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ORIGINAL PAPER

Butterfly and moth conservation: results from a global synopsis of evidence

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Abstract

Butterflies and moths face a range of anthropogenic threats with many of the best-studied populations in decline. In response, butterfly and moth conservation programmes are implementing a diverse set of actions, but to date no study has synthesised evidence for their effectiveness. We present an overview of the recently published *Conservation Evidence* synopsis of butterfly and moth conservation, describe patterns and biases in the available evidence, and compare these to similar synopses on other taxa. We find that most evidence covers butterfly conservation, focuses on community-level responses, originates from the UK and the USA, comes from studies using the least robust designs, and assesses actions addressing the threat posed by agriculture. Far less evidence is available for moth conservation, for individual species' responses, originates from Africa, Asia, Oceania and South America, comes from studies using the most robust designs, or tests actions designed to mitigate the impacts of pollution or climate change. While the geographic and study design biases reflect those found in evidence for the conservation of other taxa, the focus on community-level responses is higher than in any of the other synopses we examined. We suggest this may leave Lepidoptera conservation vulnerable to missing important, species-specific responses. We call for testing of conservation actions to be built into conservation projects for butterflies and moths, to build a robust evidence base for conserving Lepidoptera in a changing world.

Implications for insect conservation

There is a pressing need to test conservation actions for butterflies and moths as part of ongoing management, to build a robust evidence base for efficient and effective Lepidoptera conservation. This is particularly important in countries outside of Europe and North America, and for actions designed to mitigate the impact of threats other than agriculture, such as pollution and climate change.

Keywords Butterflies · Moths · Lepidoptera · Conservation actions · Conservation interventions · Evidence · Evidence-based conservation

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Introduction

Insect biodiversity is under threat from a multitude of anthropogenic actions, from land use change and pollution to invasive species introductions and climate change (Wagner et al. 2021b). While debate continues about the extent and severity of reported population declines (Saunders et al. 2020; van Klink et al. 2020), there is no doubt that these threats impact insects, and that effective conservation action to mitigate these impacts is needed (Harvey et al. 2023).

Lepidoptera, the butterflies and moths, are among the most studied insect groups. In an era of increasing concern about global declines in insect abundance (Hallmann et al. 2017; Leather 2018; van Klink et al. 2020), much of

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the evidence for these declines comes from butterflies and moths (van Swaay et al. 2010; Fox et al. 2015, 2021; van Strien et al. 2019; Wepprich et al. 2019; Bell et al. 2020; Warren et al. 2021; Wagner et al. 2021a). However, while data on threats to butterflies and moths are abundant, information on how to mitigate those threats and reverse declining population trends is less common (Williams et al. 2020).

Evidence-based knowledge of the effectiveness of actions is key for planning successful conservation strategies and for the cost-effective allocation of scarce resources (Sutherland et al. 2004). Therefore, synthesising available evidence, and mapping its distribution geographically, taxonomically, and by threats targeted is important for highlighting both where knowledge exists to inform conservation, as well as where knowledge gaps should be targeted with future research. Moreover, understanding the distribution of evidence derived from the most robust experimental studies is crucial for identifying where the evidence is most reliable, as well as highlighting where robust evidence is most needed (Christie et al. 2021). For example, where conservation actions have only been tested using less reliable study designs, there remains a pressing need for more robust evaluations of their effectiveness. Such a mapping exercise also facilitates a comparison of approaches between different taxa, allowing conservation scientists to learn from best practice across the community.

The *Conservation Evidence* project collates and summarises evidence on the effectiveness of actions for the conservation of species and habitats (Sutherland et al. 2019). Studies are compiled into a database using a Subject-Wide Evidence Synthesis (SWES) approach (Sutherland et al. 2019), whereby relevant journals and report series are systematically searched for studies testing the effectiveness of conservation actions for any taxon or habitat, and then sorted according to their focus. Since 2010, the project has compiled synopses of evidence for all vertebrate taxa (except freshwater fish) and for seven major global habitats (Conservation Evidence 2023). The recently published Butterfly and Moth Synopsis (Bladon et al. 2023) is the third focused on invertebrates, following the Bee Synopsis (Dicks et al. 2010) and Subtidal Benthic Invertebrate Synopsis (Lemasson et al. 2020). This provides a unique opportunity to assess the state of evidence for Lepidoptera conservation.

Here, we provide an overview of the global evidence for conservation actions for butterflies and moths. We address the following key questions:

1) What is the taxonomic distribution of evidence, how has this changed over time, and how does taxonomic resolution compare to similar synopses of evidence for conservation actions for other groups, specifically subtidal benthic invertebrates, bats, amphibians, bees, terrestrial mammals (except primates and bats), birds and primates?
2) What is the geographic distribution of evidence, and how does this compare to similar synopses of evidence for conservation actions for vertebrates, specifically birds and amphibians?
3) What is the quality of evidence, and how does this compare to similar synopses of evidence for conservation actions for vertebrates, specifically birds and amphibians?
4) What is the distribution of evidence for conservation actions designed to mitigate different threats to butterflies and moths?

Methods

We extracted data from the *Conservation Evidence* database on studies testing the effectiveness of conservation actions for Lepidoptera (butterflies and moths) (Bladon et al. 2023). At the time of data extraction, the *Conservation Evidence* project had screened 1,186,531 papers from 301 English language journals, 316 non-English language journals and 18 report series (see Table S1, Amano et al. (2021).

For papers that reported the outcome of a conservation action on butterflies or moths, we recorded the species or taxonomic group and resolution (species-level or community-level) on which the outcome of the action was reported, the location of the study, the experimental design, and the type of threat that the action was aiming to mitigate. Species-level outcomes included the abundance of a single species, reproductive success, survival and condition. Community-level outcomes were species richness, diversity, community composition and total abundance across multiple species.

The experimental design of the study was recorded following Christie et al. (2021), as follows: *Before-After* (BA), measurements were taken from the same locations prior to and after implementing the action; *Control Impact* (CI), measurements were taken from locations where the action was implemented and from locations where nothing was changed; *Before-After Control-Impact* (BACI), measurements were taken both prior to and after implementing the action, in both locations where the action was implemented as well as in locations where nothing was changed; *Randomized Control Trial* (RCT), measurements were only taken after implementing the action, but the implementation of the action had been randomly assigned to some sites while other sites were not changed; or *After* only, an outcome was reported without an experimental comparator; see Table 1 in Christie et al. (2021).

Wherever possible, we assigned the conservation action tested as attempting to mitigate one or more of 12 high-level

Table 1 The number and proportion of studies in eight *Conservation evidence* synopses that only report the outcomes of conservation actions at the community-level (i.e. total abundance, species richness, or diversity). The remaining studies report species-specific outcomes, for one or more individual species. Synopses are ordered by decreasing proportion of community responses

Synopsis	Studies measuring community response alone	Total studies	% community response	Reference
Butterfly and Moth Conservation	405	684	59%	Bladon et al. (2023)
Subtidal Benthic Invertebrate Conservation	88	205	43%	Lemasson et al. (2020)
Bat Conservation	41	194	21%	Berthinussen et al. (2021)
Amphibian Conservation	63	409	15%	Smith and Sutherland (2014)
Bee Conservation	17	162	10%	Dicks et al. (2010)
Terrestrial Mammal Conservation	84	933	9%	Littlewood et al. (2020)
Bird Conservation	77	1,227	6%	Williams et al. (2013)
Primate Conservation	0	80	0%	Junker et al. (2017)

IUCN threat categories: Residential & Commercial Development, Agriculture & Aquaculture, Energy Production & Mining, Transportation & Service Corridors, Biological Resource Use, Human Intrusions & Disturbance, Natural System Modifications, Invasive & Other Problematic Species, Pollution, Geological events, Climate Change & Severe Weather and Other (IUCN 2023). We left unassigned studies where it was unclear what threat was being addressed. More specific threats are nested within the high-level threats, e.g. Herbicides and Pesticides are nested within Agricultural and Forestry Effluents, which is in turn nested within Pollution.

Finally, we compared our results to data extracted from similar *Conservation Evidence* synopses on other taxonomic groups. Data on the geographic distribution of studies and quality of evidence in the Bird Conservation (Williams et al. 2013) and Amphibian Conservation (Smith and Sutherland 2014) synopses were taken from Christie et al. (2021). Data on the taxonomic resolution of studies within each synopsis were extracted directly from the *Conservation Evidence* database for eight taxon-specific synopses: butterflies and moths, subtidal benthic invertebrates, bats, amphibians, bees, terrestrial mammals (except primates and bats), birds and primates (Dicks et al. 2010; Williams et al. 2013; Smith and Sutherland 2014; Junker et al. 2017; Lemasson et al. 2020; Littlewood et al. 2020; Berthinussen et al. 2021; Bladon et al. 2023).

When extracting most data (e.g. taxonomic representation, study design and threat category), we worked at the resolution of an individual test of an action (hereafter "study")– this is because a single paper or report (hereafter "paper") could test more than one conservation action on several taxa, using different study designs. However, when extracting data on geographic location, we worked at the resolution of papers because all the studies within each paper were based in the same country or combination of countries. This ensured that papers containing multiple studies did not skew the geographic results.

Statistical tests were conducted in R version 4.2.0 (R Core Team 2023). Data handling and visualisation were carried out using base R and the 'tidyverse' suite of R packages (Wickham et al. 2019). For quantifying the taxonomic distribution of evidence and whether this had changed over time, we ran a generalized linear model with a Poisson error structure. The dependent variable was number of studies and the independent variables were year of publication, taxonomic group (butterflies or moths) and the interaction between the two. Model selection was conducted using the 'dredge' function in the 'MuMIn' R package (Bartoń 2023). The most parsimonious model within two AIC_c points of the model with the lowest AIC_c was chosen as the optimal model (Burnham and Anderson 2010).

Results

We found 384 papers testing the effectiveness of conservation actions for Lepidoptera. Since many papers tested more than one action, this represented 684 individual studies (Bladon et al. 2023).

1) What is the taxonomic distribution of evidence, how has this changed over time, and how does taxonomic resolution compare to similar synopses of evidence for conservation actions for other groups?

We found 581 studies testing conservation actions for butterflies, and 230 testing actions for moths (127 studies tested actions for both butterflies and moths). The best model selected by AIC_c retained the interaction between year and taxonomic group, indicating that the rate of increase in studies focusing on actions for butterflies was higher than the rate of increase for moths (Fig. 1; Table S2). The most frequently represented species in conservation outcomes were marsh fritillary *Euphydryas aurinia* (15 studies), regal fritillary *Speyeria idalia* (13 studies) and large copper *Lycaena*

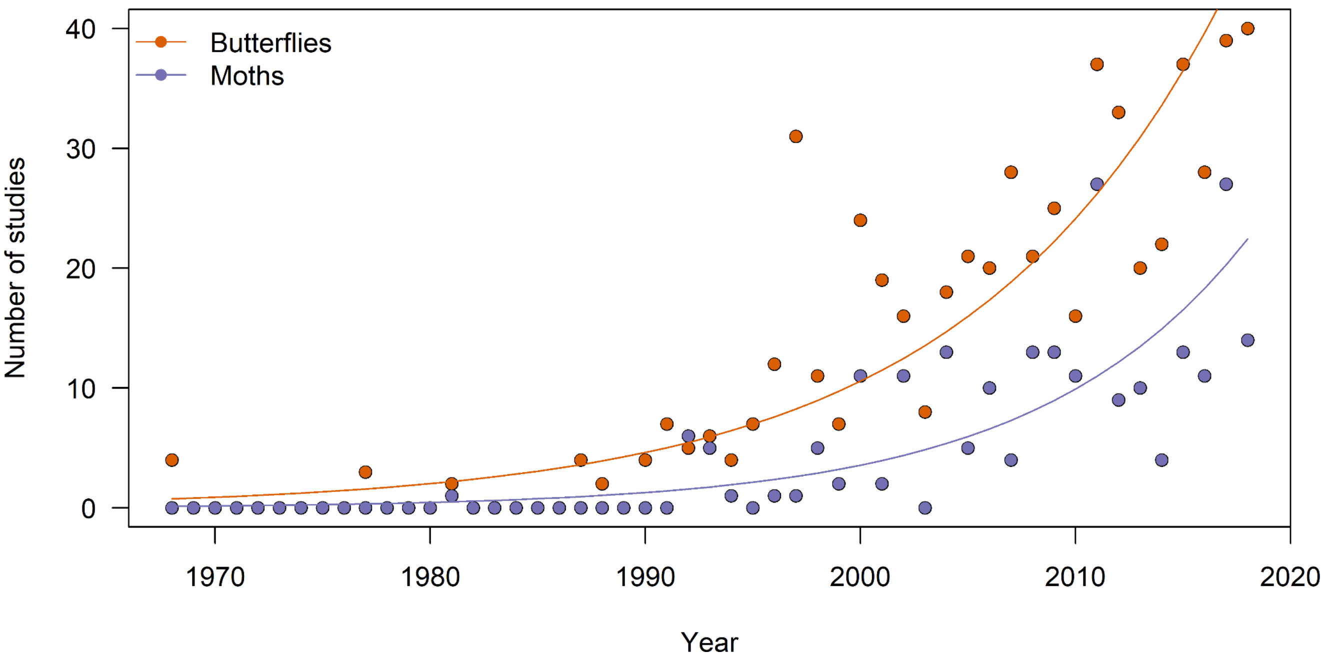

Fig. 1 The number of studies in the Conservation Evidence Butterfly and Moth Synopsis testing the effectiveness of conservation actions by taxonomic group from 1968–2018

dispar (11 studies) (Figure S1a). The most studies on a single species of moth was four, on Fisher's estuarine moth *Gortyna borelii lunata* (Figure S1b).

Of the 684 studies, 279 (41%) reported outcomes on individual species of butterfly or moth. Of these, only 66 (10% of the total) reported demographic rates, such as survival or reproductive success. The remaining 405 studies only reported community-level outcomes, such as total abundance or species richness of a broader taxonomic group, such as "butterflies", "day-flying moths" or "fruit-feeding Nymphalids". The proportion of studies reporting community-level metrics alone (59%) was much higher than in other taxon-focused *Conservation Evidence* synopses (Table 1).

2) What is the geographic distribution of evidence, and how does this compare to similar synopses of evidence for conservation actions for vertebrates?

The 384 papers featured conservation actions undertaken in 44 countries, across all six continents (Fig. 2). However, there was a heavy bias towards Europe (249 papers, 65.4%) and North America (91 papers, 23.9%), the United Kingdom (28.5%) and the USA (19.9%). Only 15 papers (3.9%) came from each of Africa and Asia, with 6 (1.6%) from Oceania and 5 (1.3%) from South America. The geographic distribution was similar to that found in synopses of evidence for amphibian and bird conservation, where 90% and 84% of studies, respectively, were conducted in North America, Europe and Oceania (Christie et al. 2021).

3) What is the quality of evidence, and how does this compare to similar synopses of evidence for conservation actions for vertebrates?

Of the 684 studies, 29 (4.2%) tested a conservation action using a Before-After Control-Impact experimental design, while 79 (11.5%) used a Randomised Control Trial. More studies used Before-After (39 studies, 5.7%) or Control-Impact (92 studies, 13.5%) designs, or After designs (432 studies, 63.2%) which only reported outcomes after an action had been implemented, with no comparable data collected before the conservation action was carried out, or from another area where the action was not implemented. Eleven studies (1.6%) were reviews, and two (0.3%) were systematic reviews (Fig. 3).

4) What is the distribution of evidence for conservation actions designed to mitigate different threats to butterflies and moths?

Of the 684 studies, 506 (74.0%) tested actions designed to mitigate the impacts of agriculture on butterflies and moths, while 199 (29.1%) tested actions trying to mitigate the impact of natural system modifications (primarily changes to fire regimes). Meanwhile, just 67 studies (9.8%) tested actions attempting to mitigate the effects of pollution

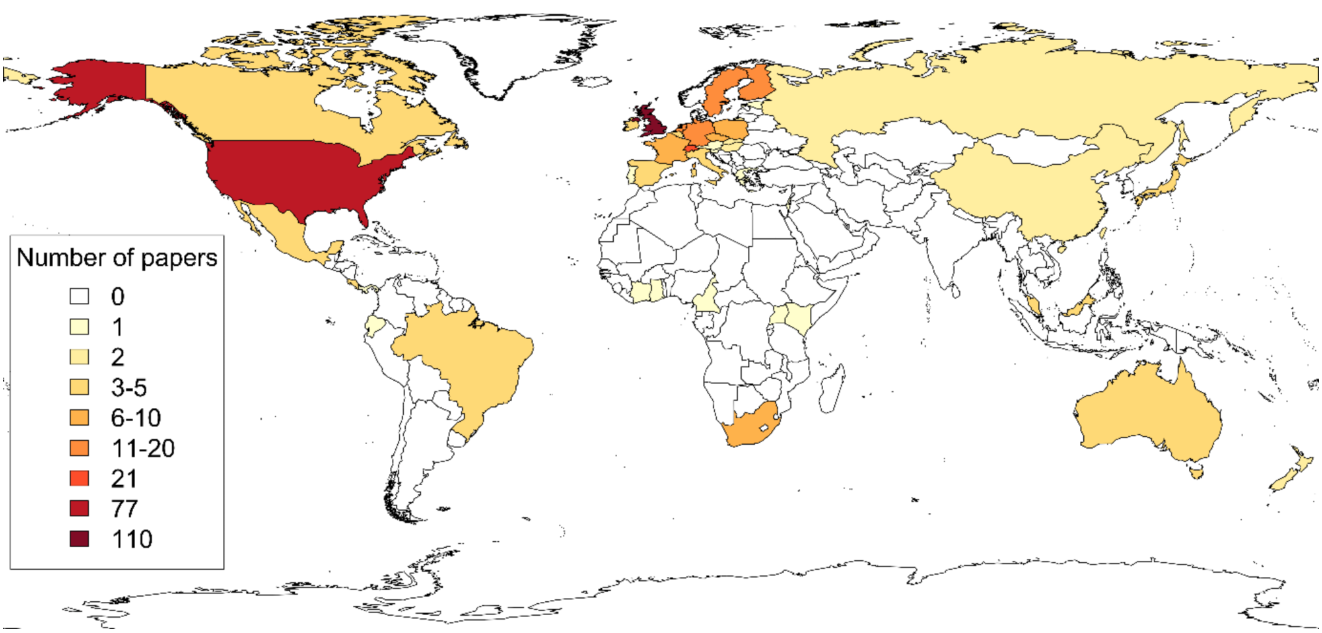

Fig. 2 The number of papers in the Conservation Evidence Butterfly and Moth Synopsis testing the effectiveness of conservation actions by country. Darker colours indicate countries that were the focus of more research papers

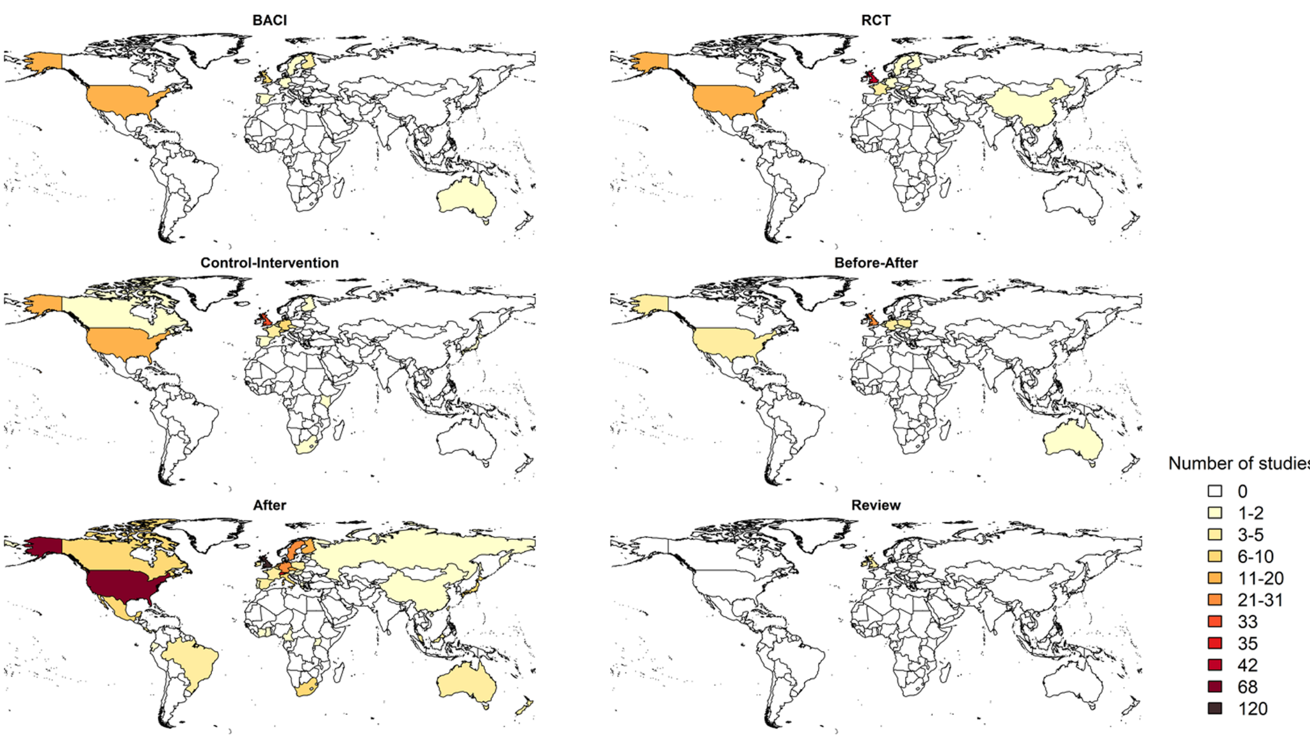

Fig. 3 The number of studies in the Conservation Evidence Butterfly and Moth Synopsis testing the effectiveness of conservation actions using different experimental designs, by country. Darker colours indicate countries which were the focus of more studies

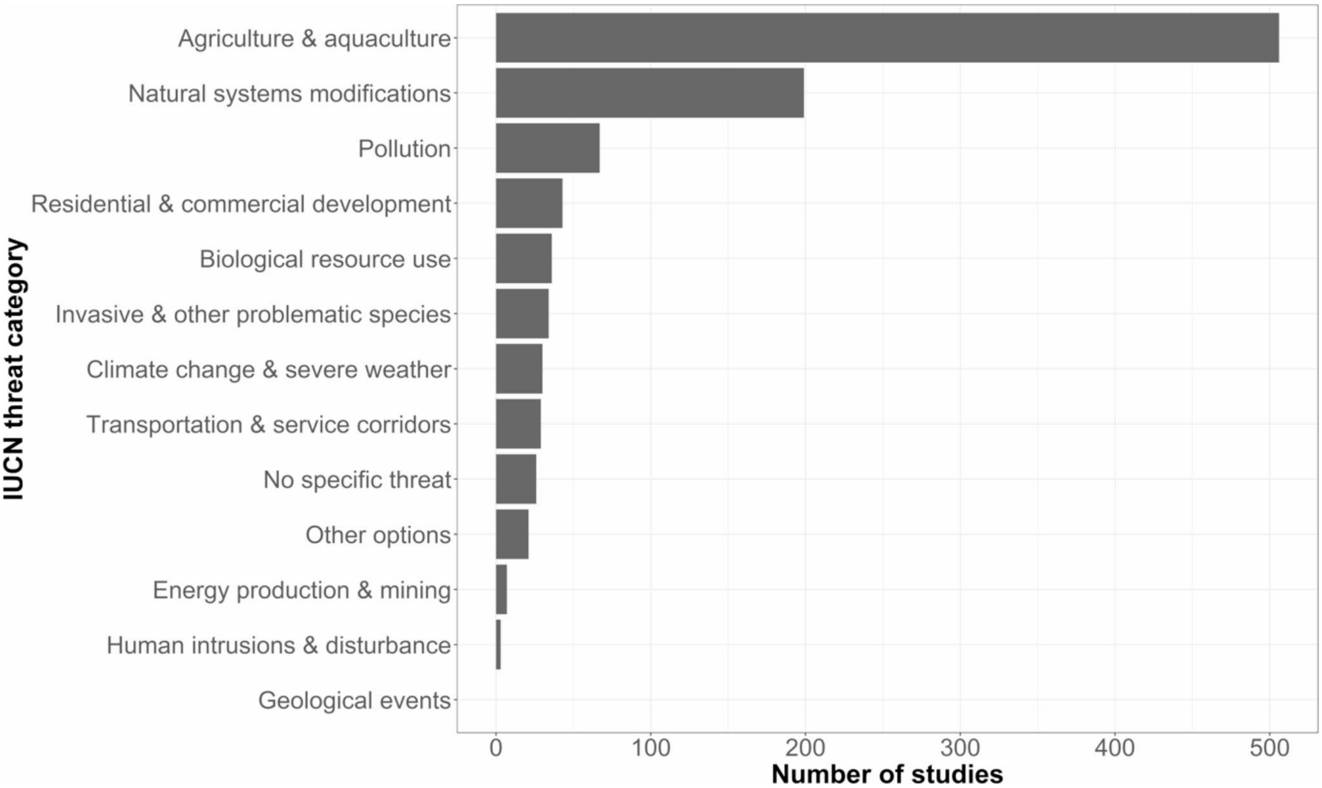

Fig. 4 The number of studies in the Conservation Evidence Butterfly and Moth Synopsis testing the effectiveness of conservation actions designed to mitigate each of 12 high-level threats to biodiversity (IUCN 2023). Studies could address more than one threat simultaneously, and in these cases are counted under both threats. Studies testing actions addressing "no specific threat" tended to involve captive-rearing and releases, or assessments of protected areas, where a specific threat to the butterfly or moth was not defined

(including agricultural and forestry effluents and light pollution), and only 30 studies (4.3%) tested an action designed to mitigate the impacts of climate change (Fig. 4, Table S3).

Discussion

We found 384 papers and reports, containing 684 studies, testing the effectiveness of conservation actions for butterflies and moths. There was a heavy bias towards butterflies (581 studies, 85%) compared to moths (230 studies, 34%). Nearly three fifths of studies reported outcomes only at the community level (e.g. total abundance or species richness), with just 279 studies reporting outcomes for individual species. We found that two-thirds of the literature on evidence for butterfly and moth conservation came from Europe, and nearly a quarter from North America, with little from the other four continents. Less than 16% of evidence came from the most robust study designs (BACI and RCT), with most evidence derived from studies where outcomes were measured only after the action had been carried out, and with no experimental control. Nearly half of the evidence tested actions aimed at mitigating the impacts of agriculture on butterflies and moths, with just 30 studies testing actions to mitigate pollution, and 18 testing actions to mitigate climate change.

A strong bias towards butterflies has been found in other conservation literature: 1,494 species of butterfly have received IUCN Red List assessments, compared to just 144 species of moth (IUCN 2023). Yet this bias runs counter to the diversity of the two groups. There are estimated to be around 160,000 species of moth globally, ten times more than the 17,500 described species of butterfly (Mallet 2014). Butterflies are diurnal, distinctive, and have wide public appeal, making their conservation easier to fund, especially for an insect (Preston et al. 2021). Yet the sheer diversity and abundance of moths makes them far more important ecologically. They are important pollinators (Ellis et al. 2023) and underpin ecological systems as a key food source, especially for birds (Kennedy 2019; Perrins 1991). Meanwhile we know far less about their threats and conservation status (IUCN 2023), as well as effective actions for their conservation. It is likely that some conservation actions, such as habitat restoration, which benefit butterflies will also benefit moths. However, some threats (e.g. light pollution, for which only seven studies exist) are undoubtedly more serious for moths, and so gathering more evidence for conservation actions for moths remains a priority.

Most studies testing the effectiveness of conservation actions for butterflies and moths only reported outcomes at the community level, primarily through changes in total abundance of groups of species, or species richness. While useful for gaining an overview of the impact of an action on a community, such high-level assessments are likely to miss key details of individual species' responses to management. Even within butterflies, species within a community have diverse ecological requirements: on chalk grasslands in the UK, species such as the small blue *Cupido minimus* and chalkhill blue *Polyommatus coridon* prefer open areas of short grass, while the Duke of Burgundy *Hamearis lucina* requires sheltered areas enclosed by scrub patches (Turner et al. 2009; Hayes et al. 2019; Ashe-Jepson et al. 2022). Managing for these three priority species at the same site is challenging and requires knowledge of each individual species' response. A study that records the effectiveness of a conservation action on only total abundance or species richness across the community risks missing declines in some species, because they occur simultaneously with an increase in others. Moreover, including measures of species' demographic rates, such as reproductive success or survival, which was only reported in 66 studies, alongside simple measures of abundance, would provide more robust evidence for the effectiveness of conservation actions (Schultz et al. 2019).

The propensity of Lepidoptera conservation studies to only assess community metrics is not reflected in other taxonomic groups. Similar synopses for vertebrates contain just 0–21% of studies reporting community-level outcomes alone (Williams et al. 2013; Smith and Sutherland 2014; Junker et al. 2017; Littlewood et al. 2020; Berthinussen et al. 2021), compared to 10% for bees (Dicks et al. 2010), 43% for sub-tidal benthic invertebrates (Lemasson et al. 2020) and 59% for butterflies and moths (Bladon et al. 2023). Perhaps this is unsurprising: if a study on mammal conservation reported how the total abundance of all carnivores changed in response to a conservation action, it would be unlikely to be deemed useful, yet this is the taxonomic equivalent of reporting a change in total abundance of Lepidoptera. To ensure that tests of conservation actions for butterflies and moths are meaningful for conservation, the responses of individual species to management must be reported wherever possible.

The vast majority of evidence for butterfly and moth conservation actions comes from Europe and North America, primarily the UK and the USA. This reflects a similar bias in tests of conservation actions for birds and amphibians (Christie et al. 2021), as well as in the availability of data on insect population trends (van Klink et al. 2020), and the availability of conservation assessments for butterflies (van Swaay et al. 2010). It may even reflect historic patterns of threat severity, at least in terms of agricultural intensification during the 20th century. But it does not reflect global Lepidopteran biodiversity, which is far higher in tropical regions (e.g. León-Cortés and Córdoba-Aguilar 2024). Threats to biodiversity are growing rapidly in these regions, and understanding which actions are most effective to mitigate threats will be crucial for future conservation (Theng et al. 2020). Moreover, unlike in previous assessments of evidence in the *Conservation Evidence* database, where the target synopses did not contain literature from non-English language journals (Christie et al. 2021), the Butterfly and Moth Synopsis included papers sourced from 316 non-English language journals. However, these journals yielded just nine papers, making an important but limited reduction in the geographic bias of available evidence.

Overall, the quality of evidence available for butterfly and moth conservation was similar to previous assessments of *Conservation Evidence* synopses (Christie et al. 2021), with less than one sixth of studies using the most robust BACI (4.2% of studies) or RCT (11.5% of studies) experimental designs. Determining the true effectiveness of conservation actions is challenging without one of these designs, with less robust study designs providing, at best, only an indication of likely effects or, at worst, an incorrect conclusion (Ferraro and Miranda 2014; Christie et al. 2021). There is a pressing need to expand the use of rigorous experimental set-ups and field trials in butterfly and moth conservation, to determine which actions are most effective, thus ensuring that limited conservation funding is spent effectively and efficiently.

The available evidence for butterfly and moth conservation actions was dominated by tests of actions designed to mitigate the impacts of agriculture (74% of studies). Agricultural expansion and intensification is widely recognised as a major, if not the major, threat to butterflies and moths, with specialist species in particular being sensitive to the loss of pristine habitat (van Swaay et al. 2010; Wepprich et al. 2019; Wagner et al. 2021b). In this sense, the wealth of evidence available for actions to mitigate agricultural threats is encouraging. However, Lepidoptera are sensitive to a range of other anthropogenic threats, not least light pollution (Boyes et al. 2021) and climate change (Settele et al. 2008; Thomas et al. 2011), and the relative lack of research on actions designed to mitigate their impacts (7 and 30 studies, respectively) represents a huge gap in the butterfly and moth conservation literature.

While we found a large body of evidence for butterfly and moth conservation, the knowledge gaps highlight where more research is needed. Although some of these are large, evidence can be built through small, incremental steps (Sutherland et al. 2022). Conservation management is, and will be, ongoing, and researchers and practitioners should work together to ensure actions are tested during their implementation (Wildlife Trust 2021). By building experiments into conservation planning, robust experimental designs– where data must be collected (BACI) or treatments randomly allocated (RCT) before the action is implemented– can be conducted more easily, thus increasing both the quality and quantity of evidence gathered. Although this may sometimes require large field trials, small scale studies suited to limited timeframes and tight budgets can yield valuable and novel evidence (Ockendon et al. 2021).

Conclusions

We found a large body of evidence testing the effectiveness of conservation actions for butterflies and moths. While the evidence for actions to mitigate the threat of agriculture, particularly on butterflies in the UK and USA, is fairly comprehensive, there are large gaps in the evidence for the conservation of moths, outside of Europe and North America, and for actions designed to mitigate other threats, most notably climate change and pollution. We call for the testing of conservation actions to be routinely built into conservation projects and management plans for butterflies and moths, to build a robust evidence base for how to conserve Lepidoptera in a changing world.

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Author contributions EKB and AJB designed the study. EKB, APC, RKS and AJB collected the data. EKB conducted the statistical analyses. EKB and AJB wrote the first draft of the manuscript. WJS established the *Conservation Evidence* programme and overviewed the work. All authors commented on the manuscript and approved the final version.

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Data availability The data used in this paper are publicly available on the *Conservation Evidence* website, www.conservationevidence.com.

Declarations

Competing interests The authors declare there are no competing or conflicting interests.

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