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Title: The Positive Impact of Conservation Action

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One-Sentence Summary: Meta-analysis reveals significant positive impacts of conservation actions on biodiversity, compared with outcomes anticipated without intervention

Abstract: Governments recently adopted new global targets to halt and reverse the loss of biodiversity. It is therefore crucial to understand the outcomes of conservation actions. We conducted a global meta-analysis of 186 studies (including 665 trials) that measured biodiversity over time and compared outcomes under conservation action with a suitable counterfactual of no action. We find that in two-thirds of cases, conservation either improved the state of biodiversity, or at least slowed declines. Specifically, we find that interventions targeted at species and ecosystems, such as invasive species control, habitat loss reduction and restoration, protected areas, and sustainable management, are highly effective, with large effect sizes. This provides the strongest evidence to date that conservation actions are successful, but require transformational scaling-up to meet global targets.

Main Text: Ongoing and dramatic declines in global biodiversity, and the associated negative consequences for human well-being, are among the most pressing contemporary risks to society (*1*). Governments have thus adopted goals to tackle biodiversity loss and its drivers: 20 Aichi Biodiversity Targets in the Strategic Plan for Biodiversity 2010-2020 through the Convention on Biological Diversity, and now 4 goals for 2050 and 23 targets for 2030 in the 2022 Kunming-Montreal Global Biodiversity Framework (GBF) (*2*). Similar targets are echoed in the 17 Sustainable Development Goals (*3*). More than $121 billion is invested annually into biodiversity conservation worldwide (*4*). Yet despite this, none of the Aichi Targets were fully met (*1*). It could be concluded that responses to the ongoing biodiversity crisis are either insufficient, ineffective, or both (*5, 6*) and that the targets established in the new GBF will also likely not be achieved. However, such conclusions are premature: conservation interventions could represent progress, and be at least partly effective, even if global policy targets have not yet been achieved in full. There is consequently a need for a robust evaluation of policy targets, and an assessment of whether conservation interventions are working – that is, having positive impacts and providing better outcomes than the absence of interventions – as governments start committing resources and implementing the GBF.

Robust impact assessment using a counterfactual approach (*7*) reveals that conservation action has prevented extinctions (*8*) and reduced extinction risk (*9*) for species across taxonomic groups compared with an absence of conservation action. There has been an increase over the last decade in studies evaluating the impact of specific conservation actions, from global to local scales, using counterfactual comparisons, including for protected areas (*10*), payments for environmental services (*11*), invasive alien species (IAS) eradications (*12*), and sustainable management of ecosystems (*13*). Other studies have undertaken meta-analyses or systematic reviews, but only for individual conservation actions (*14–16*). Similarly, the Conservation Evidence website (*17*) provides a compendium of evidence for the effectiveness of a wide range of individual conservation interventions. However, since conservation actions started over a century ago, there has been no comprehensive meta-analysis of the impact of conservation across the full suite of conservation actions and intervention types, multiple levels and metrics of biodiversity, and over time. Such an assessment is critically needed to inform implementation of the GBF.

Here we conduct a meta-analysis of the impact of a wide range of conservation interventions globally. Meta-analysis provides a powerful and informative method to summarize results from multiple studies and accounts for unequal precision among studies in the calculation of effect sizes. We evaluate the impact of conservation actions that address direct pressures on biodiversity, promote restoration and recovery of populations and habitat, and aim to safeguard the environment across different levels of biological organization, compared with outcomes expected without intervention. Specifically, we consider seven intervention types aiming to tackle the direct drivers of environmental degradation: establishment and management of protected areas; other measures to reduce habitat loss and degradation (including policy and restoration); sustainable use of species; sustainable management of ecosystems; control of pollution; eradication and control of invasive alien (and problematic native) species; and climate change adaptation. These classes of intervention were identified based on the strategies of the intergovernmental environmental agreements, especially the nine Aichi Targets in Strategic Goals B and C of the Strategic Plan for Biodiversity 2011-2020 (Table S1), aligned in turn to the targets of the GBF and Sustainable Development Goals 14 (Life Below Water) & 15 (Life on Land). We consider impacts on biodiversity at ecosystem, species, and genetic levels.

We conducted a Rapid Evidence Assessment (see Methods) and meta-analysis of studies published in English that present a counterfactual-based analysis of the impact of conservation actions over time (*18*). Our literature search yielded 1,445 studies (published papers) spanning spatial scales from local to continental, and more than a century (1890-2019) (Table S2; Fig. S1). Of these, we retained only studies that contained temporal data, where we could express outcomes as effect sizes generated from the 'rate of change under the intervention' compared with 'rate of change under a counterfactual scenario' (*19*), yielding 186 studies that were included in our meta-analysis (Table S3). Using a rate of change to calculate the effect size allowed us to assess conservation actions over different time scales, avoiding premature conclusions based on study duration. Where studies measured change in biodiversity using more than one metric (e.g. different species), each was treated as a distinct trial nested within that study, totaling 665 trials across the dataset.

Our comprehensive dataset shows the variable outcomes of conservation outcomes. As such, interventions that generate gains in the state of biodiversity compared with a counterfactual in which biodiversity declines, stays the same, or improves to a lesser degree than the intervention, reveal absolute positive impacts of conservation action (Fig. 1a). Relative positive impacts of conservation action result when biodiversity declines, but the intervention slows the decline compared with the counterfactual (Fig. 1b). Conversely, relative negative impacts of conservation action occur when biodiversity improves, but the counterfactual reveals greater improvements than the intervention (Fig. 1c). Absolute negative impacts of conservation action result when biodiversity declines following the intervention while it improves, stays the same, or declines to a lesser degree in the counterfactual (Fig. 1d). These four categories are mutually exclusive.

Results

We find that in the majority of cases, biodiversity conservation works. Our meta-analysis shows that the 'Overall' impact of conservation is positive and significant (mean Hedges' g [± 95% CI] = 3.24 [2.95 – 3.52], $p<0.001$), indicating that, conservation interventions yield beneficial outcomes for biodiversity compared with the outcome in the absence of an intervention (Fig. 2a). We also show that conservation actions can yield positive impacts in both an absolute and a relative sense (Fig. 1). In two-thirds of trials, conservation either improved the state of biodiversity ("absolute positive impacts", 45.4%), or at least slowed declines ("relative positive impacts", 20.6%). However, in one-fifth of trials, biodiversity under the intervention declined more than no action ("absolute negative impacts", 20.6%), while in a smaller number of cases biodiversity improved in both the intervention and counterfactual, but the counterfactual revealed greater improvements ("relative negative impacts", 11.6%). There was no difference between intervention and counterfactual for 1.8% of trials. Moreover, we find that the effect sizes of some individual interventions are high in magnitude and positive, indicating a substantial positive impact of those actions on the whole.

All types of intervention assessed that had more than five trials showed a significant positive effect compared with a counterfactual (Fig. 2a; Fig. S2) – eradication and control of invasive alien and problematic native species (7.07 [6.1–8.04], $p<0.001$), sustainable management of ecosystems (5.70 [4.66–6.74], $p<0.001$), habitat loss reduction & restoration (5.58 [4.5–6.7], $p<0.001$), and establishment and management of protected areas (1.41 [1.03–1.78], $p<0.001$).

The impact of efforts towards sustainable use of species is inconclusive (2.07 [-0.71–4.84], p=0.15), with large confidence intervals possibly related to the small number of studies ($N_{studies}$=5, N_{trials}=7). There were too few studies assessing the impact of interventions of pollution control or climate change adaptation to analyze separately (each had five or fewer trials) but these were included in the calculation of the Overall effect size. Likewise 'Other' studies that did not fit into one of the seven key intervention categories (e.g. food supplementation ($N_{studies}$=1), culling of diseased individuals ($N_{studies}$=1), and captive breeding and release ($N_{studies}$=5)) were only included in the calculation of the Overall effect size (categorized as "Other" in the Figures). Studies focused on the impact of controlling problematic native species were combined with studies on IAS given the similarity of the interventions involved.

The impact of actions targeting different levels of ecological organization are positive and significant, with the greatest impact shown for actions targeting species (3.56 [3.14–3.97], p<0.001), followed by ecosystems (2.88 [2.46–3.29], p<0.001), and then genetic diversity (3.84 [1.35–6.32], p=0.002), which had wide confidence intervals because there were few studies (Fig. 2b). In terms of geographic breakdown, effect sizes were positive and significant on all continents (Table S4). Our dataset also shows that effect sizes are positive and significant across each of the differing approaches to measuring the impact of an intervention (Table S5).

The timespan of datasets analyzed in the different studies was highly variable, with the shortest being 1 month and the longest 110 years (median=4.7, mean=7.4) (Fig. 3). These date back to 1890, and show a trend that studies mainly focused on protected areas until the 1990s, but after this, diversified to a wider range of interventions. Studies with a longer duration were not significantly more likely to show more beneficial or detrimental impacts of conservation actions than shorter studies (Fig. S3). Meta-regression of effect sizes against year of publication (Fig. 4) indicated that more recent studies were more likely to show a positive effect of conservation action, although the low R^2 shows that other factors influence effect sizes, as would be expected (because many factors in addition to the intervention determine effect sizes).

Half of the studies that met our meta-analysis inclusion criteria (95/186) were conducted in Western Europe, North America, Australia, and New Zealand (Fig. 3). Of the seven intervention types examined, the largest proportion focused on terrestrial and marine protected areas (38%) and the eradication and control of invasive alien and problematic native species (25%). Fewer studies evaluated other conservation actions for ecosystems (e.g. restoration, habitat conservation policy, sustainable management), for species (e.g. sustainable use, reintroductions), and for genetic diversity (e.g. supplementation, supportive breeding; Table S3).

Our results remain largely unchanged in sensitivity analyses designed to test the impact of different methodological considerations (Fig. S4), including: imputing the rate of change when it was zero in either the intervention or counterfactual; nesting trials within studies; and undertaking a supplemental literature search. Cumulative meta-analysis revealed that effect sizes stabilize after the addition of studies published from approximately 2011 onwards (Fig S5), and in assessing publication bias, the symmetrical nature of our funnel plots (Fig. S6), combined with a Fail-safe N of 1,280, led us to conclude that any publication bias in our dataset is minimal.

Discussion

We have shown that across a full suite of conservation actions and intervention types, multiple levels and metrics of biodiversity, and over a century of action, conservation has improved the state of biodiversity – or at least slowed its decline – compared with no conservation action. Our calculated effect sizes are often large and positive, meaning that the outcomes from conservation actions are substantially better than no action at all.

Among the different conservation actions evaluated in our study, the eradication, control and management of IAS showed the largest impact of conservation action (as highlighted by the largest effect size in our intervention groupings), followed by actions to reduce habitat loss and degradation, sustainable management of ecosystems, and protected areas (Fig. 2a). IAS eradication and control has generated some of the most striking conservation successes reported to date, particularly on islands (*20*, *21*). There were numerous studies evaluating the impact of IAS control and eradication that were excluded from our meta-analysis because they report data for only one time point, but these tend to also show a positive impact.

Although few in number, studies assessing actions to reduce habitat loss and degradation, including restoration, did show positive results (Fig. 2a) consistent with global analyses (*22, 23*). Efforts to ensure sustainable management of ecosystems, particularly on land, also generally increased native species abundance and habitat cover (Fig. 2a). These results are consistent with global analyses of sustainable management of ecosystems under agriculture and forestry (*24, 25*).

Protected areas have been shown to be effective in reducing conversion of natural land cover (*10*), terrestrial habitat loss (*15*), coral loss (*26*), tropical forest fires (*27*), species extinction risk (*28*), and in increasing biomass and density of marine organisms (*14, 29*). Protected area effectiveness varies geographically, in terms of their effectiveness in preventing deforestation (*30*) and reducing anthropogenic pressure (*31*). Poor performance of protected areas often results from shortfalls in human and financial capacity (*32, 33*), while protected area downgrading, downsizing and degazettement presents another major challenge in some regions (*34*). However, our results concur that while their effectiveness is not universal (*31*), protected areas are an important tool for achieving conservation outcomes (Fig. 2a).

The impacts of efforts to address unsustainable use of species in the ocean and on land were mixed (Fig. 2a), but the number of studies meeting the criteria for inclusion in our meta-analysis was small ($N_{studies}$=5).

Across our dataset, 137 trials (21% of cases) provide examples in which conservation interventions were not only associated with a negative rate of change, but performed more poorly than counterfactuals for biodiversity state. Eradicating and controlling invasive alien and problematic native species can negatively impact non-target species through incidental damage or mortality, or meso-predator release, and this explains the negative impacts observed for this group of papers. For example, in the United States, application of herbicides to invasive alien plants harmed native forbs (*35*), and in India, physical removal of invasive alien algae caused further spread and establishment elsewhere (*36*) (Fig. 1). Protected areas can show negative impacts if there is poor enforcement and insufficient resourcing, leading to higher rates of resource extraction, poaching, or agricultural expansion compared with counterfactual areas (*37*), or if protection increases the abundance of both predators and the target species in a no-take marine protected area (*38*). These unintended outcomes emphasize the importance of evidence-based interventions alongside effective monitoring, so that negative responses can be quickly detected and conservation measures adjusted accordingly.

More and better counterfactual studies are needed for a wider range of conservation interventions and geographic regions. Particular gaps include assessments of pollution control, climate change adaptation, sustainable use of species, habitat loss reduction (beyond protected areas), actions targeting species and genetic diversity, and conservation actions in the Global South.

The finding that contemporary studies were more likely to show a positive effect of conservation actions (Fig. 4) may be due to increases in funding and project-level resources, more targeted interventions, or indeed, that conservation practice is improving over time as lessons are learned from previous failures, and methods are improved. These same factors may help explain the larger effect sizes of more rigorous experimental/quasi-experimental study designs (Table S5), since their application (particularly quasi-experimental) tends to be more recent. That the relationship between effect size vs. study duration (Fig. S3) showed no general trend in direction indicates that valuable insights can be gained even for studies that are short in duration, provided the study design is appropriate. This further underscores the necessity of counterfactual evaluation and meta-analysis to assess conservation impact.

Overall, global conservation efforts have helped to slow declines in biodiversity, and could eventually bend the curve of absolute biodiversity loss (*39*). Quantifying and evidencing the relative biodiversity outcomes (typically gains) of conservation is crucial, to contextualize and explain declining state indicator and increasing response indicator trends. While the state of biodiversity is declining across the globe in absolute terms, conservation actions work most of the time – the challenge is now to expand these to the scale necessary to reverse the global biodiversity crisis. That is, conservation interventions are working, but there are simply not enough conservation actions implemented, or in the right places. Realizing the highly ambitious vision of the GBF not simply to slow declines of biodiversity by the end of the decade, but to reverse them (*2*), will require ongoing assessment of the impact of specific conservation interventions, to inform adaptive management with evidence. Even more importantly, however, it will require substantially scaled-up funding and commitment for implementation of demonstrably effective conservation interventions – a real transformational change – which in turn depends on increased political will and investment.

Such an increase in conservation action and associated outcomes will require expanded implementation and significant additional investment across many sectors of society, particularly beyond the traditional conservation sector. Meeting global biodiversity conservation targets to reduce the extinction risk of all species and safeguard sites of international biodiversity importance was estimated to cost around $80 billion annually over a decade ago (*40*). A comprehensive global conservation program would require an investment of $178-524 billion annually (*4*), much of it focused in highly biodiverse countries. Although high, these costs are dwarfed by the value that biodiversity provides to society through the delivery of ecosystem services (*41*). Thus, conservation actions are investments rather than payments – and, as our study demonstrates, they are typically investments that yield genuine, high-magnitude positive impacts.

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Data and materials availability: The dataset and code generated and analyzed during the current study is available at (*44*).

Supplementary Materials

Materials and Methods

Figs. S1 to S6

Tables S1 to S5

References (*45–236*)

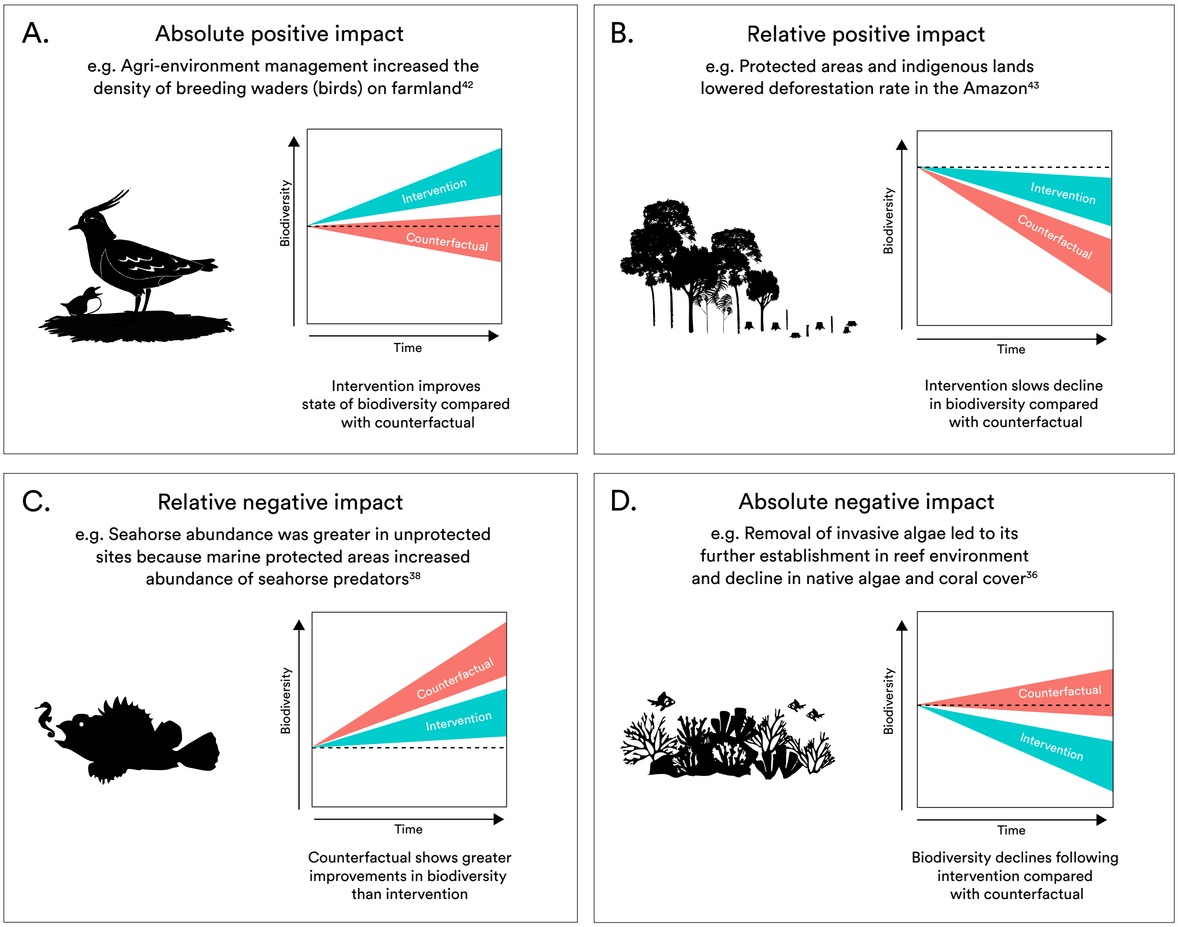

Fig. 1. Schematic representation of different broad categories of conservation impact, with illustrative case studies drawn from our dataset (example reference numbers in superscript). **(A)** 'Absolute positive impact' = intervention outperforms counterfactual and there is an increasing biodiversity trend under the intervention. **(B)** 'Relative positive impact' = intervention outperforms counterfactual but there is a declining biodiversity trend under both intervention and counterfactual. **(C)** 'Relative negative impact' = counterfactual outperforms intervention but there is an increasing biodiversity trend under both intervention and counterfactual. **(D)** 'Absolute negative impact' = counterfactual outperforms intervention and there is a declining biodiversity trend under intervention.

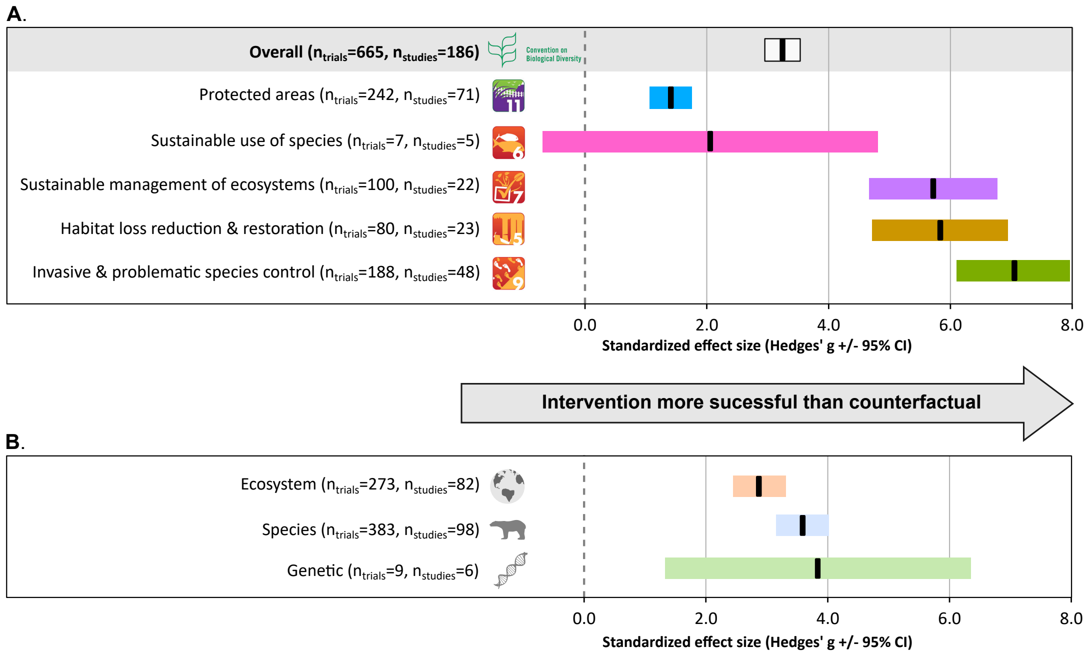

Fig. 2. Effect sizes of conservation interventions **(A)** Overall, and by class of intervention, and **(B)** for different levels of ecological organization. The number of intervention vs counterfactual trials of data (n_{trials}), and unique studies ($n_{studies}$) are reported in parentheses. Mean standardized effect size (Hedges' g) is indicated by the vertical line, and 95% confidence intervals are represented by the bar width. Where the confidence intervals do not overlap zero, the effect size is significant. Vertical dashed lines show zero effect, whilst effect sizes to the right indicate that the intervention is more successful than the counterfactual. Interventions with five or fewer trials (pollution control, climate change adaptation and those classified as 'other'), are not shown, but do contribute to the calculation of the Overall effect size. The icons (Copyright BIP/SCBD) in (A) show the primary Aichi target that the intervention classes align with, however, as shown in Table S1, these interventions also align with a suite of other goals and targets from intergovernmental environmental agreements.

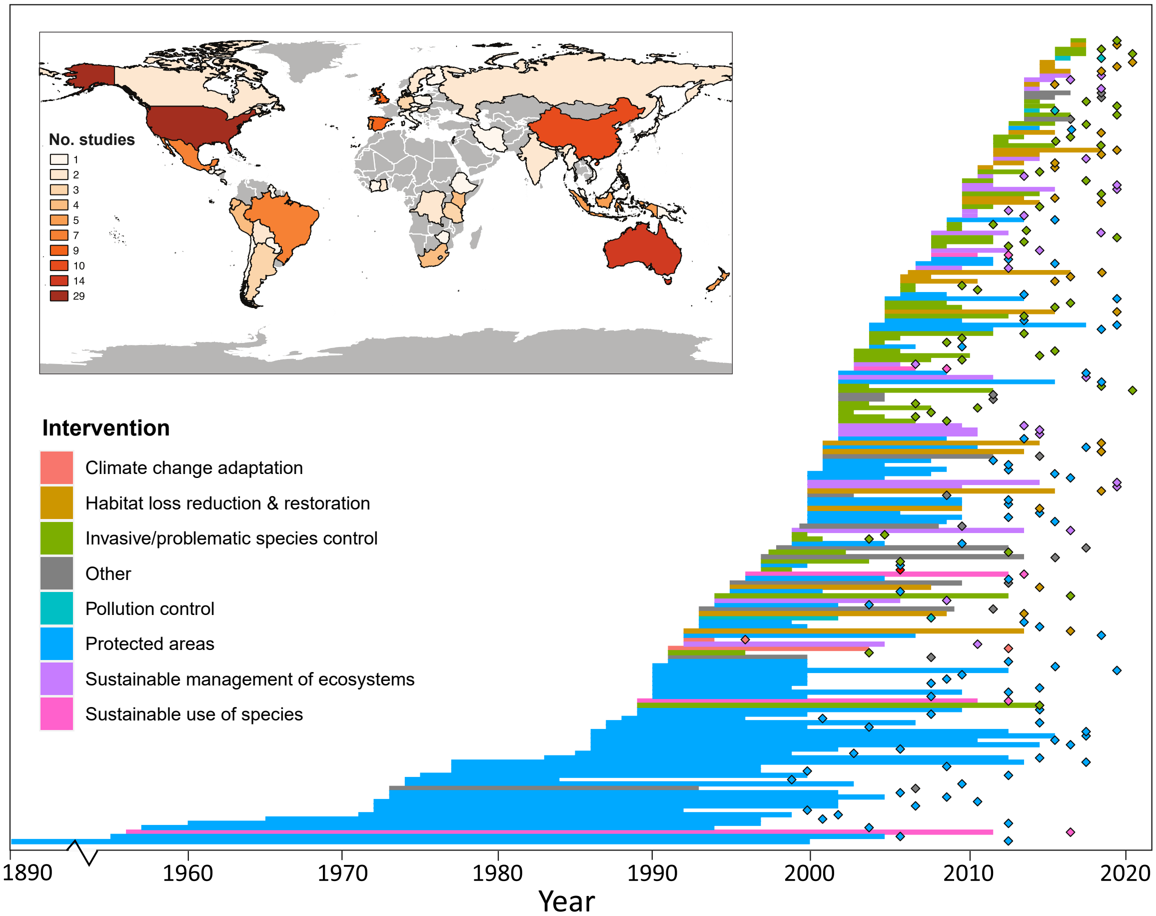

Fig. 3. Characteristics of the studies (n=186) included in the meta-analysis. Each bar represents a single study included within the meta-analysis, and shows (against the x-axis) the timescale (start to end years) covered by the dataset in that study (note break in the scale). The color of each bar denotes the intervention type explored by that study. Points show the year in which the associated study was published in the literature. Inset: world map showing the number of studies carried out in each country represented within the meta-analysis (number of countries=42).

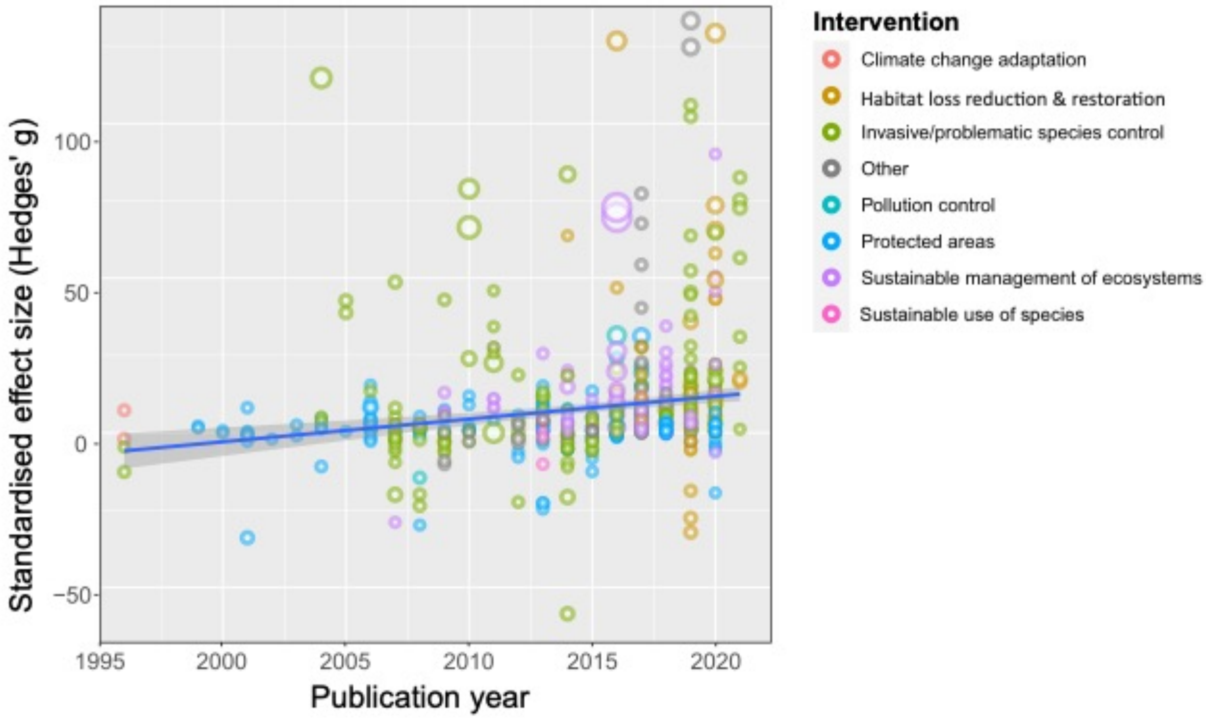

Fig 4. Publication year vs. mean standardized effect sizes for each study, colored by intervention. Blue line and dark grey shaded area show linear line of best fit with 95% confidence intervals. Linear regression is significant ($p<0.001$) but R^2 is small ($R^2=0.03$), as would be expected.