

RESEARCH ARTICLE

Twenty Years of Evidence-Based Conservation: Progress, Promise, and Future Directions

Conservation evidence is biased but can support decision-making for prevalent and severe threats in tetrapods

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Funding information

Natural Environment Research Council, Grant/Award Number: NE/S007261/1; Danish Independent Research Council, Grant/Award Number: 0165-00018B; Imperial College Research Fellowship

Handling Editor: Paul Franklin

Abstract

1. Tackling the global decline in biodiversity requires effective conservation actions to manage ongoing threats. Evidence from the success of past interventions can help identify effective actions. Such evidence-based conservation is facilitated by searchable resources that synthesize knowledge across taxa and conditions. The existing evidence base has known taxonomic and geographic gaps, but how the diversity and prevalence of threats affecting biodiversity is represented remains unclear.
2. We assessed the availability of evidence to address conservation threats, testing whether more evidence exists for actions tackling threats that affect more species (taxonomic prevalence) and from locations where threats are more likely (spatial prevalence). We focused on amphibians, reptiles, birds and mammals, groups with published conservation evidence synopses and completed IUCN Red List assessments listing threats.
3. Overall, there were more studies testing conservation actions directed at more common threats (high taxonomic prevalence). Actions tackling threats linked to agriculture and exploitation of natural resources, which affect the largest number of species (34.9% and 31.0% of 35128 species, respectively), had more evidence (20.6% and 18.5% of 3662 studies, respectively). However, actions for some threats were understudied (e.g. energy production and mining), while some had more evidence than expected (e.g. invasive species). Actions targeting more prevalent threats were not identified as more effective or better understood.
4. More studies tested conservation actions in areas where species were more likely to be impacted by threats (high spatial prevalence). However, only limited or no evidence was available for some highly impacted areas. For example, none of the 253 studies of actions addressing the impact of agriculture on

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birds were located in Africa, a region where 12% of the land is classed as high agriculture impact.

5. Synthesis and applications: Despite taxonomic and spatial biases, substantial conservation evidence is available to support decision-making by practitioners, particularly for the most prevalent and severe threats. Given the current biodiversity crisis, it is critical that this information is more widely used and that coordination among academic and practitioner partners is encouraged to evaluate current evidence and fill gaps, for example, regarding energy production and mining. A reliable and transferable evidence base is essential to effectively tackle the biodiversity crisis.

KEYWORDS

amphibians, bias, birds, evidence-based conservation, interventions, knowledge gaps, mammals, reptiles

1 | INTRODUCTION

Humans have appropriated, overexploited and transformed much of the planet, disrupting ecosystem processes and altering biotic communities (Barnosky et al., 2011; Bernardo-Madrid et al., 2019; Howes et al., 2023; Richardson et al., 2023; Vitousek et al., 1997). There are multiple pressures and drivers of biodiversity changes that can act in isolation or in combination (González-Suárez & Revilla, 2014; Johnson et al., 2023). In an effort to summarize this diversity of drivers and facilitate standardized assessments, the IUCN has developed a threat classification scheme that captures the main human activities and natural events that can increase risk of extinction for living organisms (Salafsky et al., 2008; Salafsky et al., 2025). This scheme includes 13 major categories, most of which are further subdivided into additional hierarchical levels, and is applied during IUCN Red List assessments to identify those threats affecting evaluated species. Threats are comprehensively assessed and listed for all species with a threatened status, but threat assessments are not always completed for non-threatened species. The information from the assessments can then be used to quantify listed threat prevalence across species and regions (Böhm et al., 2013; Dias et al., 2019; Ducatez & Shine, 2017) and has also been used to generate maps of predicted probability of impact (Farooq et al., 2024; Harfoot et al., 2021). These quantifications have shown that some threats are more prevalent than others as they affect many more species. For example, currently the most prevalent threat among assessed species is 'Agriculture & aquaculture' (as of 7 July 2025 this threat is listed as affecting 53,281 of the 169,420 assessed species by the IUCN Red List <https://www.iucnredlist.org/>). Threat prevalence also varies spatially, with the probability of being affected by a given threat being different across regions of the world. For example, birds are more likely to be impacted by logging in tropical areas, but are more likely to be affected by climate change near polar regions (Harfoot et al., 2021).

Humans are largely responsible for the biodiversity crisis, but many of us are also working to tackle it (Hoffmann et al., 2010; Langhammer

et al., 2024; Simkins et al., 2025). Conservation science aims to address the biodiversity crisis by identifying and predicting vulnerabilities and risks and developing and enabling the implementation of actions to manage them, as well as evaluating their impact. Conservation faces many challenges, including the need to act with urgency; to consider trade-offs in natural, cultural, political and socioeconomic systems to avoid or reduce negative impacts; and to maximize effectiveness (Guénard et al., 2025). The goal is to find the most effective and efficient solution that best reduces loss or restores biodiversity with the smallest investment and no negative consequences. Solutions have historically been identified based on individual or group knowledge, but this is not effective (Sutherland et al., 2004). Large-scale standardized testing and comparison of a range of actions to quantify their effectiveness and costs across taxa and environments could be an alternative, but such testing is often logistically and financially prohibitive or at least difficult. Alternatively, solutions may be identified via searchable resources that compile and synthesize evidence from actions tried and tested across various conditions (Salafsky et al., 2019; Sutherland et al., 2004). For conservation practice, this approach has been implemented via the freely available, searchable Conservation Evidence database (www.conservationevidence.com). Evidence-based conservation can be very valuable, with evidence informing decisions when it is available, ideally compiled from a robust and diverse set of studies testing a range of actions across conditions (Sutherland et al., 2019). However, its value depends on the availability and quality of the evidence base on which it is built (Christie et al., 2020).

Conservation Evidence resources are more reliable and transparent than expert opinion as they are based on systematic and documented searches and synthesis of the literature, but they are also susceptible to bias as they rely on the available published and grey literature (Christie et al., 2020, 2021). This literature, and consequently any database it informs, is itself subject to various forms of bias, including geographic (Culumber et al., 2019; Wilson et al., 2016), taxonomic (Culumber et al., 2019; dos Santos et al., 2020), negative result bias (Wood, 2020) and language of

publication (Amano et al., 2016, 2021). These biases not only present concerns for individual studies and the often-discussed reproducibility crisis but also perpetuate uncertainty when literature is summarized, making it harder for conservation practitioners to follow the best course of action given their situation (Christie et al., 2020). For example, a practitioner working in a region that is geographically underrepresented in the evidence base may apply an intervention that worked in another region and unknowingly cause harm due to unforeseen differences (Christie et al., 2020). While previous research has found that the distribution of studies present in Conservation Evidence is to some degree biased both spatially and taxonomically (Christie et al., 2020, 2021; Spooner et al., 2015), the extent to which this affects the availability of information regarding actions tackling the different threats impacting extant species is currently unclear.

Here, we address this question by asking whether the evidence available regarding conservation actions is representative of the diversity and prevalence of threats affecting tetrapods: amphibians, reptiles, birds and mammals. We ask: Do more studies test actions targeting those threats that affect more species? Are more studies conducted in areas where the threats are more prevalent? Are actions targeting more common threats more effective? We focus on the four tetrapod vertebrate classes because the evidence base for their conservation has been compiled into published Conservation Evidence synopses, and the taxa have been comprehensively assessed by the IUCN, allowing us to estimate taxonomic threat prevalence and map the probability of impacts for six major threats to define spatial prevalence. If evidence is representative, we expect more studies testing actions that target the most common threats and, thus, affect more species. We also expect more studies to be conducted in areas where the probability of impact is highest (highest spatial prevalence). Deviations may occur if conservation actions targeting some threats are easier or cheaper to implement, or more likely to be tested and reported. For example, local actions to tackle climate change may be less common and challenging to implement than actions to limit the local spread or promote removal of an invasive species. Lack of evidence on actions tackling some threats could result in fewer actions implemented and, in turn, a reduced accumulation of evidence in a potentially worrying feedback loop. Inversely, if some actions have been historically popular, the higher accumulation of evidence could make these actions appear as preferable or more successful and perpetuate their implementation even if potential better alternatives exist.

2 | MATERIALS AND METHODS

2.1 | Threat prevalence

To quantify the listed taxonomic prevalence of different threats to tetrapod vertebrates, we gathered data from the IUCN Red List of Threatened Species on 1 July 2024. We obtained a list of threats affecting each species under the Threat Classification

Scheme v 3.3 using the *rredlist* package (Chamberlain, 2020) in R 4.4.1 (R Core Team, 2024). We calculated the number of species listed as affected by each Level 1 threat (Table 1) as a percentage of the total number of species in each taxonomic class that are recognized and have been assessed by the IUCN. We considered a species as affected by a given threat if the threat was listed under their IUCN entry under any severity category (overall prevalence). We also quantify severe prevalence by only counting species as affected by a given threat if the threat was listed under their IUCN entry with one of the following severity categories: Causing/could cause fluctuations; rapid declines; slow, significant declines; very rapid declines; and also dividing that number by the total number of species in each taxonomic class that are recognized and have been assessed by the IUCN. Effectively we represent the listed percentage of affected, or severely affected, species from the total of assessed species. We note that the Threat Classification Scheme is not always comprehensive evaluated for species with a non-threatened Red List status (Least Concern, Near Threatened and Data Deficient); thus, our percentages may underestimate the true threat prevalence.

To characterize spatial threat prevalence, we used global maps of the probability of impact for six major threats for birds, mammals, amphibians and reptiles (Table 1). These maps represent the spatially predicted probabilities of threat impact to a randomly selected species in a given area and were created following the previously published methods (Farooq et al., 2024; Harfoot et al., 2021), with threat data from the IUCN Red List (version 2023-1). This approach uses IUCN Red List data on threats affecting each species and accounts for the spatial uncertainty that arises from not knowing where in their range, a species is affected by a given threat by weighing the contribution of each species by the inverse cube-transformed range. This means that large-ranging species contribute less to the probability than smaller ranging species. Four maps represent level 1 threats from the IUCN (Table 1), but the threat 'Biological resource use' is separated into two categories that reflect very distinct processes (Logging and Hunting) that are best spatially predicted separately (Farooq et al., 2024; Harfoot et al., 2021).

2.2 | Conservation Evidence

To characterize the availability of evidence for conservation actions targeting different threats, we obtained data from seven of the taxa synopses produced by Conservation Evidence (data accessed on 7 July 2022. Berthinussen, Richardson, & Altringham, 2021a; Berthinussen, Smith, & Sutherland, 2021b; Junker et al., 2017; Littlewood et al., 2020; Sainsbury et al., 2021; Smith & Sutherland, 2014; Williams et al., 2012). These represent the four tetrapod classes, with amphibians, reptiles and birds completed as one synopsis per class, and mammals divided into four groups that we merged (bats, primates, marine and freshwater mammals and terrestrial mammals). The Conservation Evidence

TABLE 1 Level 1 threat types described by the IUCN Threat Classification Scheme v3.3 and their match to threats represented in the risk maps (Farooq et al., 2024; Harfoot et al., 2021).

IUCN level 1 threat	Definition	Threat risk map category matches
1. Residential & commercial development	Threats from human settlements or other non-agricultural land uses with a substantial footprint	—
2. Agriculture & aquaculture	Threats from farming and ranching as a result of agricultural expansion and intensification, including silviculture, mariculture and aquaculture	Agriculture
3. Energy production & mining	Threats from production of non-biological resources	—
4. Transportation & service corridors	Threats from long narrow transport corridors and the vehicles that use them including associated wildlife mortality.	—
5. Biological resource use	Threats from exploitation of living organisms via hunting and collection of terrestrial animals, fishing and harvesting of marine resources and logging, harvesting and gathering of terrestrial plants.	Logging (5.3) Hunting (5.1 and 5.4: hunting and collection of terrestrial animals, fishing and harvesting of marine resources)
6. Human intrusions & disturbance	Threats from human activities that alter, destroy and disturb habitats and species associated with non-consumptive uses of biological resources	—
7. Natural system modifications	Threats from actions that convert or degrade habitat in service of 'managing' natural or semi-natural systems, often to improve human welfare.	—
8. Invasive & other problematic species, genes & diseases	Threats from non-native and native plants, animals, pathogens/microbes or genetic materials that have or are predicted to have harmful effects on biodiversity following their introduction, spread and/or increase in abundance.	Invasives
9. Pollution	Threats from introduction of exotic and/or excess materials or energy from point and nonpoint sources.	Pollution
10. Geological events	Threats from catastrophic geological events.	—
11. Climate change & severe weather	Threats from long-term climate changes which may be linked to global warming and other severe climatic/weather events that are outside of the natural range of variation, or potentially can wipe out a vulnerable species or habitat.	Climate change
12. Other	The threats classification scheme is intended to be comprehensive, but as there are often new and emerging threats, this option allows for these new threats to be recorded.	—

Note: Not all Level 1 threats were mapped as some were rare and their expected risk could not be robustly calculated. Level 1 category 'Biological resource use' was represented in two threat maps (Hunting and Logging) reflecting different level 2 threats as listed below. The threat category Other was not considered in our study.

synopses are produced using subject-wide evidence synthesis (Sutherland et al., 2019). This includes systematically searching for relevant studies from English and non-English languages journals, along with 'grey literature' that can be systematically searched (e.g. dated/numbered unpublished studies and report series). To be included, studies must include a test of an action that could be carried out by conservationists and report quantitatively on the outcome on biodiversity. Each study is summarized in a paragraph of around 200 words and collated under the relevant action category. These categories are defined specifically for each synopses and, thus, although often the same/similar, not strictly comparable across synopses for specific taxa or habitat. Once a synopsis has been published, a panel of experts anonymously scores the effectiveness, certainty and possible harms for each action category by reviewing the collated evidence, using a modified Delphi method (Sutherland et al., 2019). For each study, the threats addressed by

the tested actions are tagged using the IUCN Threat Classification (Table 1). In some cases, threats are classified into Level 2 categories, but because this is not done consistently we focused on the Level 1 classification. For each taxonomic class, we calculated the total number of action categories and of studies that had provided evidence for each threat and the percentages those actions and studies represented from the total number of actions or studies for the taxonomic class. We also calculated the mean and standard deviation of the effectiveness, certainty and harm scores across all actions targeting each threat.

In addition, we mapped the location of interventions conducted by the studies compiled in the synopses onto the threat maps (using a Mollweide projection). Interventions were defined as distinct combinations of tackled threats, locations and studies for each taxa (some studies contributed information for multiple locations and/or multiple threats; some locations were used in multiple studies). The

probability of threat impact for the corresponding taxonomic class and the threat(s) tackled by an intervention was retrieved by overlapping the mapped locations with the probability of impact maps described above. Matching of categories is described in Table 1 (90 studies did not provide information on the Level 2 threat categories for Level 1 threat 'Biological resource use' and could not be assigned to a threat risk map category). The Conservation Evidence synopses included 2139 georeferenced locations from 1916 studies in which interventions had been conducted targeting one or more of six threats represented in the probability of threat impact maps. Probability values could not be obtained for 402 locations (which excluded 312 studies) where probabilities were not predictable (marine areas or regions not occupied by any species in the taxa). Our final dataset included 2133 interventions representing 1738 locations and 1576 studies. Marine areas for figures were defined using the level 1 shorelines represented in the Global Self-consistent, Hierarchical, High-resolution Geography Database (GSHHG) Version 2.3.7 (NOAA, 2017; Wessel & Smith, 1996).

2.3 | Data analyses

To assess whether the quantity of evidence describing the effects of conservation actions increased with taxonomic threat prevalence, we used linear mixed effect models for each taxonomic class. We tested two response variables: (1) the percentage of studies within a taxonomic class that provided evidence of conservation actions targeting a threat and (2) the percentage of action categories within a taxonomic class described as targeting a threat. In both cases, the predictor variable was the percentage of species in the taxonomic class listed as impacted by that threat. We also assessed whether the quality of the evidence describing the effects of conservation actions increased with taxonomic threat prevalence using linear mixed effect models. We fitted one model for each score, respectively, associated with effectiveness, certainty and harm of actions. Scores of action categories targeting a threat were the response variable predicted by the percentage of species (within the taxonomic class) listed as impacted by that threat. We also refitted these five models using as an alternative predictor the percentage of species in the taxonomic class listed as severely impacted by that threat (see above). In all models, taxonomic class was included as a random intercept factor. Models were fitted using the lmer function from package lme4 (Bates et al., 2015) in R v4.4.1 (R Core Team, 2024), with conditional and marginal R^2 estimated with the function performances in the package performance (Lüdtke et al., 2021). We checked model assumptions were met using the check_model function also in the package performance.

We also tested if, for each of the mapped threats, the availability of evidence (number of tested interventions) increased in areas of higher spatial threat prevalence (areas where the predicted risk from individual threats was predicted to be higher). To do this, we first defined four prevalence levels for each threat and taxa defined by the quartiles of all mapped values, each representing one-fourth of the mapped area. From the extracted probability

of threat impacts for each intervention, we then calculated the overall percentage of interventions in each prevalence quartile for each taxon and threat. If interventions were randomly distributed, we would expect on average 25% in each prevalence quartile. We more explicitly tested this assumption with two null models: global and study-specific. The global null model assumed interventions could have been tested anywhere in the world where threat impacts have been mapped. Under this model, for each threat and taxa, we defined 500 samples randomly selecting locations from threat maps, from which we extracted probabilities of threat impact to define the percentage of random locations in each prevalence quartile. The study-specific null model was more conservative and assumed that the locations of intervention are constrained by the availability of resources and teams, such that interventions could only be tested in studied locations (preserving the spatial bias in the studies), but allowing different threats and taxa to be tested at a location. For each threat and taxa, we defined 100 random samples (we reduced replication to account for the much smaller pool of locations) selecting locations where studies have been conducted (for any taxa) and extracting the probabilities of threat impact for the relevant threat and taxa. In both null models, random samples had the same number of locations as interventions in the evidence base for each threat and taxa. We considered observed percentages to be significantly different from percentages derived from null models if they were outside the central 95% of null model values (i.e. smaller than the lowest 2.5% or greater than 97.5% of null model values).

Finally, we evaluated whether we could predict the number of interventions per grid cell based on the probability of threat impacts. We fitted a negative binomial regression model, with the number of tested interventions for each threat and taxa located in each grid cell as the response variable. The predictors were the probability of impact for each threat in that grid cell, the threat category, the taxonomic class and a categorical descriptor of the threat with an interaction term between threat category and probability of impact to allow for different threat effects of the probability impact values on the number of interventions. These models were fitted using the function glm.nb from the MASS library in R (Venables et al., 2003). We checked that model assumptions were met using the check_model and check_zeroInflation functions in the package performance.

3 | RESULTS

We analysed data from 3662 studies describing conservation actions linked to IUCN Level 1 threats. There were more studies providing evidence for mammals ($n=1416$) and birds ($n=1229$) than for reptiles ($n=707$) and amphibians ($n=408$). Most studies provided evidence for a single class, but 87 studies provided evidence for multiple taxonomic classes, which included, for example, studies describing the effectiveness of installing barrier fencing along roads to prevent animal-vehicle road collisions.

3.1 | Do more studies test actions targeting those threats that affect more species?

Overall, we found more evidence for conservation actions tackling more taxonomically prevalent threats. There were more studies and action categories describing the effects of actions targeting the threats that affect a higher percentage of species within a taxonomic group (Figure 1, Table 2). These results did not change when considering prevalence based on threats listed by the IUCN Red List as more severe (Figure S1, Table 2). We do note that there are no studies testing actions to tackle 'Human intrusions & disturbance' for amphibians, which is listed as a threat for 435 species, 5.45% of the class or studies tackling impacts of 'Geological events' for amphibians and reptiles, listed for 102 (1.28%) and 42 (0.41%) species, respectively.

Generally, higher probability of threat was associated with more evidence, but some threats, such as 'Invasive species & problematic species, genes & diseases', had consistently more evidence than expected across all four taxa (Figure 2, Figure S2). Conversely, there was less evidence than expected for threats such as 'Energy production & mining' and 'Residential & commercial development' (Figure 2, Figure S2). In some cases, for example for 'Agriculture & aquaculture', the level of evidence varied among groups, with more studies and action categories than expected for birds and mammals, but fewer than expected for amphibians and reptiles (Figure 2, Figure S2). Deviations were generally similar when considering only prevalence of threats listed as severe (Figure S2). However, when considering severe prevalence, 'Residential & commercial development' and 'Agriculture & aquaculture' were no longer understudied in amphibians.

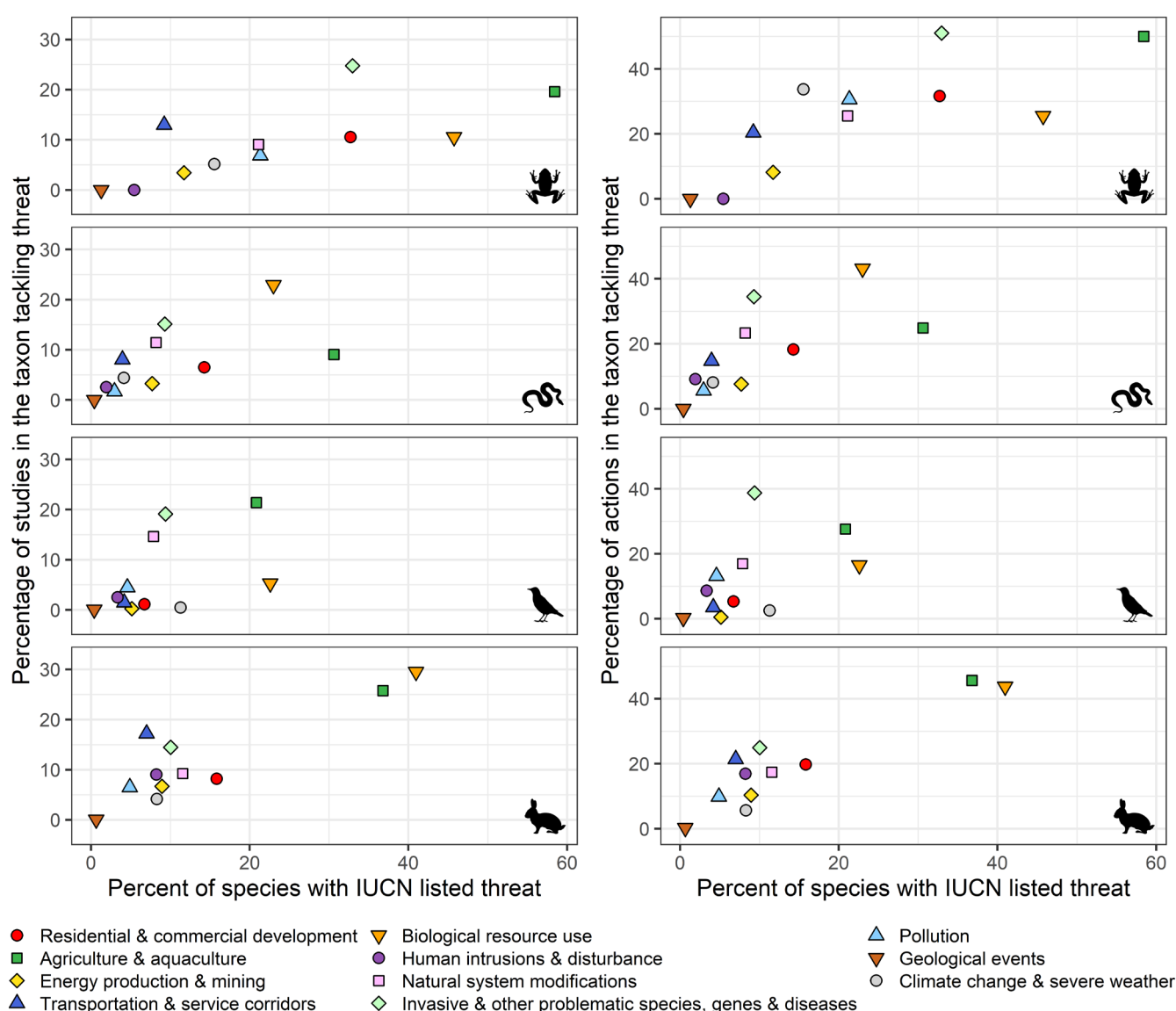


FIGURE 1 Relationship between the percentage of species from each tetrapod class listed as impacted by a threat under the IUCN Red List compared to the percentages of studies (left panels) and the percentage of action categories (right panels) per class providing evidence of conservation actions targeting that same threat as listed by the Conservation Evidence synopses. Threats represent the Level 1 of the Threat Categories Scheme from the IUCN, excluding the category 'Other'.

TABLE 2 Model estimates from linear mixed effect models explaining the percentage of studies and the percentages of action categories in a taxonomic class providing evidence of conservation actions targeting a threat (the two tested response variables) as a function of the percentage of species (within the taxonomic class) listed as impacted by a threat (considering all threat severities and only those considered as severe threats).

Model/variables	B	SE	p
All threat severities			
Percentage of studies $R^2_c = 0.50$, $R^2_m = 0.44$			
Intercept	3.15	1.660	0.106
Percentage species listed by IUCN	0.41	0.071	<0.001
Percentage of actions $R^2_c = 0.59$, $R^2_m = 0.59$			
Intercept	6.69	2.061	0.002
Percentage species listed by IUCN	0.85	0.108	<0.001
Only severe threats			
Percentage of studies $R^2_c = 0.48$, $R^2_m = 0.30$			
Intercept	4.82	2.259	0.104
Percentage species listed by IUCN	1.28	0.281	<0.001
Percentage of actions $R^2_c = 0.50$, $R^2_m = 0.24$			
Intercept	11.64	4.973	0.088
Percentage species listed by IUCN	2.19	0.532	<0.001

Note: Taxonomic Class was included as a random intercept factor. Threat categories represent Level 1 categories 1–11 (category Other was excluded). We report the best estimate (B), its standard error (SE), estimated *p*-value and conditional and marginal R^2 for each model.

3.2 | Are actions targeting common threats more effective?

Having more studies testing the outcome of actions for the more prevalent threats could result in better and more certain information about their effectiveness and lack of harm. However, we did not find a relationship between taxonomic threat prevalence and the effectiveness or certainty of the action categories addressing those threats (Figure 3, Figure S3, Table 3). This partly reflects the high variation in effectiveness scores and number of studies across types of actions described in the Conservation Evidence data: action categories with many studies generally have high effectiveness scores, but categories with few studies include a wide range of effectiveness scores (Figure S4). We found a small positive relationship between taxonomic threat prevalence and harm score (Figure 3, Table 3), such that threats affecting more species may be more likely to have actions that lead to harm rather than benefits. This relationship was not significant when considering only the prevalence of severe threats (Figure S3, Table 3).

3.3 | Are more interventions tested in areas where the threats are more prevalent?

We mapped and retrieved the probability of threat impact of 2133 interventions representing 1738 locations from 1576 studies (Figures S5–S8). For most taxa and threats, interventions were

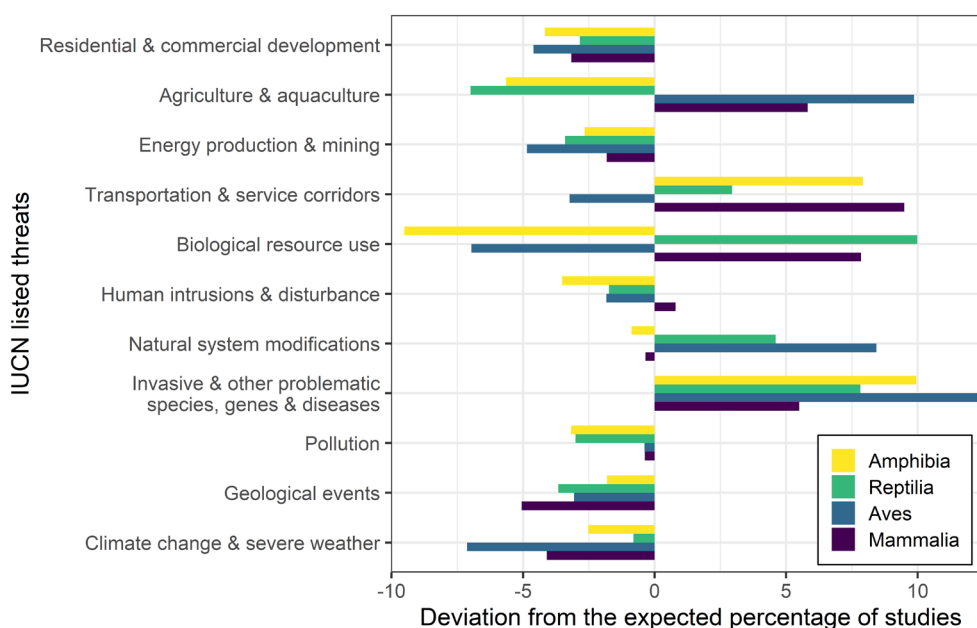


FIGURE 2 Deviations from the number of studies expected to provide evidence of conservation actions targeting a threat in the Conservation Evidence synopses for each taxon given the number of species listed as threatened by that threat by the IUCN Red List. Deviations represent standardized model residuals from the *All threat severities* model in Table 1. Positive values indicate more studies observed than expected based on the percentages of species affected, with negative values indicating fewer studies than expected. Threats represent the Level 1 of the Threat categorization from the IUCN excluding the category 'Other'.

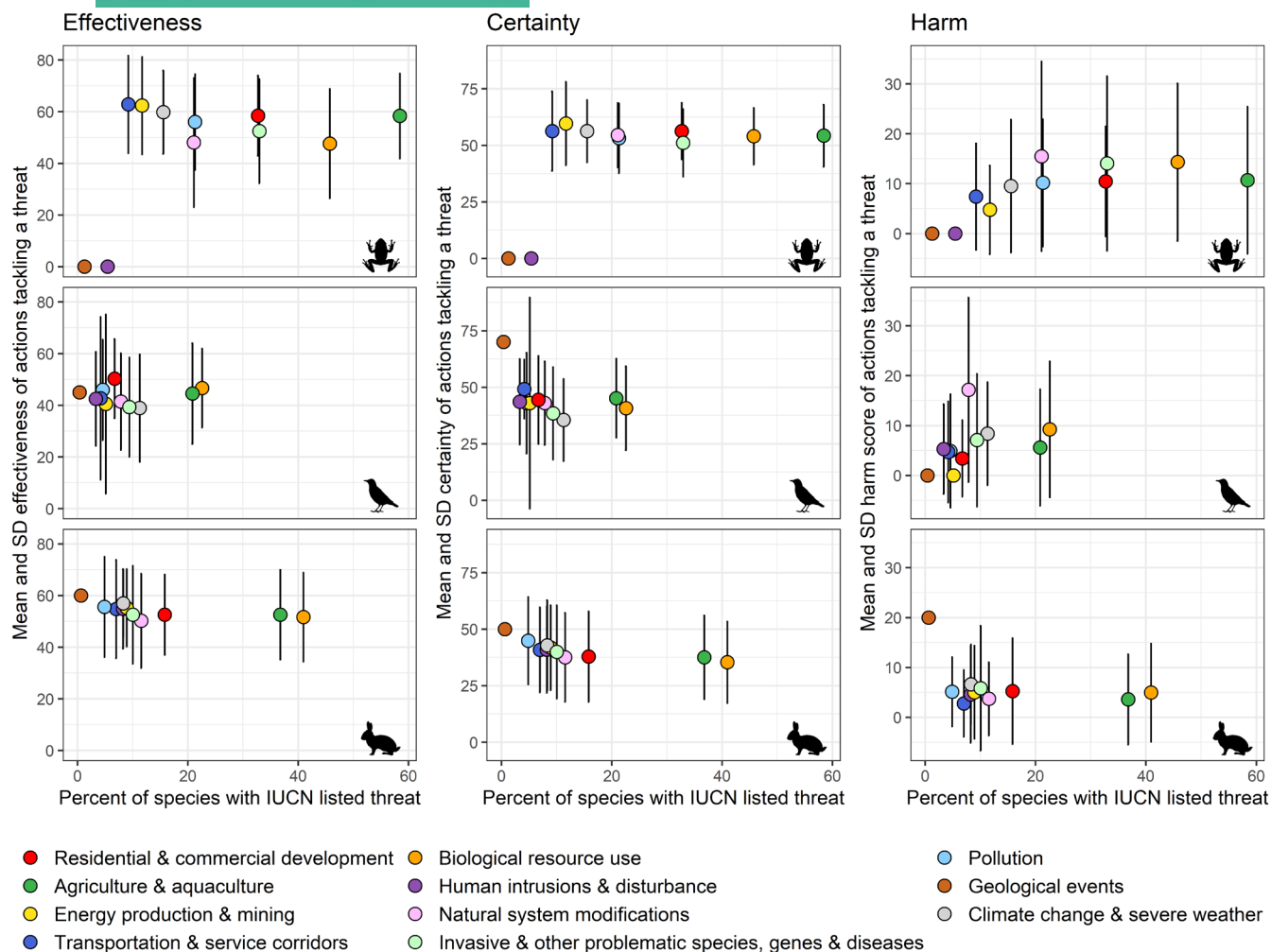


FIGURE 3 Relationship between the percentage of species from each tetrapod class (except Reptilia for which action scores were not available) listed as impacted by a threat under the IUCN Red List compared to the effectiveness, certainty and harm scores of the actions targeting that same threat as listed by the Conservation Evidence synopses. Threats represent the Level 1 of the Threat Scheme categories from the IUCN excluding the category 'Other'.

more likely to have been carried out in areas where the probability of threat impact was higher (top quartiles), with significant differences from expected under both null models, particularly for amphibians and mammals (Figure 4, Table S1). A notable exception was the observed absence of interventions in high impact areas tackling the impact of logging in birds, which was significantly lower than the expected under both null models (Figure 4, Table S1). The areas with the lowest probability of impact were commonly underrepresented, with an exception in mammals for which the areas of the lowest impact for Hunting were significantly more represented than expected under the global model, although significantly less than the expected for the study-specific model (Figure 4, Table S1). The number of interventions was (weakly) predictable from the probability of threat impact in a location, with significant increases in the number of interventions predicted for higher probabilities of impacts for Agriculture, Logging, Invasives and Pollution, but no relationship for Logging and Climate Change (Figure S9, Table S2). Overall, interventions were generally more likely to be tested in areas where threats are more prevalent, but evidence was generally available across the range of

threat impact, thus, offering evidence from locations with varying threat levels (Figures S5–S8).

Although interventions overall represented diverse threat prevalence levels, the range of evidence was more limited for some regions of the world (Figures S5–S8). For example, areas of the highest prevalence for agriculture existed in all continents (Figure 5), yet there were no studied testing interventions tackling this threat for amphibians and birds in Africa, where 11.6% and 18.6% of the land were classed in the highest prevalence quartile (quartiles were defined globally). For mammals and reptiles, evidence for actions tackling impacts from agriculture was available for all continents, but some regions of the highest prevalence were still understudied (Figure 5). This type of geographic variation occurred in all other mapped threats (Figures S5–S8).

4 | DISCUSSION

The evidence available for conservation actions is generally representative of the diversity and prevalence of threats affecting

TABLE 3 Model estimates from linear mixed effect models explaining the three scores associated with effectiveness, certainty and harm of action categories targeting a threat (response variables) as a function of the percentage of species (within the taxonomic class) listed as impacted by a threat (considering all threat severities and only those listed as more severe).

Model/variables	B	SE	p
Effectiveness			
All threat severities $R^2_c = 0.19$, $R^2_m = 0.09$			
Intercept	43.23	4.400	<0.001
Percentage species listed by IUCN	0.30	0.173	0.088
Only severe threats $R^2_c = 0.09$, $R^2_m = 0.02$			
Intercept	47.36	4.073	<0.001
Percentage species listed by IUCN	0.15	0.615	0.807
Certainty			
All threat severities $R^2_c = 0.05$, $R^2_m = 0.05$			
Intercept	40.33	3.527	<0.001
Percentage species listed by IUCN	0.22	0.170	0.209
Only severe threats $R^2_c = 0.003$, $R^2_m = 0.003$			
Intercept	44.36	3.224	<0.001
Percentage species listed by IUCN	-0.20	0.591	0.742
Harms			
All threat severities $R^2_c = 0.12$, $R^2_m = 0.12$			
Intercept	5.09	1.215	<0.001
Percentage species listed by IUCN	0.12	0.059	0.044
Only severe threats $R^2_c = 0.05$, $R^2_m = 0.01$			
Intercept	6.59	1.315	0.012
Percentage species listed by IUCN	0.11	0.216	0.625

Note: Taxonomic Class was included as a random intercept factor. Action categories have not been scored for Reptilia. Threat categories represent Level 1 categories 1–11. Category Other was excluded. Table reports the best estimate (B), its standard error (SE), estimated *p*-value and conditional and marginal R^2 for each model.

amphibians, reptiles, birds and mammals. There is generally more evidence for actions that tackle threats affecting more species (more studies and more types of actions described), and there is more evidence from locations where threats are more likely to affect species. However, there are several opportunities for improvement. The evidence base available for some threats is weaker than expected given their prevalence, which could limit implementation of effective actions to mitigate or remove the impacts from those threats. Similarly, the lack of evidence from some areas of the world raises questions about how generalizable the effectiveness of different interventions may be, given intervention effects can vary depending on the local context and conditions (Christie et al., 2020; Spake et al., 2025).

The most prevalent threats among tetrapods are 'agriculture & aquaculture' and 'biological resource use' which affect >20% of species in all four taxa (both affecting >40% of amphibians). These two threats also generally had more evidence for actions available, representing 5%–30% of the studies in the evidence base for each

class (and 16%–50% of the actions described). More studies and actions provide more opportunities to support decision-making, from the synthesized information in the synopses, to the details from the individual studies that practitioners can access to gain further information regarding conditions and taxa for which actions worked best. For example, an action tested by 10 studies could have been found to be very effective overall, but harmful in one location. A practitioner in a similar area (or context) to the study in which the action was harmful may decide against implementing the action and seek alternatives that, while globally less effective, may be safer in their area. If the action had been tested by a single study, the potential to identify context dependency is lost.

While, in general, there was more evidence available for more prevalent threats, there were some noticeable deviations. In all groups, the evidence base (studies and actions) for the threat of 'Energy production and mining' was less than expected. Others have highlighted the need for further research and action to tackle this threat (Sonter et al., 2018). Mining and energy production can take different forms, from large-scale operations carried out by big companies to small-scale, sometimes illegal operations, and can occur in diverse areas from regions with a long history of exploitation to relatively intact environments (Cortinhas Ferreira Neto et al., 2024). These are also rapidly expanding activities, which can even be prioritized from a sustainability and conservation point of view (mining certain resources is key for sustainable development; Yang et al., 2024). Understanding how to best manage their impacts is essential and would likely benefit from additional partnership with industry to facilitate learning, testing and evidence collation. There was also consistently less evidence for actions tackling 'Residential & commercial development' and 'Climate change & severe weather', particularly for reptiles, birds and mammals, and no evidence for actions tackling impacts of 'Human intrusions & disturbance' in amphibians (which affects ~5% of the known species). These are also expanding threats and the implementation and documentation of actions to tackle their impacts may be lagging behind. Climate change is a global scale threat that needs large-scale actions to be effectively tackled (Calvin et al., 2023); however, local mitigation is possible and can offer benefits and key safety nets for biodiversity (Patino-Martinez et al., 2012).

Conversely, we found consistently more evidence than expected for 'Invasive & other problematic species, genes and diseases' in all groups. This may reflect the fact that, for all taxa, this threat was >1.7 times more prevalent when considering only threats listed as severe, meaning that for many tetrapods, invasives and diseases represent serious threats that practitioners are prioritizing for management. More evidence than expected could also reflect a long history of management of invasive species and diseases (Barratt et al., 2018), and types of actions that may be viewed as more feasible or socially acceptable locally. Although the drivers that result in the introduction of non-aliens or diseases can be very much global in scale (Early et al., 2016), the removal of their local presence may be perceived as simpler than tackling the effects of changes in temperatures and precipitation associated with climate change for example. These studies are also potentially easier to conceptualize as testing of a conservation action (e.g. removal of invasive rodents from an island

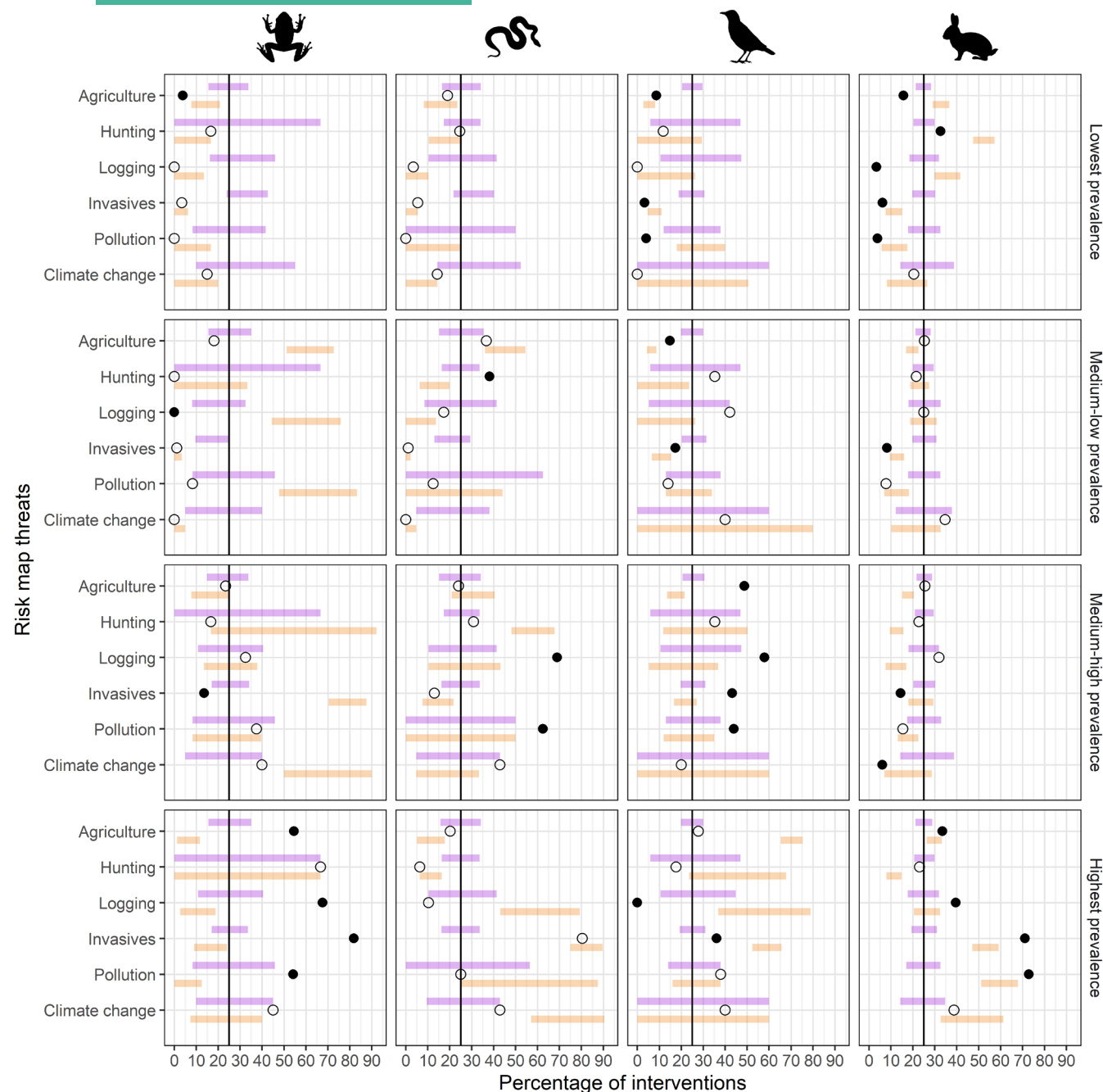


FIGURE 4 Percentage of Conservation Evidence interventions located in areas within each quartile level of threat prevalence for six threats in Amphibia, Reptilia, Aves and Mammalia (circles) and expected percentages based on two null models (bars represent the central 95% of expected percentages, with violet bars above the circle reflecting values from the global null model, and orange bars below the circle representing values from the study-specific model). Quartile levels were defined using the global threat impact maps for each threat and taxa and each covered 25% of global mapped areas. Vertical lines mark the 25% threshold, with observed values >25% indicate overrepresentation of evidence at that prevalence level, and values below indicating underrepresentation. Solid circles mark observed percentages significantly different from both null models (these circles do not overlap either bar); hollow circles mark observed percentages that were not significantly different from one or both null models (overlap one or both associated bars). All values are provided in [Table S1](#).

to protect nesting seabirds or reptiles) and are, thus, more likely to be published compared to more complicated studies that may evaluate intervention with more complex outcomes.

Actions tested by more studies had higher effectiveness and certainty scores and lower harm scores. However, more prevalent threats did not have better quality evidence (more certainty of effectiveness)

because actions listed as tackling more prevalent threats included both those well supported by many studies and those with more limited information. This may reflect one of the challenges in the synthesis of evidence. Grouping information into more generic actions can increase the number of relevant studies providing evidence, but less specific actions are less useful for practitioners seeking to implement

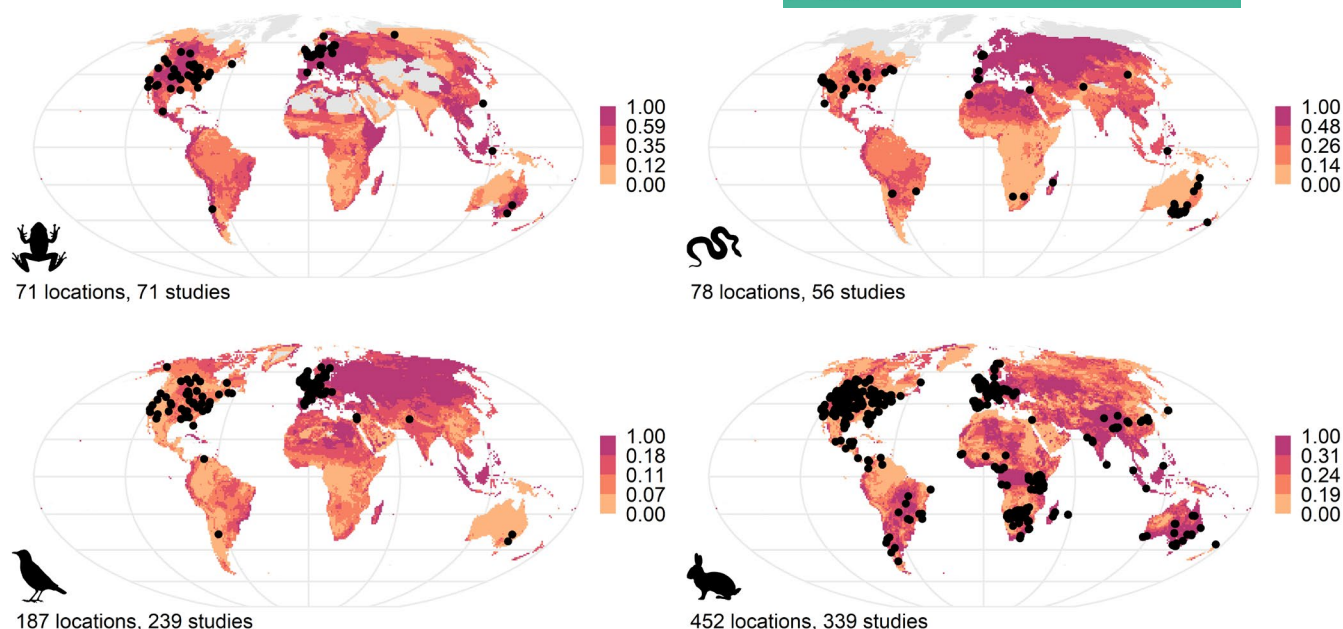


FIGURE 5 Global distribution of the location sites for studies that provide evidence of interventions tackling the threat of agriculture (black circles) mapped with the probability of impact from agriculture predicted in each land region for amphibians, reptiles, birds and mammals. The probability of impact is represented in the quartile groups we used for comparisons (Figure 4), with the scales indicating the cut-off points. Grey regions represent areas not occupied by any species of a given taxonomic class where probability of impact was not predicted. Different studies could use the same location (in birds, there are more studies than locations) and studies could report interventions in multiple locations (in reptiles, there are more locations than studies).

clearly defined interventions. Conversely, actions that are too specific can scatter the evidence and introduce uncertainty in decision-making. A more robust evidence base requires not only developing and testing new actions but also testing and documenting actions already trialled previously under new sets of conditions. Additional experimental comparisons of actions to more directly assess trade-offs has great potential and could help identify context dependencies to improve management (Ockendon et al., 2021).

Testing the same action across locations is essential to critically evaluate its effectiveness in light of likely context dependencies (Christie et al., 2020; Nichols et al., 2019; Spake et al., 2025). We found more studies have been conducted in areas where threats are likely to be most impactful, but studies were also conducted in areas where impacts may not be as prevalent which could occur to protect a particular species or due to protected area status that promotes management. Knowledge from diverse areas and conditions is very valuable, and we join previous authors in calling for additional testing and sharing of interventions in some regions (Cadotte et al., 2025; Ockendon et al., 2021; Smith et al., 2023). For example, there were no studies included in Conservation Evidence addressing the impact of agriculture on birds or amphibians in Africa (out of 253 and 80 studies addressing agriculture in each class, respectively), a region where 12% and 18% of the land are described as high impact for agriculture for birds and amphibians, respectively. These gaps highlight opportunities for additional testing, but likely also hide unpublished or inaccessible studies that tested interventions and could contribute to the evidence base. Providing necessary incentives, resources and support for that information to be published and accessible is critical.

Our evaluation had some limitations. The IUCN Red List does not comprehensively assess threats for all listed taxa, and the estimated taxonomic threat prevalence likely underestimates actual impacts. The Conservation Evidence dataset has not been updated to include studies published after 2022, and thus, some of the limitations of evidence we described here may be partly remedied by newer studies that could be added to the evidence base. Finally, we could not explore the spatial prevalence for threats that affect fewer species as their probabilities of impact cannot be reliably mapped. Similarly, a few studies had to be excluded for the spatial analyses as they were located in areas without an estimated probability of threat impact (areas not occupied by any species in the taxon) or had an unspecified Level 2 threat category for 'Biological resource use'.

While some evidence gaps and biases remain, conservation practitioners faced with making decisions about management interventions should feel encouraged and reassured by the general availability and depth of the existing collated and synthesized evidence. The transparent inclusion of evidence, particularly that which has been systematically collated and can be checked rapidly and without financial barriers, is likely to substantially improve the strength of decision-making and support justification of particular courses of action (Smith et al., 2023), and thus improve outcomes for biodiversity. The scarcity of evidence for particular topics, such as 'Energy production and mining' or 'Climate change & severe weather', could be consequential in practice and practitioners would need careful consideration prior to implementing mitigation actions, including the use of pilot studies for testing the feasibility and effectiveness of an action before wider roll-out. However,

specific limitations should not detract practitioners from capitalising on the otherwise extensive availability of information to support improved decision-making. Topics with more limited evidence are important areas of opportunity for developing and testing new actions that could support the protection of biodiversity in future years, but it remains crucial for the testing and evaluation to be published in some format. Co-production of evidence-based guidance that transparently incorporates expert opinion and unpublished data alongside published evidence can also improve the evidence base as has already been done for climate change impacts on seabirds (Häkkinen et al., 2023) and for the restoration, creation and management of salt marshes and tidal flats (Cutts et al., 2024).

5 | CONCLUSIONS

Overall, the evidence base can support decision-making for a wide range of ongoing threats to tetrapods, but there are clear opportunities for improvement (O'Connell et al., 2024). We identify four targets below.

1. Create and promote tools and incentives to facilitate testing of actions and sharing of results (Cadotte et al., 2025; Smith et al., 2023). Practitioners are often operating under severe time and resource constraints and generally lack strong incentives to robustly test and publish results. We call on academics in conservation science to make themselves available to support these efforts. Publishing tests of interventions, particularly if unsuccessful, may not be viewed as priorities by academics (unlikely to be published in high impact journals); however, these are valuable contributions and could be considered part of our citizenship as academics. They could be transparently valued during hiring and promotion processes and recognized by awards. Collaborations could be based on existing relationships, but we see an opportunity to go further. For example, new interactions could be promoted via creation of a directory of academics willing to support practitioners in the design and publication of interventions which could be queried by practitioners and/or a 'classified ads' portal where practitioners could post to seek an academic partner before an intervention. Completed work can then be published, for example, in the Conservation Evidence Journal which was designed specifically for practitioners, to enable free, open-access publication of tests of actions and has an article template to aid the process (Smith et al., 2023). Results of these studies are summarized and incorporated into new or updated synopses of evidence that are available on the searchable Conservation Evidence database (<https://www.conservativevidence.com/>).
2. Expand the evidence base to cover actions tackling threats for which few actions have been tested. We do not expect practitioners to prioritize actions towards specific threats based on our global analyses, but rather we propose priority is given to the testing and publication of results of actions tackling those threats. For example, funds could be strategically allocated to test actions that tackle threats with evidence gaps, like 'Energy production & mining'.

3. Support 'redundant' testing of actions. More studies result in higher quality evidence and while adding evidence to understudied topics is critical, we must not ignore the value of replication to ensure context dependencies are well captured (Christie et al., 2020; Nichols et al., 2019). Replicating tests of actions in different areas or in different taxa can offer valuable insight and may be particularly important to prioritize in understudied areas (see below).
4. Allocate resources strategically to reduce observed geographic biases. A wide range of languages is considered when gathering evidence is already an important step to address geographic biases (Amano et al., 2016; Christie et al., 2021). Further allocation of resources to areas where conservation actions may be implemented, but are not regularly tested or published, is critically important for advancing the evidence base in these contexts. For example, academics could prioritize supporting and seeking connections with practitioners working in these areas to reduce the knowledge gap. Such new links may require working across cultural and language barriers and should ideally lead to the development of local capacity in both academia and practice.

There is substantial conservation evidence available to support decision-making by practitioners, particularly to tackle the most prevalent and severe threats affecting tetrapods. Making use of this information, which can be easily accessed from the Conservation Evidence synopses, is key to improve conservation practice and efficiently tackling the current biodiversity crisis.

AUTHOR CONTRIBUTIONS

Manuela González-Suárez conceived the study; Manuela González-Suárez, Kerry Stewart, Lizzie Brisco, Sophie Gompertz, Dassia Wheatley, Maria Sage and Alec P. Christie designed the methodology; Rebecca K. Smith, Harith Farooq, Mike Harfoot, Silviu Petrovan, Jonas Geldmann and Alec P. Christie collected the data; Manuela González-Suárez and Kerry Stewart analysed the data; Manuela González-Suárez led the writing of the manuscript; Kerry Stewart, Lizzie Brisco, Rebecca K. Smith, Harith Farooq and Alec P. Christie contributed critically to the drafts. All authors gave final approval for publication.

ACKNOWLEDGEMENTS

Kerry Stewart was funded by a PhD studentship from the SCENARIO NERC Doctoral Training Partnership (grant NE/S007261/1). Alec P. Christie was funded by Imperial College London with an Imperial College Research Fellowship. Jonas Geldmann and Harith Farooq were supported by the Danish Independent Research Council (grant 0165-00018B). Conservation Evidence is grateful to generous funders listed here (<https://www.conservativevidence.com/content/page/24#support-received>) and all other collaborators.

CONFLICT OF INTEREST STATEMENT

The authors have no conflict of interests. Manuela González-Suárez is an Associate Editor of *Journal of Applied Ecology*, but took no part in the peer review and decision-making processes for this paper.

DATA AVAILABILITY STATEMENT

Summary datasets and code for analyses in R to reproduce all statistical analyses and most figures are available via Figshare Digital Repository <https://doi.org/10.6084/m9.figshare.31239466> (González-Suárez et al., 2026). The full datasets supporting this study can be requested for research from the data owners: Conservation Evidence (<https://www.conservationalevidence.com/>) and IUCN Red List website (<https://www.iucnredlist.org/>).

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Figure S1. Relationship between the percentage of species from each tetrapod class listed as impacted by a threat severely under the IUCN Red List compared to the percentages of studies (left panels) and the percentage of actions (right panels) per class providing evidence of conservation actions targeting that same threat as listed by the Conservation Evidence synopses.

Figure S2. Deviations from the predicted number of studies (top panels) and actions (bottom panels) expected to provide evidence of conservation actions targeting a threat in the Conservation Evidence synopses for each taxa given the number of species listed with any threat severity (left panels) or only those listed as severely threatened (right panel) by the IUCN Red List.

Figure S3. Relationship between the percentage of species from each tetrapod class (except Reptilia for which action effectiveness categories were not available) listed as impacted severely by a threat under the IUCN Red List compared to the proportion of actions targeting that same threat as listed by the Conservation Evidence synopses and classified under effectiveness categories: beneficial (original categories of “Beneficial” and “Likely to be beneficial”), harmful (original categories “Likely to be ineffective or harmful” and “Unlikely to be beneficial”), and uncertain (original categories “Trade off between benefit and harms” and “Unknown effectiveness”).

Figure S4. Relationship between the number of studies listed for a particular action in the Conservation Evidence synopses for three vertebrate groups compared to the Effectiveness, Certainty and Harm scores given to those actions.

Figure S5. Global distribution of the locations for studies that provide evidence of interventions on amphibians tackling six threats (black circles) mapped with the probability of impact from each of those threats predicted in each land region.

Figure S6. Global distribution of the locations for studies that provide evidence of interventions on reptiles tackling six threats (black circles) mapped with the probability of impact from each of those threats predicted in each land region.

Figure S7. Global distribution of the locations for studies that provide evidence of interventions on birds tackling six threats (black circles) mapped with the probability of impact from each of those threats predicted in each land region.

Figure S8. Global distribution of the locations for studies that provide evidence of interventions on mammals tackling six threats (black circles) mapped with the probability of impact from each of those threats predicted in each land region.

Figure S9. Predicted number of studies testing interventions for each threat in each terrestrial grid cell of the world (where at least one species of the class lives, $n=310,044$) estimated from the probability of threat impact for each mapped threat for each taxonomic class in each grid cell.

Table S1. Representation of 2133 interventions described in 1576 evidence conservation studies for each studied taxa and threat type across locations with varying probabilities of threat impact (summarising into four prevalence levels defined from the quartiles of the probabilities of threat impact).

Table S2. Model estimates from negative binomial regression model explaining the number of interventions tested against a given threat in each terrestrial grid cell (response variable) as a function of the probability of impact of that threat in that grid cell, the taxonomic class, the threat category, and the interaction between threat category and the probability of impact.

How to cite this article: González-Suárez, M., Stewart, K., Brisco, L., Smith, R. K., Farooq, H., Gompertz, S., Wheatley, D., Sage, M., Harfoot, M., Petrovan, S., Geldmann, J., & Christie, A. P. (2026). Conservation evidence is biased but can support decision-making for prevalent and severe threats in tetrapods. *Journal of Applied Ecology*, 63, e70337. <https://doi.org/10.1111/1365-2664.70337>