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Global priorities of environmental issues to combat food insecurity and biodiversity loss

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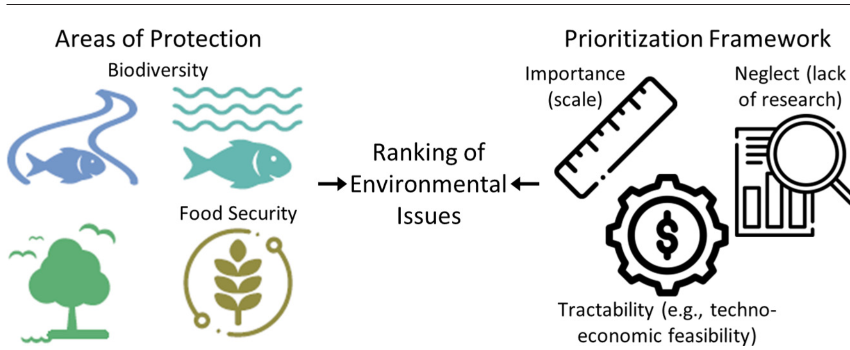
HIGHLIGHTS

- We must prioritize global biodiversity and food threats for effective protection.
- Our comprehensive prioritization included importance, neglect, and tractability.
- Pollinator loss and soil degradation are top priorities for food security.
- Biodiversity is best served by combatting ocean acidification and land use change.
- Our results call for a shift in attention towards the high-priority challenges.

GRAPHICAL ABSTRACT



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ABSTRACT

Various environmental challenges are rapidly threatening ecosystems and societies globally. Major interventions and a strategic approach are required to minimize harm and to avoid reaching catastrophic tipping points. Setting evidence-based priorities aids maximizing the impact of the limited resources available for environmental interventions. Focusing on protecting both food security and biodiversity, international experts prioritized major environmental challenges for intervention based on three comprehensive criteria – importance, neglect, and tractability. The top priorities differ between food security and biodiversity. For food security, the top priorities

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are pollinator loss, soil compaction, and nutrient depletion, and for biodiversity conservation, ocean acidification and land and sea use (especially habitat degradation) are the main concerns. While climate change might be the most pressing environmental challenge and mitigation is clearly off-track, other issues rank higher because of climate change's high attention in research. Research and policy agendas do not yet consistently cover these priorities. Thus, a shift in attention towards the high-priority environmental challenges, identified here, is needed to increase the effectiveness of global environmental protection.

1. Introduction

In the face of severe environmental challenges driven by ongoing global change (Ceballos et al., 2017; Sutherland et al., 2019), society must use its limited resources as effectively as possible to protect ecosystems and human well-being. Given limited time, funding, and human labour (Walls, 2018), we need to set priorities among the prevailing environmental challenges for how best to allocate these scarce resources. Wise decisions must be made on which sustainability targets to pursue (Allen et al., 2019), which topics to investigate (Rivero and Villasante, 2016), and which data to collect (Geijzendorffer et al., 2016) and where (Meyer et al., 2015), and funding must match these needs (Ibarguchi et al., 2018). It is crucial to act now to avoid crossing more tipping points (Dakos et al., 2019) and to reduce costs by implementing a proactive rather than a reactive agenda (Walls, 2018). Without evidence-based prioritization of the environmental challenges that we face, we risk focusing on arbitrary, politically expedient, or easy-to-achieve targets that fail to exploit the full potential (Allen et al., 2019) of environmental research and initiatives, and create mitigation gaps by focusing on less effective actions (Wynes and Nicholas, 2017).

To prioritize among 16 prominent environmental challenges, we applied a cause prioritization framework based on three criteria: (1) importance, (2) neglect, and (3) tractability (Todd, 2013; Wiblin, 2017). (1) If a problem is not important, there is no need to invest resources in its solution (where “resources” is used in a broad sense). (2) If resources are already heavily invested in a problem, additional contributions may be unlikely to make an appreciable difference. (3) If a problem is intractable, investing resources in addressing it is likely to be futile. This framework has been applied to a wide variety of issues (Todd, 2014) and, in a few scientific studies, it has proven useful for prioritizing animal welfare issues (Broad, 2018; Elder and Fischer, 2017), but it has not yet been used to prioritize environmental challenges. Previous studies on environmental priorities have often considered fewer challenges and have focused solely on their importance for biodiversity conservation (IPBES, 2019; Knapp et al., 2017), which is prone to disproportionate attention and needlessly high resource investments by disregarding neglect and tractability. Recently, Allen et al. (2019) prioritized environmental sustainable development targets using three criteria related to our own: the level of urgency (importance), the policy gap (neglect), and the systemic impact (tractability), but the study was restricted to the Arab region and did not target a specific area of protection (or a specific factor of core environmental concern). Here, we distinguish two areas of protection: food availability as the primary prerequisite for food security (Barrett, 2010; Ingram, 2011) which links environmental integrity through agricultural production to human well-being, and biodiversity as a prerequisite for ecosystem functioning (Oliver et al., 2015; Reiss et al., 2009; Tilman et al., 2014) which also links to wildlife welfare (Paquet and Darimont, 2010). As such, we cover both anthropocentric and ecocentric pro-environmental attitudes.

2. Methods

2.1. Prioritization framework

The study follows effective altruism principles, which aim to maximize desired outcomes using evidence and reason (MacAskill, 2017). However, the potential of effective environmentalism is largely untapped by the effective altruism community. To prioritize among various environmental issues, we apply a cause prioritization framework based on three criteria: (1) importance, (2) neglect, and (3) tractability. This framework was developed by 80,000 Hours, a non-governmental organization, in collaboration with the University of Oxford (Todd, 2013; Wiblin, 2017).

We distinguish two areas of protection: food availability and biodiversity. These are related to what we consider as ultimate areas of protection: human well-being and ecosystem functioning. Human well-being is the focus of an anthropocentric ethic, and ecosystem functioning which is the foundation of all life in general and links to wildlife welfare is the focus of an ecocentric ethic. Although the economy also depends on the environment, we do not consider it as an area of protection, as it can only indirectly contribute to human well-being, which is already covered. The environment affects human well-being in many ways. The most important way might be food supply (Raudsepp-Hearne et al., 2010). Ample food supply benefits human well-being in terms of improved agricultural employment (World Bank, 2018), reduced poverty, and increased health. Hunger and malnutrition negatively affect labour productivity and economic earnings (Reinhardt and Fanzo, 2014). Moreover, the leading health risk factor is related to food choices and malnutrition (Forouzanfar et al., 2016). Food availability is only one of three pillars of food security, along with food access and food utilisation. However, these pillars are hierarchical and food availability forms the basis for the other two (Barrett, 2010). Also, whereas the other pillars are mostly affected by socio-economic conditions, food availability is by far the most affected by the environment (Ingram, 2011). The relationship between the environment and ecosystem functioning is difficult to quantify and at an early stage of research. In contrast, the relationship between the environment and biodiversity is much better understood. Biodiversity is a prerequisite for ecosystem functioning (Huang et al., 2018; Oliver et al., 2015; Reiss et al., 2009; Tilman et al., 2014), and we may assume that environmental conditions which benefit biodiversity also benefit wildlife welfare (Paquet and Darimont, 2010). Although humans are not the focus of an ecocentric ethic, they are included. Ecosystem functioning also benefits human well-being through ecosystem services (Myers et al., 2013; Suich et al., 2015), which goes beyond human health benefits of food availability alone.

The 16 environmental challenges we examine include the 11 challenges already examined previously (Knapp et al., 2017) in relation to terrestrial and marine biodiversity. In addition, we include other challenges covered by the life cycle assessment framework, which is a framework to quantify various environmental impacts of products or services to support decision-making and avoid burden shifting. The 16 selected environmental challenges partly differ between biodiversity or food availability as the area of protection. For food availability, we replaced biological invasions with pests and diseases, habitat loss with land scarcity, and eco-toxicants with human toxicants. Moreover, we removed habitat fragmentation and hunting/fishing, and added nutrient depletion and pollinator loss.

2.2. Importance

The importance, scale, or scope of a problem describes its size and severity. We conducted an online survey among experts in the fields of food security and agriculture, and of biodiversity and ecosystems to estimate the importance of various environmental issues for these areas of protection. Because there can be trade-offs between environmental protection for either of these two areas, we conducted separate surveys to derive distinct importance scores. Importance is the most subjective among the three criteria and it is, therefore, crucial to attract many participants to cover a broad range of opinions and to reduce the influence of individual, possibly extreme opinions. Here, a simple survey as opposed to an iterative survey, like the Delphi technique, is better suited to attracting many participants, as it is less time-consuming and gives more freedom as to when to respond to the survey. We implemented the online survey in Qualtrics (https://www.qualtrics.com/). The survey software fulfilled the requirements of (1) potentially over one hundred responses within one month (a sample size reached in previous online surveys on environmental issues; Wood et al., 2018), (2) branch logic, which is needed to allow food and biodiversity experts to take different paths through the survey and to skip irrelevant questions, and (3) data export capability to facilitate subsequent analysis. For guidance in survey design and reporting, Andrews et al. (2003) and Bennett et al. (2011) were consulted, besides previous survey studies among which we took inspiration from Wood et al. (2018).

The survey consisted of nine questions. It started with five questions collecting anonymous demographic information about the institutional affiliation type (exclusive choice: university or research institute, NGO or international organization, public authority, and private sector), the academic degree (exclusive choice: doctorate, master, bachelor, none), the country (exclusive choice of over 200 countries), the number of years of experience (exclusive choice: <1, 1–5, 5–10, >10), and the area of expertise (open-ended, text only). This information served to assess the representativeness of the sample, to perform grouped analyses, and to discard some responses. Being slightly stricter than Wood et al. (2018), we only considered respondents with at least a master degree or at least one year of experience. After providing the demographic information, the participants selected the area of protection – biodiversity & ecosystems, agriculture & food security, or both – to which the three core questions would be related (see next paragraph).

Finally, the participants gave importance scores for different environmental challenges. The importance was defined for challenges for which action is required, challenges from the past that have not been solved yet, and challenges in the coming decades that could still be prevented. Like Knapp et al. (2017), we instructed participants to give the most important challenge a maximum score of 100, and to evaluate others relative to the main challenge. This was done separately for general environmental challenges and for two sub-groups with challenges related to either chemical emissions or land/sea use (resulting in three core questions). In the tables, the environmental challenges were sorted in alphabetical order to avoid a response bias through perceived suggestions of importance. A partial completion of the survey was not permitted. To ensure that the respondents filled in integers between 0 and 100 and did not leave any entry of the table empty, each entry was validated. Invalid responses that did not adhere to the instruction to give at least one score of 100 were increased by a scaling factor to fit the maximum to that value. Responses where identical scores were given for all three biogeographic realms or where all scores of a sub-group were zero were excluded. If respondents were not familiar with the term used to describe an environmental challenge, they could hover over the term to get a short explanation (supplementary information). Although the survey instructions pointed to the explanations, we acknowledge that they may have been overlooked by some respondents and, therefore, environmental challenges may have been misinterpreted. The complete survey, including all questions and the survey flow (i.e. branch logic), is presented in the supplementary information.

A pilot test was performed among seven co-authors and two more co-authors provided feedback to identify and improve unclear instructions, to judge and improve the content validity, and to estimate the completion time (11 min), which was integrated into the survey introduction. We integrated a check for unique submissions, and prevented automated submissions with a captcha at the end of the survey. The survey supported multiple browsers, was mobile friendly, and was tested in Internet Explorer, Mozilla Firefox, Google Chrome, Safari, 360 (a Chinese internet browser), Android, and iOS to check for technical issues. To increase the convenience in filling out the survey, a progress bar was displayed and it was possible to save responses and continue later. Since the survey did not collect any identifiable personal data, and the core questions did not relate to human subjects but to environmental challenges, an ethics review was not necessary.

We distributed the survey over multiple channels (supplementary information). Co-authors shared the survey with colleagues at their institutes or research collaborators through direct emails. The survey was also shared through mailing lists (listservs) and by some organizations through their networks and social media. Additionally, we announced the survey in several relevant LinkedIn and Facebook groups, and sent direct emails to 300 top authors who were identified through a search in the Web of Science. After submitting the survey response, we asked participants in the thank-you message to forward the survey to competent colleagues (snowball technique, supplementary information). After journal publication, the survey results will be distributed over the same primary channels (excluding secondary referrals) to provide feedback to participants. The survey could be accessed from 15 March 2019 until paper submission, and in some distribution channels one to two reminders were sent. No material incentives to increase the response rate were offered.

Because of non-normality and heteroscedasticity, significance of the differences in the mean scores of different environmental challenges was tested using Welch's F test on ranks (Cribbie et al., 2007). As post-hoc analysis, Welch's F test on ranks was also performed pairwise, and the *p*-values were adjusted for multiple comparisons using the Benjamini and Hochberg correction (Benjamini and Hochberg, 1995).

A common bias in surveys is the central tendency bias where respondents tend to give scores close to the midpoint, while they avoid the endpoints of a scale (Douven, 2018). Under a high cognitive load, this bias is likely to increase (Allred et al., 2016). In the context of our study, the bias is better described as restricted range bias. The survey design did not allow participants to avoid high values, as participants were instructed to give the most important environmental challenge the maximum score of 100. We tested, however, if participants restricted the range of scores by either avoiding small values or by using a limited number of individual scores.

2.3. Neglect

Neglect or uncrowdedness describes the lack of resources invested in a problem. Here, we limited ourselves to research resources, which we measured by the number of scientific publications. We performed a bibliometric analysis of publications accessed from the literature database Scopus, which is the largest formal database for scientific literature (Mongeon and Paul-Hus, 2016). Where a sufficient body of published research is available, a bibliometric analysis is a more objective method than expert elicitation through a survey. The R package rscopus (Muschelli III, 2018) served to count the number of publications on a specific subject. Terms were searched within the title, abstract, and keywords of an article without restricting the year of publication.

The more publications, the lower is the neglect score. Therefore, the number of publications were rescaled such that the topic with the highest number of publications has the score 0, and the topic with the lowest number of publications has the score 100.

For each environmental challenge, we included several synonyms or closely related terms in our search (e.g., climate change, global warming, etc.; see supplementary information) to ensure inclusion of as many publications as possible. In addition, we avoided too general terms that are used in very different contexts (e.g., erosion as in soil erosion or coastal erosion but also in dental erosion and the erosion of citizenship). The search for environmental issues was independent of the areas of protection, i.e. biodiversity and food security, as neglect can be quantified without considering such links. The neglect score is sensitive to the search terms applied. To get an estimate of the associated uncertainty, we performed a Monte Carlo cross-validation (Molinaro et al., 2005) by calculating the neglect scores 100 times and each time randomly omitting one of the terms for each environmental challenge.

2.4. Tractability

Tractability or solvability describes the potential and ease of alleviating a problem. Factors that play a role include technical feasibility, cost-effectiveness (Wiblin, 2017), closeness to tipping points, and socio-political challenges. Tractability does not reflect a lack of awareness or commitment. This criterion is the most difficult to quantify and we, thus, applied the Delphi technique (Dalkey and Helmer, 1963; Hsu and Sandford, 2010). The Delphi technique relies on iterative surveys of an expert panel. The iterative process makes it more reliable than a simple survey, and the smaller number of experts needed allows to be more selective.

We conducted the survey anonymously and electronically within three rounds, which is usually sufficient, as more iterations may not bring about stronger consensus (Hsu and Sandford, 2010), but may increase the attrition rate (Mukherjee et al., 2015). Participants were given two weeks to complete each round of the survey. The facilitator then took a week to process responses, to limit the time between rounds and reduce the effort of participants to re-familiarize with the survey (Mukherjee et al., 2015). Each round took on average about 60 min. In the initial round of inquiry, participants gave tractability scores between 0 and 100. Furthermore, they were asked to assess their confidence level, to briefly justify their judgement, and to optionally refer to key literature. For the following rounds, the facilitator provided the responses from the previous round of the respective participant, summary statistics (average, median, and range) of scores from all participants of the previous round, and a summary of their statements. The participants then had the opportunity to revise their scores and supporting arguments. Before the final round, their statements were integrated into brief literature reviews and supported by additional details and arguments (supplementary information).

Here, the expert panel consisted of eleven co-authors of the article, who are experts in either biodiversity and ecosystems, or food security and agriculture. The number of participants is within the range of 10–15, considered adequate for the Delphi technique (Hsu and Sandford, 2010). Besides their areas of expertise, co-authors were selected as participants in the Delphi assessment based on their number of citations on Google Scholar, their number of peer-reviewed articles in international journals, and their complementarity for an international coverage and thus a broad set of views. The first author facilitated the Delphi assessment and did not provide responses herself. In addition, another independent co-author gave feedback on the survey design.

Consensus was measured through the coefficient of variation, defined as the ratio of the standard deviation to the average. 50% or less was considered acceptable, and >80% was considered dissent. Changes in the coefficient of variation between two successive rounds further described the stability and convergence of responses (Gracht, 2012).

2.5. Integration

All scores were collected on a normal scale ranging from 0 to 100. For aggregation of scores for the three criteria into one priority score, we considered two cases. First, we scaled the range of the scores for each of the three criteria from 0 to 100, and considered an importance score of <10 as a defeater condition, nullifying priority. If a cause has very little impact (importance), it would be justified that the cause receives little attention (neglect), and it does not matter that the cause is not solvable (tractability). Therefore, it should not be a priority. Second, we used the ranks instead of the actual values. To attain a priority score, we aggregated the scores of the three underlying criteria by weighted averaging. Following the recommendation by 80,000 Hours (Wiblin, 2017), we assumed weights of 4, 3, and 2 for importance, neglect, and tractability.

3. Results

3.1. Importance of environmental challenges

A total of 140 international experts participated in the public online survey and provided importance scores. Only two sets of responses were discarded. Of the remaining 138 respondents, 51 selected the area of protection “biodiversity and ecosystems” as within their expertise, 58 selected “food security and agriculture”, and 28 selected both. Most respondents were affiliated with a university or research institute (71%), had a doctorate (64%), and had >10 years of experience (62%) (Fig. A2). Respondents were based in all continents (Fig. A2), covering 36 countries.

Climate change was judged as the most important or severe environmental challenge for marine ecosystems and food security, while land/sea use was judged as the most important for terrestrial and freshwater ecosystems. Photochemical ozone formation and soil compaction were considered the least important (Fig. 1). However, the spread among responses is very high with coefficients of variation (or relative standard deviations) ranging from 0.22 to 1.6, and interquartile ranges from 20 to 60 (for scores from 0 to 100). The Pearson correlation coefficient between these interquartile ranges and the average scores is −0.37 ($p < 0.01$). This means that there is more agreement among respondents about those environmental challenges judged as most important. Despite the large spread, the difference among the mean scores of environmental challenges was highly statistically significant ($p \ll 0.01$) for all four cases: the three ecosystem types and food security. The post-hoc analysis showed that each environmental challenge differs significantly from at least 7 others out of 15 possible comparisons, and each most important challenge for an area of protection differs significantly from at least 10 others. The score of climate change as the most important environmental challenge for food security is statistically significantly different from all 15 other environmental challenges in the same area of protection, in line with the above correlation coefficient between interquartile ranges and average scores.

What was judged as most important also differs among sub-groups as defined by either respondent affiliation or level of expertise (in terms of the degree and years of experience) (Fig. A3). Affiliation matters more than the level of expertise in determining their importance assessment. Responses from the private sector deviate most from the rest, but also comprise the smallest sub-group. For example, the private sector considers habitat loss as much less important and acidification as much more important for freshwater ecosystems than other sub-groups. In contrast, respondents with different affiliations agree well on the high importance of climate change for marine ecosystems and food security. A total of 48 respondents only gave a minimum score of 20 or higher, and respondents gave, on average, 9 unique scores out of

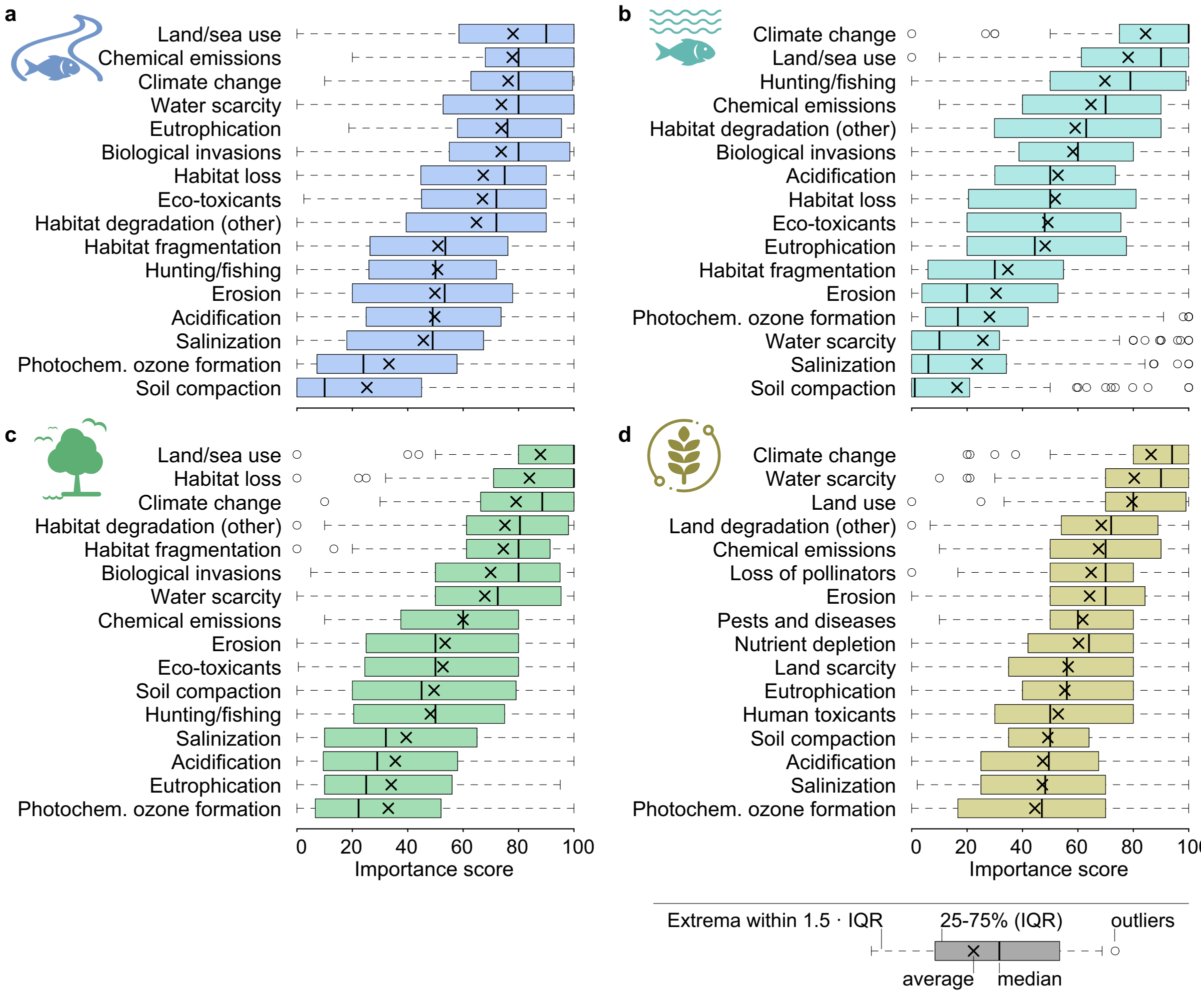

Fig. 1. Importance scores based on a public online survey for protection of (a) freshwater biodiversity, (b) marine biodiversity, (c) terrestrial biodiversity, and (d) food security. Crosses represent averages. The whiskers of the boxplots extend to at most 1.5 times the interquartile range, beyond which data points are considered as outliers and represented by circles. Sample size: 138. For the raw data, please see the supplementary data.

16 ratings. This suggests that a potentially restricted range may have biased the scores of some respondents. Another bias that may have affected the scores, especially of climate change, is the discounting of environmental outcomes that are uncertain, geographically distant, and far in the future (Weber, 2010).

3.2. Neglect of environmental challenges

Climate change is a topic that already receives plenty of attention, and is in the focus of scientific literature. Other issues, such as pollinator loss and habitat fragmentation are considered more neglected (Fig. 2). While we assume that the attention that environmental challenges receive in research is correlated with that given by stakeholders, specific environmental challenges may deviate from this pattern. Uncertainties also arise from an inconsistent phrasing of key concepts where synonyms or related terms can describe the same environmental challenge. The number of search terms differs among environmental challenges, but neither (a) the deterministic neglect score nor (b) the variation in scores, as measured by the coefficient of variation, is correlated with that number ((a) $r = -0.23$, $p = 0.28$; (b) $r = -0.06$, $p = 0.78$).

There is a moderate negative correlation between importance and neglect scores (biodiversity: $r = -0.41$, $p = 0.083$; food security: $r = -0.37$, $p = 0.16$). This correlation is slightly stronger and significant for score ranks (biodiversity: $r = -0.64$, $p < 0.01$; food security: $r = -0.50$, $p = 0.050$). It suggests that important environmental challenges tend to get studied more. Conversely, it could also imply that environmental challenges that receive more attention are perceived as more important. The latter explanation is consistent with the availability bias (Tversky and Kahneman, 1973) and availability cascade (Kuran and Sunstein, 1999) theories. The availability bias refers to the overestimation of importance if something is easily available in our minds (Tversky and Kahneman, 1973). It can, for example, be caused by exposure to media information (Schmidt et al., 2014). The availability cascade, in turn, describes a self-reinforcement of the availability bias (Kuran and Sunstein, 1999).

3.3. Tractability of environmental challenges

Importance and tractability scores are strongly negatively correlated (biodiversity: $r = -0.66$, $p < 0.01$; food security: $r = -0.79$, $p < 0.01$), suggesting that severe environmental challenges are also less tractable. The negative correlations between importance on the one hand and neglect and tractability on the other hand also imply that the three criteria can compensate for each other. Although one may assume that more research on an environmental challenge makes it more tractable or that a more tractable challenge stimulates less research, the neglect and tractability scores do not seem to be correlated (biodiversity: $r = -0.14$, $p = 0.56$; food security: $r = +0.37$, $p = 0.15$).

Despite different fields of expertise, the Delphi participants reached consensus on the tractability of addressing each issue. For each environmental challenge, there were one to seven Delphi participants in the first round with high or very high confidence, but also one or more

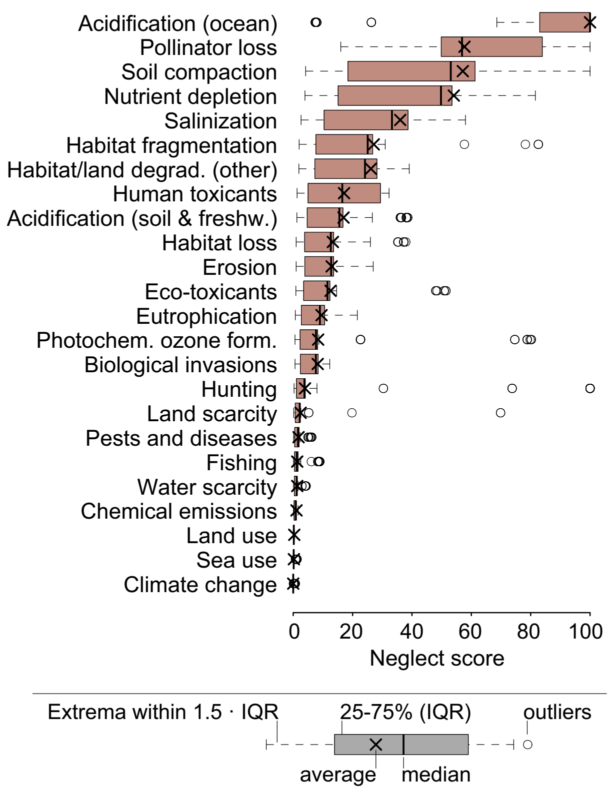

Fig. 2. Neglect scores based on a bibliometric analysis in Scopus. Crosses represent the deterministic values based on the full set of search terms, and the boxplots are derived from the Monte Carlo leave-one-out cross-validation with 100 iterations. The whiskers of the boxplots extend to at most 1.5 times the interquartile range, beyond which data points are considered as outliers and represented by circles. For the raw data, please see the supplementary data.

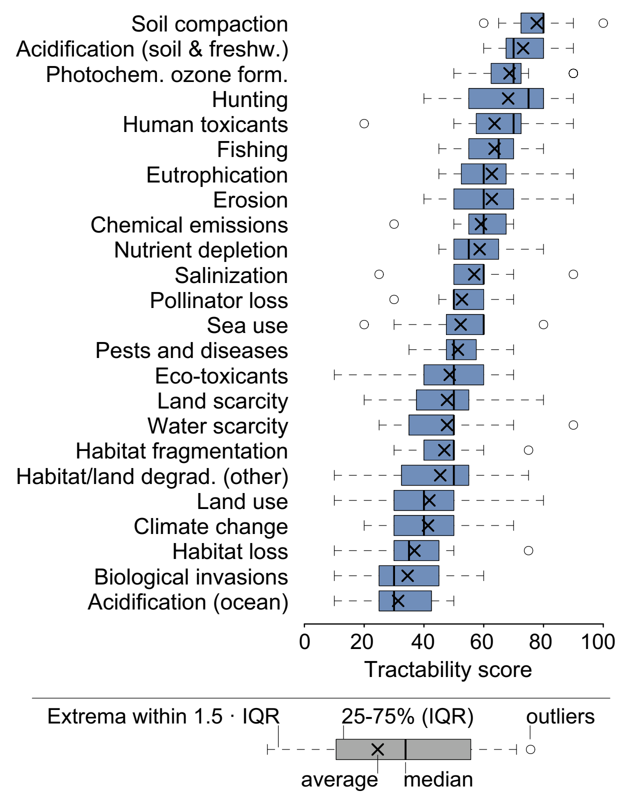

Fig. 3. Tractability scores based on the third and final round of a Delphi assessment. Crosses represent averages. The whiskers of the boxplots extend to at most 1.5 times the interquartile range, beyond which data points are considered as outliers and represented by circles. Sample size: 11. For the raw data, please see the supplementary data.

with low or very low confidence, reflecting the group's complementarity. In the final round, the lowest confidence level remained for the assessment of sea use with a low to moderate average confidence. Over the three rounds of the Delphi assessment, tractability scores converged. While there was only a consensus (coefficient of variation ≤50%) for 11 out of 23 environmental challenges in the first round, in the third and final round, all 24 environmental challenges (acidification was split in the second round into soil and freshwater vs. ocean acidification) reached consensus (Fig. A4, Table A1). There was no dissent (coefficient of variation >80%) in any round for any environmental challenge.

The tractability of climate change, which scored highest in importance for two areas of protection (Fig. 1), was judged to be low (Fig. 3). To meet the 1.5 °C climate target, we have just over a decade to make dramatic changes (Rogelj et al., 2018). Many interventions already exist for climate change mitigation (Pacala and Socolow, 2004; Scherer and Verburg, 2017). Others, like carbon capture and storage (CCS) and negative-emissions technologies which are also key, are still in development and face considerable ecological, technical, and economic challenges (Bui et al., 2018). However, even if carbon dioxide emissions ceased immediately, climate change would be irreversible for the next millennium (Solomon et al., 2009).

Like climate change, ocean acidification, which scored highest in neglect (Fig. 2), is driven by CO_2 emissions. Unconventional, non-passive measures, such as ocean fertilization, may be required in addition to reducing CO_2 emissions. Such measures and their ecological impacts remain little explored, may be highly risky, and may not be feasible for use at large scales (Rau et al., 2012). Consequently, the tractability of ocean acidification was judged as lowest. In contrast, the tractability of soil and freshwater acidification was judged as relatively high (Fig. 3). Solutions include, among others, emission control of sulphur dioxide (SO_2), nitrogen oxides (NO_x), and ammonia (NH_3) (Zhao et al., 2009), liming (Mant et al., 2013), and biochar amendment (Dai et al., 2017).

Tractability can be considered higher if a measure can simultaneously tackle multiple environmental challenges. For example, mitigating climate change and ocean acidification both heavily rely on reducing CO_2 emissions. The Delphi participants in this study evaluated the tractability of each environmental challenge separately. Incorporating co-benefits into the evaluation of tractability becomes more relevant when prioritizing potential solutions to the high-priority challenges identified here.

3.4. Priority of environmental challenges

By integrating all three criteria – importance, neglect, and tractability – the loss of pollinators has the highest priority for food security, independent of the choice of aggregation based on either average scores or ranks (Fig. 4, Fig. A5). Although its tractability is moderately low, its importance is moderately high, and its neglect is high. Several potential solutions exist (Dicks et al., 2016), but no panacea. The drivers are multi-faceted (Potts et al., 2010) and require a combination of multiple tactics. Which strategy works best depends on site-specific characteristics (Barzman et al., 2015). Soil compaction and nutrient depletion (Fig. 4, Fig. A5) are also high priorities for food security. Soil compaction rated low on importance, but is highly neglected and tractable, while nutrient depletion rated moderately high on importance and tractability, but is also highly neglected. Because of the high tractability of soil compaction, reducing soil compaction is easy (i.e. a low-hanging fruit), and still leaves room for other environmental interventions. However, the importance score of soil compaction only slightly exceeds the threshold below which a challenge is disregarded from prioritization (the defeater condition). Increasing the threshold from 10 to 20

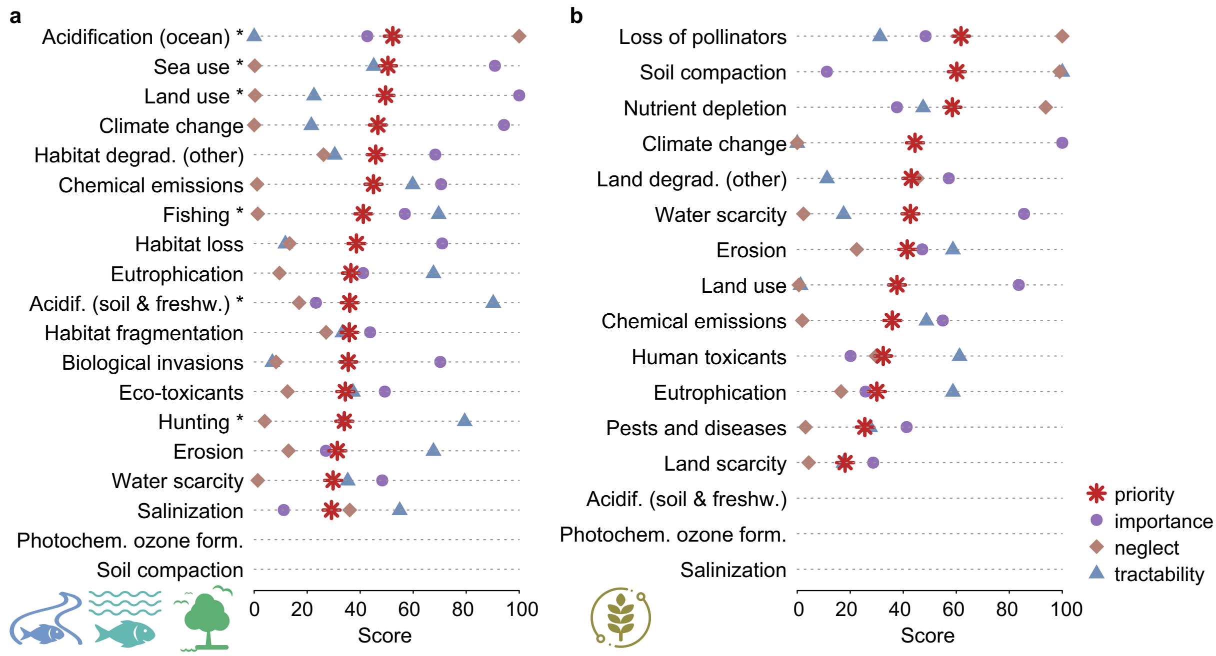

Fig. 4. Priority scores based on rescaling and low importance (<10) as a defeater condition for protection of (a) biodiversity and (b) food security. If the defeater condition applies, the environmental challenge is disregarded from prioritization, and shown at the bottom of the figure without any score. The asterisk after some of the environmental challenges on the y-axis of (a) indicates that it is not relevant for all three types of ecosystems.

would exclude soil compaction related to food security and salinization related to biodiversity from prioritization.

Ocean acidification, and sea and land use (Fig. 4), especially habitat degradation (Fig. A5), are key priorities for biodiversity conservation. While the tractability of ocean acidification is very low (as discussed above), and its importance is moderate, it is highly neglected. Likewise, the importance and tractability of habitat degradation are moderate, while its neglect is high.

While the high importance score allocated to climate change confirms that it is one of the most severe environmental challenges our planet faces, it is not the highest priority (Fig. 4, Fig. A5). The tractability of climate change is low, and, more importantly, it already receives most of the attention in research relative to the other environmental issues. Climate change's complexity may justify this high attention, but a high attention also diminishes the value of additional contributions. Despite this, climate change ranks fourth when using the rescaled scores for both biodiversity and food security (Fig. 4). Considering that it ranks relatively high for both, while higher-ranked issues are either specific to one area of protection or rank very differently, mitigating climate change might achieve the greatest combined benefits for biodiversity conservation and food security. Since the prioritization is based on scientific publications to measure neglect, it applies mostly to research and possibly to advocacy and policy discussions. However, the prioritization does not represent actions. Even climate change actions are neglected. This is, for example, demonstrated by the current country pledges within the Paris Agreement, which are insufficient to meet the climate target (Rogelj et al., 2016).

4. Discussion

There are many reasons for protecting the environment: its instrumental value to humans through ecosystem services, its intrinsic value essential to ecosystem functioning and wildlife welfare, and its relational value concerning relationships between humans and the environment (Chan et al., 2016). Our concern for the environment is likely to increase in the future with our expanding moral boundaries (Crimston et al., 2016) and ongoing global change. Independent of why we value nature, setting priorities for effective environmental protection is crucial and urgent.

The prioritization will require periodic revisions to remain relevant. Importance, neglect, and tractability can all evolve over time (Elder and Fischer, 2017), through closing the mitigation gap, successful advocacy, or promising emerging technologies. For example, the United Nations recently declared the next decade the UN Decade on Ecosystem Restoration (UN Environment, 2019), and at the same time researchers have developed a framework for designing and implementing rewilding, restoration focused on promoting self-regulating ecosystems (Perino et al., 2019). This helps reduce the neglect, but also increases the tractability of habitat degradation, and as such will change its prioritization. Moreover, the environmental challenges considered in this analysis are not exhaustive, so the scope of the prioritization can be expanded and changed in the future. Emerging impacts, such as noise, light pollution, and electromagnetic radiation (Winter et al., 2017), are also missing. They require further research (Cucurachi et al., 2014) before they can be properly judged within our presented framework. The annual horizon scan of emerging issues for biodiversity conservation (Sutherland et al., 2019) is valuable to identity which emerging impacts, impact drivers, and potential solutions require more fundamental research. Similarly, key research questions for the future of agriculture have been identified through horizon scanning (Pretty et al., 2010). We suggest periodic revisions every five to ten years to allow for reassessment in light of progress in research and successes in interventions that would demand significant changes in priorities.

Following our analysis, a logical next step is to prioritize among potential solutions for the identified high-priority environmental challenges. An excellent example of such an endeavour is the ranking of 100 climate solutions by Project Drawdown (Hawken, 2017). Refrigerant management, including phasing out of HFCs and careful disposal of refrigerants, ranks as the highest-priority solution in that assessment. Other important solutions include onshore wind turbines, food waste reduction, and plant-based diets (Hawken, 2017). Another example is the identification of priority solutions for sustainable intensification of agriculture in the United Kingdom (Dicks et al., 2019). Similar endeavours need to follow for other environmental challenges. Where tractability is low, possible solutions still have to be developed and explored. Along with technological innovations to decouple environmental impacts from growth in population and affluence, these must include behaviour and system changes (O'Rourke and Lollo, 2015). Besides prioritization, effective environmental protection calls for globally coordinated assessments and mitigation efforts for all high-priority challenges, as done for climate change through the Intergovernmental Panel on Climate Change (IPCC) and the Paris Agreement.

5. Conclusions

Our analysis enables more strategic choices to tackle environmental issues. Environmental challenges vary in their importance, neglect, and tractability, which together determine their degree of priority. Aiming at food security and biodiversity conservation under resource constraints, our analysis suggests, within the limits of our sample and potential biases, prioritizing land and sea use and its associated habitat degradation, ocean acidification, nutrient depletion, soil compaction, and the loss of pollinators. These priorities call for a shift in attention to better align the focus of research and to connect advocacy with the importance and tractability of environmental challenges.

CRediT authorship contribution statement

Laura Scherer: Conceptualization, Methodology, Formal analysis, Visualization, Writing - original draft. **Jens-Christian Svenning:** Writing - review & editing. **Jing Huang:** Writing - review & editing. **Colleen Seymour:** Writing - review & editing. **Brody Sandel:** Writing - review & editing. **Nathaniel Mueller:** Writing - review & editing. **Matti Kummu:** Visualization, Writing - review & editing. **Mateete Bekunda:** Writing - review & editing. **Helge Bruelheide:** Writing - review & editing. **Zvi Hochman:** Writing - review & editing. **Stefan Siebert:** Writing - review & editing. **Oscar Rueda:** Conceptualization, Writing - review & editing. **Peter M. van Bodegom:** Methodology, Writing - review & editing.

Declaration of competing interest

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

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Appendix A. Supplementary material

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