Ten-year assessment of the 100 priority questions for global biodiversity conservation

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Abstract

In 2008, a group of conservation scientists compiled a list of 100 priority questions for the conservation of the world's biodiversity [Sutherland *et al*. (2009) *Conservation Biology*, **23**, 557–567]. However, now almost a decade later, no one has yet published a study gauging how much progress has been made in addressing these 100 high-priority questions in the peer-reviewed literature. Here we take a first step toward re-examining the 100 questions and identify key knowledge gaps that still remain. Through a combination of a questionnaire and a literature review, we evaluated each of the 100 questions on the basis of two criteria: relevance and effort. We defined highly-relevant questions as those which – if answered – would have the greatest impact on global biodiversity conservation, while effort was quantified based on the number of review publications addressing a particular question, which we used as a proxy for research effort. Using this approach we identified a set of questions that, despite being perceived as highly relevant, have been the focus of relatively few review publications over the past ten years. These questions covered a broad range of topics but predominantly tackled three major themes: the conservation and management of freshwater ecosystems, the role of societal structures in shaping interactions between people and the environment, and the impacts of conservation interventions. We see these questions as important knowledge gaps that have so far received insufficient attention and may need to be prioritised in future research.

Introduction

The ability to prioritise research in conservation science is critical to ensuring that available resources are used as effectively as possible to safeguard biodiversity. One approach to defining high-priority areas of research is to identify key questions which – if addressed – would contribute most towards advancing a given field. In recent years, this type of priority-setting exercise has become increasingly common in the environmental sciences (Fig. 1a). In the context of conservation science, Sutherland *et al.* (2009) were the first to compile a list of 100 questions of importance for the practise of conserving the world's biodiversity. As of July 2016, Sutherland *et al.* (2009) has been cited 229 times, 70 of which did so specifically to justify research on topics highlighted in the paper (Fig. 1b–c). However, now a decade since these questions were first published, which ones should still be considered a high priority?

In an attempt to address this question, here we provide a preliminary assessment of how much progress has been made in addressing the 100 priority questions for global biodiversity conservation outlined in Sutherland *et al.* (2009). Through a combination of a questionnaire and a literature survey, we revisit the 100 questions with the aim of identifying which ones constitute key knowledge gaps that limit the effectiveness of conservation practises worldwide. Specifically, we ask which of the 100 questions are currently considered most relevant by conservation scientists and practitioners, which ones have researchers focused most of their efforts on and which instead have featured less in the published literature. In doing so we aim to develop a framework through which priority questions from any field of research can be monitored and updated through time.

Methods

Compiling the original 100 questions

In 2008, a group of conservation scientists and practitioners convened for a workshop with the objective of outlining a set of key questions which – if answered – would have the greatest impact on conservation practices worldwide. Participants included representatives from both international conservation organisations and academic institutions based predominantly in Western Europe and North America, but with strong working experience

outside these areas. Through a series of group discussions and voting sessions, attendees converged on a list of 100 priority questions that featured in Sutherland *et al.* (2009) (see Appendix S1 in Supporting Information for a list of the 100 questions). For convenience, the questions were grouped into 12 broad themes: "*Ecosystem function and services*", "*Climate change*", "*Technological change*", "*Protected areas*", "*Ecosystem management and restoration*", "*Terrestrial ecosystems*", "*Marine ecosystems*", "*Freshwater ecosystems*", "*Species management*", "*Organisational systems and processes*", "*Societal context and change*", "*Impacts of conservation interventions*". Here we follow the above grouping structure, although we note that Sutherland *et al.* (2009) suggested that this is only one of several ways in which the 100 questions could be organised into themes.

Revising the 100 questions

We evaluated each of the 100 questions on the basis of two criteria: relevance and effort. *Relevance* ranks questions based on their potential to positively impact biodiversity conservation on a global scale. Questions that are highly relevant are those which – if answered – would have the greatest impact on global biodiversity conservation. *Effort*, instead, quantifies how much research has been directed towards a particular question, for which we used number of review papers as a proxy. In this framework, questions that are deemed highly relevant but have relatively few associated review publications constitute knowledge gaps that limit the ability to effectively conserve biodiversity. Below we outline how relevance and effort scores were quantified for each of the 100 questions.

Relevance

Relevance scores for each of the 100 questions were obtained through a questionnaire. Respondents were presented with 10 randomly selected questions and asked to score each of these on a scale of 1 (low relevance) to 10 (high relevance), where questions that are highly relevant are those which – if answered – would have the greatest impact on global biodiversity conservation. Respondents were also asked to identify how familiar they were with the topic of each question on a scale of 1 (no familiarity) to 10 (very familiar). Additionally, we gathered information on each respondent's gender, career stage and continent of origin. The survey was distributed globally among conservation scientists and practitioners via targeted mailing lists and social media outlets using the Qualtrics web application (https://www.qualtrics.com). A copy of the questionnaire can be accessed here: http://cambridge.eu.qualtrics.com/jfe/form/SV_42wbtBiTo25ncH3. The survey was conducted anonymously and ethics clearance was obtained before its launch.

We used structural equation models (SEMs) fit using the *lavaan* package in R (R Core Development Team, 2016) to tease apart how relevance scores were associated with a respondent's gender, career stage and familiarity score. Based on this, when calculating mean relevance scores for each of the 100 questions we chose to weight participant's scores according to their degree of familiarity with the question (although we note that almost identical results were obtained when using an un-weighted measure of relevance). This implicitly assumes that respondents that are more familiar with a given topic are better placed to judge its relevance.

Effort

To gauge the degree of effort that has gone into addressing each of the 100 questions, we undertook a literature review. Given the large number and diverse range of topic covered by the 100 questions, we chose to restrict bibliographic searches to review articles only. We reasoned that review papers would provide a good indicator that research on a given topic had matured enough to warrant a synthesis. Furthermore, a preliminary analysis of the bibliographic data we collected revealed a very strong correlation between number of review papers and primary articles returned by a given search (Pearson's correlation coefficient (ρ) = 0.97). Nonetheless, we acknowledge that by focusing on review papers alone we ignore other equally important publication outlets (e.g., primary literature, grey literature, books or reports), as well as other meaningful metrics of effort (e.g., expenditure or number of funded projects). As such, ours should be viewed as a preliminary first step towards quantifying research effort for Sutherland *et al.*'s (2009) 100 questions.

The literature review was conducted using the Scopus search engine, and followed a protocol which we provide in full in Appendix S2. Briefly, we started by generating keyword searches for each of the 100 questions and running them through Scopus. Search outputs were then screened to only include review papers published since 2009. For each question, all review papers returned by the search were then classified as either pertinent or not to the question based on information contained in the title and abstract of the paper (although we note that titles and abstracts may not always fairly represent the content of an article). For searches that returned >100 review papers, this assessment was based on a random

subset of 100 reviews (see Appendix S2 for details). The total number of pertinent reviews papers identified through the above process was used as a proxy for research effort for each of the 100 questions.

In Appendix S3 and S4 we explore the extent to which these effort scores are influenced by the time window across which searches were conducted, the choice of key words selected for each question and the subjective interpretation of which review papers to consider as pertinent to a particular question. Note that the majority of our keyword searches included one or more of the terms: biodiv*, species, conserv* and ecosyst* (see Appendix S1 for a complete list of keywords). This constrained our search to review papers that explicitly linked a given topic and its application to conservation. We acknowledge that many articles and reviews that are relevant to the conservation of biological diversity may not recognize or emphasize that connection in the text.

Relating relevance and effort scores to identify knowledge gaps

We analysed the relevance and effort scores calculated for each of the 100 questions to identify which ones are currently considered most relevant, and highlight questions that have been the subject of relatively few review articles and therefore may constitute knowledge gaps that, if filled, could lead to the development of more effective conservation practises. Knowledge gaps were defined as questions that scored higher than average in terms of relevance, while also having a lower than average effort score. Additionally, we quantified how closely relevance and effort scores correlated across the 100 questions to

explore whether questions that are deemed highly relevant by those that are familiar with the topic have also been the focus of a greater number of review articles. For these analyses effort scores were log-transformed to better capture the right-skewed distribution of the data, following which both metrics were normalized between 0–1 to aid interpretation of the results. Data were analysed both at the individual question level and at the aggregated theme level (i.e., after grouping questions into their 12 themes).

Results

Relevance

A total of 222 respondents took part in the survey to score the 100 questions according to relevance. Of these, the majority were from Europe and the United States, although respondents from all continents except Antarctica took part in the survey (Fig. 2). Respondents were equally balanced among men (52%) and women (48%), and represented a diverse range of career stages (career length ranged from 1–40 years; Fig. 2). SEMs revealed that multiple factors contributed to shaping a person's perception of relevance, including their gender, career stage and familiarity with the topic (Fig. 3). The clearest pattern to emerge was that, on average, respondents tended to assign higher relevance scores to questions they were most familiar with (Fig. 3b). In turn, respondents that had been working in conservation the longest were more likely to express familiarity with the topic of a given question. However, compared to early-career participants, respondents who had been working in conservation for longer tended to attribute lower relevance to a given

question. Lastly, while a participant's gender had little direct influence on their perception of relevance or familiarity of a given topic, we did find that participants who had been working in conservation the longest were predominantly male (Fig. 2). Of the top 10 ranked questions according to relevance scores, four belong to the "*Climate change*" theme (Appendix S1).

Effort

The literature survey returned a total of 23611 review papers published since the beginning of 2009 that matched the selected keywords. For 45 of the 100 questions, literature searches returned > 100 review papers. Because in these cases a subset of 100 review papers was selected at random for scoring, the total number of publications we assessed was 6934. Of these, 2142 were classified as pertinent to a particular question based on their title and abstract. Based on this, we estimated a mean of 53 pertinent reviews per question. When questions were ranked according to their effort score, three of the top five questions with the lowest effort scores were found to belong to the "*Impacts of conservation interventions*" theme (Appendix S1).

Knowledge gaps

Questions and themes varied considerably in terms of both their relevance and effort scores (Fig. 4). Nonetheless, when looking across the 100 questions, a weak yet significantly positive correlation emerged between relevance and effort scores (ρ = 0.29, P = 0.003; Fig. 4a). We identified 21 questions that met our criteria for knowledge gaps (Fig. 4b). When

data were aggregated by theme, strong differences between groups emerged. For instance, questions in the "*Technological change*" formed a clear outlier, having received (on average) significantly lower relevance scores in the questionnaire compared to other themes. By contrast, the "*Freshwater ecosystems*" theme scored among the highest in terms of relevance, despite the fact that on average questions in this theme tended to have low effort scores. Similarly, questions from the "*Societal context and change*", "*Protected areas*" and "*Impacts of conservation interventions*" themes also tended to have low effort scores given their perceived relevance. This is in contrast to questions from the "*Climate change*" and "*Marine ecosystems*" themes, where high relevance scores were associated with equally high effort scores.

Discussion

We found considerable variation among the 100 questions in terms of their perceived relevance and the degree of research effort they have attracted (Fig. 4). Yet questions from the "*Technological change*" theme emerged as a clear outlier – having scored significantly lower than average in terms of relevance on the questionnaire. This could be interpreted as a general perception among conservation scientists and practitioners that technological advances have little to contribute when it comes to achieving conservation outcomes. However, this seems unlikely to us, especially when considering how technologies such as gene drives, eDNA and drones (to name a few) have gained such traction in conservation in recent years. A simpler explanation for the low relevance scores attributed to the questions in this theme may be that survey respondents were simply unfamiliar with the topics of

these questions – which included nanotechnologies, genetically modified organisms, renewable energy and bioeconomy markets. Questions in the "*Technological Change*" theme scored by far the lowest in terms of familiarity in the questionnaire. Given that survey participants tended to assign higher relevance scores to questions they were most familiar with (Fig. 3), the fact that questions relating to technological change were perceived as being of low relevance to biodiversity conservation may therefore reflect a lack of awareness when it comes these topics.

Another pattern to emerge from our analysis was the tendency of questions within the "*Freshwater ecosystems*" theme to score low in terms of research effort. Freshwater ecosystems are globally threatened by anthropogenic disturbance (Vörösmarty *et al.*, 2010). The implications of jeopardising the functionality of freshwater ecosystems are not lost on the conservation community, as questions pertaining to the conservation and management of these systems scored amongst the highest in terms of relevance in the questionnaire (Fig. 4). Despite this, we found that research output related to the conservation of freshwater systems was generally lower compared to that addressing similar issues in terrestrial and marine realms. This pattern was consistent with a *post-hoc* analysis of the literature, which highlighted that during the past five years there have been 72% more publications addressing questions explicitly pertaining to the conservation of marine biodiversity compared to those tackling similar topics in freshwater ecosystems (assessed by recording the number of articles returned when searching for the terms "*biodiversity AND conservation*" in association with either "*marine*" or "*freshwater*" in Scopus). In particular,

compared to marine systems, we found fewer coordinated studies on the impacts of climate change on the biodiversity and hydrology of the world's freshwater systems.

A third theme that emerged when looking across questions with higher-than-average relevance scores and low numbers of associated publications is captured by a group of questions that broadly address how societal structures and processes influence interactions between people and the environment. Specifically, to us they suggest a need to better understand how education, development and economic growth shape the relationships between people and nature (Questions 74, 82–84), as well as the importance of identifying the most effective strategies for building broad, long-lasting societal support for conservation interventions (Questions 92 and 98). These issues are well summarized by Question 83 which addresses the implications of increased human dissociation from nature for biodiversity conservation, a topic of research which despite being perceived as highly relevant by conservation scientists and practitioners who took part in the survey (Fig. 4) has only recently started to gain traction in the literature (e.g., Soga & Gaston, 2016).

At the opposite end of the spectrum, our assessment also allowed us to identify a set of high-priority questions that have been relatively well studied. These questions fell under a variety of themes, but of the top 10 questions with the highest research effort scores, four were from the "*Climate change*" theme. The fact that these questions have been the focus of a relatively large number of review publications to us reflects the severity of the threat posed by climate change to the world's biodiversity. However, it does raise the question of why certain topics are perceived as more relevant than others, and whether this in turn

contributes to determining the high variability in research effort which we observe among the 100 questions.

Two key results from our study relate to this question. The first is a clear trend that emerged from the questionnaire, whereby respondents tended to attribute greater relevance to topics they were most familiar with (Fig. 3). The second is the fact that – on average – questions that were deemed most relevant are also those that have been the focus of the greatest number of review papers (Fig. 4a). Together, these findings pose important further questions. For instance, do these patterns emerge because researchers work hardest to address those problems that are genuinely most pressing? Or are they more likely to have been exposed to, become familiarized with, and work on topics that have been the focus of extensive previous research? Distinguishing between these and other scenarios is an important issue to resolve if prioritisation exercises are to be used as an effective tool to guide the future direction of a field of research.

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Supporting information

Relevance and effort scores for each of the 100 questions (Appendix S1), literature review protocol (Appendix S2), sensitivity analysis of bibliographic searches and inter-rater agreement (Appendix S3), key assumptions and limitations (Appendix S4), and citation report for Sutherland *et al*. (2009) (Appendix S5) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

Literature Cited

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Figures

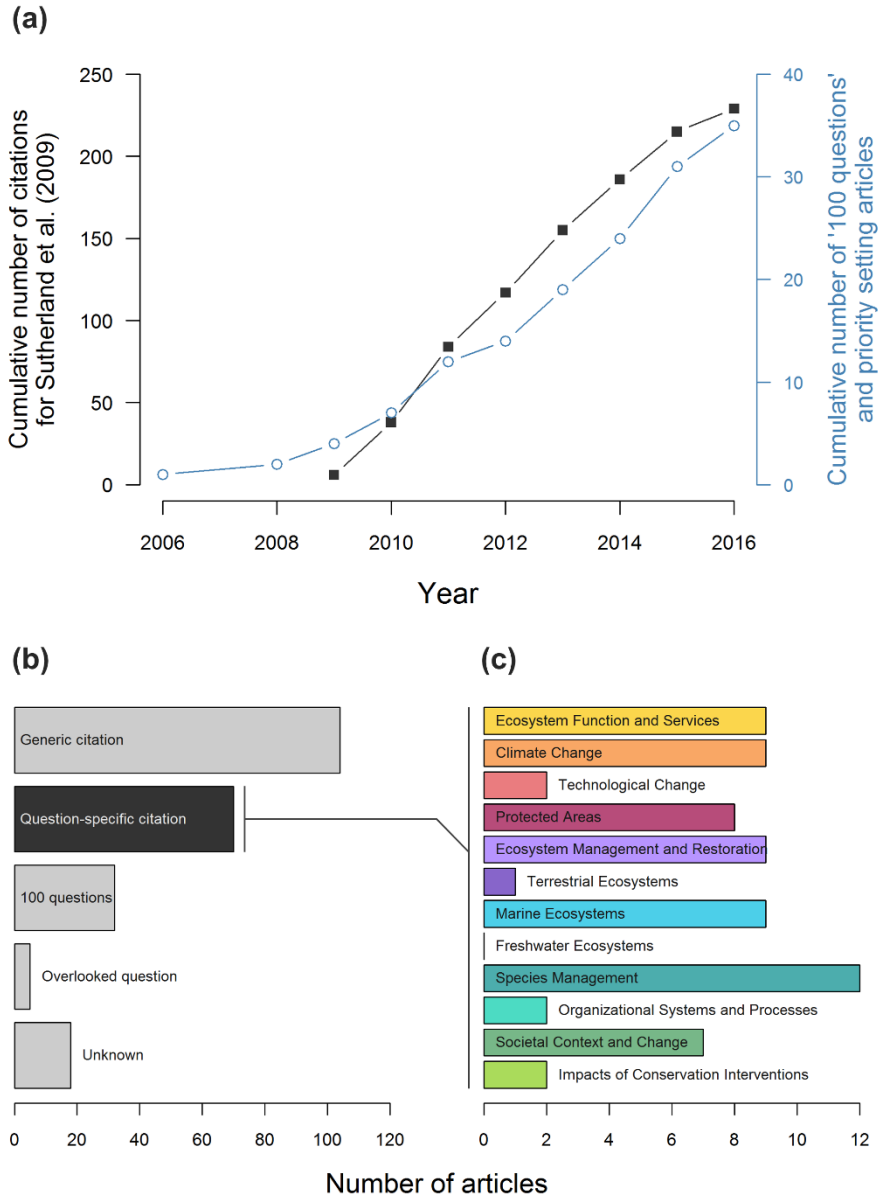

Fig. 1: Citation report for Sutherland *et al.* (2009). Filled squares in panel (**a**) represent the cumulative number of papers that have cited Sutherland *et al.* since its publication in 2009 (*n* = 229 as of 1st July 2016 based on a Scopus search). Empty circles instead illustrate the cumulative number of studies published between 2006 and 2016 that have identified topics of research priority in the environmental sciences (i.e., *'100 questions'–style* papers; *n* = 35 based on a Scopus search of article titles using the following keywords: "*100 questions*", "*one hundred questions*", "*50 questions*", "*fifty questions*" and "*priority questions*"). Panel (**b**) shows a breakdown of the most common motivations for citing Sutherland *et al.* (2009). Of the 229 papers to have cited Sutherland *et al.* (2009), 70 did so specifically to justify research on a specific questions or theme highlighted in the paper (dark grey

bar). In contrast, 104 papers cited Sutherland *et al.* (2009) to support a generic statement on the importance of conserving biodiversity, 32 did so when compiling their own list of research priority questions (i.e., *'100 questions'–style* papers), while five papers highlighted topics they felt should have made the original list of 100 questions. Panel (**c**) provides a breakdown of the 70 papers that cite Sutherland *et al.* (2009) in reference to a specific research topic or question [see Appendix S5 for the full list of papers that cite Sutherland *et al.* (2009)].

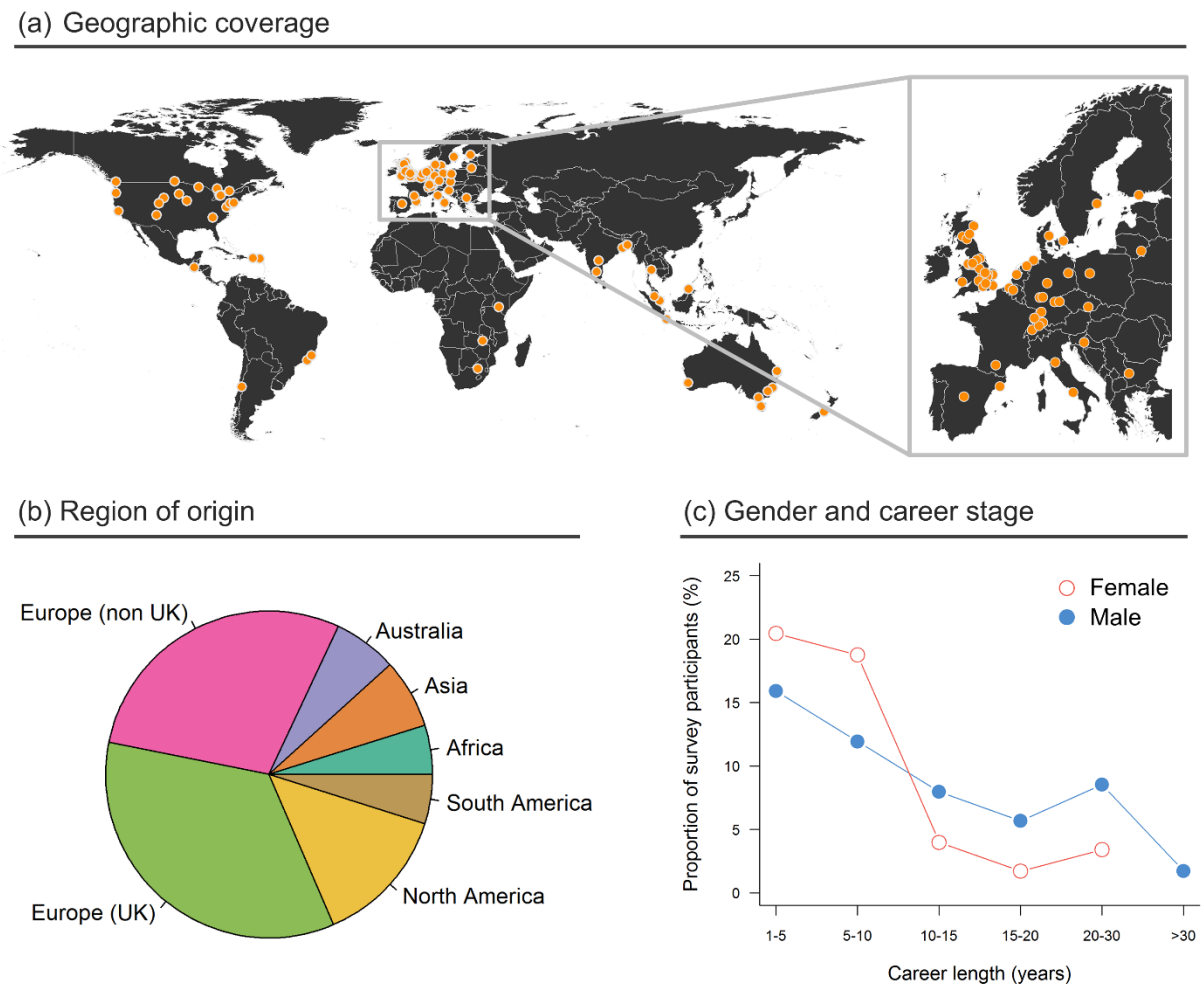

Fig. 2: Overview of survey participants. Panel (**a**) illustrates the geographic distribution of participants who responded to the survey using the Qualtrics web application (locations based on IP addresses), with an enlargement of Europe. Panel (**b**) shows the breakdown of respondent according to their continent of origin (note that for many survey participants this differed from the geographic location from where they took the survey). Panel (**c**) shows the distribution of survey respondents according to gender and career stage.

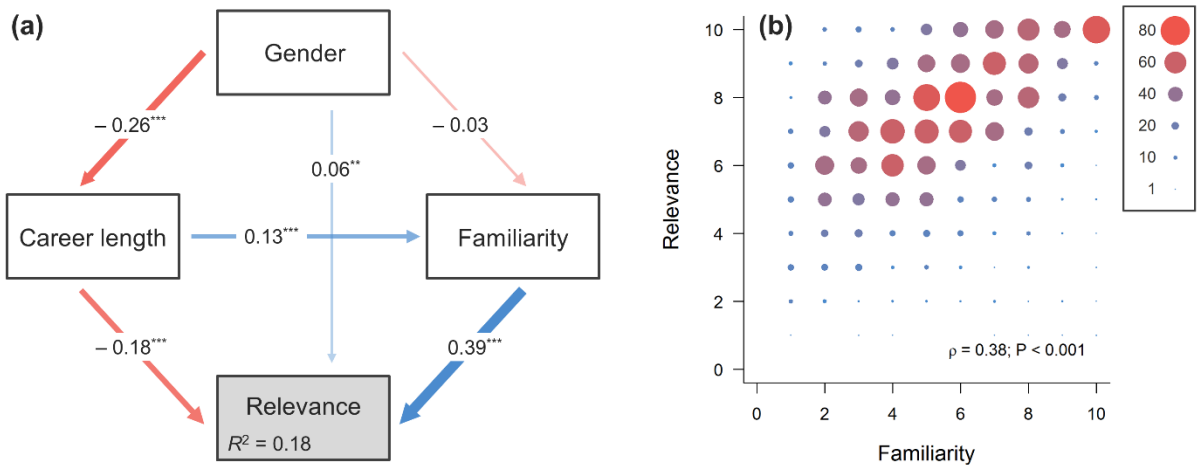

Fig. 3: Results of the questionnaire used to derive relevance scores for each of the 100 questions. Panel (**a**) shows the structural equation model which relates relevance scores (1 – 10) to the respondent's familiarity with the topic of the question (score from 1 to 10), the length of their career (number of years spent working in conservation science) and their gender (coded as a binary variable, where 0 = male and 1 = female). The width of the arrows reflects the strength of the pathway and is proportional to the standardized path coefficient (which is reported for each pathway). Asterisks denote significance levels of the pathways in the model ($^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$). Panel (**b**) shows the relationships between relevance and familiarity scores across all survey participants (i.e., 222 respondents, each presented with 10 randomly selected questions). The size of the circles reflects the number of overlapping points, and the Pearson correlation coefficient (ρ) between relevance and familiarity scores is displayed in the bottom right-hand corner.

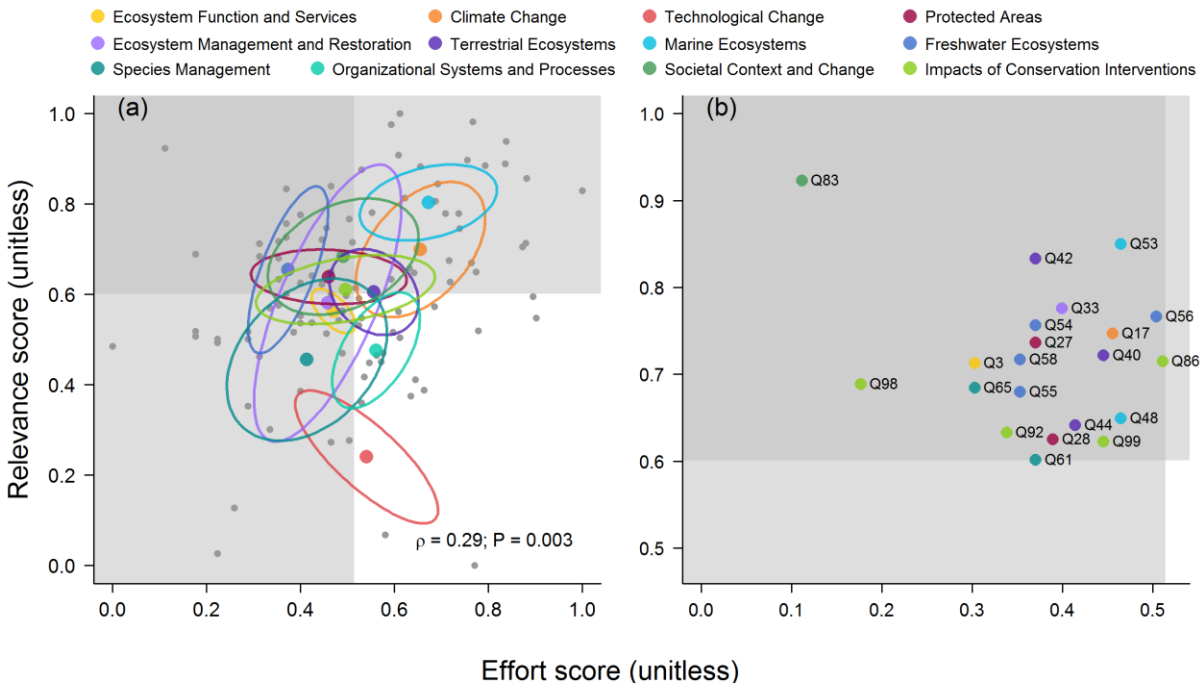

Fig. 4: Relationship between relevance and effort scores across the 100 questions. In panel (**a**) individual questions are represented by small points, whereas large points correspond to average values for each theme. Bayesian ellipses estimated using the *SIBER* package in R define the 95% confidence intervals of the bivariate means. The vertical shaded region defines the lower 50th percentile of the effort scores, while the horizontal shaded region marks the upper 50th percentile of the relevance scores. The Pearson correlation coefficient (ρ) between relevance and effort scores is displayed in the bottom right-hand corner. Panel (**b**) is an enlargement of the top left-hand sector of (**a**), and identifies questions that constitute knowledge gaps based on the definition used in the present study (i.e., those whose effort score is lower than the median, but that score above the 50th percentile in terms of relevance).