1111/cobi.12591.

Juffe-Bignoli, D., Brooks, T.M., Butchart, S.H.M., Jenkins, R.B., Boe, K., Hoffmann, M., Angulo, A., Bachman, S., Böhm, M., Brummitt, N., Carpenter, K.E., Comer, P.J., Cox, N., Cuttelod, A., Darwall, W.R.T., Marco, M.D., Fishpool, L.D.C., Goettsch, B., Heath, M., Kingston, N., 2016. Assessing the cost of global biodiversity and

conservation knowledge. PLoS One 11 (8), 8. https://doi.org/10.1371/journal.pone.0160640.
Jung, M., Dahal, P.R., Butchart, S.H.M., Donald, P.F., De Lamo, X., Lesiv, M., Kapos, V., Rondinini, C., Visconti, P., 2020. A global map of terrestrial habitat types. Scientific Data 7 (1), 1. https://doi.org/10.1038/s41597-020-00599-8.
Jung, M., Lewis, M., Lesiv, M., Arnell, A., Fritz, S., Visconti, P., 2022. The global exposure of species ranges and protected areas to forest management. Divers. Distrib. 28 (7), 1487–1496. https://doi.org/10.1111/ddi.13582.
Lehner, B., Grill, G., 2013. Global river hydrography and network routing: baseline data and new approaches to study the world's large river systems. Hydrol. Process. 27 (15), 2171–2186. https://doi.org/10.1002/hyp.9740.
Lucas, P.M., Di Marco, M., Cazalis, V., Luedtke, J., Brown, M., Langhammer, P., Neam, K., Mancini, G., Santini, L., 2024. Using comparative extinction risk analysis to prioritize the IUCN Red List reassessments of amphibians. Conserv. Biol. 14316. https://doi.org/10.1111/cobi.14316.
Lumbierres, M., Dahal, P.R., Di Marco, M., Butchart, S.H.M., Donald, P.F., Rondinini, C., 2022. Translating habitat class to land cover to map area of habitat of terrestrial vertebrates. Conserv. Biol. 36 (3), 3 https://doi.org/10.1111/cobi.13851.
Mancini, G., Santini, L., Cazalis, V., Reşit Akçakaya, H., Lucas, P.M., Brooks, T.M., Foden, W., Marco, M.D., 2023. A standard approach for including climate change responses in IUCN Red List assessments. Conserv. Biol., cobi.14227 https://doi.org/10.1111/cobi.14227.
Mancini, G., Santini, L., Cazalis, V., Ficetola, F., Meiri, S., Roll, U., Silvestri, S., Pincheira-Donoso, D., Di Marco, M., 2024. Generation Length of the World's Amphibians and Reptiles. https://doi.org/10.1101/2024.05.23.595540.
Nic Lughadha, E., Bachman, S.P., Leão, T.C.C., Forest, F., Halley, J.M., Moat, J., Acedo, C., Bacon, K.L., Brewer, R.F.A., Gâteblé, G., Gonçalves, S.C., Govaerts, R., Hollingsworth, P.M., Krisai-Greilhuber, I., Lirio, E.J., Moore, P.G.P., Negrão, R., Onana, J.M., Rajaovelona, L.R., Walker, B.E., 2020. Extinction risk and threats to plants and fungi. Plants, People, Planet 2 (5), 5. https://doi.org/10.1002/ppp3.10146.
Pacifici, M., Santini, L., Marco, M.D., Baisero, D., Francucci, L., Marasini, G.G., Visconti, P., Rondinini, C., 2013. Generation length for mammals. Nature Conservation 5, 89–94. https://doi.org/10.3897/natureconservation.5.5734.
Pekár, S., Wolff, J.O., Černecká, Ľ., Birkhofer, K., Mammola, S., Lowe, E.C., Fukushima, C.S., Herberstein, M.E., Kučera, A., Buzatto, B.A., Djoudi, E.A., Domenech, M., Enciso, A.V., Piñanez Espejo, Y.M.G., Febles, S., García, L.F., Gonçalves-Souza, T., Isaia, M., Lafage, D., Cardoso, P., 2021. The World Spider Trait database: a centralized global open repository for curated data on spider traits. Database 2021, baab064. https://doi.org/10.1093/database/baab064.
Pelletier, T.A., Carstens, B.C., Tank, D.C., Sullivan, J., Espíndola, A., 2018. Predicting plant conservation priorities on a global scale. Proc. Natl. Acad. Sci. 115 (51), 51 https://doi.org/10.1073/pnas.1804098115.
R Core Team, 2024. R: A Language and Environment for Statistical Computing, R Foundation for Statistical Computing. https://www.R-project.org/.
Ridley, F., et al.. Mapping Area of Habitat (AOH) for Freshwater Species (in prep).
Rodrigues, A., Pilgrim, J., Lamoreux, J., Hoffmann, M., Brooks, T., 2006. The value of the IUCN Red List for conservation. Trends Ecol. Evol. 21 (2), 2 https://doi.org/10.1016/j.tree.2005.10.010.
Rondinini, C., Di Marco, M., Visconti, P., Butchart, S.H.M., Boitani, L., 2014. Update or outdate: long-term viability of the IUCN Red List. Conserv. Lett. 7 (2), 2 https://doi.org/10.1111/conl.12040.
Santini, L., Butchart, S.H.M., Rondinini, C., Benítez-López, A., Hilbers, J.P., Schipper, A.M., Cengic, M., Tobias, J.A., Huijbregts, M.A.J., 2019. Applying habitat and population-density models to land-cover time series to inform IUCN Red List assessments. Conserv. Biol. 33 (5), 5 https://doi.org/10.1111/cobi.13279.
Santini, L., Benítez-López, A., Dormann, C.F., Huijbregts, M.A.J., Martins, I., 2022. Population density estimates for terrestrial mammal species. Glob. Ecol. Biogeogr. 31 (5), 978–994. https://doi.org/10.1111/geb.13476.
Santini, L., Tobias, J.A., Callaghan, C., Gallego-Zamorano, J., Benítez-López, A., 2023. Global patterns and predictors of avian population density. Glob. Ecol. Biogeogr. 32 (7), 1189–1204. https://doi.org/10.1111/geb.13688.
SCBD. (2010). Aichi biodiversity targets. In: COP 10 Decision X/2: Strategic Plan for Biodiversity 2011–2020. Secretariat of the Convention on Biological Diversity.
SCBD, 2022a. Kunming-Montreal Global Biodiversity Framework. CBD/COP/15/L.25. Secretariat of the Convention on Biological Diversity.
SCBD, 2022b. Monitoring Framework for the Kunming-Montreal Global Biodiversity Framework. CBD/COP/15/L.26. Secretariat of the Convention on Biological Diversity.
Schloerke B., Allen J., 2024. _plumber: An API Generator for R_. R package version 1.2.2, <https://CRAN.R-project.org/package=plumber>.
Soria, C.D., Pacifici, M., Di Marco, M., Stephen, S.M., Rondinini, C., 2021. COMBINE: a coalesced mammal database of intrinsic and extrinsic traits. Ecology 102 (6), 6. https://doi.org/10.1002/ecy.3344.
Stuart, S.N., Wilson, E.O., McNeely, J.A., Mittermeier, R.A., Rodriguez, J.P., 2010. The barometer of life. Science 328 (5975), 5975. https://doi.org/10.1126/science.1188606.
Theobald, D.M., Kennedy, C., Chen, B., Oakleaf, J., Baruch-Mordo, S., Kiesecker, J., 2020. Earth transformed: detailed mapping of global human modification from 1990 to 2017. Earth System Science Data 12 (3), 1953–1972. https://doi.org/10.5194/essd-12-1953-2020.
Tobias, J.A., Sheard, C., Pigot, A.L., Devenish, A.J.M., Yang, J., Sayol, F., Neate-Clegg, M.H.C., Alioravainen, N., Weeks, T.L., Barber, R.A., Walkden, P.A., MacGregor, H.E.A., Jones, S.E.I., Vincent, C., Phillips, A.G., Marples, N.M., Montaño-Centellas, F.A., Leandro-Silva, V., Claramunt, S., Schleuning, M., 2022. AVONET: morphological, ecological and geographical data for all birds. Ecol. Lett. 25 (3), 581–597. https://doi.org/10.1111/ele.13898.
Tracewski, Ł., Butchart, S.H.M., Di Marco, M., Ficetola, G.F., Rondinini, C., Symes, A., Wheatley, H., Beresford, A.E., Buchanan, G.M., 2016. Toward quantification of the impact of 21st-century deforestation on the extinction risk of terrestrial vertebrates: effects of deforestation on vertebrates. Conserv. Biol. 30 (5), 5 https://doi.org/10.1111/cobi.12715.
Turner, J.A., Starkey, M., Dulvy, N.K., Hawkins, F., Mair, L., Serckx, A., Brooks, T., Polidoro, B., Butchart, S.H.M., Carpenter, K., Epps, M., Jabado, R.W., Macfarlane, N.B.W., Bennun, L., 2024. Targeting ocean conservation outcomes through threat reduction. Npj Ocean Sustainability 3 (1), 1–10. https://doi.org/10.1038/s44183-023-00040-8.
Visconti, P., Bakkenes, M., Baisero, D., Brooks, T., Butchart, S.H.M., Joppa, L., Alkemade, R., Di Marco, M., Santini, L., Hoffmann, M., Maiorano, L., Pressey, R.L., Arponen, A., Boitani, L., Reside, A.E., van Vuuren, D.P., Rondinini, C., 2016. Projecting global biodiversity indicators under future development scenarios: projecting biodiversity indicators. Conserv. Lett. 9 (1), 1 https://doi.org/10.1111/conl.12159.
Yamazaki, D., Ikeshima, D., Tawatari, R., Yamaguchi, T., O'Loughlin, F., Neal, J.C., Sampson, C.C., Kanae, S., Bates, P.D., 2017. A high-accuracy map of global terrain elevations. Geophys. Res. Lett. 44 (11), 5844–5853. https://doi.org/10.1002/2017GL072874.
Zamin, T.J., Baillie, J.E.M., Miller, R.M., Rodríguez, J.P., Ardid, A., Collen, B., 2010. National red listing beyond the 2010 target. Conserv. Biol. 24 (4), 4 https://doi.org/10.1111/j.1523-1739.2010.01492.x.
Zizka, A., Silvestro, D., Andermann, T., Azevedo, J., Duarte Ritter, C., Edler, D., Farooq, H., Herdean, A., Ariza, M., Scharn, R., Svantesson, S., Wengström, N., Zizka, V., Antonelli, A., 2019. CoordinateCleaner: standardized cleaning of occurrence records from biological collection databases. Methods Ecol. Evol. 10 (5), 5 https://doi.org/10.1111/2041-210X.13152.
Zizka, A., Silvestro, D., Vitt, P., Knight, T.M., 2021. Automated conservation assessment of the orchid family with deep learning. Conserv. Biol. 35 (3), 3.
Zizka, A., Andermann, T., Silvestro, D., 2022. IUCNN – deep learning approaches to approximate species' extinction risk. Divers. Distrib. 28 (2), 2 https://doi.org/10.1111/ddi.13450.