

Expert perspectives on global biodiversity loss and its drivers and impacts on people

Forest Isbell^{1*}, Patricia Balvanera^{2†}, Akira S Mori^{3†}, Jin-Sheng He^{4,5†}, James M Bullock^{6†}, Ganga Ram Regmi^{7,8}, Eric W Seabloom¹, Simon Ferrier⁹, Osvaldo E Sala¹⁰, Nathaly R Guerrero-Ramírez¹¹, Julia Tavella¹², Daniel J Larkin¹³, Bernhard Schmid^{14,15}, Charlotte L Outhwaite¹⁶, Pairoi Pramual¹⁷, Elizabeth T Borer¹, Michel Loreau¹⁸, Taiwo Crossby Omotoriogun^{19,20,21}, David O Obura²², Maggie Anderson¹, Cristina Portales-Reyes¹, Kevin Kirkman²³, Pablo M Vergara²⁴, Adam Thomas Clark^{25,26,27}, Kimberly J Komatsu²⁸, Owen L Petchey²⁹, Sarah R Weiskopf³⁰, Laura J Williams³¹, Scott L Collins³², Nico Eisenhauer^{27,33}, Christopher H Trisos^{34,35,36}, Delphine Renard³⁷, Alexandra J Wright³⁸, Poonam Tripathi³⁹, Jane Cowles¹, Jarrett EK Byrnes⁴⁰, Peter B Reich^{31,41,42}, Andy Purvis^{43,44}, Zati Sharip⁴⁵, Mary I O'Connor⁴⁶, Clare E Kazanski⁴⁷, Nick M Haddad⁴⁸, Eulogio H Soto⁴⁹, Laura E Dee⁵⁰, Sandra Díaz^{51,52}, Chad R Zirbel¹, Meghan L Avolio⁵³, Shaopeng Wang⁵⁴, Zhiyuan Ma⁵⁴, Jingjing Liang⁵⁵, Hanan C Farah¹, Justin Andrew Johnson⁵⁶, Brian W Miller⁵⁷, Yann Hautier⁵⁸, Melinda D Smith⁵⁹, Johannes MH Knops⁶⁰, Bonnie JE Myers⁶¹, Zuzana V Harmáčková⁶², Jorge Cortés^{63,64,65}, Michael BJ Harfoot⁶⁶, Andrew Gonzalez⁶⁷, Tim Newbold¹⁶, Jacqueline Oehri²⁹, Marina Mazón⁶⁸, Cynnamon Dobbs⁶⁹, and Meredith S Palmer⁷⁰

Despite substantial progress in understanding global biodiversity loss, major taxonomic and geographic knowledge gaps remain. Decision makers often rely on expert judgement to fill knowledge gaps, but are rarely able to engage with sufficiently large and diverse groups of specialists. To improve understanding of the perspectives of thousands of biodiversity experts worldwide, we conducted a survey and asked experts to focus on the taxa and freshwater, terrestrial, or marine ecosystem with which they are most familiar. We found several points of overwhelming consensus (for instance, multiple drivers of biodiversity loss interact synergistically) and important demographic and geographic differences in specialists' perspectives and estimates. Experts from groups that are underrepresented in biodiversity science, including women and those from the Global South, recommended different priorities for conservation solutions, with less emphasis on acquiring new protected areas, and provided higher estimates of biodiversity loss and its impacts. This may in part be because they disproportionately study the most highly threatened taxa and habitats.

Front Ecol Environ 2022; doi:10.1002/fee.2536

Recent global reports (Díaz *et al.* 2019; IPBES Secretariat 2019; CBD 2020) have rigorously synthesized the large scientific literature on biodiversity and have identified major knowledge gaps. These gaps include large uncertainties in how

many species are threatened with extinction (Díaz *et al.* 2019; CBD 2020; IUCN 2020), a lack of estimates for the impacts of global biodiversity loss on ecosystems and people (Isbell *et al.* 2017), and geographic and taxonomic biases in the available information (Tydecks *et al.* 2018). It remains difficult to fill these knowledge gaps due in part to the impressive diversity and complex biogeographic patterns of life on Earth. For example, in the past two decades, only about 1% of the estimated number of species have been assessed for risk of extinction by the International Union for Conservation of Nature (IUCN) (Mora *et al.* 2011; CBD 2020). Additional sources of information are urgently needed to inform global biodiversity conservation goals, targets (Díaz *et al.* 2020; Rounsevell *et al.* 2020; CBD 2021), and the policies and other transformative changes that will be needed to achieve them (CBD 2020).

Decision makers often rely on expert judgement to fill knowledge gaps (Cooke 1991; Sutherland and Burgman 2015; Cooke *et al.* 2018). Expert judgement has provided estimates and predictions of key unknowns in fields as diverse as nuclear-power safety (Cooke 1991), volcanic eruptions (Aspinall 2010), climate change (Bamber *et al.* 2019), and biodiversity loss (Schlapfer *et al.* 1999; Sala *et al.* 2000). The most accurate estimates and predictions come from large and diverse groups of experts, in part because expertise declines precipitously outside an individual's area of specialization (Aspinall 2010; Burgman

In a nutshell:

- Biodiversity experts estimated that about 30% (uncertainty range: 16–50%) of species have been globally threatened or driven to extinction since the year 1500
- There was overwhelming consensus that global biodiversity loss will likely decrease ecosystem functioning and nature's contributions to people
- Global biodiversity loss and its impacts may be greater than previously thought, due to higher estimates provided for understudied taxa and by underrepresented experts
- Experts estimated that greatly increasing conservation investments and efforts now could remove the threat of extinction for one in three species that may otherwise be threatened or extinct by the year 2100

¹Department of Ecology, Evolution and Behavior, University of Minnesota, St Paul, MN ^{*}(isbell@umn.edu); ²Instituto de Investigaciones en Ecosistemas y Sustentabilidad, Universidad Nacional Autónoma de

et al. 2011; Sutherland and Burgman 2015). For example, biodiversity experts often study a small subset of taxa and ecosystems, whereas the drivers of biodiversity loss and sustainable solutions vary from place to place (Balvanera *et al.* 2017). Furthermore, even when small groups of specialists are carefully selected to ensure a diversity of expertise and geographic representation, the typical selection criteria (eg academic credentials, numbers of publications, years of experience) do not necessarily correspond to an expert's ability to provide accurate estimates or predictions (Burgman *et al.* 2011; Sutherland and Burgman 2015). Instead, the best judgements tend to come from experts who are less self-assured and assertive, and who integrate information from diverse sources (Sutherland and Burgman 2015). Input from a large and diverse group of biodiversity experts could therefore add to existing information and help fill remaining gaps in knowledge of global biodiversity loss.

Here, our objective was to gather and synthesize estimates and perspectives from thousands of biodiversity experts worldwide who collectively study all major taxa and habitats in freshwater, terrestrial, and marine ecosystems. We developed a survey to (1) identify points of global consensus, (2) help fill knowledge gaps for understudied taxa and regions, and (3) test for significant differences in estimates and perspectives among groups of experts. We compared survey results to other sources of information, where available (eg for well-studied taxa). Survey questions were developed by an international team of biodiversity experts to ensure that they were widely relevant and understandable to a geographically and linguistically diverse group of experts. Detailed methods are provided in WebPanel 1 and the full survey is provided in WebPanel 2.

We identified biodiversity experts as corresponding authors of papers published in scientific journals over the past decade on the topic of biodiversity (WebPanel 1). Focusing on the taxa and ecosystems they are most familiar with, these experts estimated past and future global biodiversity loss, which was defined in the survey as the percentage of species that are globally threatened or extinct (WebTable 1). Experts also ranked the drivers of global biodiversity loss and estimated its impacts on ecosystems and people. We received 3331 responses from biodiversity experts (WebTable 2) residing in 113 countries and conducting research on biodiversity in nearly all (187) countries (WebFigure 1), including all major habitats in freshwater, terrestrial, and marine ecosystems. Results reveal a few points on which experts overwhelmingly agreed and, notably, substantial differences in estimates and perspectives among geographic and demographic groups of experts. A follow-up survey (WebPanel 3) formally assessed the accuracy of estimates for a subset of experts (WebPanel 1; Cooke 1991; Colson and Cooke 2018; Quigley *et al.* 2018).

■ Magnitudes of past and future global biodiversity loss

Biodiversity experts estimated that about 30% (uncertainty range: 16–50%) of species have been globally threatened or

driven extinct since the year 1500 (Figure 1a). Estimates of past biodiversity loss were highest among experts who study freshwater ecosystems, amphibians, mammals, and freshwater plants (Figure 1a; WebTable 3). Many tropical habitats (eg tropical and subtropical rivers, wetlands, and forests) were estimated to have the greatest percentage of species threatened or driven extinct since 1500 (Figure 2a).

Biodiversity experts studying terrestrial or freshwater invertebrates (which are mostly insects) estimated that about 30% (uncertainty range: 20–50%) of these species have been threatened or driven extinct since 1500 (Figure 1a). For these hyperdiverse and understudied taxa, expert estimates help fill an important knowledge gap and suggest that many more species may be threatened than previously thought. In particular, insects are the most diverse and understudied group of species, given that they make up about 75% of all species of animals and plants (Díaz *et al.* 2019; Purvis *et al.* 2019; IUCN 2020) and the IUCN has assessed threatened status for less than 0.2% of the roughly six million species (Purvis *et al.* 2019; IUCN 2020). A recent estimate that at least one million species of animals and plants are currently threatened with extinction assumed that 10% of insect species are threatened, based on a comprehensive review of the limited available evidence (Díaz *et al.* 2019; Purvis *et al.* 2019). Our survey estimates, which were provided by 629 experts who study terrestrial and freshwater invertebrates, therefore suggest that the percentage of insect species that are threatened may be much higher. Further investigations of the diversity and threatened status of insects and other hyperdiverse and understudied taxa are urgently needed (Clausnitzer *et al.* 2009; Eisenhauer *et al.* 2019; van Klink *et al.* 2020), especially in light of large recent declines in insect abundance in some locations (Eisenhauer *et al.* 2019; van Klink *et al.* 2020).

For well-studied groups of animals and plants, where at least 80% of the species have been assessed by the IUCN (IUCN 2020), expert estimates were not systematically higher or lower than IUCN estimates (Figure 1a, paired *t* test: $t = -0.93$, $P = 0.39$), although expert estimates were somewhat higher than previous estimates for birds and mammals (IUCN 2020) and somewhat lower than previous estimates for plants (Figure 1a; Nic Lughadha *et al.* 2020). Expert estimates would be expected to be slightly higher because they include not only currently threatened species but also extinctions since 1500 (Ceballos *et al.* 2015; Humphreys *et al.* 2019). For the species groups assessed by the IUCN, survey estimates may be partly influenced by IUCN estimates, creating an unavoidable circularity in comparisons. When responding to survey questions, experts were instructed to use their knowledge of the scientific literature, but to provide their current best estimates rather than rely on their recollection of previously published estimates.

If current trends continue, then further loss of biodiversity is expected, and experts estimated that 37% (uncertainty range: 20–50%) of species might be threatened or

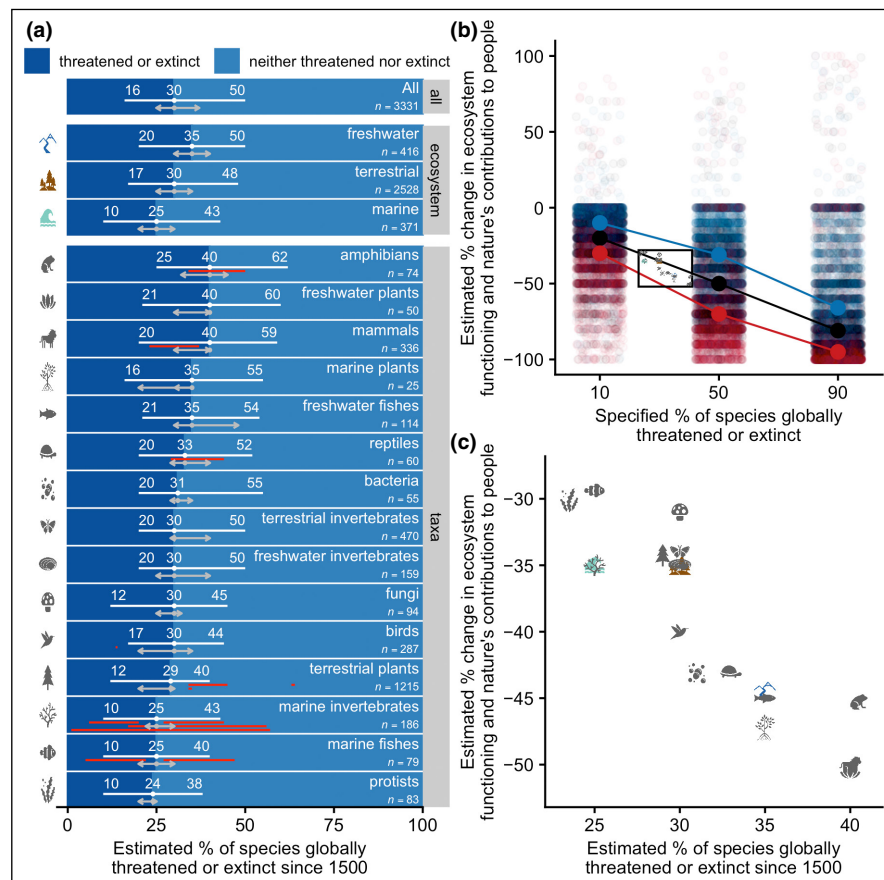


Figure 1. Expert estimates of (a) global biodiversity loss and (b, c) its impacts. (a) Medians of estimates and upper and lower bounds for past biodiversity loss (white circles, lines) and future biodiversity loss by 2100 if current trends continue (rightward gray arrows) or if conservation efforts are increased (leftward gray arrows). Where available, IUCN estimates are shown (red lines). (b) Expert estimates (black) as well as lower (blue) and upper (red) bounds for impacts of three levels of biodiversity loss (jittered on the x-axis). (c) Combining estimates of past biodiversity loss (a) and its impacts (b, linearly interpolated) shows the estimated impacts of past biodiversity loss. Sample sizes show the number of responses, which do not always sum to the total because respondents were not required to answer all questions.

driven to extinction by 2100 (Figures 1a and 2). Furthermore, many currently threatened species were predicted to go extinct before the end of this century. Most experts (84%) expected species to go extinct less than 100 years after becoming threatened, with 75% of experts expecting extinctions to occur within decades (10–100 years) and an additional 9% of experts expecting extinctions to occur within 10 years. Alternatively, if conservation investments and efforts are increased now, immediately implementing all currently known strategies, then experts estimated that 25% (rather than 37%) of species could be threatened or driven to extinction by 2100 (Figures 1a and 2). Thus, greatly increasing conservation investments and efforts now might remove the threat of extinction for about one in three of the species predicted to be threatened or driven to extinction by the end of this century (Figures 1a and 2). Reversing past global biodiversity loss (Mace *et al.* 2018; Leclère *et al.* 2020) will require new and ambitious transformative changes (Díaz *et al.* 2019). As more threatened species become globally extinct, biodiversity loss becomes increasingly irreversible.

Impacts of global biodiversity loss on ecosystems and people

We found overwhelming consensus (96% of experts agreed) that global biodiversity loss is decreasing ecosystem functioning and nature's contributions to people (NCP; Figure 1b). Experts estimated that the global threatening or extinction of species reduces ecosystem functioning and NCP by roughly 10–70%, accounting for large uncertainties in both the estimated magnitude of past global biodiversity loss and its estimated impacts (Figure 1b). That is, experts estimated that a lower bound of global biodiversity loss (10% of species threatened or driven to extinction) could decrease ecosystem functioning and NCP by at least 10%, and an upper bound of global biodiversity loss (50% of species threatened or driven to extinction) could decrease ecosystem functioning and NCP by as much as 70% (Figure 1b). Estimates of the impacts of global biodiversity loss were highest for freshwater ecosystems (Figure 1c; WebTable 3; WebFigure 2b) and for people's experiences in nature, water quality, opportunities for learning and inspiration, and the regulation of detrimental organisms, extreme events, soils, and climate (WebFigure 3). These estimated impacts of the global threatening or

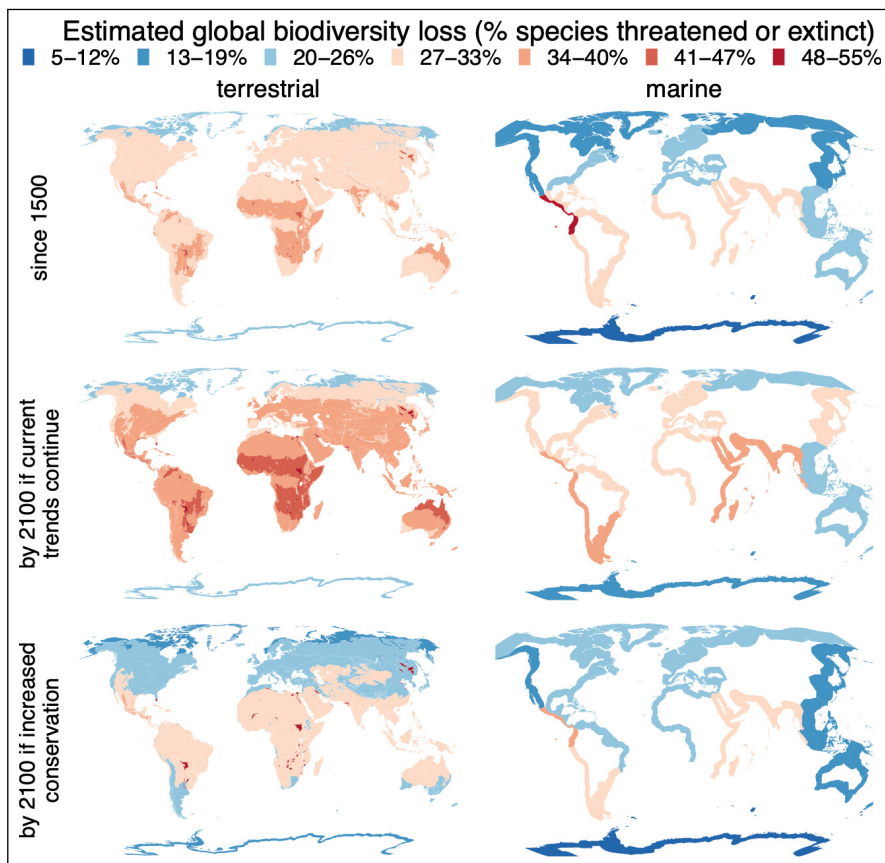


Figure 2. Expert estimates of changes in global biodiversity in terrestrial biomes (left column) and marine realms (right column) since 1500 (top row), by 2100 if current trends continue (middle row), or by 2100 if conservation efforts are intensified (bottom row). Values represent medians across all responses received from experts investigating biodiversity in each terrestrial biome and marine realm and are shown for terrestrial biomes and marine realms with at least ten responses (minimum = 11, median = 35, maximum = 470 responses per biome or realm). See WebFigure 2 for additional marine and freshwater habitats.

extinction of species are larger than the observed impacts of local species loss, which have been thoroughly studied in hundreds of biodiversity experiments and dozens of observational and theoretical studies (Loreau *et al.* 2022; O'Connor *et al.* 2017; van der Plas 2019). However, the impacts of global and local biodiversity loss are not expected to be equivalent (Isbell *et al.* 2017). For example, additional effects of biodiversity on ecosystem functioning can arise at larger spatial and temporal scales (Yachi and Loreau 1999; Isbell *et al.* 2011; Mori *et al.* 2018) and declines in the abundance of threatened species may have impacts before species are locally or globally lost.

■ Drivers of global biodiversity loss

Expert rankings of direct drivers of biodiversity loss differed substantially and significantly ($P < 0.05$) among taxa and ecosystems (Figure 3, a and c; WebTable 4; WebFigures 4 and 5). Previous studies (Sala *et al.* 2000; Maxwell *et al.* 2016; Purvis *et al.* 2019) identified land-use change

and overexploitation as top drivers of global biodiversity loss, but primarily considered terrestrial ecosystems (Sala *et al.* 2000) or the few groups of species that have been thoroughly assessed by the IUCN (Joppa *et al.* 2016; Maxwell *et al.* 2016). Consistent with previous research (Sala *et al.* 2000; Maxwell *et al.* 2016; Purvis *et al.* 2019), we found land- and sea-use change was the top-ranked driver of global biodiversity loss (Figure 3a; WebTable 4), overexploitation was ranked as a major driver for losses of mammals and fishes (Figure 3c; Maxwell *et al.* 2016), and climate change was ranked as a major driver of losses in some of the most rapidly warming terrestrial ecosystems, including the tundra (WebFigures 4 and 5; Sala *et al.* 2000). We also found that climate change and overexploitation were top-ranked drivers of marine biodiversity loss, whereas land- and sea-use change and pollution were top-ranked drivers of freshwater biodiversity loss (Figure 3c; WebTable 4). Land- and sea-use change was identified as the most important driver of biodiversity loss for many well-studied taxa (eg amphibians, mammals, reptiles, birds) and for some hyperdiverse taxa whose threats have not yet been widely assessed by the IUCN (eg terrestrial invertebrates, some plant groups) (Figure 3, a and c). Climate change and pollution were among the major drivers of biodiversity loss for many other understudied taxa, including aquatic invertebrates and microbes (Figure 3c). While demonstrating

that land- and sea-use change is essential to address, our results also indicate that comprehensively conserving biodiversity will require tackling many other drivers of biodiversity loss as well.

Magnitudes of biodiversity loss are expected to increase with further habitat loss (Haddad *et al.* 2015; Isbell *et al.* 2015) and climate change (Urban 2015; Trisos *et al.* 2020). Experts estimated that losing 50% or 90% of habitat threatens or drives to extinction about 41% (range: 30–60%) or 80% (range: 63–95%) of species, respectively (WebFigure 6a). The experts also estimated that global warming by 2°C or 5°C threatens or drives to extinction about 25% (range: 15–40%) or 50% (range: 32–70%) of species, respectively (WebFigure 6b). These estimates are higher than some previous related estimates; for instance, previous studies have projected that loss of 50% or 90% of habitat could lead to loss of 7–36% or 21–78% of species, respectively (Isbell *et al.* 2015), and that warming of 4.3°C could threaten 16% of species (Urban 2015).

Globally, most species are threatened by multiple drivers of biodiversity loss (Maxwell *et al.* 2016). We found overwhelming

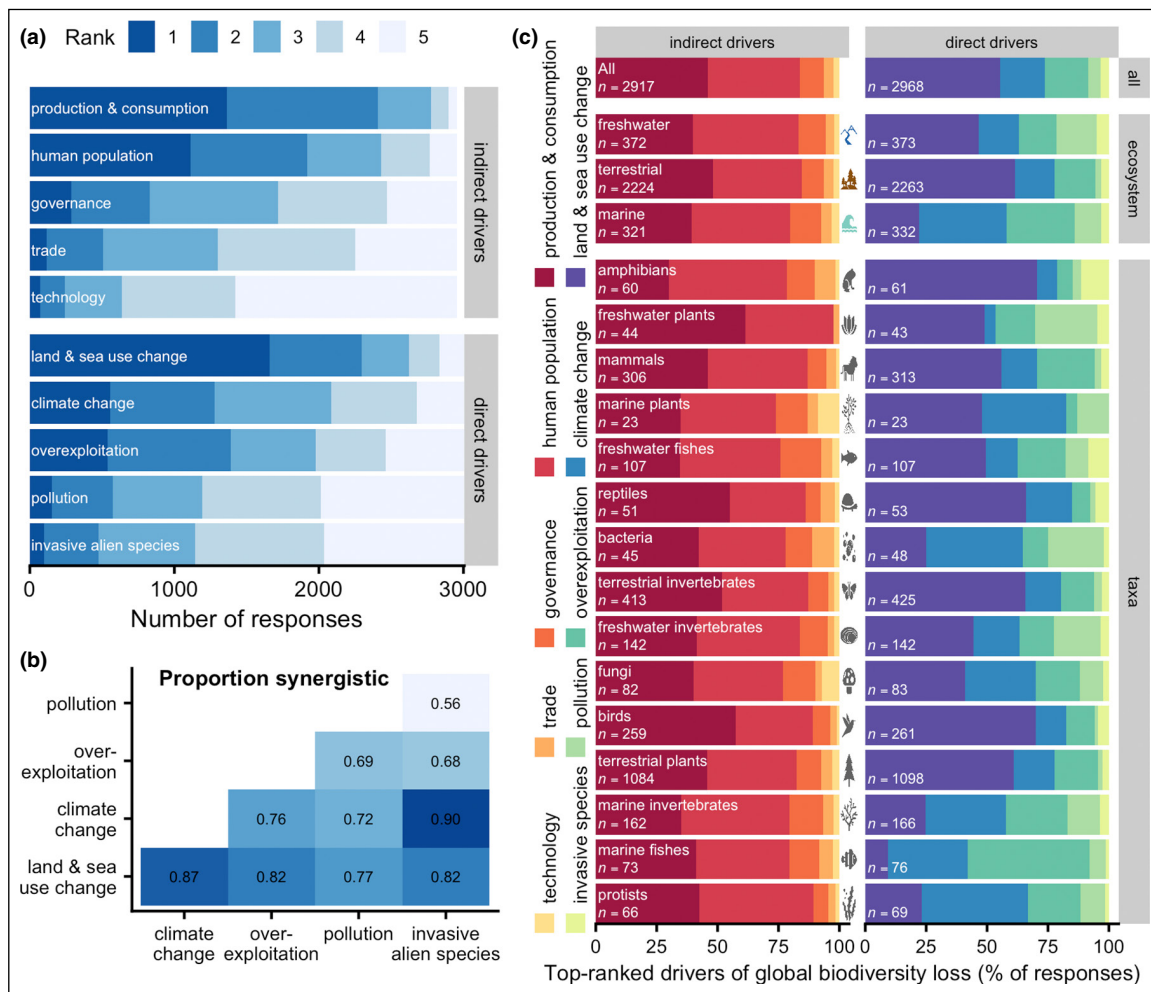


Figure 3. (a) Expert rankings of drivers of biodiversity loss, (b) their synergistic interactions, and (c) top-ranked drivers by ecosystem type and taxa. (a) Low numbers correspond to large impacts on biodiversity. Experts indicated biodiversity loss is driven primarily by changes in land use and sea use resulting from production and consumption patterns and human population growth. (b) Dark colors indicate that many experts expected the pair of drivers to synergistically reduce biodiversity to a greater degree than the sum of their individual effects. See WebTable 4 for tests of significant differences in rankings and WebFigures 5 and 6 for driver rankings by habitat.

consensus (94% of experts agreed) that there are synergistic interactions between pairs of direct drivers of biodiversity loss, such that the combined effects of multiple drivers are greater than the sum of their individual effects. This consensus could help improve the specification and accuracy of projections of future changes in biodiversity (Sala *et al.* 2000). When asked about specific pairs of drivers, 90% of experts reported synergistic interactions between climate change and invasive alien species, whereas just over half (56%) of experts reported synergistic interactions between pollution and invasive alien species (Figure 3b).

Upstream from these direct drivers of biodiversity loss are indirect drivers, which can be considered root causes and leverage points for addressing biodiversity loss (Díaz *et al.* 2019). We asked experts to rank the relative importance of five classes of indirect drivers. Experts reported that biodiversity loss is driven indirectly, in order of decreasing relative importance, by production and consumption, human population dynamics,

governance, trade, and technology (Figure 3, a and c; WebTable 4). In contrast to the rankings of direct drivers, these rankings of indirect drivers remained fairly consistent across ecosystems, habitats, and taxa (Figure 3c; WebFigures 4 and 5; WebTable 4).

Demographic and geographic differences in experts' estimates and recommendations

In addition to helping fill knowledge gaps and identify points of consensus, expert judgement can also reveal important demographic and geographic differences in perspectives and estimates. Demographic and geographic groups of experts provided similar rankings of direct and indirect drivers of biodiversity loss (Figure 4b; WebTable 4), but recommendations for allocating conservation budgets varied (Figure 4c; WebTable 3). Specifically, we asked experts to indicate their recommended allocation of conservation investments to five

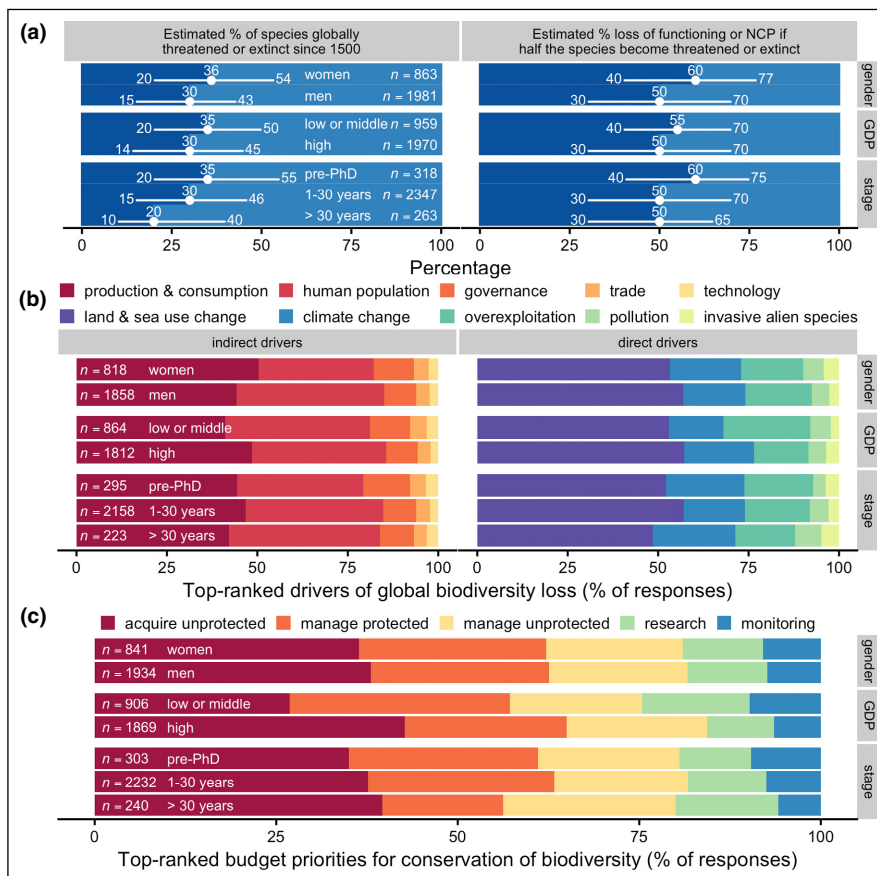


Figure 4. Demographic and geographic groups of experts provided (a) different estimates of biodiversity loss and its impacts, (b) similar rankings of drivers, and (c) different recommended top priorities for conservation budgets. Symbols, lines, and colors in (a) and (b) match those in Figure 1 and Figure 3, respectively. Genders were self-identified. NCP = nature's contributions to people. See WebTable 2 for other genders with small sample sizes. For gross domestic product (GDP) comparisons, countries were grouped into high-income countries or all other income groups, following the World Bank's classification for 2020. For career stage, the number of years of related work post-PhD is provided.

categories: acquire new protected areas, manage protected areas, manage unprotected areas, monitor biodiversity, and research biodiversity. Experts who identified as women recommended investing more in monitoring biodiversity ($P < 0.01$) and less in acquiring unprotected areas ($P < 0.001$) than experts who identified as men (Figure 4c; WebTable 3). Experts who live in low- or middle-income countries recommended investing more in researching and monitoring biodiversity ($P < 0.001$), and less in acquiring and managing unprotected areas ($P < 0.001$), than experts who live in high-income countries (Figure 4c; WebTable 3). Experts less than 30 years post-PhD recommended investing more in managing protected areas ($P < 0.05$) and monitoring biodiversity ($P < 0.01$) than experts at later stages in their careers (Figure 4c; WebTable 3). In addition, a multivariate analysis of variance indicated a significant two-way interaction between gender and income group ($F_{2,2764} = 3.82$, $P < 0.01$), as well as significant main effects of gender ($F_{4,2764} = 4.07$, $P < 0.01$), income group ($F_{4,2764} = 32.64$, $P < 0.001$), and career stage ($F_{4,2764} = 8.67$, $P < 0.001$) on the overall recommended

budget allocation strategy. Men from wealthy countries, who tend to be overrepresented in biodiversity science and policy (Tydecks *et al.* 2018; Maas *et al.* 2021; Mori 2022), recommended investing in significantly different priorities than their colleagues, especially women from the Global South. Experts who recommended allocating more funds to research also recommended allocating more funds to monitoring (Pearson's $r = 0.27$, $t = 14.74$, $P < 0.001$).

Furthermore, demographic and geographic groups of experts provided significantly different estimates for the magnitude of biodiversity loss and its impacts (Figure 4a; WebTables 2 and 3). Notably, certain groups of experts that have been underrepresented in global biodiversity science, including experts who identify as women and who are from the Global South (Tydecks *et al.* 2018; Maas *et al.* 2021; Mori 2022), provided significantly ($P < 0.01$) higher estimates for past biodiversity loss and its impacts (Figure 4a; WebTables 2 and 3). There are several potential explanations for this variability in estimates (Figure 4a).

First, groups of experts may provide higher estimates if they disproportionately study the places or taxa that are experiencing the greatest biodiversity loss. For example, low- and middle-income regions are known to harbor a disproportionate share of the world's ecoregions and threatened species (Tydecks *et al.* 2018). Therefore, it is perhaps unsurprising that experts who live in these countries, and who compose the majority (79% of responses) of all experts who study biodiversity in those nations, provided higher estimates of biodiversity loss (Figure 4a). Indeed, we found that even experts who live in high-income countries provided higher estimates of past biodiversity loss if they study biodiversity only in low- or middle-income countries than if they study biodiversity only in high-income countries (Mood's median test, $Z = -2.30$, $P = 0.021$). Moreover, we found that experts who identify as women disproportionately study taxa that experts estimated are under greatest threat. That is, estimates of past biodiversity loss were higher for the taxa that are disproportionately studied by women, regardless of whether we considered all experts (Mood's median test, $Z = 3.21$, $P = 0.0014$) or, to avoid circularity, only those who identify as men (Mood's median test, $Z = 3.09$, $P = 0.0020$). Consequently, at least some of the geographic and demographic variation in estimates is likely due to underlying variation in rates of biodiversity loss and differences in which locations or what taxa various groups of experts tend to study.

It is also possible that differences in estimates are due to some groups of experts providing more accurate estimates than other groups, although we found no evidence of this. To formally assess the accuracy and informativeness of expert estimates, a follow-up survey, which included test questions with accepted answers, was completed by 59 coauthors of this paper (WebPanel 1). We then used the classical model of expert elicitation (Cooke 1991; Quigley *et al.* 2018) to analyze results. We found considerable variation in the accuracy and informativeness of estimates within all groups of experts (WebTable 5; WebFigure 7), but no significant differences between demographic or geographic groups of experts (WebTable 6). We also found no evidence that experts who provided higher or lower estimates of past biodiversity loss also tended to provide more accurate or informative estimates (WebPanel 1).

■ Survey limitations

We acknowledge some limitations of our survey and explain how we attempted to address them, even if imperfectly. Our main survey did not include test questions with accepted answers. We did, however, include test questions in our follow-up survey to (1) test for systematic bias in estimates and (2) assess the statistical accuracy of several equal-weighted or performance-weighted approaches for combining expert estimates (WebPanel 1). We found no evidence for systematic bias in estimates (WebPanel 1; WebFigure 7). We also determined that the equal-weighted median approach, which we used throughout our analysis to combine expert estimates, was sufficiently statistically accurate, albeit less so than performance-weighting (WebPanel 1; WebTable 5).

Our survey and its sample of biodiversity experts were biased toward experts who publish and communicate in English. Although the invitation to complete the survey was translated into several languages (see “author contributions” in the Acknowledgements), our main survey was offered only in English. In addition, although we received responses from a large and diverse group of experts, our process of identifying biodiversity experts as corresponding authors of scientific papers published in English failed to include many other experts, such as many Indigenous peoples, conservation practitioners (Sandbrook *et al.* 2019), and other experts who primarily publish or communicate in non-English languages. Failing to include non-English-language studies can bias ecological meta-analyses (Amano *et al.* 2016; Konno *et al.* 2020). In an effort to make the survey questions relevant and accessible to experts worldwide, we iteratively revised the questions with an international team of experts who together study all major taxonomic groups and ecosystem types, and represent multiple career stages, genders, and regions of the world. We encourage future studies that collaboratively develop and translate surveys into multiple languages and that fully include the perspectives and voices of more biodiversity experts worldwide, including those in the Global South and East (Mori 2022).

Other biases in the sample of biodiversity experts were also apparent. We received twice as many responses from experts who identified as men than from experts who identified with other genders, and twice as many responses from experts who live in Europe and Central Asia than from experts who live in any other region of the world (WebTable 2). Often, the over-represented groups of experts provided relatively low estimates for the magnitude of past biodiversity loss and its impacts on ecosystems and people (WebTable 2). Thus, the overall values we report likely underestimate the projections that would be provided by a demographically or geographically stratified sample.

■ Conclusions

Our results help fill knowledge gaps, identify points of consensus, and reveal important differences in experts' estimates and recommendations. The expert estimates reported here complement, but do not supersede, other existing empirical evidence. Together, our results suggest that more species may be threatened than previously thought, given relatively high estimates of biodiversity loss for understudied and hyperdiverse taxa and from some historically marginalized groups of experts, including experts who identify as women or are from the Global South (Tydecks *et al.* 2018; Maas *et al.* 2021). Furthermore, our results suggest that a currently emphasized biodiversity conservation solution – the expansion of protected areas (Dinerstein *et al.* 2019; CBD 2021) – is perceived as a higher priority by historically overrepresented groups of experts, including experts who identify as men or who live in the Global North (Tydecks *et al.* 2018; Maas *et al.* 2021). We encourage biodiversity experts to use these results to learn how their own perspectives differ from those of other experts (Sandbrook *et al.* 2019; Mori 2022), and to ensure that a diversity of perspectives is included when conducting global biodiversity assessments, setting global biodiversity goals and targets, and formulating the novel policies and other transformative changes needed to conserve biodiversity.

■ Acknowledgements

We thank all biodiversity experts who responded to our survey. Funding was provided by the US National Science Foundation (DEB-1545288, DEB-1845334, DBI-2021898). NE gratefully acknowledges the support of the German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig funded by the German Research Foundation (FZT 118, 202548816) as well as the Jena Experiment (DFG; FOR 5000). *Author contributions:* FI conceived the project, created the first draft of the survey, analyzed the data, and wrote the paper, with substantial input from all coauthors. An international team with expertise in all major taxonomic groups and ecosystem types, and who represent multiple career stages, genders, and regions of the

world, provided feedback on multiple drafts of the survey, including: MA, MLA, PB, JMB, JEKB, ATC, SLC, JCow, JCor, LED, NE, AG, NRG-R, NMH, YH, CEK, KK, KJK, DJL, JL, ML, ASM, TN, MIO, MSP, OLP, PP, CP-R, PBR, DR, OES, BS, EWS, MDS, CHT, LJW, AJW, and CRZ. To encourage survey responses from parts of the world where English is not the primary language, PB, ASM, and J-SH translated the survey invitation into other languages (Spanish, Japanese, Chinese), and PB, ASM, J-SH, and JMB helped disseminate the survey to ecological societies. To promote geographic and gender diversity of coauthors, and to avoid “helicopter science” (<https://doi.org/10.1016/j.cell.2020.12.019>), multiple experts, including those identifying as women, were invited as coauthors from each habitable continent. To promote equity in author order, coauthors were randomly, rather than alphabetically, ordered into two groups, with PB, ASM, J-SH, and JMB contributing the most. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the US Government.

■ Data Availability Statement

Data and metadata are available through the Environmental Data Initiative at <https://doi.org/10.6073/pasta/127ceb32ee80675b1484e154c3920b45>.

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- México, Morelia, México; ³Research Center for Advanced Science and Technology, The University of Tokyo, Tokyo, Japan; ⁴Department of Ecology, Key Laboratory for Earth Surface Processes of the Ministry of Education, Peking University, Beijing, China; ⁵State Key Laboratory of Grassland Agroecosystems, College of Pastoral Agriculture Science and Technology, Lanzhou University, Lanzhou, China; ⁶UK Centre for Ecology and Hydrology, Wallingford, UK; ⁷Third Pole Conservancy, Bhaktapur, Nepal; ⁸Clouded Leopard Working Group, c/o Small Wild Cat Conservation Foundation, Corrales, NM; ⁹CSIRO Land and Water, Canberra, Australia; ¹⁰Global Drylands Center, School of Life Sciences and School of Sustainability, Arizona State University, Tempe, AZ; ¹¹Biodiversity, Macroecology and Biogeography, Faculty of Forest Sciences and Forest Ecology, University of Göttingen, Göttingen, Germany; ¹²Universidad de Buenos Aires, Facultad de Agronomía, Cátedra de Botánica General, Buenos Aires, Argentina; ¹³Department of Fisheries, Wildlife, and Conservation Biology and Minnesota Aquatic Invasive Species Research Center, University of Minnesota, St Paul, MN; ¹⁴Department of Geography, University of Zurich, Zurich, Switzerland; ¹⁵Institute of Ecology, College of Urban and Environmental Sciences, Peking University, Beijing, China; ¹⁶Centre for Biodiversity and Environment Research, Department of Genetics, Evolution and Environment, University College London, London, UK; ¹⁷Department of Biology, Faculty of Science, Mahasarakham University, Maha Sarakham, Thailand; ¹⁸Theoretical and Experimental Ecology Station, CNRS, Moulis, France; ¹⁹AP Leventis Ornithological Research Institute, University of Jos, Jos, Nigeria; ²⁰Biotechnology Unit, Department of Biological Sciences, Elizade University, Ilara-Mokin, Nigeria; ²¹Natural History Museum, University of Oslo, Oslo, Norway; ²²Coastal Oceans Research and Development – Indian Ocean (CORDIO) East Africa, Mombasa, Kenya; ²³School of Life Sciences, University of KwaZulu-Natal, Pietermaritzburg, South Africa; ²⁴Universidad de Santiago de Chile, Facultad Tecnológica, Departamento de Gestión Agraria, Santiago, Chile; ²⁵Institute of Biology, University of Graz, Graz, Austria; ²⁶Department of Physiological Diversity, Helmholtz Centre for Environmental Research, Leipzig, Germany; ²⁷German Centre for Integrative Biodiversity Research Halle-Jena-Leipzig, Leipzig, Germany; ²⁸Smithsonian Environmental Research Center, Edgewater, MD; ²⁹Department of Evolutionary Biology and Environmental Studies, University of Zurich, Zurich, Switzerland; ³⁰US Geological Survey, National Climate Adaptation Science Center, Reston, VA; ³¹Department of Forest Resources, University of Minnesota, St Paul, MN; ³²Department of Biology, University of New Mexico, Albuquerque, NM; ³³Institute of Biology, University of Leipzig, Leipzig, Germany; ³⁴African Climate and Development Initiative, University of Cape Town, Cape Town, South Africa; ³⁵Centre for Statistics in Ecology, the Environment and Conservation, University of Cape Town, Cape Town, South Africa; ³⁶National Socio-Environmental Synthesis Center, University of Maryland, Annapolis, MD; ³⁷CEFE, University of Montpellier, CNRS, EPHE, IRD, Montpellier, France; ³⁸California State University, Los Angeles, Los Angeles, CA; ³⁹International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal; ⁴⁰Department of Biology, University of Massachusetts Boston, Boston, MA; ⁴¹Hawkesbury Institute for the Environment, Western Sydney University, Penrith, Australia; ⁴²Institute for Global Change Biology, and School for Environment and Sustainability, University of Michigan, Ann Arbor, MI; ⁴³Department of Life Sciences, Natural History Museum, London, UK; ⁴⁴Department of Life Sciences, Imperial College London, Silwood Park campus, Ascot, UK; ⁴⁵Water Quality and Environment Research Centre, National Water Research Institute of Malaysia, Seri Kembangan, Malaysia; ⁴⁶Department of Zoology, Biodiversity Research Centre, University of British Columbia,

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Supporting Information

Additional, web-only material may be found in the online version of this article at <http://onlinelibrary.wiley.com/doi/10.1002/fee.2536/supinfo>

Vancouver, Canada; ⁴⁷The Nature Conservancy, Minneapolis, MN; ⁴⁸WK Kellogg Biological Station, Department of Integrative Biology, Michigan State University, Hickory Corners, MI; ⁴⁹Centro de Observación Marino para Estudios de Riesgos del Ambiente Costero, Facultad de Ciencias del Mar y de Recursos Naturales, Universidad de Valparaíso, Viña del Mar, Chile; ⁵⁰Department of Ecology and Evolutionary Biology, University of Colorado Boulder, Boulder, CO; ⁵¹Consejo Nacional de Investigaciones Científicas y Técnicas, Instituto Multidisciplinario de Biología Vegetal, CONICET, Córdoba, Argentina; ⁵²Universidad Nacional de Córdoba, Facultad de Ciencias Exactas, Físicas y Naturales, Departamento de Diversidad Biológica y Ecología, Córdoba, Argentina; ⁵³Morton K Blaustein Department of Earth & Planetary Sciences, Johns Hopkins University, Baltimore, MD; ⁵⁴Institute of Ecology, College of Urban and Environmental Sciences and Key Laboratory for Earth Surface Processes of the Ministry of Education, Peking University, Beijing, China; ⁵⁵Forest Advanced Computing and Artificial Intelligence Laboratory, Department of Forestry and Natural Resources, Purdue University, West Lafayette, IN; ⁵⁶Department of Applied Economics, University of Minnesota, St Paul, MN; ⁵⁷US Geological Survey, North Central Climate Adaptation Science Center, Fort Collins, CO; ⁵⁸Ecology and Biodiversity Group, Department

of Biology, Utrecht University, Utrecht, the Netherlands; ⁵⁹Department of Biology, Graduate Degree Program in Ecology, Colorado State University, Fort Collins, CO; ⁶⁰Health and Environmental Sciences Department, Xian Jiaotong-Liverpool University, Suzhou, China; ⁶¹US Geological Survey, National Climate Adaptation Science Center/North Carolina Cooperative Fish and Wildlife Research Unit, Department of Applied Ecology, North Carolina State University, Raleigh, NC; ⁶²Global Change Research Institute of the Czech Academy of Sciences, Brno, Czech Republic; ⁶³Centro de Investigación en Ciencias del Mar y Limnología, Universidad de Costa Rica, San Pedro, Costa Rica; ⁶⁴Escuela de Biología, Universidad de Costa Rica, San Pedro, Costa Rica; ⁶⁵CIBET-Museo de Zoología, Universidad de Costa Rica, San Pedro, Costa Rica; ⁶⁶UN Environment Programme–World Conservation Monitoring Centre, Cambridge, UK; ⁶⁷Department of Biology, McGill University, Montreal, Canada; ⁶⁸Centro de Investigaciones Tropicales del Ambiente y la Biodiversidad (CITIAB), Universidad Nacional de Loja, Loja, Ecuador; ⁶⁹Center for Modelling and Monitoring Ecosystems, School of Forest Engineering, Universidad Mayor, Santiago, Chile; ⁷⁰Department of Ecology and Evolutionary Biology, Princeton University, Princeton, NJ; †coauthors are randomly ordered within two groups, with this group contributing the most

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WebPanel 1. Detailed Methods

Survey design. The survey requested experts' estimates of global biodiversity loss and its consequences for ecosystem functioning and nature's contributions to people. It aimed to extend previous related research (Sala *et al.* 2000, Schlapfer *et al.* 1999) by including more experts and by being more quantitative, in terms of estimates and their uncertainty. An international team of biodiversity experts collaboratively developed the survey questions to ensure that they were clear and accessible to respondents worldwide. Questions were iteratively revised to increase clarity and avoid ambiguity. To avoid constraining responses and the functional forms of relationships between biodiversity loss and its consequences, quantitative questions allowed responses of any integer from 0 to 100%. To help quantify the large uncertainties around estimates, respondents were asked to provide lower and upper bounds for each estimate provided.

The survey was designed in collaboration with survey professionals from the Minnesota Center for Survey Research in the Office of Measurement Services at the University of Minnesota. The survey was developed and disseminated using Qualtrics Survey Software. This project was reviewed and approved by the Institutional Review Board at the University of Minnesota.

Respondents were instructed to (1) skip questions where they were unable to provide estimates; (2) indicate levels of uncertainty by a range for estimates; (3) use knowledge of the scientific literature, but provide current best estimates, rather than recall previously published estimates; and (4) hover over or click on underlined text to see clarifications. Definitions of terms and other clarifications were provided in hover over text (WebTable 1). Terminology was made as consistent as possible with that used in a recent global report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (Díaz *et al.* 2019). The full survey is available in WebPanel 2.

Survey content. The first section of the survey asked respondents to identify areas of expertise. Display logic was used to ask follow-up questions. That is, experts first indicated the type of ecosystem they know best: terrestrial, marine, or freshwater. Depending on this response, they were then asked which terrestrial biome (Olson *et al.* 2001), marine realm (Spalding *et al.* 2007, Spalding *et al.* 2012), or freshwater major habitat type (Abell *et al.* 2008) they know best. Experts were also asked to indicate the direct driver(s) of biodiversity loss they know best. Experts were required to choose only one taxonomic group, and only one of the 18 major groups of nature's contributions to people (Díaz *et al.* 2018) or one of two ecosystem functions (i.e., primary productivity or decomposition), they know best.

The second section of the survey requested estimates of global biodiversity loss and its consequences for ecosystem functioning or nature's contributions to people. Global biodiversity loss was defined as the threatening or extinction of species, following the IUCN's definitions for threatened species (WebTable 1). Respondents were reminded to consider only the type of ecosystem, taxa, and function or contribution that they know best, as indicated in the first section of the survey. Experts were also asked to indicate uncertainty for estimates by providing the likely lower and upper bounds for the mean estimate. Hover over text (WebTable 1) clarified that sources of uncertainty may include those arising from a low quantity or quality of evidence, low level of agreement of evidence, and any gaps in personal knowledge of the literature. Experts who indicated that global biodiversity loss was expected to either decrease or increase ecosystem functioning or nature's contributions to people were asked to provide estimates and uncertainty for specified amounts of global biodiversity loss.

The third section of the survey asked respondents to rank direct and indirect drivers from those that currently threaten biodiversity most to least, and asked whether synergistic, antagonistic, or no interactions were expected between co-occurring drivers and between specific pairs of direct drivers. Experts who indicated expertise in land/sea use change and/or climate change in the first section were asked to estimate the magnitudes of global biodiversity loss expected to occur under specified magnitudes of changes in these direct drivers. Respondents

were again reminded to consider only the type of ecosystem, taxa, and function or contribution that they know best.

The final section of the survey asked questions about respondent demographics and perspectives on conservation. Demographic questions included the highest level of related education, years of related work experience, place of work, country of residence (which were grouped into regions and income groups according to the World Bank's classification), and self-identified gender. Respondents were asked to place their perspectives along non-mutually exclusive continuums for values related to biodiversity conservation, indicate the spatial scales at which they conduct the majority of their biodiversity research, recommend allocation of conservation budgets, and indicate levels of global biodiversity loss that they would consider to be a planetary boundary with respect to sustaining the integrity of nature or its contributions to people.

Survey dissemination. We used a repeatable search to identify biodiversity experts as corresponding authors of articles and reviews published in scientific journals over the last decade on the topic of biodiversity. On the 1st of January 2020, we searched the Web of Science Core Collection for articles or reviews published in English on the topic of biodiversity during the decade from 2010 to 2019. Specifically, we used the following search terms: (WC=(Biodiversity & Conservation OR Ecology OR Multidisciplinary Sciences) AND TS=biodiversity) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article OR Review). This search returned 37,779 results. We downloaded the full record for each of these publications, which included the contact information for corresponding authors. We then used the `ex_email` function in the `qdapRegex` package in R to extract email addresses for all corresponding authors. This returned 50,950 email addresses. Unsurprisingly, many of these email addresses were duplicates, given that many biodiversity experts have been a corresponding author on more than one paper during the past decade. After removing duplicates, there were 35,970 unique email addresses. On the 8th of January 2020, an invitation to complete the survey was sent to each of these email addresses. Two reminders to complete the survey were sent on the 15th and 27th of January. Subsequently, to encourage additional responses globally, the survey invitation was translated by coauthors into Spanish, Japanese, and Chinese, and requests for distribution were made to the Ecological Societies of Argentina, Chile, China, Japan, Mexico, and the UK, and to Institutes of the Chinese Academy of Sciences. Only 6% of responses came from this additional dissemination effort. The survey was closed on the 25th of March 2020.

Survey responses. We received 3,331 responses from biodiversity experts (WebTable 2) who live in 113 countries (WebFigure 1A) and research biodiversity in 187 countries (WebFigure 1B), including all terrestrial biomes and major habitats in freshwater and marine ecosystems (WebFigure 2). Respondents were allowed to retake the survey if they wished to provide responses for different taxa or habitats. However, only 1.7% of email addresses submitted multiple responses, and only 3.9% of IP addresses submitted multiple responses, some of which may have been responses from different experts. Only 0.7% of responses came from duplicate combinations of email and IP addresses. Due to small sample sizes, archaea (N = 8) were grouped with bacteria and seaweeds (N = 46) were grouped with protists. The demographics of survey responses matched some of the previously reported demographic biases in authors of the related scientific literature (Maas *et al.* 2021, Tydecks *et al.* 2018). In particular, most of our survey responses came from experts who identify as men or who live in Europe or North America (WebTable 2).

We are unable to quantify the total number of experts invited to complete the survey or the percentage of experts who responded. Our methods used de-identified email addresses of corresponding authors, which are not associated with names of individuals in the exported Web of Science records. Note that many experts have used multiple email addresses over the last decade as they have advanced their careers or changed workplaces for other reasons. Thus, the number of biodiversity experts invited to complete this survey is likely substantially lower than the number of unique email addresses (35,970) invited to complete the survey. An unknown number of the non-responses are due to inactive emails formerly used by experts who may have responded to the survey using a current email address.

The median time for survey completion was 21 minutes, with 30% of responses taking more than 30 minutes and 10% of responses taking less than 10 minutes. More than 88% of the responses finished the survey. The remaining 12% of responses ranged from 23-98% complete.

Data analyses. There are several well-studied approaches for aggregating expert estimates into a consensus estimate and range of uncertainty (Burgman *et al.* 2011, Cooke 1991, Cooke *et al.* 2008, Hora *et al.* 2013, Lichtendahl *et al.* 2013, Stone 1961). Based on these previous results and results of a follow-up survey (described below), throughout the manuscript, we aggregated expert estimates by taking the median estimate, the median lower bound, and the median upper bound across all experts within each group of interest (e.g., taxonomic group, ecosystem, gender). Results were similar when the mean, rather than the median, was used. We tested for significant differences in median estimates between groups (e.g., between freshwater, terrestrial, and marine ecosystems) by using Mood's median test, which was implemented with the `median_test` function in the `coin` package of R (WebTable 3). Kruskal-Wallis tests were used to test for differences in ranks among drivers. When significant, Conover's Test was then used for multiple comparisons between pairs of groups, using Tukey's method to control for multiple *a posteriori* comparisons.

There was some evidence of anchoring in responses. In particular, when given percentages of species that were threatened or extinct, some experts reported similar estimates of percentage changes in ecosystem functioning or NCP (Figure 1b). To assess how this may have affected our results, we considered how exclusion of these responses altered median estimates. Removing these responses had either no effect or a slightly positive effect on median estimates, suggesting that anchoring may have slightly decreased some estimates of the impacts of biodiversity loss.

Follow-up survey to assess the accuracy and informativeness of estimates. To begin to assess the accuracy and informativeness of estimates from biodiversity experts, and to test for bias in estimates, we conducted a follow-up survey that included seed questions (also known as calibration or test questions) with accepted answers. Specifically, we developed a second survey that included seed questions, as well as repeats of some questions from the original survey, and disseminated it to coauthors of this paper. The follow-up survey was completed by 59 coauthors of this paper and is provided in WebPanel 3.

Expert elicitation and aggregation of expert estimates. Expert elicitation is increasingly employed in research and policy (Cooke 1991, Cooke 2018, Sutherland and Burgman 2015). It has been used, for example, to project future changes in biodiversity (Sala *et al.* 2000) and sea level rise (Bamber *et al.* 2019), to consider the impacts of local species loss on ecosystem functioning (Schlapfer *et al.* 1999), and to quantify the social cost of carbon (National Academies of Sciences and Medicine 2017), the number of bird and mammal extinctions prevented by recent conservation actions (Bolam *et al.* 2020), and the impacts of aquatic invasive species on ecosystem services (Rothlisberger *et al.* 2012), as well as a wide range of other applications (Colson and Cooke 2017, Colson and Cooke 2018, Cooke and Goossens 2008, Eggstaff *et al.* 2014) in nuclear safety, investment banking, volcanology, public health, and aerospace. Approaches for engaging experts range from using a single unsubstantiated opinion to formal expert elicitation with validation (Cooke 1991, Cooke 2018). Approaches can be categorized as behavioral, in which a group consensus emerges from negotiation or facilitation by a group leader, or mathematical, in which a group consensus is quantified according to a rule (Hora *et al.* 2013). Well-studied rules include taking the unweighted average of probabilities (Stone 1961), the unweighted average of quantiles (Lichtendahl *et al.* 2013), the unweighted median of probabilities (Hora *et al.* 2013), and nonoptimized (*sensu* Rothlisberger *et al.* 2012) or optimized performance-weighted means of probabilities (Cooke 1991). Other weighting schemes based on citation rates or peer rankings have been considered, but do not necessarily indicate accuracy or consistently outperform simpler equal-weighting approaches (Burgman *et al.* 2011, Cooke *et al.* 2008). Here we describe results from a follow-up survey in which we formally assessed the performance of four aggregation approaches: two unweighted approaches (mean and median of probabilities) and two performance-weighted approaches (nonoptimized and optimized). These results

informed our decision to use the unweighted median of probabilities when aggregating responses from our main survey.

Seed questions. There is often a wide range in the accuracy and informativeness of information provided by experts (Colson and Cooke 2018). Although experts are not expected to know the exact answers to survey questions, they may still be able to provide statistically accurate probabilistic statements about unknown quantities. For instance, experts are often asked to provide a median (50th percentile) and 90% credible range (5th and 95th percentile) such that the accepted answer is equally likely to be above or below the median and there is a 90% chance that the accepted answer is within the credible range. If the assessment includes seed questions that have accepted answers (also known as calibration or test questions), in addition to target questions of interest, then responses to seed questions can be used to assess whether experts' probabilistic statements are statistically accurate (i.e., whether observed distributions significantly differ from expected distributions) and can also be used to weight expert estimates when combining estimates for unknown quantities of interest (Cooke 1991). For example, if an expert's 90% credible range fails to include the accepted answer for much more than 90% of the seed questions, then the expert is overconfident and is underestimating the stated level of uncertainty. If an expert's median is below (or above) the accepted answer for much more than half the seed questions, then the expert's estimates are statistically biased.

Seed questions should be closely related to the target questions of interest (Quigley *et al.* 2018). Seed questions should not be general knowledge questions because experts do not outperform nonexperts on generic questions and performance on generic questions does not necessarily predict performance on the discipline-specific unknown variables of interest (Cooke *et al.* 1988). For example, some biodiversity experts may accurately estimate biodiversity loss even if they poorly estimate answers to generic trivia questions, or vice versa. Thus, seed questions should be closely related to the variables of interest to ensure that performance on seed questions corresponds, even if imperfectly, to performance on the target questions of interest.

Developing seed questions is particularly challenging when considering global biodiversity loss, in part because there are an enormous number of unknown variables of interest, i.e., combinations of taxa and ecosystems worldwide, each of which may have different magnitudes, drivers, and consequences of biodiversity loss. A biodiversity expert may, for example, be able to provide accurate estimates of the magnitudes of biodiversity loss for the taxa and ecosystems they know best, even if they are unable to provide accurate estimates for other taxa or ecosystems. Thus, in our original survey, we would have ideally developed a series of seed questions specific to each combination of ecosystem and taxonomic group, with answers that would become available shortly after respondents completed the survey (i.e., domain predictions (Quigley *et al.* 2018)). In the absence of the information needed to develop many sets of specific seed questions with answers that would become known soon after our survey, and to keep our original survey short enough to get multiple responses for many combinations of taxa and ecosystems, we included seed questions (domain retrodictions (Quigley *et al.* 2018)) in a follow-up survey.

The follow-up survey was completed by 59 coauthors of this paper and is provided in WebPanel 3. Seed questions were deliberately chosen from information provided in recent international reports (CBD 2020, Díaz *et al.* 2019, IPBES 2019) to ensure that the accepted answers to seed questions were generated by collaborative processes that included biodiversity experts from around the world. Failing to use information from such collaborative international processes could bias results towards finding that over-represented groups of experts provided more accurate estimates. Seed questions were related to the magnitude of global biodiversity loss and its direct and indirect drivers and included questions about terrestrial and marine ecosystems, and about mammals and other well-studied taxa. We acknowledge that experts could possibly provide accurate estimates of biodiversity loss for the taxa and ecosystems they know best even if they could not do so for these seed questions. The mapping of accuracy from seed to target questions is inevitably imperfect.

Statistical accuracy scores. Expert estimates are statistically accurate if the accepted answers to seed questions fall between the estimated quantiles at the expected frequencies. For example, if

there were 20 seed questions, then we would expect the accepted answer to fall below the 5th percentile for one question, between the 5th and 50th percentiles for nine questions, between the 50th and 95th percentile for nine questions, and above the 95th percentile estimate for one question. If the accepted answer fell outside the 90% credible interval for many more than 2 out of 20 questions, then the expert would be overconfident and would be inaccurately reporting uncertainty. If the accepted answer fell below the 50th percentile for many more than half the questions, then the expert would be inaccurately providing biased estimates of the median. These inaccuracies can be measured by formally comparing the observed and expected proportions of seed questions on which the accepted answer falls in each of these four intervals (i.e., less than 5th percentile, between 5th and 50th percentile, between 50th and 95th percentile, or above the 95th percentile).

Following the classical method for structured expert judgement (Cooke 1991, Quigley, *et al.* 2018), we used the Kullback-Leibler divergence measure, $I(s, p)$, to quantify the difference between the observed and expected probability distributions for each expert and for each decision maker (i.e., aggregated distribution across all experts, see below):

$$I(s, p) = \sum_{i=1}^n s_i \ln \left(\frac{s_i}{p_i} \right) \quad [1]$$

where s_i and p_i are respectively the observed and expected proportions of realizations in interval i , and n is the number of intervals. The probability distribution of the KL divergence measure can be related to the χ^2 distribution (Cooke 1991, Quigley *et al.* 2018):

$$Pr\{2NI(s, p) \leq x\} \rightarrow \chi_{n-1}^2(x), \text{ as } N \rightarrow \infty \quad [2]$$

where N is the number of seed questions and $\chi_{n-1}^2(x)$ is the Cumulative Distribution Function of the χ^2 distribution evaluated at x with $n-1$ degrees of freedom. For our follow-up survey, $N = 9$ seed questions and $n = 4$ intervals. This allows calculation of the probability of observing a KL divergence measure as large as the observed one, which is the familiar P-value. These P-values are used as a statistical accuracy score (Cooke 1991, Quigley *et al.* 2018), $C(e)$, for each expert e :

$$C(e) = 1 - \chi_R^2[2NI(s, p)] \quad [3]$$

where R is the number of quantiles elicited from the expert ($R = n - 1$). These P-values range from zero to one, with higher P-values indicating that expert estimates closely match the expected distribution. These P-values can be used to down-weight or unweight expert estimates (Cooke 1991, Quigley *et al.* 2018), as described below. Accuracy scores (P-values) for individual experts and decision makers (see below) are included in WebTable 5. It is notable that 25 of the 59 experts (42%) had statistical accuracy scores above 0.05, which is a large percentage of experts given that 20% of previous studies had no experts with an accuracy score greater than 0.05 (Colson and Cooke 2018).

Information scores. Experts can have high statistical accuracy scores without providing much information, in the sense that wide credible ranges can lead to high statistical accuracy, without constraining the range of possible values. To counterbalance this to some extent, information scores quantify the density of a distribution relative to a background distribution (Cooke 1991, Quigley *et al.* 2018). In the specific case of our seed questions, in which units of all questions are on a percentage scale, information scores can be thought of as an estimate of precision. Narrow stated credible ranges produce higher information scores. There are many measures of the extent to which a distribution is concentrated or spread out. Many of these measures, such as the standard deviation, have the units of the answer to the question(s), and thus are only comparable between questions or studies that have the same units and scales. Here, to compare our results to other expert elicitation studies, we use a scale invariant measure that has been used across a wide range of elicitation studies (Cooke 1991, Quigley *et al.* 2018).

Specifically, following the classical method for structured expert judgement (Cooke 1991, Quigley *et al.* 2018), we used the Kullback-Leibler divergence measure to quantify the difference between the observed probability distribution and a uniform distribution. The information score for expert e is averaged across all N questions:

$$I(e) = \frac{1}{N} \sum_{j=1}^N \left[\ln(x_{jR+1} - x_{j0}) + \sum_{r=1}^{R+1} p_r \ln \left(\frac{p_r}{x_{jer} - x_{je(r-1)}} \right) \right] \quad [4]$$

where x_{j0} and x_{jR+1} are respectively the lower and upper bounds of the intrinsic range for question j and are the same for all experts e (and thus this indexing subscript is omitted) and where x_{je1} , x_{je2} , and x_{je3} are respectively the 5th, 50th, and 95th quantiles provided by expert e for question j . The lower and upper bounds are often chosen as 10% below and above the observed minimum and maximum values (Cooke 1991, Quigley *et al.* 2018). However, all our seed questions answers were on a percentage scale and respondents were offered the range from 0 to 100%. We therefore use $x_{j0} = 0$ or $x_{jR+1} = 100$. To avoid division by zero where $x_{jer} = x_{je(r-1)}$, we added or subtracted 0.1, ensuring that $0 = x_{j0} < x_{je1} < x_{je2} < x_{je3} < x_{jR+1} = 100$. Information scores (P-values) for individual experts and decision makers (see below) are included in WebTable 5.

Combining accuracy and information scores to quantify weights for each expert. The most useful expert estimates will be both accurate (i.e., the credible range includes the accepted answer as often as expected and the median is above as often as below the accepted answer) and informative (i.e., the credible range is narrow). When combining estimates across experts to estimate an aggregated consensus distribution (also known as a decision maker), it may be desirable to weight each expert's estimates by a combined measure of their accuracy and informativeness. Following the classic model for structured judgement (Cooke 1991, Quigley *et al.* 2018), we quantified weights for each expert e as:

$$w_e = \frac{C(e) \times I(e) \times 1_\alpha(C(e))}{\sum_{e=1}^E C(e) \times I(e) \times 1_\alpha(C(e))} \quad [5]$$

where $1_\alpha(C(e)) = 1$ if $C(e) \geq \alpha$ and $1_\alpha(C(e)) = 0$ if $C(e) < \alpha$. That is, experts with accuracy scores below acceptable levels, as defined by α (the type I error rate), are unweighted (Cooke 1991, Quigley, *et al.* 2018). This ensures that weights obey an asymptotically strictly proper scoring rule: an expert maximizes their long run expected weight if and only if their quantile assessments correspond to their true beliefs (Cooke 1991, Quigley *et al.* 2018). If $\alpha = 0$, then all experts are retained and experts with low accuracy scores, low information scores, or both receive low weights. Here we consider this nonoptimized performance-weighted mean (NPWM) case (*sensu* Rothlisberger *et al.* 2012), as well as an optimized performance-weighted mean (OPWM) case in which an optimal P-value ($0 < \alpha < 1$) is chosen to maximize the numerator of Equation [5] for the performance-weighted decision maker (Cooke 1991, Quigley *et al.* 2018) (see below). In practice, this was done by gradually increasing α such that an increasing number of experts (i.e., all those for which $C(e) < \alpha$) were unweighted (i.e., $1_\alpha(C(e)) = 0$), recalculating weights for each subset of experts, and recalculating the performance-weighted mean decision maker (see below) until the numerator of its weight (Equation [5]) was maximized. Nonoptimized and optimized weights for individual experts are included in WebTable 5. In our study, as in several other studies (Colson and Cooke 2017), the optimal decision maker includes only the single best expert with the highest combined (accuracy and information) score. Note that this single best expert is identified *a posteriori*, rather than *a priori*, and thus this result should not be misinterpreted as suggesting that it is best to seek the judgement of a single expert. In our study and many others (Colson and Cooke 2017, Cooke and Goossens 2008), accuracy scores vary across experts by many orders of magnitude, whereas information scores typically vary much less than an order of magnitude. Consequently, weights are driven largely by accuracy scores and an expert with a low accuracy score cannot achieve a high weight simply by providing a narrow credible range (Colson and Cooke 2018).

Decision makers aggregate individual responses into a consensus. After weights are quantified by combining accuracy and information scores, these weights can be used (or not) to aggregate individual responses into a combination of expert assessments, which is also known as a decision maker (Colson and Cooke 2018). The simplest and most common method for aggregating responses is to simply take the arithmetic mean of each quantile across all experts (Stone 1961). This produces a new consensus distribution, but one that typically (Colson and Cooke 2017), and in our case (WebTable 5), performs worse than performance-weighted alternatives. The weights described above can be used to create a performance-weighted mean that is either nonoptimized, with all experts included (Rothlisberger, *et al.* 2012) (though this fails to obey the asymptotically strict scoring rule described above), or optimized and including only the most accurate experts. A fourth alternative approach takes the median of each quantile, across all experts (Hora *et al.* 2013), which we refer to as the equal-weighted median (EWMN) decision maker. We find that this approach performs better than the equal-weighted mean (EWMN) decision maker, though not as high as the performance-weighted means (WebTable 5). We use this median-based approach when combining results from our main survey, given that the lack of seed questions in our main survey prevents us from using a performance-weighted approach. Note that the equal-weighted median approach was sufficiently statistically accurate, given that the P-value for the decision maker produced by this aggregation approach was much higher (which is desired) than the typical cutoffs of 0.05 or 0.01 that are often used (Colson and Cooke 2018, Quigley *et al.* 2018) for levels of type I error rates (WebTable 5). In other words, although we could have likely produced better estimates for at least some target questions of interest by using performance-weighted means in our main survey (WebFigure 7), results from our follow-up survey suggest that taking the medians across all experts likely leads to sufficiently accurate estimates (WebTable 5).

Quantifying bias in estimates. The above accuracy and information scores compare distributions, and the statistical accuracy score is higher when half the accepted answers are above the estimated medians. The above scores do not, however, assess how close the estimated medians are to the accepted answers, or which direction estimates may be systematically biased above or below the accepted answers. To consider whether median estimates were over- or under-estimated, and by how much, we averaged responses for individuals across seed questions. This was possible only because all seed questions were on a percentage scale and thus had the same units. We then created the four decision makers from these individual averaged (across all seed questions) responses (lower right panel in WebFigure 7). This shows that, for the three decision makers that included all experts, accepted answers were somewhat underestimated, whereas for the optimized performance-weighted mean decision maker, which includes only the expert(s) with acceptably high accuracy, accepted answers were slightly overestimated (WebFigure 7). Specifically, the EWMN or OWMN decision makers were respectively underestimated by 7.6% or overestimated by 3.9% when quantified across all seed questions (WebFigure 7).

In addition to assessing bias across all seed questions, we are particularly interested in the responses to the question about the percentage of threatened species across all well-studied taxonomic groups (upper left panel in WebFigure 7), given that this question is most closely related to the expert estimates that were requested in the main survey. For this test question, three of the four decision makers (EWMN, NPWM, and OPWM) somewhat overestimated the accepted percentage of threatened species across all well-studied taxonomic groups (WebFigure 7). For example, the OPWM decision maker overestimated this value by 15%. In contrast, the equal weighted median decision maker, which we used for the main survey, was unbiased (bias = 0%) (WebFigure 7).

Testing for differences among demographic and geographic groups of experts

Demographic and geographic groups of experts had similar median weights, accuracy scores, and information scores. Mood's median test was implemented with the `median_test` function in the `coin` package of R. Such tests must be cautiously conducted and interpreted, especially when seed questions have currently accepted, rather than absolute, answers, which might be biased towards the expertise of experts from over-represented groups of scientists. However, we found

no significant differences between demographic or geographic groups of experts (WebTable 6), except that the median information score was marginally significantly higher for experts who were later in their careers (median information scores: pre-PhD = 0.77; 1-30 years post-PhD = 1.05; > 30 years post-PhD = 1.36). Furthermore, we found no significant correlations between expert estimates of past biodiversity loss and their accuracy scores (Pearson's correlation $t = 0.0487$, $P = 0.961$) or their information scores (Pearson's correlation $t = -0.921$, $P = 0.361$).

Testing for differences in estimates between respondents to the main and follow-up surveys

The set of coauthors is not a random sample of all experts. When considering how the results of the follow-up survey may compare to those of the main survey, it may be useful to know whether the coauthors of our paper provided higher, similar, or lower estimates for biodiversity loss than the larger set of respondents to the main survey. The coauthors of our paper have greater representation of women (44% of follow-up survey respondents vs. 29% of main survey respondents who answered the question about gender), but also a greater representation of late-career experts (12% of follow-up survey respondents vs. 9% of main survey respondents who answered the questions about career stage) and a greater representation of experts who live in high-income countries (76% of follow-up survey respondents vs. 67% of main survey respondents who answered the question about home country). We found a statistically significant, albeit very small (1%) difference, between the medians of estimates provided by the two sets of respondents to a question about the magnitude of past biodiversity loss, which was included in both surveys (Mood's median test $Z = -2.908$, $P = 0.004$). Specifically, the thousands of respondents to the main survey estimated that 30% of species have been threatened or extinct since 1500, when considering the taxa and ecosystems they know best (Figure 1a). Similarly, the 59 coauthors of our paper who completed the follow-up survey estimated that 29% of species have been threatened or driven extinct since 1500, when considering the taxa and ecosystems they know best.

Testing for differences between types of estimates and intervals. Our main survey asked experts to provide an estimate for the mean and its lower and upper bounds. In retrospect, it would have been better for us to elicit probabilistic information about specified quantiles, as we did in the follow-up survey. To test whether there were significant differences in the distributions of responses between these two types of intervals, we included two questions in the follow-up survey that were identical, except that they requested these two different types of estimates (mean vs. median) and intervals (lower and upper bounds vs. 5th and 95th percentiles). We found no significant difference between the lower bound and 5th percentile estimates (Mood's median test $Z = -0.571$, $P = 0.568$), the mean and median estimates ($Z = -0.917$, $P = 0.359$), or the upper bound and 95th percentile estimates ($Z = -0.746$, $P = 0.455$). This suggests that the intervals provided in our main survey may be consistent with a probabilistic interpretation.

Note: Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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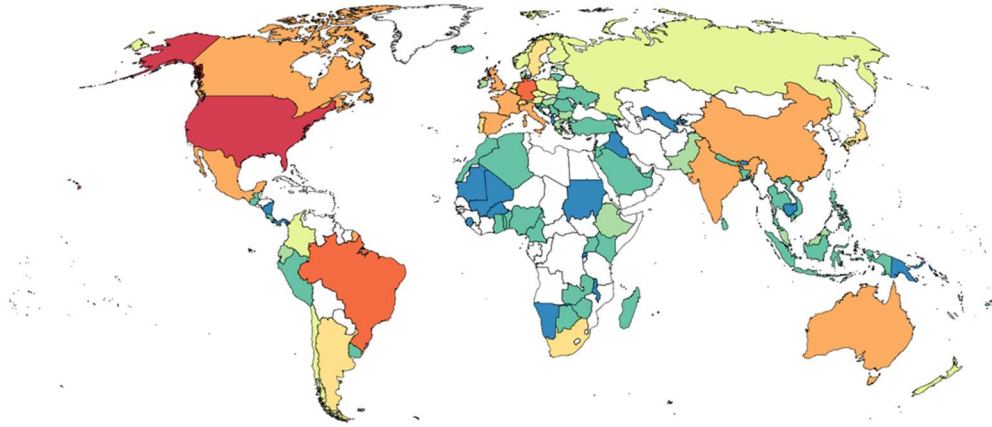
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A

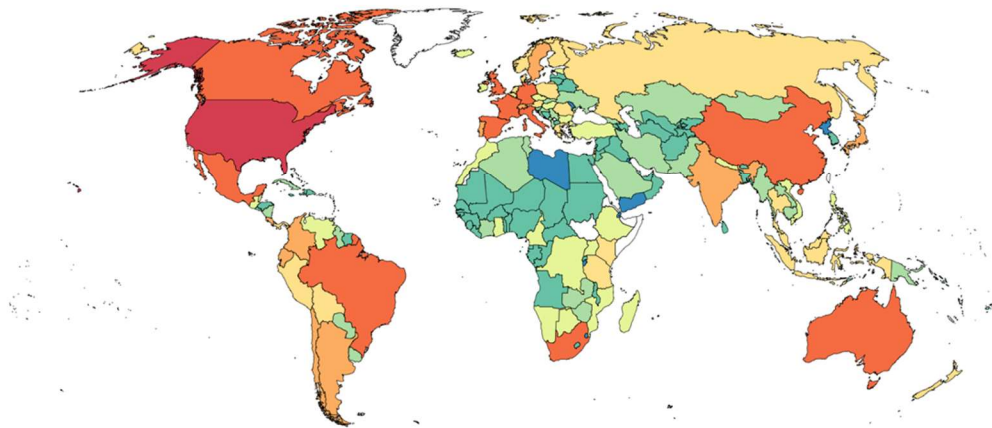
Number of responses by where experts live

1 2–10 11–20 21–40 41–80 81–160 161–320 320–431 NA

**B**

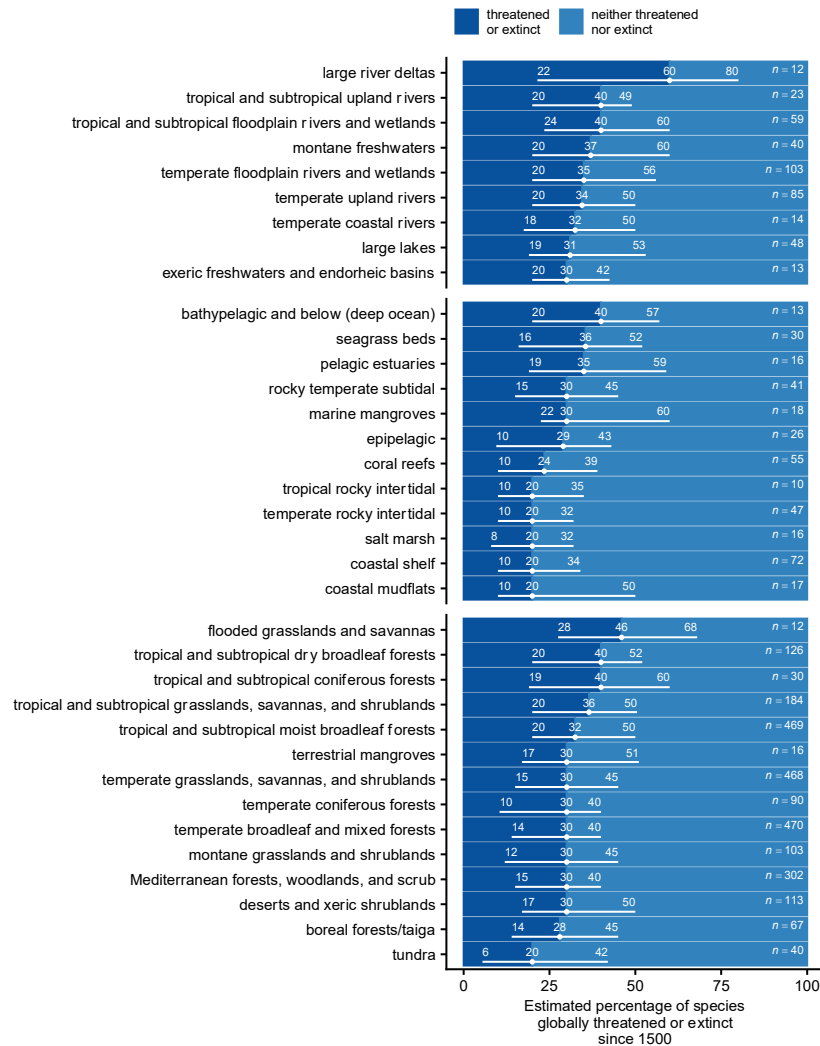
Number of responses by where experts research biodiversity

1 2–10 11–20 21–40 41–80 81–160 161–320 320–519 NA

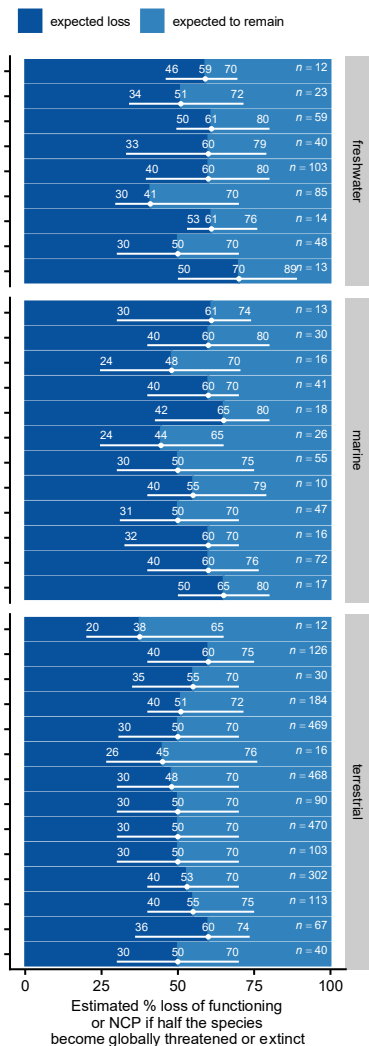


WebFigure 1. Numbers of responses by (A) where experts live and (B) where they investigate biodiversity. Note that color gradients use a \log_2 (doubling) scale. Experts who responded to our survey live in 113 countries and research biodiversity in 187 countries.

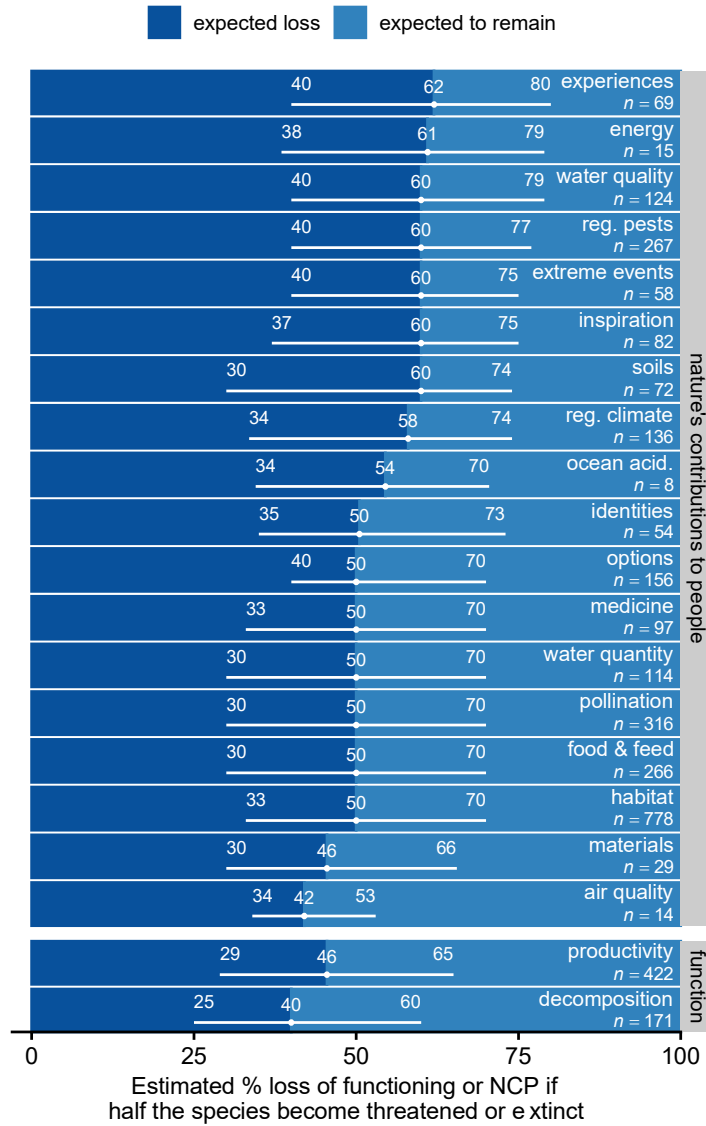
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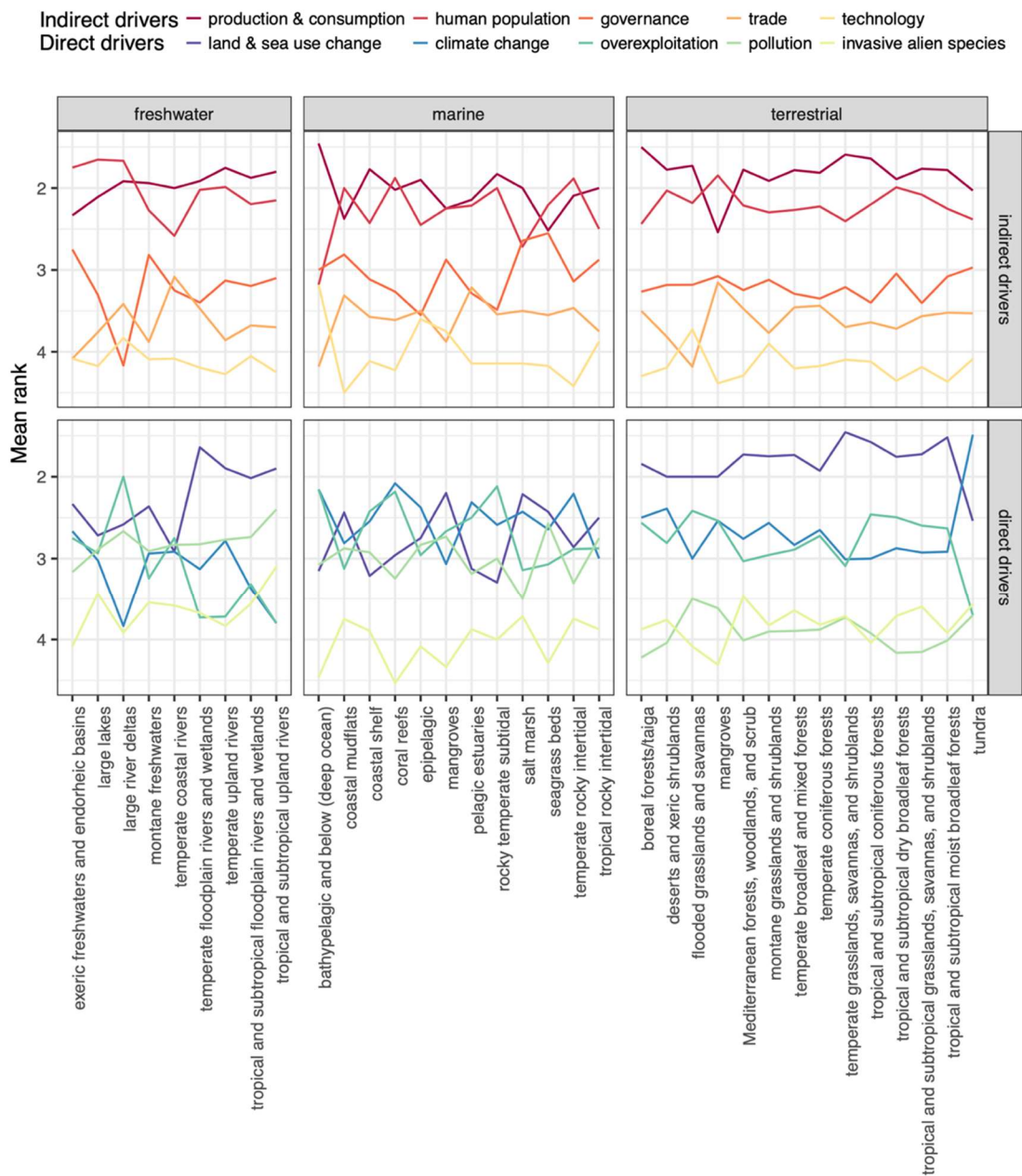
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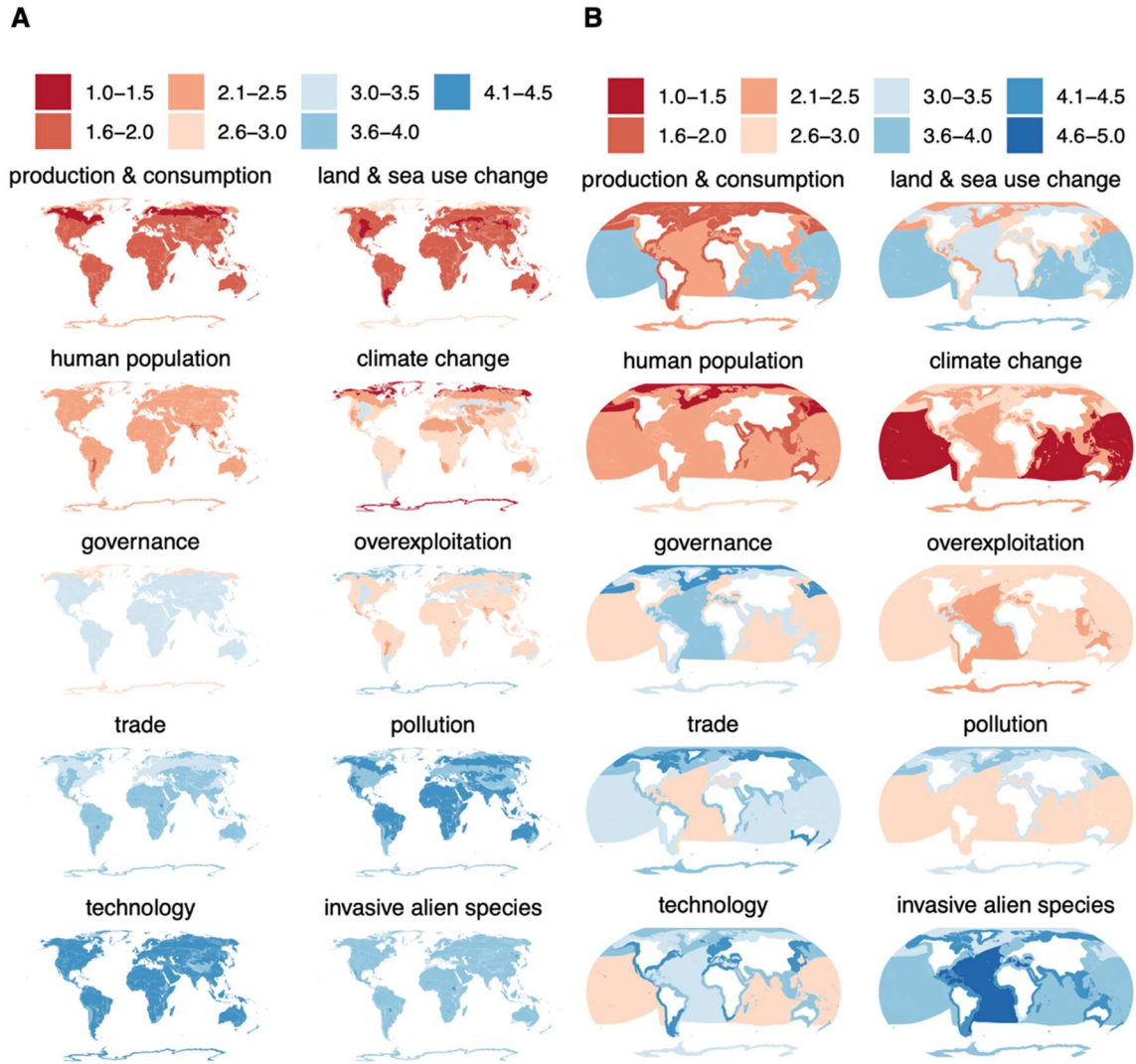
WebFigure 2. Estimated previous global biodiversity loss (A) and estimated impacts of further biodiversity loss on ecosystem functioning and nature's contributions to people (B) by habitat. The white points show the median of expert estimates. Sample sizes are indicated on the right side of each bar. The white lines extend to the median of lower and upper bounds for estimates.



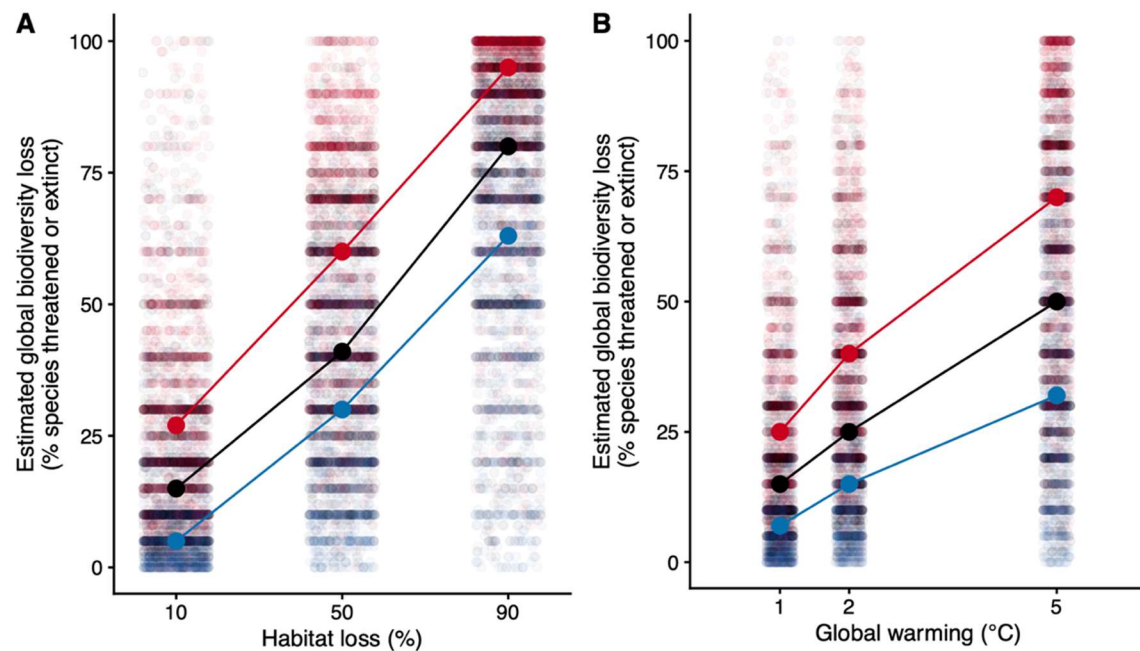
WebFigure 3. Estimated impacts of further global biodiversity loss on ecosystem functioning and nature's contributions to people. Expected loss of each ecosystem function or NCP if half the species become threatened or extinct, quantified across all ecosystems and taxa. White points show the median of expert estimates. The white lines extend to the median of lower and upper bounds for estimates. See WebTable 1 and reference (Díaz *et al.* 2018) for more detailed explanations of NCP.



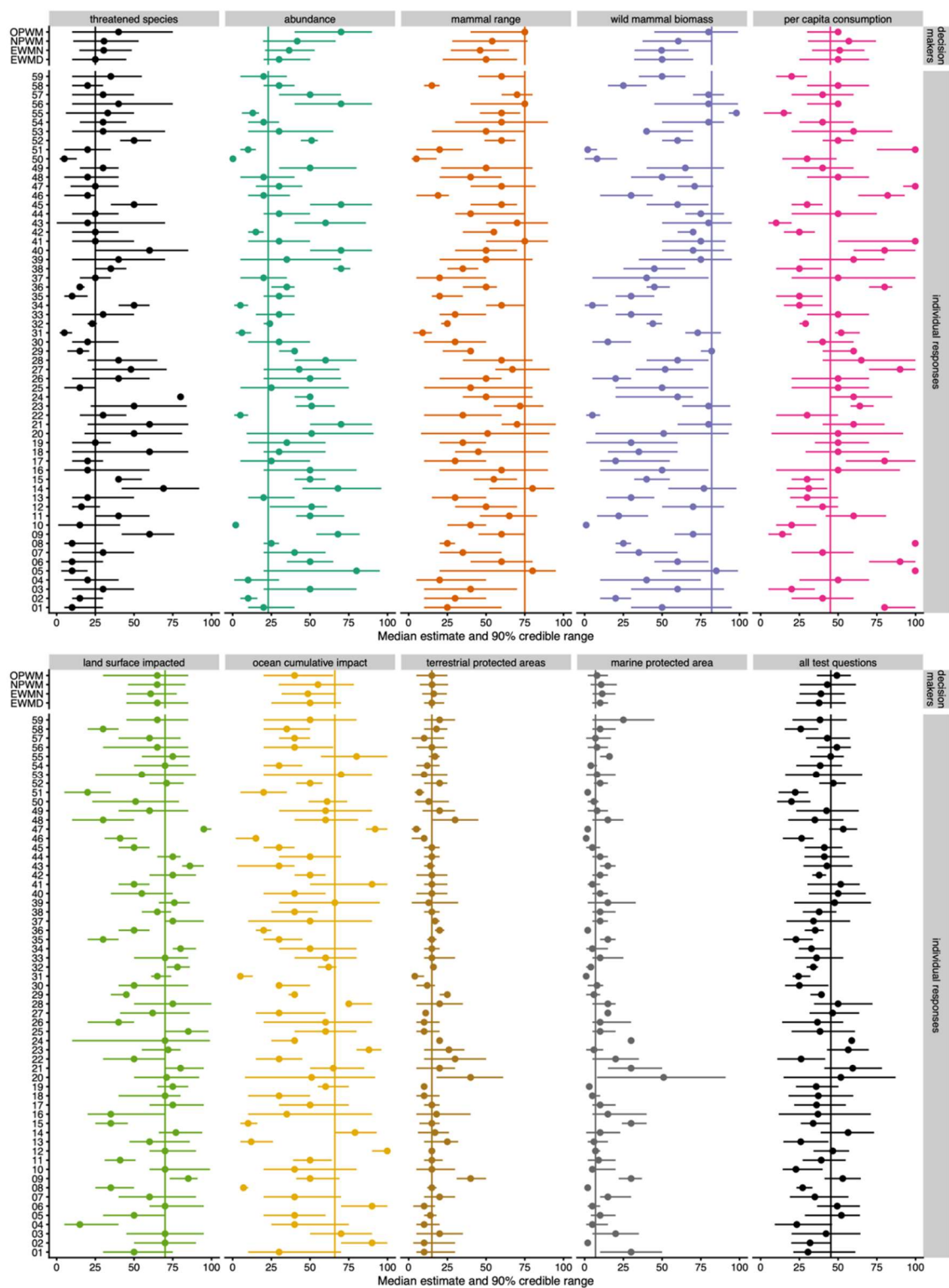
WebFigure 4. Average ranks of drivers by habitat type. The y-axis scale is reversed such that low numbers, which correspond to large expected impacts on biodiversity, are at the top.



WebFigure 5. Average ranks of drivers by (A) terrestrial biomes and (B) marine realms. Low numbers correspond to large expected impacts on biodiversity. In terrestrial ecosystems, climate change is thought to be the greatest threat to biodiversity in the tundra. In contrast, in marine ecosystems, climate change is thought to be most threatening in the tropical oceans. See WebFigure 4 for driver ranks by freshwater habitats.



WebFigure 6. Expert estimates of magnitudes of global biodiversity loss for specified amounts of (A) habitat loss or (B) global warming. Expert estimates are shown in black lines and points. Lower and upper bounds for these estimates, which experts also provided, are respectively shown in blue and red. Lines show linear interpolation between large points, which are the median values. In both panels, the values labeled on the x-axis are those for which expert estimates were requested and small points are jittered on the x-axis to help see overlapping points.



WebFigure 7. Decision makers and individual responses for seed questions on the follow-up survey. OPWM = optimized performance-weighted mean, NPWM = nonoptimized performance-weighted mean, EWMN = equal-weighted mean, EWMD = equal-weighted median.

WebTable 1. Definitions and clarifications provided in hover over text in the survey. Definitions of nature's contributions to people follow reference (Díaz *et al.* 2018). Definitions for threatened and extinct follow the IUCN.

Underlined survey text	Hover over text
terrestrial biome	This list follows Olson <i>et al.</i> (2001 <i>BioScience</i>)
marine realm	This list includes 12 coastal and shelf realms (Spalding <i>et al.</i> 2007 <i>BioScience</i>) and 4 pelagic realms (Spalding <i>et al.</i> 2012 <i>Ocean and Coastal Management</i>)
freshwater major habitat	This list is a consolidation of the freshwater ecoregions of the world delineated by Abell <i>et al.</i> (2008 <i>BioScience</i>)
habitat creation and maintenance	The formation and continued production, by ecosystems, of ecological conditions necessary or favorable for living beings important to humans
pollination and dispersal of seeds	Facilitation by animals of movement of pollen among flowers, and dispersal of seeds, larvae, or spores of organisms beneficial or harmful to humans
regulation of air quality	Regulation (by impediment or facilitation) by ecosystems, of atmospheric gasses; filtration, fixation, degradation, or storage of pollutants
regulation of climate	Climate regulation by ecosystems (including regulation of global warming) through effects on emissions of greenhouse gases, biophysical feedbacks, biogenic volatile organic compounds, and aerosols
regulation of ocean acidification	Regulation by photosynthetic organisms of atmospheric CO ₂ concentrations and so seawater pH
regulation of freshwater quantity, location, and timing	Regulation, by ecosystems, of the quantity, location and timing of the flow of surface and groundwater
regulation of freshwater and coastal water quality	Regulation – through filtration of particles, pathogens, excess nutrients, and other chemicals – by ecosystems of water quality
formation, protection and decontamination of soils	Formation and long-term maintenance of soils including sediment retention and erosion prevention, maintenance of soil fertility, and degradation or storage of pollutants
regulation of hazards and extreme events	Amelioration, by ecosystems, of the impacts of hazards; reduction of hazards; change in hazard frequency
regulation of detrimental organisms and biological processes	Regulation, by ecosystems or organisms, of pests, pathogens, predators, competitors, parasites, and potentially harmful organisms
energy	Production of biomass-based fuels, such as biofuel crops, animal waste, fuelwood, and agricultural residue
food and feed	Production of food from wild, managed, or domesticated organisms on land and in the ocean; production of feed
materials and assistance	Production of materials derived from organisms in cultivated or wild ecosystems and direct use of living organisms for decoration, company, transport, and labor
medicinal, biochemical, and genetic resources	Production of materials derived from organisms for medicinal purposes; production of genes and genetic information
learning and inspiration	Opportunities for developing capabilities to prosper through education, knowledge acquisition, and inspiration for art and technological design (e.g., biomimicry)
physical and psychological experiences	Opportunities for physically and psychologically beneficial activities, healing, relaxation, recreation, leisure, and aesthetic enjoyment based on close contact with nature
supporting identities	The basis for religious, spiritual, and social-cohesion experiences; sense of place, purpose, belonging, rootedness or connectedness, associated with different entities of the living world; narratives and myths, rituals and celebrations; satisfaction derived from knowing that a particular landscape, seascape, habitat or species exists
maintenance of options	Capacity of ecosystems, habitats, species, or genotypes to keep human options open in order to support a later good quality of life
threatening	vulnerable (high risk of extinction in the wild), endangered (very high risk of extinction in the wild), or critically endangered (extremely high risk of extinction in the wild)
extinction	exhaustive surveys fail to find any individuals in the wild

Underlined survey text	Hover over text
species	considering the taxa you know best
uncertainty	including uncertainty arising from a low quantity or quality of evidence, low level of agreement of evidence, and any gaps in your knowledge of the literature
no conservation efforts	no acquisition of protected lands, management of protected and unprotected lands, biodiversity monitoring, and biodiversity research
current conservation efforts	current levels of acquisition of protected lands, management of protected and unprotected lands, biodiversity monitoring, and biodiversity research
all currently known conservation strategies	acquisition of protected lands, management of protected and unprotected lands, biodiversity monitoring, and biodiversity research
ecosystem functioning or nature's contribution to people	considering the function or contribution you know best
global biodiversity loss	the percentage of species threatened with extinction or driven extinct by human activities
societal factors	indirect drivers (sensu IPBES 2019), which are upstream from and the underlying causes of the direct drivers listed in the previous question
approximately equals the sum of individual effects	e.g., if mostly non-overlapping sets of species are driven extinct by each driver
is greater than the sum of the individual effects	e.g., if many species extinctions are due to the combination of multiple drivers
is less than the sum of the individual effects	e.g., if some species extinctions that would arise from individual drivers are prevented by other drivers, or if somewhat overlapping sets of species are driven extinct by different drivers
no interaction	the combined effect of multiple drivers approximately equals the sum of the individual effects (e.g., if mostly non-overlapping sets of species are driven extinct by each driver)
synergistic	the combined effect of multiple drivers is greater than the sum of the individual effects (e.g., if many species extinctions are due to the combination of multiple drivers)
antagonistic	the combined effect of multiple drivers is less than the sum of the individual effects (e.g., if some species extinctions that would arise from individual drivers are prevented by other drivers, or if somewhat overlapping sets of species are driven extinct by different drivers)
related education	for any degrees or postdoctoral research training that inform your responses on this survey
related work experience	for any work that informs your responses on this survey, including postdoctoral research
manage protected areas	e.g., provide staff, land management, and all other ongoing costs of maintaining and restoring biodiversity within protected areas
manage unprotected areas	e.g., incentivize biodiversity conservation and reduce or mitigate threats to biodiversity outside of protected areas
planetary boundary	a boundary that is a 'safe' distance from thresholds or dangerous levels

WebTable 2. Summary of response demographics.

	# of responses	% of responses	Past biodiversity loss*	Impacts of biodiversity loss**
Highest level of related education				
Undergraduate degree in progress	10	< 1	49	65
Undergraduate degree completed	31	1	39	50
Master's degree in progress	24	1	49	64
Master's degree completed	102	3	35	60
Doctorate in progress	205	6	35	60
Doctorate completed	588	18	30	52
Postdoctoral research in progress	424	13	30	50
Postdoctoral research completed	1571	47	30	50
No response to this question	376	11	35	51
Years of related work experience				
Have not completed PhD	318	10	35	60
1-5 years of work post-PhD	672	20	30	51
6-10 years of work post-PhD	541	16	30	50
11-20 years of work post-PhD	739	22	30	50
21-30 years of work post-PhD	395	12	29	50
31-40 years of work post-PhD	192	6	20	50
> 40 years of work post-PhD	71	2	20	50
No response to this question	403	12	36	51
Place of work				
Academic institution	2339	70	30	50
Governmental agency	296	9	30	50
Nongovernmental agency	186	6	30	50
Other	135	4	30	60
No response to this question	375	11	35	50
Current self-identified gender				
Men	1981	59	30	50
Nonbinary	11	< 1	19	50
Prefer not to answer	83	2	30	40
Prefer to self-describe	12	< 1	37	60
Women	863	26	36	60
No response to this question	381	11	35	50
Spatial scale(s) of biodiversity research***				
Local communities	2160	65	30	50
Metacommunity	1887	57	30	50
Ecoregion	1633	49	30	50
Global	858	26	30	50
No response to this question	23	1	30	50
Region of residence				
East Asia & Pacific	421	13	30	51
Europe & Central Asia	1216	37	30	50
Latin America & Caribbean	432	13	35	60
Middle East & North Africa	38	1	34	50
North America	542	16	29	50
South Asia	118	4	40	52
Sub-Saharan Africa	162	5	34	50
No response to this question	402	12	35	50

*Median estimated % of species threatened or extinct since 1500. **Median estimated % loss of ecosystem functioning and NCP if half the species become threatened or extinct. ***Spatial scales exceed 100% because many experts study multiple spatial scales.

WebTable 3. Brown-Mood Median test results for differences in estimates for past biodiversity loss (% of species threatened or extinct since 1500), impacts of biodiversity loss (% loss of ecosystem functioning or NCP if half the species become globally threatened or extinct), and recommended allocation of conservation budgets to five categories (% of budget) by ecosystem and taxa (Figure 1), and by expert's self-identified gender, GDP group of home country, and career stage (Figure 4). Test statistics are either for the K-Sample Brown-Mood Median Test for predictors with more than two factor levels (χ^2 for ecosystems, taxa, and career stage) or the Two-Sample Brown-Mood Median Test for predictors with only two levels (Z for gender identity and GDP group).

	Past biodiversity loss	Impacts of biodiversity loss	Acquire unprotected areas	Manage protected areas	Manage unprotected areas	Research biodiversity	Monitor biodiversity
ecosystem	16.9***	10.9**	3.4	16.6***	11.7**	7.6*	11.5**
taxa	93.1***	44.5***	9.7	48.8***	34.3**	28.6*	29.4**
gender	-6.8***	5.5***	2.7**	-1.0	0.6	-0.7	-3.6***
GDP	7.2***	3.3**	8.2***	-1.7^	2.4*	-6.6***	-4.6***
stage	31.1***	18.6***	2.0	7.2*	0.0	2.0	12.1**

***P < 0.001, **P < 0.01, *P < 0.05, ^P < 0.1

WebTable 4. Results of tests for significant differences in ranks of direct and indirect drivers of global biodiversity loss for (A) ecosystems and (B) groups of experts. Kruskal-Wallis tests were used to test for differences in ranks among drivers (all $P < 0.05$). Conover's Test was then used for multiple comparisons between pairs of groups, using Tukey's method to control for multiple *a posteriori* comparisons. Values are mean ranks. Within each of the 20 groups of five drivers below, mean ranks with different lowercase letters are significantly different ($P < 0.05$).

(A) Ecosystems	All Ecosystems		Freshwater Ecosystems		Terrestrial Ecosystems		Marine Ecosystems	
Direct drivers								
land & sea use change	1.86	a	2.08	a	1.68	a	2.89	a
climate change	2.81	b	3.10	b	2.82	b	2.45	b
overexploitation	2.88	b	3.40	c	2.84	b	2.59	b
pollution	3.69	c	2.79	d	3.94	c	3.01	a
invasive alien species	3.75	c	3.63	c	3.73	d	4.05	c
Indirect drivers								
production & consumption	1.80	a	1.91	a	1.75	a	2.02	a
human population	2.21	b	2.03	a	2.25	b	2.20	a
governance	3.20	c	3.22	b	3.21	c	3.10	b
trade	3.58	d	3.67	c	3.57	d	3.56	c
technology	4.20	e	4.16	d	4.22	e	4.12	d

(B) Groups of Experts	Women	Men	Low- or middle GDP	High GDP	Pre-PhD	1-30 years	> 30 years
Direct drivers							
land & sea use change	1.95 a	1.83 a	1.90 a	1.85 a	1.94 a	1.84 a	2.04 a
climate change	2.72 b	2.85 b	2.99 b	2.73 b	2.69 b	2.85 b	2.59 b
overexploitation	2.96 c	2.85 b	2.59 c	3.03 c	2.79 b	2.89 b	2.94 c
pollution	3.67 d	3.70 c	3.65 d	3.71 d	3.90 c	3.66 c	3.71 d
invasive alien species	3.69 d	3.77 c	3.87 e	3.69 d	3.69 c	3.76 d	3.72 d
Indirect drivers							
production & consumption	1.76 a	1.81 a	1.92 a	1.73 a	1.87 a	1.77 a	1.91 a
human population	2.32 b	2.15 b	2.12 b	2.24 b	2.27 b	2.20 b	2.12 a
governance	3.06 c	3.28 c	3.22 c	3.20 c	3.06 c	3.23 c	3.26 b
trade	3.60 d	3.59 d	3.61 d	3.59 d	3.63 d	3.58 d	3.73 c
technology	4.26 e	4.17 e	4.13 e	4.23 e	4.16 e	4.22 e	3.99 c

WebTable 5. Accuracy scores and information scores for experts and decision makers, and nonoptimized weights and optimized weights for experts.

	Accuracy score	Information score	Nonoptimized weights	Optimized weights
Decision makers				
OPWM	0.731	1.15		
NPWM	0.571	0.668		
EWMD	0.254	0.829		
EWMN	0.154	0.857		
Individual experts				
56	0.731	1.15	0.1290	1.0
25	0.706	0.753	0.0820	
16	0.706	0.344	0.0374	
53	0.593	0.751	0.0686	
49	0.593	0.675	0.0617	
44	0.571	1.03	0.0906	
39	0.571	0.503	0.0443	
41	0.479	1.19	0.0881	
17	0.266	0.907	0.0371	
07	0.266	0.685	0.0280	
37	0.254	0.941	0.0369	
33	0.254	0.861	0.0337	
18	0.254	0.783	0.0307	
59	0.254	0.746	0.0292	
21	0.254	0.704	0.0276	
20	0.254	0.148	0.00582	
05	0.200	1.41	0.0435	
57	0.164	0.945	0.0239	
03	0.154	0.541	0.0129	
54	0.0912	1.02	0.0143	
28	0.0760	0.954	0.0112	
14	0.0760	0.806	0.00945	
40	0.0626	0.769	0.00742	
23	0.0508	1.05	0.00822	
48	0.0508	0.697	0.00546	
11	0.0392	0.961	0.00580	
30	0.0374	1.23	0.00708	
26	0.0374	0.739	0.00426	
13	0.0135	0.96	0.00200	
04	0.0135	0.83	0.00173	
27	0.00847	1.65	0.00216	
12	0.00648	1.81	0.00181	
01	0.00648	0.953	0.000952	
47	0.00521	1.85	0.001490	
19	0.00496	1.23	0.000939	
22	0.00496	0.957	0.000732	
32	0.00379	2.34	0.001370	
38	0.00379	1.19	0.000695	
58	0.00221	1.18	0.000403	
06	0.00174	1.09	0.000294	
55	0.000628	1.44	0.000140	
34	0.000628	1.36	0.000132	
52	0.000628	1.34	0.000130	
43	0.000628	1.10	0.000106	
29	0.000478	2.93	0.000216	
24	0.000478	2.65	0.000196	
42	0.000358	1.66	9.16E-05	
02	0.000277	1.23	5.23E-05	
10	0.000207	1.86	5.93E-05	
50	0.000207	1.76	5.60E-05	
08	0.000165	2.35	5.99E-05	
09	2.65E-05	1.08	4.41E-06	
35	5.65E-06	1.33	1.16E-06	
45	5.28E-06	1.12	9.11E-07	
31	1.48E-06	1.93	4.40E-07	
46	1.48E-06	1.66	3.77E-07	
15	3.79E-07	1.30	7.61E-08	
51	4.13E-08	1.77	1.13E-08	
36	3.20E-09	1.83	9.02E-10	

WebTable 6. Mood's median test for differences between demographic and geographic groups of experts in weights, accuracy scores, and information scores. Test statistics are either for the K-Sample Brown-Mood Median Test for predictors with more than two factor levels (χ^2 for career stage) or the Two-Sample Brown-Mood Median Test for predictors with only two levels (Z for gender identity and GDP group).

	Weights		Accuracy scores		Information scores	
career stage	$\chi^2 = 3.039$	$P = 0.219$	$\chi^2 = 3.080$	$P = 0.214$	$\chi^2 = 5.454$	$P = 0.065$
GDP group	$Z = 1.142$	$P = 0.254$	$Z = 0.999$	$P = 0.318$	$Z = -1.286$	$P = 0.199$
gender	$Z = 0.405$	$P = 0.685$	$Z = 0.177$	$P = 0.860$	$Z = 0.926$	$P = 0.355$

Career stage is a factor with three levels: early or mid- to late-career. Self-identified gender is a factor with two levels: woman or man. GDP region is a factor with two levels: experts living in high GDP countries or in low- to middle-GDP countries.

WebPanel 2

Main Survey. These survey questions received 3,331 responses. See WebTable 1 for definitions provided in hover over text.

This survey requests expert estimates of global biodiversity loss and its consequences for ecosystem functioning and nature's contributions to people. The survey seeks to extend previous related research by including more experts and by being more quantitative, in terms of estimates and their uncertainty. Survey results will be submitted for publication. The survey is estimated to require 20 minutes to complete. All responses are anonymous.

Instructions:

- Skip questions where you are unable to provide estimates.
- Indicate levels of uncertainty by providing a range of estimates.
- Use your knowledge of the scientific literature, but note that this survey seeks your current best estimates, rather than your recollection of previously published estimates.
- Hover over or click on underlined text to see clarifications.

Thank you for sharing your expertise.

Identify your areas of expertise. Throughout the survey, you will be asked to consider only the type of ecosystem, taxa and ecosystem function or nature's contribution to people that you know best.

Q01. Select the **type of ecosystem** that you know best.

- ☐ terrestrial
- ☐ marine
- ☐ freshwater

Display This Question:
If Select the type of ecosystem that you know best. = terrestrial

Q02. Select the **terrestrial biome** that you know best.

- ☐ tropical and subtropical moist broadleaf forests
- ☐ tropical and subtropical dry broadleaf forests
- ☐ tropical and subtropical coniferous forests
- ☐ temperate broadleaf and mixed forests
- ☐ temperate coniferous forests
- ☐ boreal forests/taiga
- ☐ tropical and subtropical grasslands, savannas, and shrublands
- ☐ temperate grasslands, savannas, and shrublands
- ☐ flooded grasslands and savannas
- ☐ montane grasslands and shrublands
- ☐ tundra
- ☐ Mediterranean forests, woodlands, and scrub
- ☐ deserts and xeric shrublands
- ☐ mangroves

Display This Question:

If Select the type of ecosystem that you know best. = marine

Q03. Select the **marine realm** that you know best.

- ☐ Arctic
- ☐ Temperate Northern Atlantic
- ☐ Temperate Northern Pacific
- ☐ Tropical Atlantic
- ☐ Western Indo-Pacific
- ☐ Central Indo-Pacific
- ☐ Eastern Indo-Pacific
- ☐ Tropical Eastern Pacific
- ☐ Temperate South America
- ☐ Temperate Southern Africa
- ☐ Temperate Australasia
- ☐ Southern Ocean
- ☐ Pelagic: Northern Coldwater
- ☐ Pelagic: Indo-Pacific Warmwater
- ☐ Pelagic: Atlantic Warmwater
- ☐ Pelagic: Southern Coldwater

Display This Question:

If Select the type of ecosystem that you know best. = marine

Q04. Select the **marine habitat** that you know best.

- ☐ salt marsh
- ☐ coastal mudflats
- ☐ temperate rocky intertidal
- ☐ tropical rocky intertidal
- ☐ mangroves
- ☐ seagrass beds
- ☐ pelagic estuaries
- ☐ rocky temperate subtidal
- ☐ coral reefs
- ☐ coastal shelf
- ☐ epipelagic
- ☐ mesopelagic
- ☐ bathypelagic and below (deep ocean)

Display This Question:

If Select the type of ecosystem that you know best. = freshwater

Q05. Select the **freshwater major habitat type** that you know best.

- ☐ large lakes
- ☐ large river deltas
- ☐ montane freshwaters
- ☐ oceanic islands
- ☐ polar freshwaters
- ☐ temperate coastal rivers
- ☐ temperate floodplain rivers and wetlands
- ☐ temperate upland rivers
- ☐ tropical and subtropical coastal rivers
- ☐ tropical and subtropical floodplain rivers and wetlands
- ☐ tropical and subtropical upland rivers
- ☐ exeric freshwaters and endorheic basins

Q06. Select the **driver(s)** of global biodiversity loss that you know best.

- ☐ climate change (Q06a)
- ☐ land/sea use change (Q06b)
- ☐ invasive alien species (Q06c)
- ☐ overexploitation (Q06d)
- ☐ pollution (Q06e)

Q07. Select the **taxa** that you know best.

Reminder: Throughout the survey, consider only the taxa selected here.

- ☐ amphibians
- ☐ birds
- ☐ fishes
- ☐ mammals
- ☐ reptiles
- ☐ invertebrates
- ☐ fungi
- ☐ plants
- ☐ seaweeds
- ☐ protists
- ☐ bacteria
- ☐ archaea

Q08. Select one of **nature's contributions to people** (IPBES 2019), or one of the two **ecosystem functions**, that you know best.

Reminder: Hover over or click on each option below to see a brief explanation. Throughout the survey, consider only the function or contribution selected here.

- ☐ habitat creation and maintenance
- ☐ pollination and dispersal of seeds
- ☐ regulation of air quality
- ☐ regulation of climate
- ☐ regulation of ocean acidification
- ☐ regulation of freshwater quantity, location, and timing
- ☐ regulation of freshwater and coastal water quality
- ☐ formation, protection, and decontamination of soils
- ☐ regulation of hazards and extreme events
- ☐ regulation of detrimental organisms and biological processes
- ☐ energy
- ☐ food and feed
- ☐ materials and assistance
- ☐ medicinal, biochemical, and genetic resources
- ☐ learning and inspiration
- ☐ physical and psychological experiences
- ☐ supporting identities
- ☐ maintenance of options
- ☐ primary productivity
- ☐ decomposition

Estimate global biodiversity loss (i.e., the threatening or extinction of species) and its consequences for ecosystem functioning or nature's contribution to people.

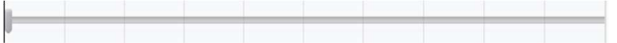
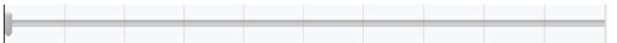
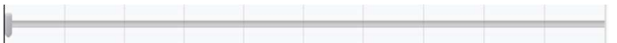
Reminder: Consider only the type of ecosystem, taxa, and function or contribution that you know best.

A note on uncertainty: here and throughout this survey, indicate uncertainty for your mean estimate by providing the likely lower and upper bounds for your mean estimate.

Q09. Estimate the percentage of species either threatened with extinction or driven globally extinct by human activities...

...from the year 1500 to 2020.

0 10 20 30 40 50 60 70 80 90 100

Q09a. mean estimate	
Q09b. lower bound	
Q09c. upper bound	

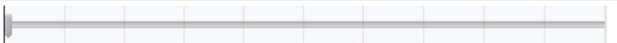
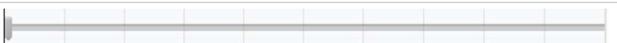
...from 1500 to 2100, if there are no conservation efforts in the future.

0 10 20 30 40 50 60 70 80 90 100

Q09d. mean estimate	
Q09e. lower bound	
Q09f. upper bound	

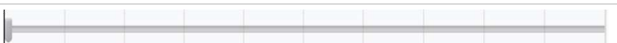
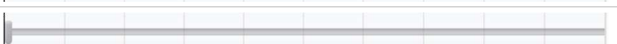
...from 1500 to 2100, if current conservation efforts continue in the future.

0 10 20 30 40 50 60 70 80 90 100

Q09g. mean estimate	
Q09h. lower bound	
Q09i. upper bound	

...from 1500 to 2100, if all currently known conservation strategies are fully-funded, implemented now, and sustained in the future.

0 10 20 30 40 50 60 70 80 90 100

Q09j. mean estimate	
Q09k. lower bound	
Q09l. upper bound	

Q10. Global biodiversity loss (i.e., the threatening or extinction of species) will likely...

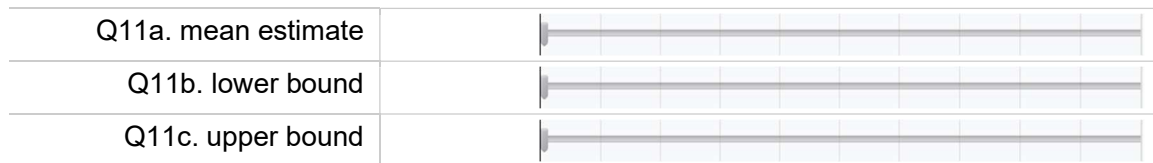
- ☐ decrease ecosystem functioning or nature's contribution to people
- ☐ have no effect on ecosystem functioning or nature's contribution to people
- ☐ increase ecosystem functioning or nature's contribution to people

Skip To: Q12 If Global biodiversity loss (i.e., the threatening or extinction of species) will likely... = have no effect on ecosystem functioning or nature's contribution to people

Q11. Estimate the percentage change in ecosystem functioning or nature's contribution to people resulting from the threatening or extinction of...

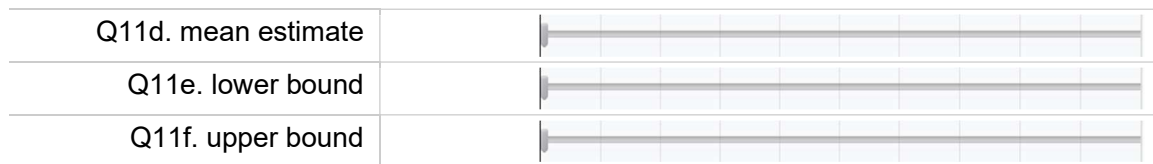
...10% of species

0 10 20 30 40 50 60 70 80 90 100



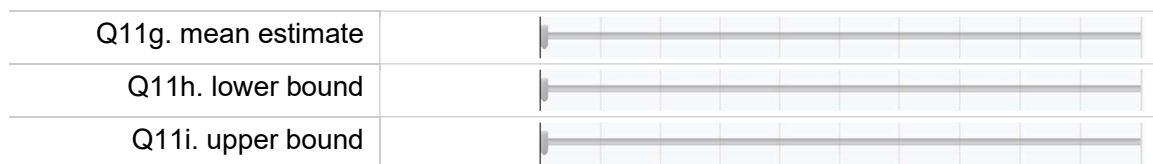
...50% of species

0 10 20 30 40 50 60 70 80 90 100



...90% of species

0 10 20 30 40 50 60 70 80 90 100



Q12. Assume current trends in drivers and conservation efforts will continue. After species become threatened, global extinctions are expected to typically occur within...

- ☐ less than 10 years
- ☐ decades: 10-100 years
- ☐ centuries: 100-1,000 years
- ☐ millennia: more than 1,000 years

Drivers of global biodiversity loss.

Reminder: Consider only the type of ecosystem and taxa that you know best.

Q13. Drag the drivers to rank them from those that currently threaten biodiversity most (top) to least (bottom).

- _____ climate change (Q13a)
- _____ land/sea use change (Q13b)
- _____ invasive alien species (Q13c)
- _____ overexploitation (Q13d)
- _____ pollution (Q13e)

Q14. Drag the societal factors to rank them from those that currently influence biodiversity most (top) to least (bottom).

- _____ human population dynamics (Q14a)
- _____ local through global governance (Q14b)
- _____ production and consumption patterns (Q14c)
- _____ technological innovations (Q14d)
- _____ trade (Q14e)

Q15. Multiple drivers of biodiversity loss often co-occur. Which of the following types of interactions among drivers would you expect is most common?

- ☐ **No net interaction:** the combined effect of multiple drivers approximately equals the sum of individual effects
- ☐ **Synergistic:** the combined effect of multiple drivers is greater than the sum of the individual effects
- ☐ **Antagonistic:** the combined effect of multiple drivers is less than the sum of the individual effects

Q16. Which of the following types of interactions would you expect for each pair of drivers?

	<u>No interaction</u>	<u>Synergistic</u>	<u>Antagonistic</u>
Q16a. climate change & invasive alien species	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Q16b. climate change & land/sea use change	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Q16c. climate change & overexploitation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Q16d. climate change & pollution	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Q16e. invasive alien species & land/sea use change	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Q16f. invasive alien species & overexploitation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Q16g. invasive alien species & pollution	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Q16h. land/sea use change & overexploitation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Q16i. land/sea use change & pollution	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Q16j. overexploitation & pollution	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

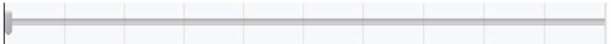

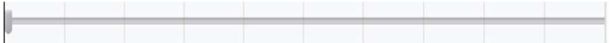
Display This Question:

If Select the driver(s) of global biodiversity loss that you know best. = land/sea use change

Q17. Estimate the percentage of species either threatened with extinction or driven globally extinct by the...

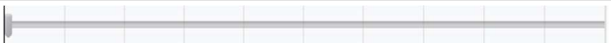
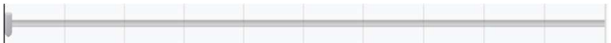
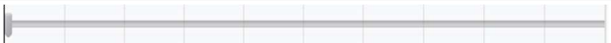
...loss of 10% of habitat area

0 10 20 30 40 50 60 70 80 90 100

Q17a. mean estimate	
Q17b. lower bound	
Q17c. upper bound	

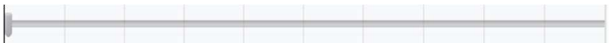
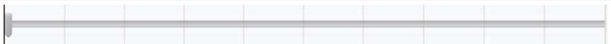
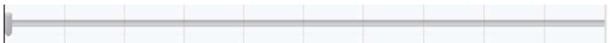
...loss of 50% of habitat area

0 10 20 30 40 50 60 70 80 90 100

Q17d. mean estimate	
Q17e. lower bound	
Q17f. upper bound	

...loss of 90% of habitat area

0 10 20 30 40 50 60 70 80 90 100

Q17g. mean estimate	
Q17h. lower bound	
Q17i. upper bound	

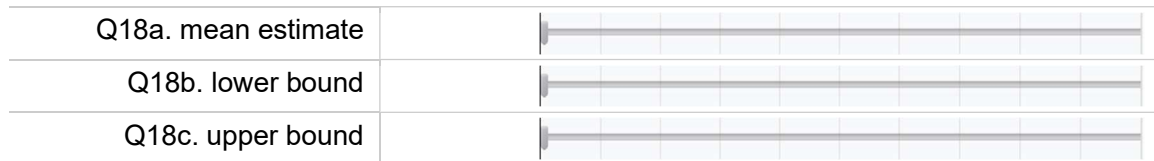
Display This Question:

If Select the driver(s) of global biodiversity loss that you know best. = climate change

Q18. Estimate the percentage of species either threatened with extinction or driven globally extinct by...

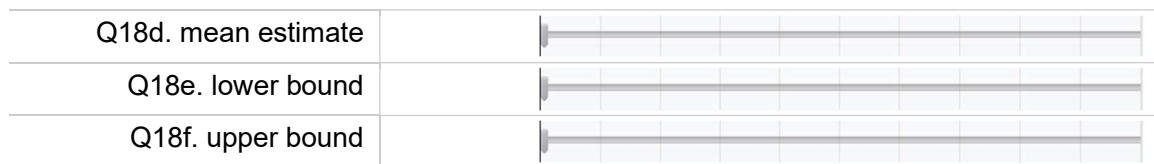
...1° C of global warming above pre-industrial levels

0 10 20 30 40 50 60 70 80 90 100



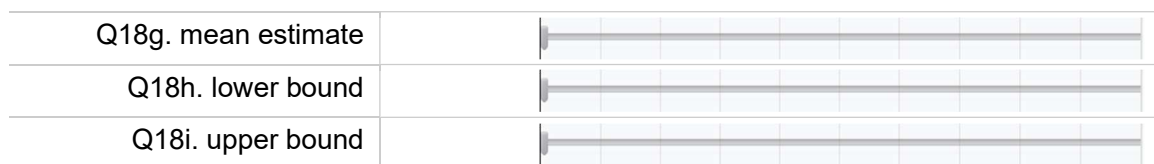
...2° C of global warming above pre-industrial levels

0 10 20 30 40 50 60 70 80 90 100



...5° C of global warming above pre-industrial levels

0 10 20 30 40 50 60 70 80 90 100



Please share a bit about yourself and your perspectives on conservation strategies. This survey seeks to include respondents from a wide range of career stages, geographic locations, and perspectives.

Q19. Indicate your highest level of related education.

- ☐ Undergraduate degree in progress
- ☐ Undergraduate degree completed
- ☐ Master's degree in progress
- ☐ Master's degree completed
- ☐ Doctorate in progress
- ☐ Doctorate completed
- ☐ Postdoctoral research in progress
- ☐ Postdoctoral research completed

Q20. Indicate your years of related work experience after completion of your PhD.

- ☐ Have not completed PhD
- ☐ 1-5 years of work post-PhD
- ☐ 6-10 years of work post-PhD
- ☐ 11-20 years of work post-PhD
- ☐ 21-30 years of work post-PhD
- ☐ 31-40 years of work post-PhD
- ☐ > 40 years of work post-PhD

Q21. Which of the following options best describes your current place of work?

- ☐ Academic institution
- ☐ Governmental agency
- ☐ Nongovernmental organization
- ☐ Other

Q22. In which country do you currently reside?

▼ Afghanistan ... Zimbabwe

Q23. Select one or multiple countries in which you conduct biodiversity research.

☐

Afghanistan

☐

...

☐

Zimbabwe

Q24. What is your current gender identity?

☐

Man

☐

Woman

☐

Nonbinary

☐

Prefer to self-describe: _____

☐

Prefer not to answer

Q25. Please place your perspectives on biodiversity conservation along the following scales.
Choose the middle if you equally agree with both options.

	-2	-1	0	1	2	
Q25a. Nature-centered conservation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Q25a. People-centered conservation
Q25b. Biodiversity supports natural capital	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Q25b. Biodiversity has intrinsic value
Q25c. Conserve threatened species	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Q25c. Conserve threatened ecosystems
Q25d. Restore degraded biodiversity	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Q25d. Preserve biodiversity hotspots
Q25e. Protect pristine places	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Q25e. No place is pristine
Q25f. Biodiversity <i>or</i> ecosystem services: tradeoff	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Q25f. Biodiversity <i>and</i> ecosystem services: win-win

Q26. At what spatial scale(s) do you conduct the majority of your biodiversity research? Choose all that apply.

☐

Local community scales at which individuals interact with neighbors (Q26a)

☐

Metacommunity scales over which local communities are connected by dispersal (Q26b)

☐

Ecoregion scales (Q26c)

☐

Global scale (Q26d)

Q27. Indicate your recommended allocation of conservation investments to minimize the loss of global biodiversity. The total must sum to 100%.

Q27a. Acquire new protected areas : _____

Q27b. Manage protected areas : _____


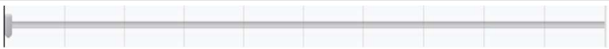
Q27c. Manage unprotected areas : _____

Q27d. Monitor biodiversity : _____

Q27e. Research biodiversity : _____

Q28. What level of global biodiversity loss would you consider to be a planetary boundary, with respect to...

0 10 20 30 40 50 60 70 80 90 100

Q28a. sustaining the integrity of nature and its <u>processes</u>	
Q28b. sustaining nature's contributions to people	

Q29. Please include any additional comments here.

WebPanel 3

Follow-Up Survey. These survey questions received 59 responses by coauthors of this paper.

This survey requests expert estimates of global biodiversity loss.

Instructions:

- Answer all questions.
- Do not look up answers while completing the survey.
- Indicate levels of uncertainty by providing a range of estimates.
- Hover over or click on underlined text to see clarifications.

Thank you for sharing your expertise.

Identify your areas of expertise.

Select the **type of ecosystem** that you know best.

- ☐ terrestrial
- ☐ marine
- ☐ freshwater

Display This Question:

If Select the type of ecosystem that you know best. = terrestrial

Select the **terrestrial biome** that you know best.

- ☐ tropical and subtropical moist broadleaf forests
- ☐ tropical and subtropical dry broadleaf forests
- ☐ tropical and subtropical coniferous forests
- ☐ temperate broadleaf and mixed forests
- ☐ temperate coniferous forests
- ☐ boreal forests/taiga
- ☐ tropical and subtropical grasslands, savannas, and shrublands
- ☐ temperate grasslands, savannas, and shrublands
- ☐ flooded grasslands and savannas
- ☐ montane grasslands and shrublands
- ☐ tundra
- ☐ Mediterranean forests, woodlands, and scrub
- ☐ deserts and xeric shrublands
- ☐ mangroves

Display This Question:

If Select the type of ecosystem that you know best. = marine

Select the **marine realm** that you know best.

- ☐ Arctic
- ☐ Temperate Northern Atlantic
- ☐ Temperate Northern Pacific
- ☐ Tropical Atlantic
- ☐ Western Indo-Pacific
- ☐ Central Indo-Pacific
- ☐ Eastern Indo-Pacific
- ☐ Tropical Eastern Pacific
- ☐ Temperate South America
- ☐ Temperate Southern Africa
- ☐ Temperate Australasia
- ☐ Southern Ocean
- ☐ Pelagic: Northern Coldwater
- ☐ Pelagic: Indo-Pacific Warmwater
- ☐ Pelagic: Atlantic Warmwater
- ☐ Pelagic: Southern Coldwater

Display This Question:

If Select the type of ecosystem that you know best. = marine

Select the **marine habitat** that you know best.

- ☐ salt marsh
- ☐ coastal mudflats
- ☐ temperate rocky intertidal
- ☐ tropical rocky intertidal
- ☐ mangroves
- ☐ seagrass beds
- ☐ pelagic estuaries
- ☐ rocky temperate subtidal
- ☐ coral reefs
- ☐ coastal shelf
- ☐ epipelagic
- ☐ mesopelagic
- ☐ bathypelagic and below (deep ocean)

Display This Question:

If Select the type of ecosystem that you know best. = freshwater

Select the **freshwater major habitat type** that you know best.

- ☐ large lakes
- ☐ large river deltas
- ☐ montane freshwaters
- ☐ oceanic islands
- ☐ polar freshwaters
- ☐ temperate coastal rivers
- ☐ temperate floodplain rivers and wetlands
- ☐ temperate upland rivers
- ☐ tropical and subtropical coastal rivers
- ☐ tropical and subtropical floodplain rivers and wetlands
- ☐ tropical and subtropical upland rivers
- ☐ exeric freshwaters and endorheic basins

Select the **driver(s)** of global biodiversity loss that you know best.

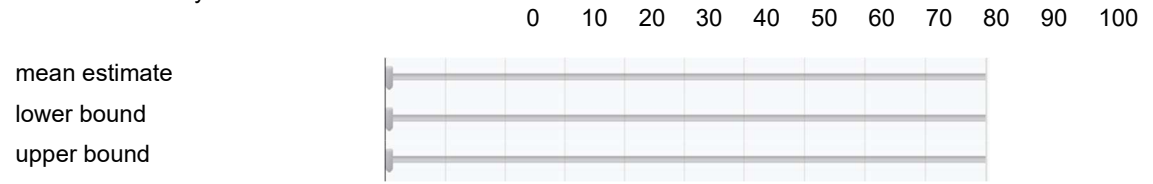
- ☐ climate change
- ☐ land/sea use change
- ☐ invasive alien species
- ☐ overexploitation
- ☐ pollution

Select the **taxa** that you know best.

- ☐ amphibians
- ☐ birds
- ☐ fishes
- ☐ mammals
- ☐ reptiles
- ☐ invertebrates
- ☐ fungi
- ☐ plants
- ☐ seaweeds
- ☐ protists
- ☐ bacteria
- ☐ archaea

For the question below, consider only the type of ecosystem and taxa that you know best and indicate uncertainty for your mean estimate by providing the likely lower and upper bounds for your mean estimate.

Estimate the percentage of species either threatened with extinction or driven globally extinct by human activities from the year 1500 to 2020.



For each of the 11 questions below, provide a median estimate (50th percentile) and a 90% credible range (5th and 95th percentiles), such that:

- the true value is equally likely to be above or below the median value, and
- there is a 90% chance that the true value is within the credible range.

Please respond to all questions, including those that ask about taxa or ecosystems that are outside of your area of expertise.

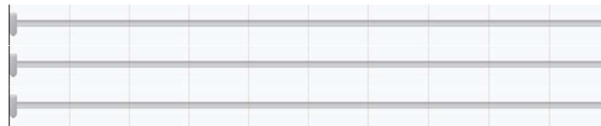
Approximately _____ % of species are currently threatened with extinction in most animal and plant groups studied.

0 10 20 30 40 50 60 70 80 90 100

median estimate

5th percentile

95th percentile



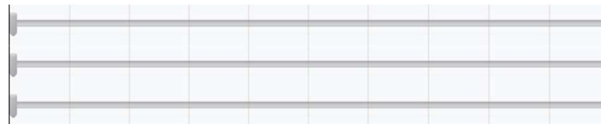
For the taxonomic group you know best, _____ % of species were either threatened with extinction or driven globally extinct by human activities from the year 1500 to 2020.

0 10 20 30 40 50 60 70 80 90 100

median estimate

5th percentile

95th percentile



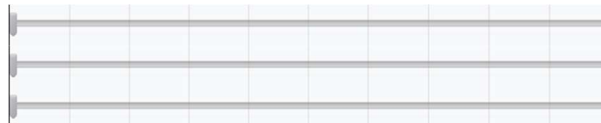
For the taxonomic group you know best, _____ % of species are currently threatened with extinction.

0 10 20 30 40 50 60 70 80 90 100

median estimate

5th percentile

95th percentile



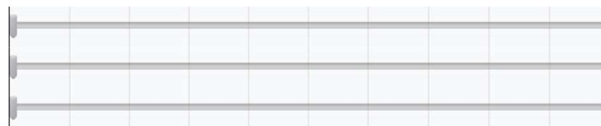
Since prehistory, the abundance of naturally-present species has declined by _____ % on average in terrestrial communities.

0 10 20 30 40 50 60 70 80 90 100

median estimate

5th percentile

95th percentile



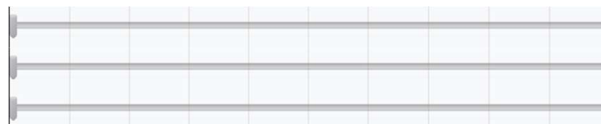
Mammals have been extirpated from _____ % of their natural ranges on average in terrestrial communities.

0 10 20 30 40 50 60 70 80 90 100

median estimate

5th percentile

95th percentile



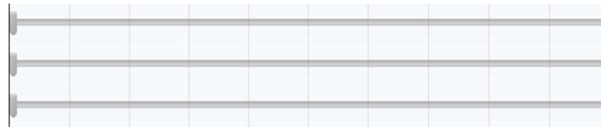
Since prehistory, the biomass of wild mammals has decreased by _____ %.

0 10 20 30 40 50 60 70 80 90 100

median estimate

5th percentile

95th percentile



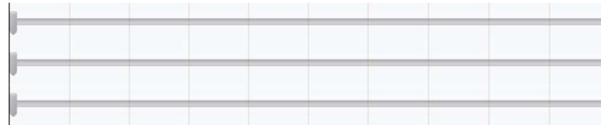
In the last 50 years, per capita consumption has increased by _____ %.

0 10 20 30 40 50 60 70 80 90 100

median estimate

5th percentile

95th percentile



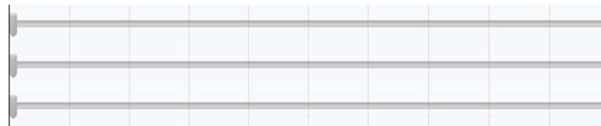
Human actions have directly altered at least _____ % of the land surface.

0 10 20 30 40 50 60 70 80 90 100

median estimate

5th percentile

95th percentile



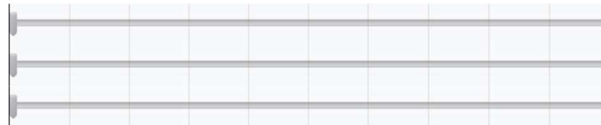
Approximately _____ % of the ocean surface is experiencing increasing cumulative human impacts.

0 10 20 30 40 50 60 70 80 90 100

median estimate

5th percentile

95th percentile



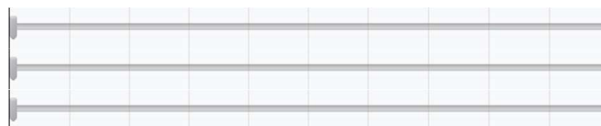
Currently, protected areas cover _____ % of terrestrial ecosystems.

0 10 20 30 40 50 60 70 80 90 100

median estimate

5th percentile

95th percentile



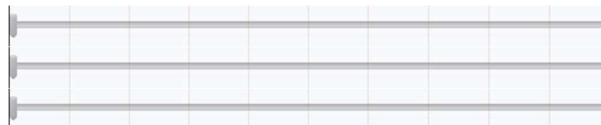
Currently, protected areas cover _____ % of the marine realm.

0 10 20 30 40 50 60 70 80 90 100

median estimate

5th percentile

95th percentile



Please share some information about yourself. This survey seeks to include respondents from a wide range of career stages, geographic locations, and perspectives.

Indicate your highest level of related education.

- ☐ Undergraduate degree in progress
- ☐ Undergraduate degree completed
- ☐ Master's degree in progress
- ☐ Master's degree completed
- ☐ Doctorate in progress
- ☐ Doctorate completed
- ☐ Postdoctoral research in progress
- ☐ Postdoctoral research completed

Indicate your years of related work experience after completion of your PhD.

- ☐ Have not completed PhD
- ☐ 1-5 years of work post-PhD
- ☐ 6-10 years of work post-PhD
- ☐ 11-20 years of work post-PhD
- ☐ 21-30 years of work post-PhD
- ☐ 31-40 years of work post-PhD
- ☐ > 40 years of work post-PhD

Which of the following options best describes your current place of work?

- ☐ Academic institution
- ☐ Governmental agency
- ☐ Nongovernmental organization
- ☐ Other

In which country do you currently reside?

▼ Afghanistan ... Zimbabwe

Select one or multiple countries in which you conduct biodiversity research.

☐

Afghanistan

☐

...

☐

Zimbabwe

What is your current gender identity?

☐

Man

☐

Woman

☐

Nonbinary

☐

Prefer to self-describe: _____

☐

Prefer not to answer

Please include any additional comments here.
