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ReS-ACUE: standardized data linking recovery objectives and ambition to habitat protection for species at risk in Australia, Canada, the United States, and the European Union

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1 Introduction

The biodiversity crisis, characterized by the rapid decline of global biodiversity, is one of the most urgent environmental issues of our time. Currently, 28% of all assessed animal, fungal, and plant species on the International Union for Conservation of Nature (IUCN) Red List are threatened with extinction (IUCN, 2025a). Up to one million species could succumb to extinction within decades (IPBES, 2019). One of the primary drivers of biodiversity loss is habitat loss and degradation (Johnson et al., 2017) from human activity, such as land- and sea- use change (IPBES, 2019). It is estimated that 9% (>500,000) of species do not have adequate habitat for long-term survival (IPBES, 2019). Effective measures for protecting, conserving and restoring habitats of threatened species are essential for safeguarding biodiversity (Corlett, 2020; Dinerestein et al., 2024).

The use of habitat protection as a mechanism for reversing biodiversity loss has a well-established history within international conservation initiatives. Signatories of the 1992 Convention on Biological Diversity were encouraged to develop or maintain legislative and regulatory provisions to protect threatened species and populations (Article 8K; CBD, 2011). The promotion of habitat protection to prevent global species extinction and biodiversity was emphasized subsequently in goals 14 and 15 of the United Nations Sustainable Development Goals (2015) and the Kunming Montreal Global Biodiversity Framework (CBD, 2022). Despite similarities in their frameworks to prevent species

extinctions, differences in legislation, terminology and species-specific recovery documentation make it difficult to access and synthesize information on species at risk across countries. This knowledge gap ultimately hampers global assessments and evaluations of the efficacy of habitat protection at halting or reversing biodiversity loss (IPBES, 2019).

We designed the ReS-ACUE database to facilitate global assessments and evaluations of species at risk recovery. It aims to minimize the duplication of effort in retrieving the same information from species recovery documents and is designed for research. We apply standard methods for extracting information on Recovery of Species (ReS) at risk in an accessible and open-data format using a subsample of data from four jurisdictions: Australia, Canada, the United States, and the European Union (ACUE). These jurisdictions were selected because of similarities in their economic standing and availability of documentation in English. ReS-ACUE allows for qualitative and quantitative evaluations of recovery planning and of habitat protection in preventing species extinction by addressing the following questions: Do species' recovery goals target a measurable recovery outcome that is tied to the identified species' threats? Are recovery goals defined by measurable outcomes of success like the IUCN Red list vulnerability criteria used for species' assessment? And is there evidence that habitat protection contributes to achieving the goal outlined for species recovery? While focused on the planning phase (defining recovery goals) of recovery frameworks, ReS-ACUE has clear links to species' assessment and recovery implementation (defining and putting into practice needed actions) that allow for establishment of criteria to assess and evaluate the efficacy of the whole recovery cycle (Scheele et al., 2018).

2 Materials and methods

We compiled lists of species at risk of extinction from Australia, Canada, the United States, and the European Union using official lists of species that have been afforded protection under their respective legislative and policy frameworks (Table 1). We refer to each geographical area as a 'jurisdiction'. Biological units on the list included species, subspecies and populations (e.g. geographically isolated or evolutionarily significant units as defined by jurisdictions; Table 1); we hereafter refer to each listed taxon as a species. Only species assessed as Critically Endangered, Endangered, and Vulnerable in Australia and the European Union, or Endangered and Threatened in Canada and the United States are included (Table 1).

We compiled data for a subsample of species from each jurisdiction using the RAND function in Excel. To ensure adequate taxonomic representation per jurisdiction (Camaclang et al., 2014), we subsampled 200 species per jurisdiction which corresponds to a minimum of 10% of the full species list (range: 10.5% to 48%; see Table 1) and compared taxonomic representation within the subsample to the broader dataset visually with bar graphs. Available online recovery documentation for each species in the sample was compiled from organizations responsible for

defining and delivering on recovery efforts (Table 1). We included published and endorsed materials (e.g. regional plans endorsed by federal agencies) posted on or before March 31, 2024. Data was extracted from multiple sources. We prioritized information on recovery objectives, geographic distribution, threats and protected habitat using a hierarchy of recovery documentation from: 1) species plans/strategies > 2) implementation and action planning documents > 3) species assessments of conservation status. By jurisdiction, this includes: a) Australia: Recovery Plan > Conservation Advice > Management Plan; b) Canada: Recovery Strategy > Action Plan > Management Plan > Assessment and Status Report; c) United States: Recovery Plan or Federal Register > Species Status Reports/Assessments; and, d) European Union: Article 12/17 Reports > Species Action Plans.

We developed and refined the initial methods for data extraction from recovery documents by assigning two individuals to populate the database for a subset of 20 Canadian species representing diverse taxa. These two individuals worked independently and compared compiled outputs. Discrepancies including misinterpretation and areas of potential subjectivity/bias were discussed until a consensus was reached. The methodology was updated, and definitions were refined for clarity to ensure consistent application for the development of the database.

A standardized data table was developed with both text and categorical formats that could be populated in a consistent and repeatable manner across jurisdictions. Some data fields were copied from recovery documentation directly (columns C-N, X and Z). In other cases, we used content analysis (Krippendorff, 2019) to interpret and classify text from recovery documents using transparent and repeatable decision rules that accommodate for differences in legislation, documentation, reporting structures, and data availability across jurisdictions. These decision rules are described in more detail in section 2.2 through 2.4. Instructions specific to extraction from documentation from each jurisdiction are included in Supplementary Information 1. The database contains 37 data fields, including but not limited to: date of listing, taxonomic group, common and scientific names, conservation status, habitat and threats descriptions, recovery goals and habitat identified for protection (see Supplementary Information 1, a data dictionary with a complete list of categories and associated metadata describing the project workflow used to ensure entries are consistent and repeatable).

2.1 General species information

General species information (columns B-N) includes common and scientific names, subpopulation (if applicable), taxonomic group, conservation status and listing date. We also record the documents used to gather the species-specific data, including primary citations, links, and publication year for each document (see Supplementary Information 2 for full citation list). All these data are directly copied from recovery documents or species profiles in each of the four jurisdictional species at risk databases. Species are assigned to taxonomic groups in column F according to: Amphibians, Birds,

TABLE 1 Data sources and attributes used to develop species lists and legislative/policy definitions for key concepts in the content analysis.

Jurisdiction, Legislation, responsible department	Biological units for listing	Status	Recovery documents	Total species	Source reference and access date for species lists for random sample	Key concepts/definitions targeted for data extraction related to species recovery and habitat protection
Australia Environmental Protection and Biodiversity Conservation Act (EPBCA), 1999 (Australian Government, 1999); Dept of Climate Change, Energy, Environment and Water	Species, sub-species and distinct populations of species (EPBCA s528)	CE, END, VUL	Recovery Plan, Conservation Advice, Management Plan	1904	Species Profile and Threat Database https://www.environment.gov.au/cgi-bin/sprat/public/sprat.pl (accessed July 7, 2023)	Recovery: <i>specific objectives to be achieved over a 5-year period</i> (duration of a recovery plan) related to population or distribution, habitat protection or restoration, and threat abatement (EPBCA s270). Habitat protection: <i>habitats critical to the survival</i> of the species defined based on specific habitat, landform, and/or hydrological requirements and described with spatial information (EPBC Reg.7.11; Australian Government, 2000).
Canada Species at Risk Act (SARA), Government of Canada (2002); Dept of Fisheries and Oceans, Environment and Climate Change Canada	Species and designatable units (discrete and evolutionarily significant) (COSEWIC, 2020)	END, THR	Recovery Strategy, Action Plan, Management Plan	444	Schedule 1 wildlife species at risk https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry.html (accessed May 26, 2023)	Recovery: <i>population and distribution objectives</i> define the best achievable condition of a species (ECCC, 2020). Habitat protection: <i>critical habitat</i> is the habitat necessary for the survival or recovery of a listed wildlife species (SARA s2).
European Union (EU) Birds Directive (1979) and Habitats Directive (1992) (European Union, 2009, 1992); European Commission	Species, sub-species (distinct populations, geographically or evolutionarily) (DG Environment, 2023a)	CE, END, VUL	Species Action Plan; EUNIS Article 12 and 17 reports	413	Habitats Directive Annex II List https://eunis.eea.europa.eu/references/2325/species Birds Directive Annex I List https://eunis.eea.europa.eu/references/2441/species EU regional status classification https://eunis.eea.europa.eu/index.jsp (accessed November 8, 2023).	Recovery: <i>favorable conservation status</i> : Habitats Directive: favorable reference population and favorable reference range (DG Environment, 2023a); Birds Directive: increasing or stable populations over the long and short term (DG Environment, 2023b). Habitat protection: <i>Natura 2000 sites</i> including: Special Areas of Conservation under the Habitats Directive (HD Art3,4); and Special Protection Areas under the Birds Directive (BD Art4).
United States Endangered Species Act 1973 (ESA) (U.S. Department of the Interior, 1973); US Fish and Wildlife Service, National Marine Fisheries Service	Species, sub-species (fish/wildlife/plant), distinct vertebrate populations that interbreed when mature (ESA s3)	END, THR	Recovery Plan, Federal Register, Species Status Assessment, Five-year status review	1694	USFWS Environmental Conservation Online System (https://ecos.fws.gov/ecp/); NMFS species directory (https://www.fisheries.noaa.gov/species-directory/threatened-endangered) (accessed July 28 2023).	Recovery: <i>objective measurable criteria</i> , which when met, result in a determination that the species be removed from the list (ESA s4f). Habitat protection: <i>critical habitat</i> includes specific areas within and outside the geographic area occupied by the species where physical and biological features essential to conservation of the species are found (ESA s3).

Fish, Mammals, Reptiles (vertebrates); Annelids, Arthropods, Cnidaria, Echinoderms, Molluscs, Porifera (invertebrates); Bryophytes, Fungi, Lichens, Thallophytes and Vascular Plants. Mammals are further subdivided into terrestrial or marine, and Fish into freshwater, marine or anadromous. These taxonomic groupings are representative of those used by the jurisdictions for their species lists. We record the geographic distribution of the species in column G as: endemic, an isolated population, at the edge of its range, a migratory species, or other (e.g., a non-migratory species whose distribution spans more than one country, see definitions in [Supplementary Information 1](#)). Column H reflects the official conservation status classifications assigned by the jurisdictions ([Table 1](#)). Column N includes a description of the species' habitat copied from recovery documentation.

Conservation Measures Partnership threat classification system (level 2, v2.0; [Salafsky et al., 2008](#); [Conservation Measures Partnership, 2016](#)). Columns S, T, and U are used to identify if the habitat-based threats are: anthropogenic threats, natural threats, and threats from invasive species, defined as habitat loss and degradation caused by actions of non-native species such as mechanical disturbance ([Figure 1](#)). The three columns are ranked from 1 to 3 to identify the relative importance of the threat types to the species' habitat. (X) indicates that the particular habitat-based threat is not among the top threats for the species. We also document when climate change exacerbates the listed habitat-based top threats in column V using a categorical (Y/N) classification. (NA) identifies species for whom the top threats are non-habitat based.

2.2 Threats to species' habitat

Threats to species are recorded in columns O-V. Column O contains species' threats copied from recovery documentation (or listing information when recovery documentation was unavailable). Columns Q through U identify whether the top threats are habitat-based i.e. risk of extinction is the result of habitat loss, fragmentation, and degradation ([Figure 1](#)). Column Q is a categorical (Y/N) answer if habitat-based threats are among the top threats to the species. If top threats are habitat-based, we identify the proximate human activities or processes causing habitat loss, fragmentation or degradation in column R using the

2.3 Identification of habitat for protection

This section of the database (columns W-X) compiles information on habitats identified for protection to aid with species recovery (see [Table 1](#) for terminology and definitions by jurisdiction). Column W documents categorically (Y/N) whether any habitat is identified for protection for each species. We extract the detailed description of the habitat identified for protection in column X if applicable. This includes 'critical habitat' in Canada and the United States, 'habitat critical to the survival of' the species in Australia, and 'special areas of conservation' and 'special protection areas' (Natura 2000 sites) in the European Union ([Table 1](#)).

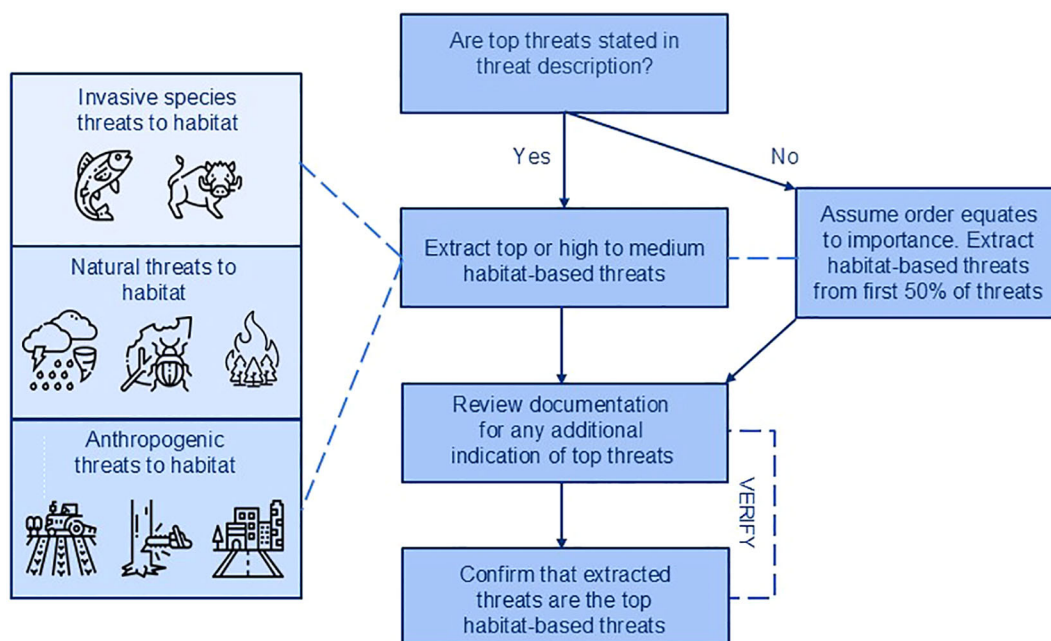


FIGURE 1

Workflow to assess threats as 'top threats', extract habitat-based top threats, and categorize threats to habitat.

2.4 Characterization of recovery goals for the species and links to habitat protection

We review recovery documentation (where available) to assess the quality of recovery goals in guiding improvements in species conservation status (columns Y-AL). Column Y documents categorically (Y/N) whether recovery goals are defined for the species and column Z contains detailed text descriptions (including goals, objectives, criteria for stabilizing and downlisting/delisting) (see [Table 1](#) for recovery goal terminology and definitions by jurisdiction). We determine if the recovery goal targets a specific outcome (e.g., population size, growth rate, number of breeding pairs, geographic range, or extinction risk) and record our answer categorically (Y/N) in column AA.

Targeted recovery goals are further characterized using the five IUCN quantitative biological criteria for extinction risk ([IUCN, 2022](#)): IUCN A. Declining population (past, present and/or projected), IUCN B. Geographic range size, fragmentation, decline or fluctuations, IUCN C. Small population size and fragmentation, decline, or fluctuations, IUCN D. Very small population or very restricted distribution, IUCN E. Quantitative analysis of extinction risk (e.g., Population Viability Analysis). Each IUCN criterion is initially categorized (Y/N) to identify the criteria of extinction risk that the recovery goal aims to address (Column AB, AD, AF, AH, AJ). If Y, the columns are populated with a second Y or N to specify whether the recovery target is clearly supported by the habitat identified for protection (see section 2.3). Country-level reporting to the European Union does not include a description of the habitats to be protected in Natura 2000 sites such that all species received a N as part of the second criteria in column AB, AD, AF, AH, AJ. This means the IUCN quantitative criteria columns are populated in one of four ways: the recovery goal is targeted but not to the given IUCN quantitative criteria (N), the recovery goal is targeted to the given IUCN criteria but it is not clearly supported by the habitat identified for protection (YN), the recovery goal is targeted to the given IUCN criteria and will be clearly supported by the habitat identified for protection (YY), or NA for species with either no recovery goal or a recovery goal that is not targeted.

Each targeted recovery goal associated to an IUCN criterion is also assigned an ambition (columns AC, AE, AG, AI, AK). A score of 1 indicates the target maintains status quo or current condition, whereas a score of 2 indicates the target aims to improve species condition or conservation status. NA indicates the lack of a recovery goal or that the goal is not targeted. Finally, we record the type of data or analysis used to define the recovery goal categorically as data deficient, expert opinion, survey data, population viability analysis (PVA), or other sources in column AL.

2.5 Technical validation

Data from each jurisdiction was validated prior to consolidation into one database. Each jurisdictional dataset (N=200 species) was reviewed by a team member who was not involved in the original

data compilation. That individual independently extracted information for a sub-set of species (10% or N=20) and compared outputs in the larger dataset. This approach allowed for quick fixes to minor variations in interpretation that arose when filling in the columns. In particular, the threat from shrub encroachment due to the abandonment of grazing in pasture lands for early successional plant species and some birds was classified under the CMP threat 2.3 livestock and farming by some and by others as 7.3 other ecosystem modifications (including abandonment of managed lands). After a review of the respective definitions of the CMP threats, both individuals reached the consensus that classification under 7.3 was most appropriate.

3 Data and applications

The ReS-ACUE database is available on the Open Science Framework data repository as a .csv file. It provides recovery information for 800 species from 4 jurisdictions, representing a wide range of taxa (32.5% vertebrates, 13% invertebrates, 53.5% vascular plants, 1% other) and conservation status categories (65.4% listed as Critically Endangered or Endangered, and 34.6% listed as Threatened or Vulnerable).

There are several ways the ReS-ACUE database can improve recovery planning for species at risk. For example, our evaluation of the usefulness of habitat protection for species at risk found that more than half of the species (507 of 800 species or 63.4%) have habitat identified for protection in their recovery documents. The percentage is slightly lower (N=319 or 53.2%) for the 600 species with detailed information on the type of habitat being protected (i.e. excludes the EU – see methods). However, a clear link or benefit of habitat protections to the species' recovery goal(s) could only be established for less than a quarter of the species with more detailed information (N=145 or 24.2%). This indicates a gap in recovery planning processes that could be related to several factors (e.g. data deficiencies, external socio-economic factors, etc.) that hinder the identification of habitats for protection that contribute to or have a positive effect on species persistence. This problem is exemplified for *Symphytotrichum praealtum* in Canada, where habitat identified for protection is based on habitat occupancy and suitability within a zone buffering occupied areas, but is acknowledged to be insufficient to meet recovery objectives ([Environment and Climate Change Canada, 2017](#)).

ReS-ACUE can also be used to analyze and define criteria for reporting on recovery progress. For example, 637 (or 79.6%) of the 800 species in the database had identified goals or objectives, but only 57.8% targeted a specific state for the species' recovery (e.g. specific population size, rate of population growth, geographic range, occupancy, etc.). The problem of non-targeted recovery is exemplified in a "specific" goal for *Boronia granitica* in Australia: "improve the long-term viability of reserved populations" ([Carter and Walsh, 2006](#)). Recovery success is difficult to assess with non-targeted recovery goals. Beyond the questions we have addressed, the ReS-ACUE database allows for the synthesis of current threats

to species habitats based on conservation status or taxa and the evaluation of the ambition of recovery goals in terms of halting versus reversing species declines and extinctions.

The ReS-ACUE database is different from previous data compilations efforts (e.g. Naujokaitis-Lewis et al., 2022) because it was developed with consideration of variations in legislative and policy frameworks to allow for cross-country or cross-jurisdictional comparisons. We found significant variability both within and across jurisdictions in the format, quality and quantity of information in recovery documents (as described in Table 1). Increasing jurisdictional efforts to make recovery documents and data on protected habitats for species at risk (e.g. within the European Union) publicly available, in concert with broader adoption of international conservation standards like those proposed by the CMP, are two recommendations that could facilitate future data extraction. Automation of data extraction could also enhance the scalability of the database to other jurisdictions for global assessments.

Global comparisons of species at risk recovery frameworks are needed to measure progress towards reversing biodiversity loss. ReS-ACUE's standardized indicators could be used to report on the contribution of habitat protection for species at risk to biodiversity by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2019), for example. The indicators could also be used to measure successful conservation outcomes for the IUCN Green List of Protected and Conserved areas (IUCN, 2025b). Our hope is that the database and ensuing future analyses will allow for more thorough assessments of the contribution of habitat protection for species at risk to biodiversity globally.

Data availability statement

The data presented in the study are deposited on the Open Science Framework data repository at the following link: <https://doi.org/10.17605/OSF.IO/VW7MD>.

Author contributions

CT: Data curation, Methodology, Validation, Writing – original draft, Writing – review & editing. EN: Conceptualization, Data curation, Methodology, Project administration, Supervision, Validation, Writing – original draft, Writing – review & editing. AS: Data curation, Methodology, Validation, Writing – original draft, Writing – review & editing. CH: Data curation, Methodology, Validation, Writing – original draft, Writing – review & editing. JC: Data curation, Methodology, Writing – original draft, Writing – review & editing. CJ: Conceptualization, Data curation, Funding acquisition, Methodology, Project administration, Supervision, Validation, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fevo.2025.1659957/full#supplementary-material>

SUPPLEMENTARY INFORMATION 1
ReS-ACUE: Data Dictionary.

SUPPLEMENTARY INFORMATION 2
ReS-ACUE: Full list of references used in data extraction and content analysis.

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