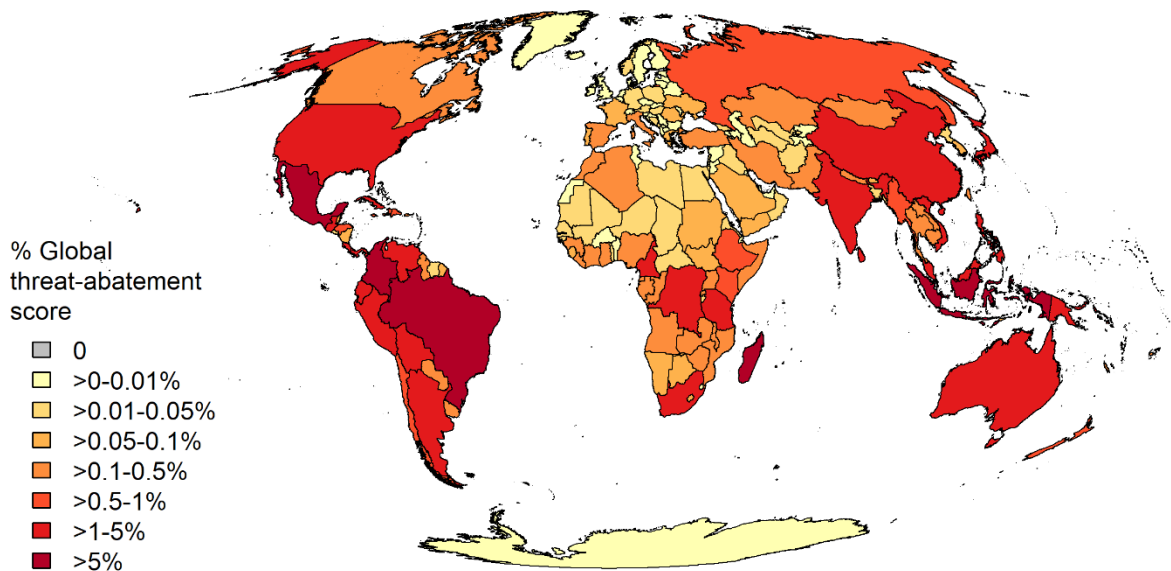
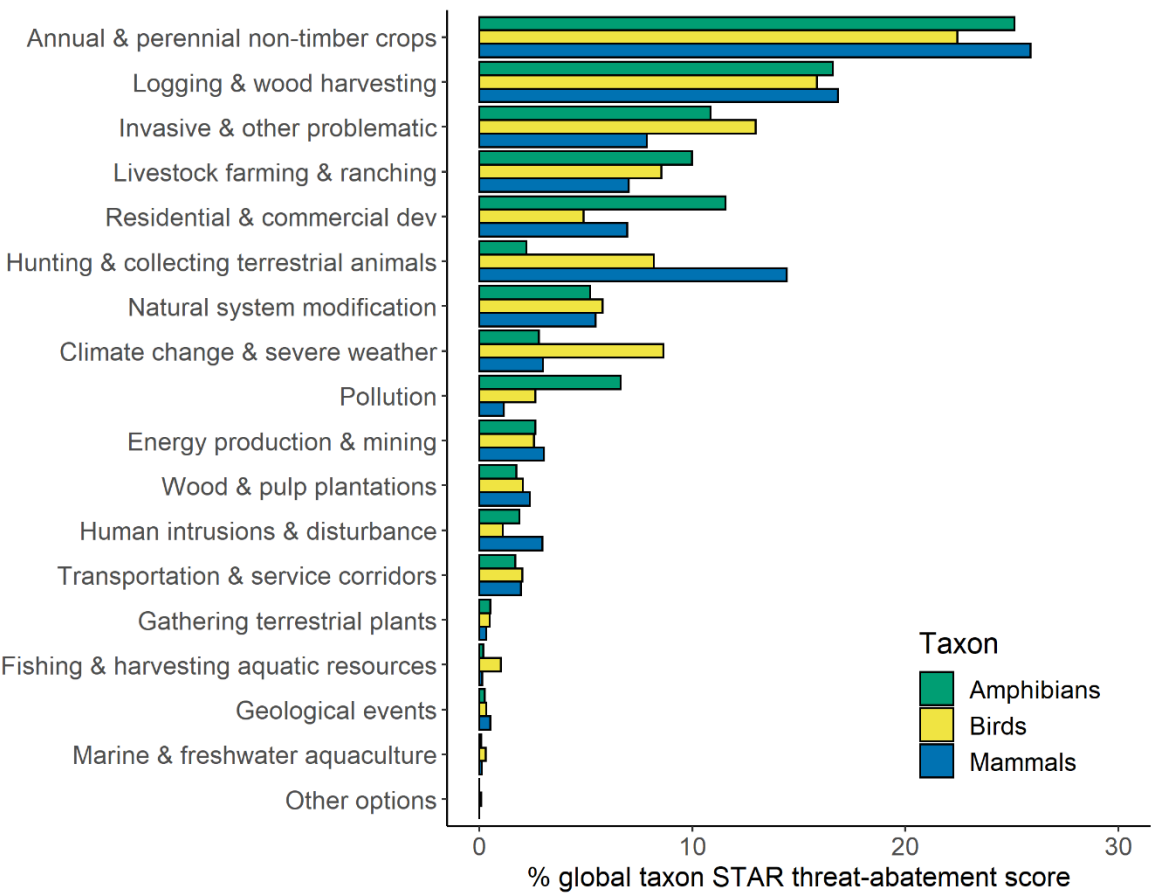


Extended Data figures



Extended Data 1. STAR threat-abatement scores for amphibians, birds and mammals per country shown as the percentage of the total global STAR threat-abatement score. The total global STAR threat-abatement score represents the global threat abatement effort needed for all Near Threatened and threatened (Vulnerable, Endangered and Critically Endangered according to the IUCN Red List) amphibian, bird and mammal species to be reclassified as Least Concern. This score can be disaggregated spatially, based on the area of habitat currently available for each species in a particular location.

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14 **Extended Data 2. The percentage of the global STAR threat-abatement score for amphibians**

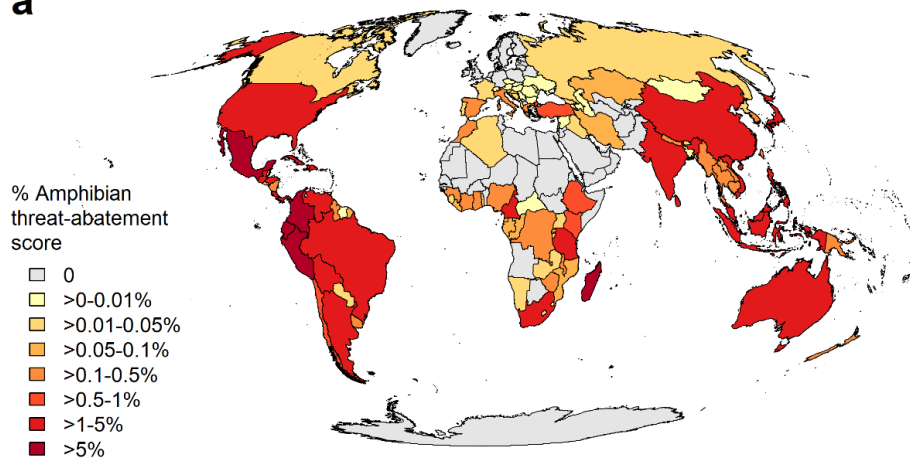
15 **(green), birds (yellow) and mammals (blue), that is contributed by each threat type.** The total

16 global STAR threat-abatement score can be calculated for each taxonomic group and then

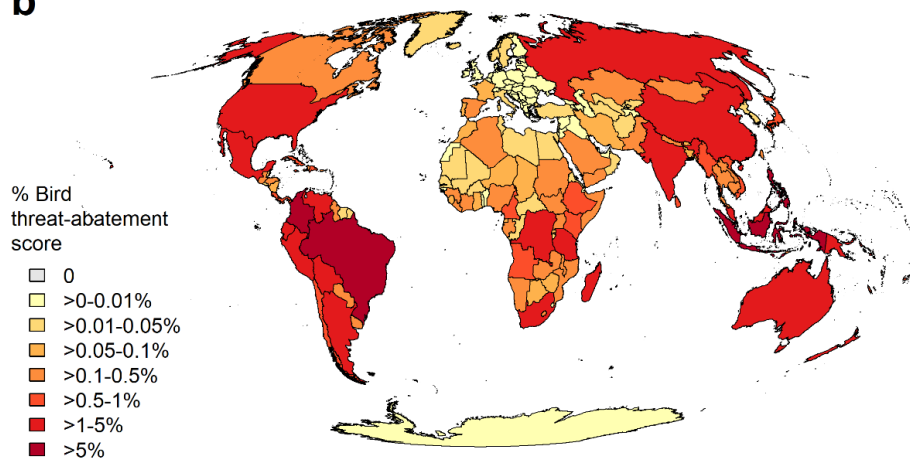
17 disaggregated by threat type, based on the known contribution of each threat to species' risk of

18 extinction.

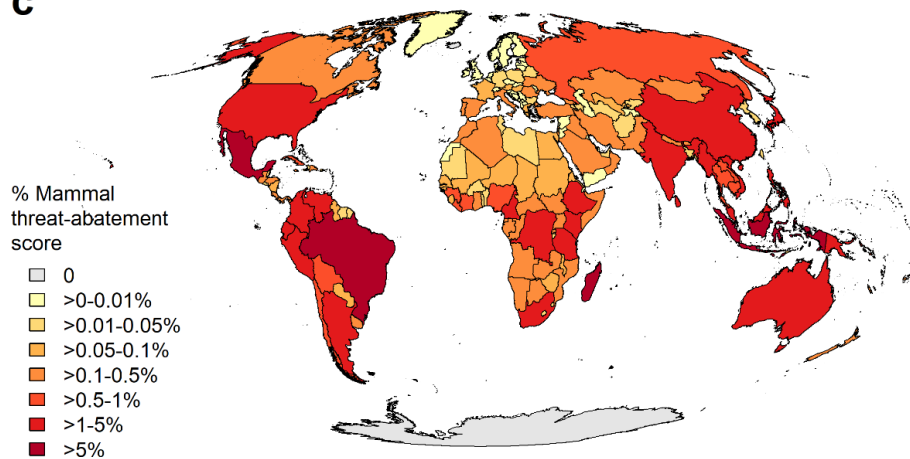
a



b



c



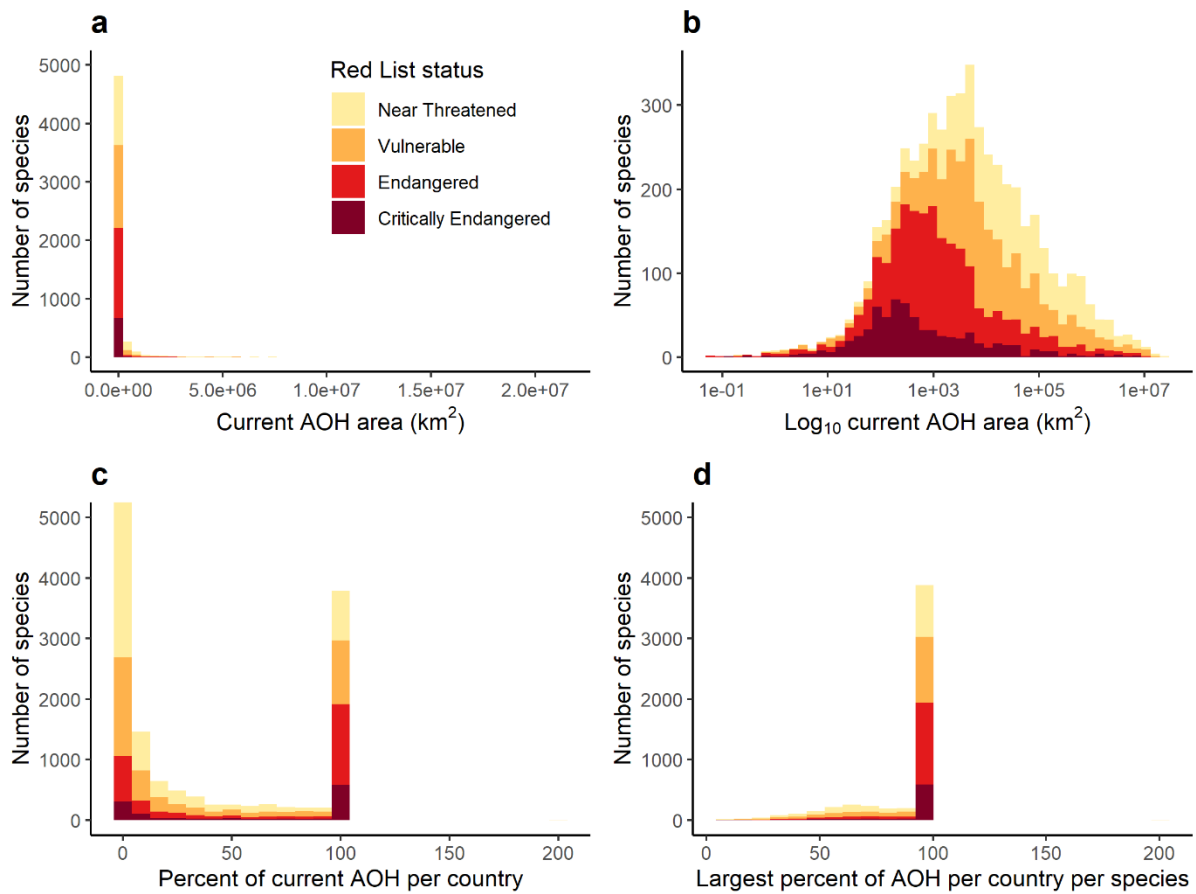
19

20 **Extended Data 3. STAR threat-abatement scores per country for (a) amphibians (b) birds and (c)**

21 **mammals shown as the percentage of the total global STAR threat-abatement score for each**

22 **taxon.** The total global STAR threat-abatement score for each taxonomic group can be

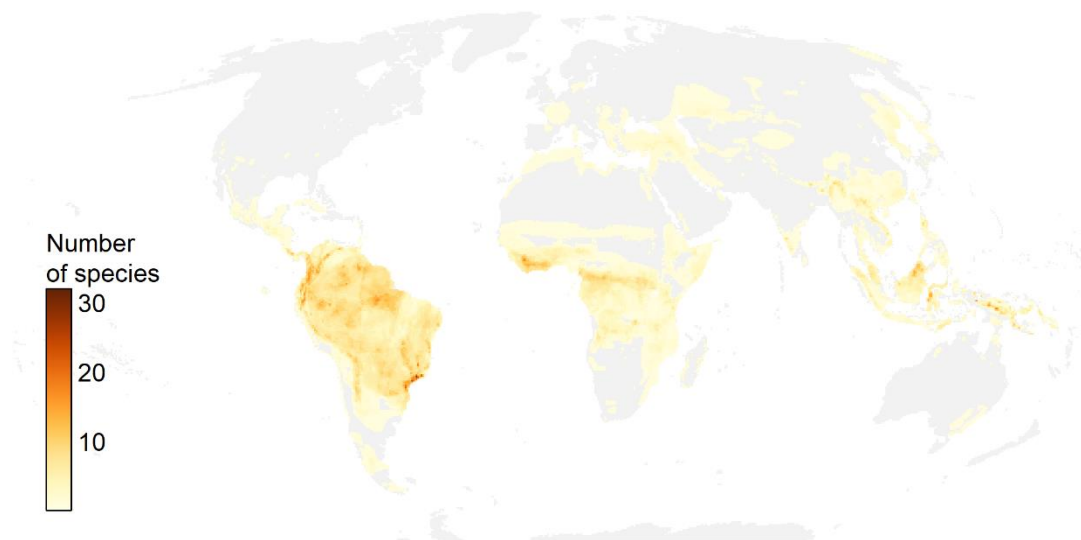
- 23 disaggregated spatially, based on the area of habitat currently available for each species in a
- 24 particular location.



26

27 **Extended Data 4. Area of species' current AOH and percentage of species current AOH per country.**

28 **(a)** The distribution, and **(b)** the log₁₀ distribution, of the area of species' current AOH. **(c)** the
 29 percent of species' current AOH per country (where species occurring across multiple countries have
 30 multiple datapoints) and **(d)** the largest percentage of current AOH per country for each species
 31 (such that there is only one datapoint per species). Colour scale indicates Red List category of
 32 species. Note the different y-axis in (b).



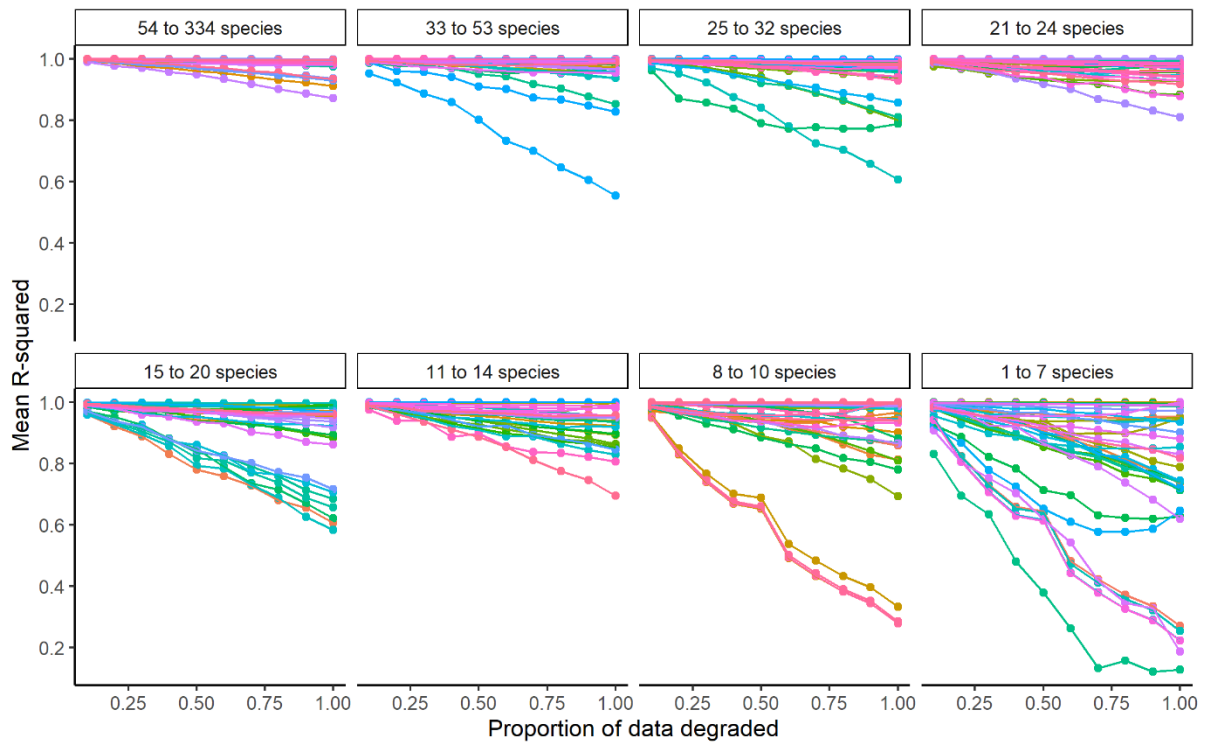
33

34 **Extended Data 5. The number of Data Deficient species of amphibians, birds and mammals on the**

35 **IUCN Red List per 50 km grid cell.** Of the 2,235 terrestrial species in these taxonomic groups that

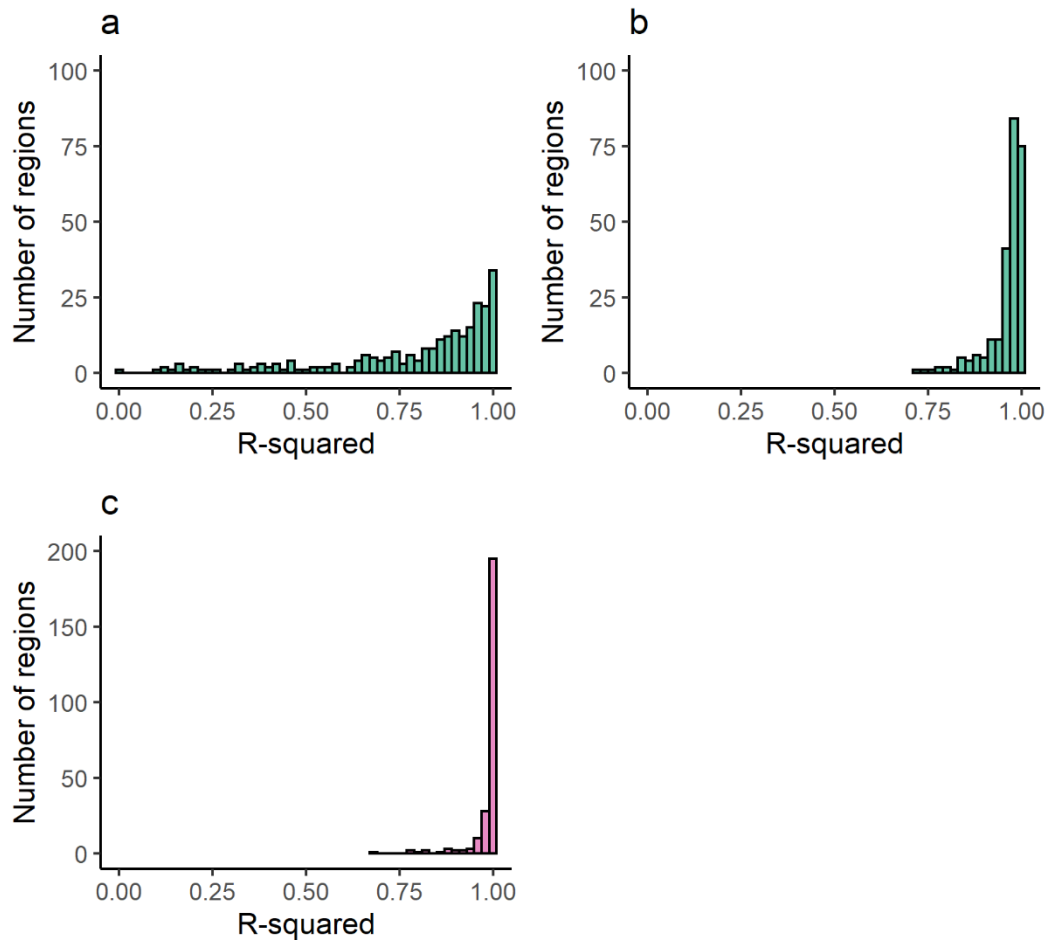
36 were assessed as Data Deficient on the Red List, 1,528 (68.4%) had Area of Habitat maps.

37



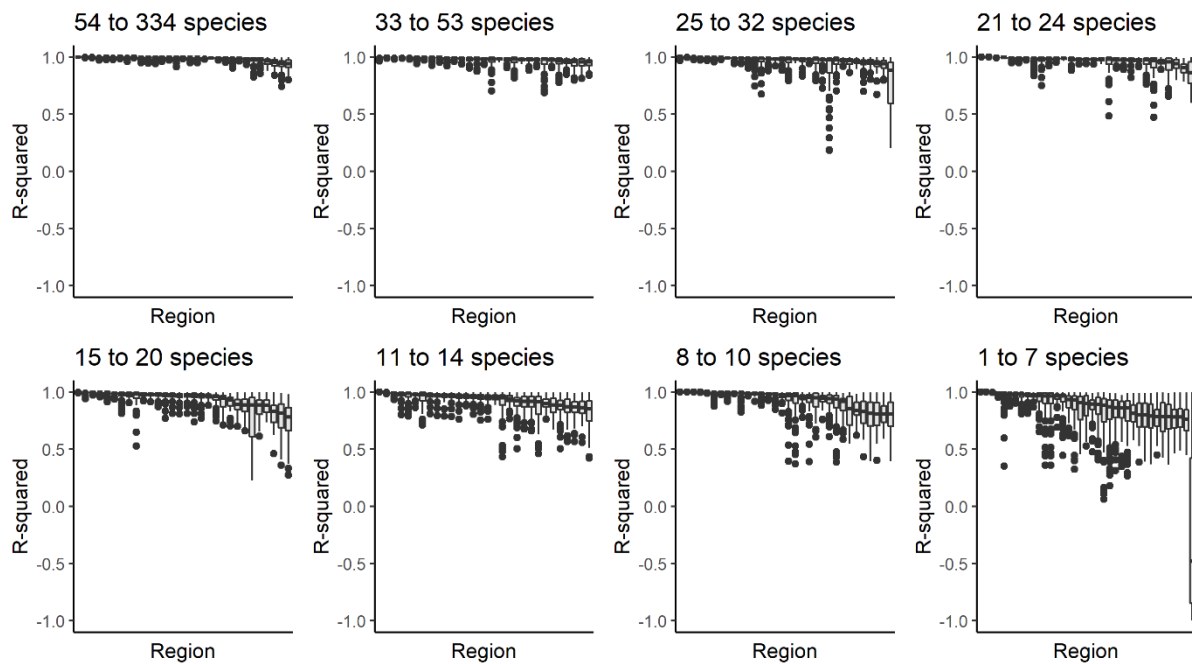
38

39 **Extended Data 6. Deviation from ‘true’ STAR threat-abatement scores for birds generated by**
 40 **increasing the proportion of threat data with missing scope and severity scores. Mean R^2 per**
 41 **region across 100 iterations at the proportion of the data degraded (i.e. proportion of scope and**
 42 **severity data treated as missing) is increased. R^2 from linear regression of STAR threat-abatement**
 43 **scores from degraded data against STAR threat-abatement scores from complete data. Each line is a**
 44 **region (N=250) and regions are grouped based on the number of bird species present.**



Extended Data 7. Variation in STAR threat-abatement scores for birds generated by (a-b) varying Red List category weights, and (c) weighting large AOH proportions more and small AOH proportions less. The distribution of R^2 values per region from regressing STAR threat-abatement scores obtained when species Red List categories were weighted using **(a)** log steps and **(b)** no weighting, against scores obtained using equal step weighting. **(c)** The distribution of R^2 values per region from regressing STAR threat-abatement scores obtained when weighting larger AOH proportions per region more and smaller AOH proportions less.

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Extended Data 8. Variation in STAR threat-abatement scores generated by varying the expected

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percentage population decline from scope and severity scores per threat. R^2 per region across 100

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iterations (each box is a region) from regressing STAR threat-abatement scores obtained using varied

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expected population decline were against scores obtained using the median expected population

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decline. Regions are grouped by the number of bird species present. Boxplots show the median,

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with hinges indicating the first and third quartiles, whiskers showing the most extreme datapoint

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that is no more than 1.5 times the interquartile range from the respective quartile, and outliers

62

beyond this distance shown as points.

Supplementary Data

Supplementary Data 1. Global STAR threat-abatement scores for terrestrial amphibians, birds and mammals at 50 km grid cell resolution in TIFF file format.

Supplementary Data 2. Global STAR restoration scores for terrestrial amphibians, birds and mammals at 50 km grid cell resolution in TIFF file format.

Supplementary Information

A metric for spatially-explicit contributions to science-based species targets

Louise Mair^{1*}, Leon A. Bennun^{2,3}, Thomas M. Brooks^{4,5,6}, Stuart H. M. Butchart^{3,7}, Friederike C. Bolam^{1,8}, Neil D. Burgess^{8,9}, Jonathan M. M. Ekstrom², E J Milner-Gulland¹⁰, Michael Hoffmann¹¹, Keping Ma¹², Nicholas B. W. Macfarlane¹³, Domitilla C. Raimondo^{14,15}, Ana S.L. Rodrigues¹⁶, Xiaoli Shen¹², Bernardo B. N. Strassburg^{17,18}, Craig R. Beatty^{13,19}, Carla Gómez-Creutzberg²⁰, Alvaro Iribarrem^{17,18}, Meizani Irmadhiany²¹, Eduardo Lacerda^{18,22}, Bianca C. Mattos²³, Karmila Parakkasi²¹, Marcelo F. Tognelli^{24,25}, Elizabeth L. Bennett²⁶, Catherine Bryan²⁷, Giulia Carbone⁴, Abhishek Chaudhary²⁸, Maxime Eiselin²⁹, Gustavo A. B. da Fonseca³⁰, Russell Galt³¹, Arne Geschke³², Louise Glew¹⁹, Romie Goedicke²⁹, Jonathan M. H. Green³³, Richard D. Gregory^{34,35}, Samantha L. L. Hill⁸, David G. Hole²⁴, Jonathan Hughes⁸, Jonathan Hutton³⁶, Marco P. W. Keijzer²⁹, Laetitia M. Navarro^{37,38}, Eimear Nic Lughadha³⁹, Andrew J. Plumptre^{3,40}, Philippe Puydarrieux⁴, Hugh P. Possingham^{41,42}, Aleksandar Rankovic⁴³, Eugenie C. Regan^{8,44}, Carlo Rondinini⁴⁵, Joshua D. Schneck¹³, Juha Siikamäki¹³, Cyriaque Sendashonga⁴, Gilles Seutin⁴⁶, Sam Sinclair⁴⁷, Andrew L. Skowno^{14,48}, Carolina A. Soto-Navarro^{8,36}, Simon N. Stuart^{27,49}, Helen J. Temple², Antoine Vallier⁵⁰, Francesca Veronesi⁵¹, Leonardo R. Viana^{24,52}, James Watson^{26,42}, Simeon Bezeng^{53,54}, Monika Böhm¹¹, Ian J. Burfield⁷, Viola Clausnitzer⁵⁵, Colin Clubbe³⁹, Neil A. Cox^{24,25}, Jörg Freyhof⁵⁶, Leah R. Gerber⁵⁷, Craig Hilton-Taylor³¹, Richard Jenkins³¹, Ackbar Joolia³¹, Lucas N. Joppa⁵⁸, Lian Pin Koh⁵⁹, Thomas E. Lacher Jr.^{60,61}, Penny F. Langhammer^{61,62}, Barney Long⁶¹, David Mallon⁶³, Michela Pacifici⁴⁵, Beth A. Polidoro^{57,64}, Caroline M. Pollock³¹, Malin C. Rivers⁶⁵, Nicolette S. Roach^{60,61}, Jon Paul Rodríguez^{66,67,68}, Jane Smart⁴, Bruce E. Young⁶⁹, Frank Hawkins¹³, Philip J. K. McGowan¹

- 1 School of Natural and Environmental Sciences, Newcastle University, Newcastle upon Tyne NE1 7RU, UK.
- 2 The Biodiversity Consultancy, 3 Kings Parade, Cambridge CB2 1SJ, UK.
- 3 Department of Zoology, University of Cambridge, Downing St, Cambridge CB2 3EJ, UK.
- 4 IUCN, Rue Mauverney 28, Gland CH-1196, Switzerland.
- 5 World Agroforestry Center (ICRAF), University of The Philippines Los Baños, Laguna, Philippines.
- 6 Institute for Marine & Antarctic Studies, University of Tasmania, Australia.
- 7 BirdLife International, David Attenborough Building, Pembroke St, Cambridge CB2 3QZ, UK.
- 8 United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC), Cambridge, CB3 0DL, UK.
- 9 The GLOBE Institute, University of Copenhagen, 1350 Copenhagen, Denmark.
- 10 Department of Zoology, Oxford University, Oxford OX1 2JD, UK.
- 11 Zoological Society of London, Regent's Park, London NW1 4RY, UK.
- 12 State Key Laboratory of Vegetation and Environmental Change, Institute of Botany, Chinese Academy of Sciences, 100093 Beijing, China.
- 13 IUCN, 1630 Connecticut Ave NW, Washington, DC 20009, USA.
- 14 South African National Biodiversity Institute, 0001 Pretoria, South Africa.

- 15 IUCN Species Survival Commission, Pretoria, South Africa.
- 16 CEFÉ, Univ Montpellier, CNRS, EPHE, IRD, Univ Paul Valéry Montpellier 3, Montpellier 34293 France.
- 17 Rio Conservation and Sustainability Science Centre, Department of Geography and the Environment, Pontifical Catholic University, Rio de Janeiro, Brazil.
- 18 International Institute for Sustainability, Rio de Janeiro 22460-320, Brazil.
- 19 World Wildlife Fund, 1250 24th Street NW, Washington, DC 20037, USA.
- 20 IUCN, Los Yoses, San Pedro de Montes de Oca, San José, Costa Rica.
- 21 PT Royal Lestari Utama Wisma Barito Pacific, Tower B Floor 3 Jl. Letjen S. Parman Kav.62-63, Slipi Jakarta Barat 11410, Indonesia.
- 22 Fluminense Federal University, Niterói, Brazil.
- 23 SSC Post-2020 Biodiversity Task Force. Calle Voluntad, 11. Seville, Spain.
- 24 Conservation International, 2011 Crystal Drive, Suite 600 Arlington, Virginia 22202, USA.
- 25 IUCN-CI Biodiversity Assessment Unit, 1630 Connecticut Ave NW, Washington, DC 20009, USA.
- 26 Wildlife Conservation Society, Bronx, New York 10460, USA.
- 27 Synchronicity Earth, 27-29 Cursitor Street, London EC4A 1LT, UK.
- 28 Indian Institute of Technology (IIT) Kanpur, 208016, India.
- 29 IUCN National Committee of The Netherlands, Amsterdam 1018 DD, Netherlands.
- 30 Global Environment Facility, Washington, DC 20433, USA.
- 31 IUCN, The David Attenborough Building, Pembroke Street, Cambridge CB2 3QZ, UK.
- 32 Integrated Sustainability Analysis, School of Physics, The University of Sydney, Sydney, Australia.
- 33 Stockholm Environment Institute York, Department of Environment and Geography, University of York, York YO10 5NG, UK.
- 34 RSPB, The Lodge, Sandy, Bedfordshire SG19 2DL, UK.
- 35 Centre for Biodiversity & Environment Research, Department of Genetics, Evolution and Environment, University College London, London WC1E 6BT, UK.
- 36 Luc Hoffmann Institute, Rue Mauverny 28, Gland 1196, Switzerland.
- 37 German Center for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, 04103 Leipzig, Germany.
- 38 Institute of Biology, Martin Luther University Halle Wittenberg, 06108 Halle (Saale), Germany.
- 39 Conservation Science Department, Royal Botanic Gardens Kew, TW9 3AE, UK.
- 40 Key Biodiversity Area Secretariat, c/o BirdLife International, The David Attenborough Building, Pembroke Street, Cambridge CB2 3QZ, UK.
- 41 The Nature Conservancy, Arlington, Virginia 22203, USA.
- 42 University of Queensland, Brisbane, QLD 4072, Australia.
- 43 Institute for Sustainable Development and International Relations, Sciences Po, Paris 75007, France.
- 44 Springer Nature, London WC1X 8HB, UK.
- 45 Global Mammal Assessment Programme, Dipartimento di Biologia e Biotechnologie "Charles Darwin", Sapienza Università di Roma, viale dell'Università 32, I-00185, Rome, Italy.
- 46 Parks Canada, Gatineau, Québec J8X 0B3, Canada.
- 47 Biodiversify, UK.

- 48 Department of Biological Sciences, University of Cape Town, Cape Town, South Africa.
49 IUCN Species Survival Commission, Bath BA2 6BZ, UK.
50 CDC Biodiversité, Paris, 75002, France.
51 Industrial Ecology Programme, Norwegian University of Science and Technology (NTNU),
7491 Trondheim, Norway.
52 Sustainable Forestry Initiative Inc., 2121 K Street NW, Washington, DC 20037, USA.
53 BirdLife South Africa, Johannesburg 2196, South Africa.
54 Department of Geography, Environmental Management and Energy Studies, University of
Johannesburg, Auckland Park 2006, South Africa.
55 Senckenberg Research Institute, 02826 Goerlitz, Germany.
56 Museum für Naturkunde, Leibniz Institute for Evolution and Biodiversity Science,
Biodiversity & Bioeconomy, Center for Integrative Biodiversity Discovery, Invalidenstraße 43,
10115 Berlin Germany.
57 Center for Biodiversity Outcomes, Arizona State University, Tempe, Arizona 85284, USA.
58 Microsoft, Redmond, WA 98052, USA.
59 Department of Biological Sciences, National University of Singapore, Singapore 117543,
Singapore.
60 Department of Ecology and Conservation Biology, Texas A&M University, Texas 77843, USA.
61 Global Wildlife Conservation, Austin, Texas 78767, USA.
62 School of Life Sciences, Arizona State University, Tempe, Arizona 85287, USA.
63 Manchester Metropolitan University, Manchester M15 6BH, UK.
64 School of Mathematics and Natural Sciences, Arizona State University, Glendale, Arizona
85306, USA.
65 Botanic Gardens Conservation International, Richmond, TW9 3BW, UK.
66 IUCN Species Survival Commission, Caracas, Venezuela.
67 Venezuelan Institute for Scientific Investigation (IVIC), Caracas, Venezuela.
68 Provita, Caracas, Venezuela.
69 NatureServe, Virginia, 22202, USA.

*Corresponding author: Louise Mair. Email: Louise.Mair@newcastle.ac.uk

Supplementary Tables

Supplementary Table 1. Summary of data requirements and sources of uncertainty in the calculation of global STAR scores, and approaches to quantifying and reducing these uncertainties.

Component of STAR	Data requirements	Sources of uncertainty in estimated global STAR calculation	Approaches to quantify and reduce uncertainty
Threat-abatement and restoration component			
Species extinction risk category	IUCN Red List species extinction risk	Data Deficient and Not Evaluated species lack data to be included (see Extended Data 5).	Conduct research on species that will allow threat status to be assessed.
		Extinction risk categories can change with improved data availability.	Metric updated in line with IUCN Red List assessment updates as data on species improves.
Threats to species	Threat documentation for species on IUCN Red List	Incomplete documentation of threats to species.	Metric updated as IUCN Red List assessments are updated;
		Incomplete documentation of scope and severity of threats.	comprehensiveness of the documentation of threats is continually improving.
		Spatial variation in occurrence and severity of threats	Spatial variation in threats refined using threat heat maps; Verify presence and severity of threats at site.
Threat-abatement component only			
Current Area of Habitat (AOH)	1. Species distribution maps (IUCN Red List) 2. Species habitat associations (IUCN Red List) 3. Species elevation limitations (IUCN Red List) 4. Digital elevation maps	Current Area of Habitat shows the distribution of existing suitable habitat within a species' range, but the presence of the species within this habitat is uncertain.	Validation of Current Area of Habitat maps using current point locality data sources; Verify presence of species at site.

5. Current land cover maps			
Restoration component only			
Restorable Area of Habitat (AOH)	1. Species distribution maps (IUCN Red List) 2. Species habitat associations (IUCN Red List) 3. Species elevation limitations (IUCN Red List) 4. Digital elevation maps 5. Land cover maps projected back in time before human impact	Restorable Area of Habitat shows the distribution of lost suitable habitat within a species' range, but the former presence of the species within this habitat is uncertain. Restoration potential of Restorable Area of Habitat at a particular site will depend upon a range of local factors including current land use.	Validation of Restorable Area of Habitat maps using historical point locality data sources; Restorable Area of Habitat refined at the site level by eliminating non-restorable areas (e.g. infrastructure; productive agriculture).
Restoration discount	Discount used in global calculation based on meta-analysis in the scientific literature (Jones et al 2018)	The global restoration multiplier is based on a meta-analysis; the recovery rate at a particular site will vary depending on local conditions.	Expected recovery rate at a site estimated based on local conditions.

Supplementary Table 2. Expected percentage population decline over 10 years or three generations from combinations of scope and severity scores per threat. For further details, see⁴².

		Severity					
		Very rapid declines	Rapid declines	Slow, significant declines	Negligible declines	No decline	Causing/could cause fluctuations
Scope	Whole (>90%)	63	24	10	1	0	10
	Majority (50-90%)	52	18	9	0	0	9
	Minority (<50%)	24	7	5	0	0	5

Supplementary Methods

Sensitivity analyses

The methods below describe the approaches taken during the development of the metric to test the different metric components and ascertain the most appropriate formulation.

Data used in sensitivity analyses

All sensitivity analyses presented here were performed on Near Threatened and threatened (Vulnerable, Endangered and Critically Endangered) birds (N=1,957). This taxonomic group was chosen because it has the best data availability.

The analyses focus on results at the regional level of 250 regions. The use of regions as spatial units provides 'site level' analyses with sites varying widely in size and species richness, and provides a larger sample size than would the use of countries (where n=195).

Missing threat scope and severity data

Threat scope and severity data are recommended but not required documentation for Red List assessments, which is why these data are not consistently documented. The majority of threats for Near Threatened and threatened birds were coded with scope and severity scores (97.0% coded with scope scores, 86.5% coded with severity scores; the remaining scores were either missing or coded as 'unknown'). However, scope and severity scores were largely missing or coded as 'unknown' for the threat data for mammals (22.5% coded with scope scores, 20.2% coded with severity scores) and amphibians (3.6% coded with scope scores, 2.6% coded with severity scores). Furthermore, the availability of scope and severity scores per threat varied greatly; 32.2% of threat categories for amphibians and 15.7% of threat categories for mammals had no information on scope, while 51.7% of threat categories for amphibians and 20.2% of threat categories for mammals had no information on severity. This lack of scope and severity information meant that it was not viable to use what data did exist on scope and severity scores to inform missing information.

Instead, the median of possible scores for scope and severity were used to replace 'unknown' or missing scope and severity data. The variation in STAR_T scores introduced by this approach was quantified using the relatively complete dataset for birds. In order to include all available data in this analysis, the small proportion of scope and severity data that were coded as 'unknown' or that were missing scores for birds were assigned the median of possible scores (median scope = "Majority (50-90%)"; median severity = "Slow, Significant Declines").

The threat data for birds were then degraded to simulate increasing proportions of missing scope and severity data. For each region, a proportion of the scope and severity scores for species threats were randomly selected and assigned as missing data. These missing data were then 'filled in' using the medians of possible scope and severity score values (median scope = "Majority (50-90%)"; median severity = "Slow, Significant Declines"). The proportion of data degraded was increased from 0.1 to 1 in intervals of 0.1. One hundred iterations were run for each level of degradation.

We assumed that the original, non-degraded dataset produced 'true' STAR_T scores. In order to explore the effect of missing scope and severity data on STAR_T scores, we assessed the deviation from true STAR_T scores that resulted from missing scope and severity data. For each region, and

each iteration of each degradation within that region, we regressed the total STAR_T scores per threat (at the second highest level of the threat categorisation scheme) against the scores obtained from the original dataset. R² values were used to quantify the amount of variation introduced due to data degradation. We calculated the mean R² across the 100 iterations for each level of degradation, and inspected the change in mean R² as the proportion of missing scope and severity data was increased. In each case, the lower the R², the further from the ‘truth’ the degraded data were considered to be.

For each region, mean R² over the 100 iterations was plotted against the proportion of scope and severity data per region that was degraded, and regions were grouped together from high to low species richness (Extended Data 6). When the proportion of scope and severity scores that were missing was one, 73.2% of regions had an R²>0.9, and 91.2% had an R²>0.7.

There was little effect on STAR_T scores for countries with very high species richness; of the 28 regions with ≥54 species, 96.8% had an R²>0.9 when the proportion of scope and severity scores that were missing was one. As species richness decreases, there was greater deviation from true STAR_T scores observed. Nevertheless, of the 69 regions with ≤10 species, 49.3% had an R²>0.9 when the proportion of scope and severity scores that were missing was one.

Varying Red List category weightings

The Red List Index weights species by Red List category using equal steps^{7,8}. We explored the effect on STAR_T scores of weighting species by log steps (NT= 0.0005, VU=0.005, EN=0.05, CR=0.5³⁹) and the effect of applying no weights (i.e. all=1).

For each region, the total STAR_T scores per threat (at the second highest level of the threat categorisation scheme) obtained when using log steps and no weights were compared against the threat-abatement scores obtained when using equal steps, and variation was quantified using R² values from linear regressions.

Weighting species Red List category using log steps resulted in large variation in STAR_T scores compared against equal step weight for some countries (Extended Data 7a-b). Across all regions, an R² of ≥0.9 was obtained in 46.4% of cases, and an R² of <0.7 was obtained in 25.6% of cases. In contrast, there was less variation in STAR_T scores when no weights were used compared to equal steps; an R² of ≥0.9 was obtained in 90.4% of cases, and no region had an R² of <0.7.

Weighting large proportions of species AOH more and small proportions less

STAR_T scores at the site level are calculated using the proportion of the species current AOH and restorable AOH present at the site. The effect of weighting larger proportions of AOH more and smaller proportions of AOH less was explored.

Species current and historical AOH proportions within each region were weighted using a sigmoid function;

$$f1(x) = 1 / (1 + e^{-((x-39)/9.5)})$$

and then transformed to scale from zero to one⁴⁹. The STAR_T scores per threat (at the second highest level of the threat categorisation scheme) obtained using these weighted species AOH proportions were regressed against the scores obtained without weighting and R² values were used to quantify the variation.

Weighting larger AOH proportions more and smaller AOH proportions less had little effect on the STAR_T scores per threat; an R² of ≥0.9 was obtained in 95.6% of cases (Extended Data 7c).

Varying the values for expected population decline

The relative contribution of each threat to a species STAR_T score is determined by the expected percentage decline in population caused by that threat. This expected population decline is derived from the combination of scope and severity categories (Supplementary Table 2). Each scope and severity category has a lower and upper bound (of percentage species population affected, and percentage population decline, respectively) and so when combined produce bounded categories of overall expected population decline due to a particular threat. The expected population decline caused by a threat could vary between the minimum and maximum value within each combination. The metric formulation uses the median expected population decline for each combination of scope and severity. Here, we test the effect of varying expected population decline within the bounds of the minimum and maximum values per combination.

The expected population decline for each combination of scope and severity was varied by taking a random sample from a uniform distribution within the bounds of expected population decline for each combination. This process was repeated over 100 iterations. For each iteration per region, the total STAR_T scores per threat (at the second highest level of the threat categorisation scheme) obtained when using varied population declines were compared against the scores obtained when using the median expected population decline, and variation was quantified using R² values from linear regressions.

Across all regions and iterations, an R² of ≥0.9 was obtained in 82.7% of cases. There was generally little variation for species-rich countries (an R² of ≥0.9 was obtained in 98.2% of cases for countries with ≥54 species). Species-poor countries were more likely to show greater variation (an R² of ≥0.9 was obtained in 65.7% of cases for countries with ≤10 species). Overall, however, there was relatively little variation in STAR_T scores generated by varying the expected population decline (Extended Data 8).

Supplementary Discussion

Sensitivity analyses: Missing threat scope and severity data

The metric was found to be relatively insensitive to variation in scope and severity scores, particularly in regions with a larger number of species (Extended Data 6). This insensitivity is due to the metric being driven, at this relatively large spatial scale, primarily by the number of threats per species and the number of threatened species per location; regions with fewer species showed greater sensitivity to variation in scope and severity scores. While this relative insensitivity allows us to make use of the available incomplete data, the ideal situation is to have all threats scored with scope and severity in order to contribute towards increased overall metric accuracy. These results also emphasise the need for verification of the presence of species, and the presence and severity of threats at the site level, in order to obtain refined STAR scores (see also Supplementary Table 1). Scope and severity scores should be substantially more comprehensive following updated Red List assessments for mammals and amphibians (in 2021 and 2022 respectively).

STAR assumptions and Red List criteria

Completeness of Red List data

When determining the Red List category for a threatened or Near Threatened species, identification of major threats is a minimum requirement. However, the RL Documentation Standards & Rules of Procedure recommend comprehensive identification and coding of threats, and recent years have seen increased efforts to do this for assessed taxa.

The teams leading/coordinating assessment of the three vertebrate groups (amphibians, birds and mammals) included for STAR in this paper make efforts to ensure that threat coding is both complete and consistent. Among Near Threatened and threatened species in Red List version 2019-3, 1,548 out of 1,589 mammals (97.4%), 2,552 out of 2,575 amphibians (97.9%) and 2,494 out of 2,503 birds (99.6%) have threats documented. Development of standard Red List guidance for threat identification and scoring, and expansion of efforts to collect and update these data, would help to underpin the future application of STAR.

Species downlisting in response to threat abatement

STAR assumes that the *complete* alleviation of threats to a given species would ameliorate extinction risk through halting decline and/or permitting recovery in population and distribution. For the great majority of species, this would be expected to achieve downlisting to the IUCN Red List category of Least Concern⁵⁰. However, there are some species for which this might not be the case in all circumstances.

Some Red List sub-criteria do not necessarily require any current or future threat for a species to be assessed as threatened. These are criteria D/D1 (requiring a very small population), and sub-criteria Bac (in the case of a small range with severe fragmentation, plus extreme fluctuations). Species uniquely assessed under these criteria that do not have any threats listed are not included in this study (among Near Threatened and threatened amphibians, birds and mammals, there are nine species uniquely assessed under D/D1 with no threats documented, and no species uniquely assessed under Bac with no threats documented). There are, however, 143 species listed uniquely under criteria D/D1 (plus one species listed uniquely under sub-criteria Bac and a further four species under sub-criteria Bab+c, two of which are listed due to severe fragmentation) that do have threats listed and are therefore included in this study. We assume that for these species, threat

abatement is very likely to reduce extinction risk, but might need to be complemented by restoration in order to achieve Least Concern status.

Species that are listed under criteria D/D1 or Bac/Bab+c (whether at the category under which they qualify on the IUCN Red List, or a lower category) plus other criteria are included in this study. There are 104 species that are listed under D/D1 plus at least one other criterion, and five species that are listed under Bac/Bab+c plus at least one other criterion. We assume that the abatement of threats to these species would halt declines such that they would no longer qualify as threatened or Near Threatened under the other listing criteria. We assume that it is also likely that for the majority of these species, which suffer from threats that drive population and/or distribution declines, the complete abatement of threats would allow recovery (increases in number of mature individuals in the case of D/D1, and reductions in fragmentation in the case of Bac/Bab+c) such that the species would not qualify as threatened or Near Threatened under criteria D/D1 or Bac/Bab+c. Again, however, some of these species may require threat abatement activities to be complemented by restoration in order to achieve Least Concern status.

There are a further two criteria that require only plausible *future* threats; these are criteria A3 (population reduction projected, inferred or suspected to be met in the future) and D2 (restricted area of occupancy or number of locations with a plausible future threat that could drive the taxon to CR or EX in a very short time). There are 126 species listed uniquely under criterion A3, 117 species listed uniquely under criterion D2 and 13 species listed uniquely under criterion D1+2 included in this study. For these species, we assume that threat abatement activities would prevent the emergence of the documented plausible future threats, such that the species could be downlisted to Least Concern.

In all cases outlined above, we assume that achieving Least Concern status through threat abatement activities, or a combination of threat abatement and restoration activities, is in principle possible for the species concerned, if all threats could be alleviated completely. There will be, however, species that naturally have very small populations and/or severe fragmentation and fluctuations, such that they cannot be downlisted to Least Concern through threat abatement and restoration activities. Other species that are declining and have a small population (listed under criterion C1) may either continue to decline after threats are abated (e.g., because of Allee effects), or may become listed under another criterion (such as D, relating to small population) by the time the decline is arrested. Although such species are included in this study, abatement of threats to these species may not be enough for them to achieve the Least Concern category. For these species, downlisting may only be achieved through other management actions in addition to threat alleviation, such as population augmentation and introductions to new locations.

There is also the possibility, under current Red List guidelines, of conservation dependence preventing species from being assessed as Least Concern. There is a particular provision in the *Guidelines for Using the IUCN Red List Categories and Criteria* that a taxon can “qualify for the Near Threatened category if it is the focus of a continuing taxon-specific or habitat-specific conservation or management programme targeted towards the taxon in question, the cessation of which would result in the taxon qualifying for one of the threatened categories ... within a period of five years”. Under this provision, dependence on conservation actions, such as those envisioned in this framework that would serve to mitigate threats and restore habitat, may result in a species in the lowest threat category of the Red List (Least Concern) being listed instead as Near Threatened (e.g. White Rhino *Ceratotherium simum*). However, with the recent development of Green Status¹⁰ metrics and the planned incorporation of these into the IUCN Red List, it is very likely that the Green Status framework will be used in future to flag conservation dependent species, and the IUCN Red

List Guidelines modified to indicate that such species should be listed as Least Concern rather than Near Threatened (assuming that they do not meet the criteria for listing as threatened).

Finally, becoming Least Concern is necessary but not sufficient for species recovery. Many species have low risk of extinction (and thus are listed as Least Concern) but continue to be of conservation concern. These include species with populations that are severely depleted compared to levels prior to human impacts, and species that have been extirpated from many parts of their historical ranges. Other systems, such as Green Status¹⁰ metrics, must be used to guide conservation action for achieving species recovery beyond decreasing extinction risks. However, it is likely that actions guided by STAR to abate threat and restore habitat for threatened species would also provide conservation benefits for many Least Concern species.

Feasibility of abating threats

The STAR calculation includes all threats, regardless of the feasibility of abatement. There is large variation (among regions, species, and types of threats) in terms of how feasible it is to abate threats. In some cases there may be options to reduce the impact of the threat rather than its actual intensity, for example through species-specific action to mitigate the effects of climate change. Other threats may cause changes that are irreversible, for instance many types of land transformation, or exploitation that leads to very small population sizes and permanently alters species biology, behaviour and demography. Other threats may be possible to reverse or abate, but not in the time frames useful for conservation decision-making, or not in a way that is practical or feasible. The overall STAR score includes these threats, as it is important to acknowledge and quantify the extent to which all threats, reversible or otherwise, impact species. However, the STAR scores that can be realized through conservation interventions for particular species and places will depend on which threats can feasibly be addressed.

Supplementary References

- 50 IUCN. IUCN Red List Categories and Criteria: Version 3.1 Second Edition., iv+32 (Gland, Switzerland and Cambridge, UK: IUCN, 2012).