Is reintroduction biology an effective applied science?

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Abstract

Reintroduction biology is scientific research aimed at informing translocations of endangered species. We review two decades of published literature to evaluate whether reintroduction science is evolving in its decision-support role, as called for by advocates of evidence-based conservation. Reintroduction research increasingly addresses *a priori* hypotheses, but it remains largely focused on short-term population establishment. Similarly, studies that directly assist decisions by explicitly comparing alternative management actions remain a minority. A small set of case studies demonstrate full integration of research in the reintroduction decision process. We encourage the use of tools that embed research in decision-making, particularly the explicit consideration of multiple management alternatives since this is the crux of any management decisions.

From reintroduction biology to reintroduction practice

In the face of unprecedented biodiversity losses, effective strategies for the conservation of endangered species are urgently required [1-3]. Among conservationists, there is almost universal agreement on the need for evidence-based management decisions and for science that supports conservation decision-making [4]. However, management decisions remain primarily based on the application of experience without careful evaluation of evidence [5-7]. For conservation management to be truly evidence-based the science should be embedded within the management problem to facilitate the choice of a best management action. Conservation science generally seeks to undertake research aimed at providing information to help choose management actions; this role should provide better outcomes than would be achieved otherwise and is our interpretation of applied science. However, most published conservation studies are not always explicit about how the information they present should be used by decision makers, and thus might not achieve a complete connection between basic and applied science [8-9]. In general, science can support management by (i) predicting the consequences of management actions based on available evidence, (ii) reducing uncertainty around choices between alternative actions, and (iii) providing specialist tools to help select the best action for a given set of objectives. Successful examples in conservation range from experimentally testing non-lethal predator exclusion methods to protect shorebird colonies [10] to developing software for optimal design of nature reserves at the continental scale [11].

The science of reintroduction biology showcases well these general criticisms. Reintroduction is a globally important form of conservation management, but reintroduction programs are complex and require numerous decisions, all of which are subject to uncertainty. This uncertainty in turn makes it difficult to select the ‘best’ set of actions, frequently resulting in poor choices that have been blamed for the low success of past reintroduction efforts [12-14]. Reintroduction biology, first formally recognised as a field of science at a conference in Australia in 1993 and later published as a proceedings in 1995 [1], is increasingly called upon to facilitate those decisions [16]. Several authors have recommended that reintroduction studies should not just collect data from practice and seek patterns *a posteriori*, but focus on the uncertainties that make reintroduction decisions difficult and rigorously evaluate project outcomes with the aim of improvement [17-22, 1].

Indeed, almost a decade ago, two of us published a paper in this journal that outlined the purpose of reintroduction biology as an applied science [17]. In that paper, they argued "that reintroduction biology will progress faster if researchers focus on the questions that need to be answered to improve species recovery and ecosystem restoration. That is, reintroduction biologists should nominate the key_research questions then use the best methods available to answer them, rather than addressing the questions that are most easily answered or that lend themselves to the most rigorous science." They then identified ten key questions for reintroduction biology across four levels: population establishment, population persistence, meta-populations, and ecosystems. Recognising that reintroduction biology to that date mostly focused on population establishment, they sought to encourage research across a broader spectrum of concerns. Moreover, they expressed concern that the focus on population establishment reflected the relative ease of research at that level, rather than its actual importance for improving reintroduction outcomes. Therefore, they also recommended that reintroduction biology as an applied science should address *a priori* questions that capture uncertainty directly affecting management decisions. Whether those calls by Armstrong & Seddon (2008) and similar advocates of evidence-based reintroduction [23,24], including the IUCN Guidelines for Reintroductions and other Conservation

Translocations [25], are being heeded in the growing literature in this field remains to be ascertained.

Here, we evaluate whether the peer-reviewed published literature in reintroduction biology since its inception at a conference in 1993 and first publication in 1995 indicates an increasing effectiveness in supporting reintroduction practice. Accordingly, we seek to understand whether reintroduction studies have (1) broadened their scope beyond population establishment to support problems relating to population persistence, meta-populations, and ecosystems, (2) addressed defined *a priori* questions, and (3) whether these questions clearly provide the scientific evidence required to select a best management action.

The reintroduction literature

We queried the reintroduction literature using the Web of Science citation search engine (23 November 2016 using the University College London institutional login) and specifying the key words: reintroduc* OR re-introduc* Or translocat* in the title field and monitoring OR population modelling OR experiment OR trial OR planning in the topic field and in the research areas of 'Environmental Sciences Ecology', 'Biodiversity Conservation' and 'Zoology' from the years 1995 – 2016 inclusive. We also queried the IUCN Global Re-introduction Perspectives book series [26-30] and retrieved any extra peer-reviewed scientific articles cited within those case studies. We only included papers which studied vertebrates and excluded papers that were purely reviews. Our search identified 309 peer-reviewed scientific journal articles from Web of Science and an additional 52 peer-reviewed scientific journal articles from the IUCN publications. One author (GT) read each article fully and carefully evaluated against our criteria. To ensure reliability with categorisation, ten papers were first simultaneously judged between three of the authors (GT, SC & JGE) and were consistently categorised. Within the introduction we searched for statements of key questions, hypothesis and objectives and within the methods and results we searched whether or not the outcomes of more than one management action were tested. Although this is not a systematic review we believe it provides a detailed picture of reintroduction biology, with its known bias toward vertebrates [31].

Which level of questions did the paper address?

We found 61% (219/361) of papers addressed questions at the population establishment level, 32% (117/361) at the population persistence level, 4% (16/361) at the metapopulation level, and 3% (9/361) at the ecosystem level (Fig 1). These results mirror the findings in Armstrong & Seddon (2008) who stated that the majority of reintroduction research to that point had focussed on population establishment. Analysis of the temporal trends in our dataset confirmed the lack of a clear change. Between 1995 and 2016, establishment and metapopulation studies decreased and persistence and ecosystem studies increased (in particular, studies addressing persistence in terms of genetic makeup). Multinomial logistic regression confirmed this trend but suggested the yearly rate of change was small and not statistically significant (proportional yearly rate of change, expressed by mean exponentiated regression coefficients: establishment: -1.8%; persistence: 2.2%; metapopulation: -4.9%; ecosystem: 8.3%; $p>0.05$). Most importantly, the proportion of metapopulation- and ecosystem-level studies was still less than 5% by 2017 (Fig 1). Note that although papers will often implicitly look at multiple questions, for the purpose of this review we assigned articles to only one question level, based on what we deemed the primary focus of the study.

Is reintroduction literature question- and management-driven?

Armstrong and Seddon (2008) argued that "questions identified *a priori* will increase the amount of useful knowledge obtained from limited conservation funds." If research does not address clearly defined *a priori* questions, it risks being purely descriptive; if it does not directly address uncertainties that are relevant to management, it risks being irrelevant for practical decision making, regardless of its potential scientific interest. To determine the extent that reintroduction literature develops *a priori* management-driven questions, we carried out two analytical steps.

First, we categorised each publication as either clearly stating *a priori* questions or not (i.e. descriptive). Second, while developing questions *a priori* moves us closer to management-driven research, management decisions normally imply a choice between alternative actions [32,33]. Therefore, explicitly discriminating among those actions represents the best support that reintroduction science can provide to decision makers. We categorised each of the 361 reintroduction papers into one of three categories: (A) studies that directly compared the consequences of alternative management actions, either by *a priori* predictive modelling or *a posteriori* analysis of field data (including deliberate manipulation by experiment or adaptive management); (B) studies that analysed results under one management action and assessed them without reference to alternative actions; (C) studies that did not obviously identify or assess a management action, but published scientific information that was considered valuable for conservation.

We found an equal split between papers that clearly stated *a priori* questions 49% (176/361), and those that did not 51% (185/361) (Fig 2). Logistic regression suggested a marked increase over the study period: the mean probability that a published study addressed *a priori* questions increased from 24% in 1995 to over 64% in 2016 (Fig 2). Only one fifth of the reviewed articles (22%, 78/361) presented data comparing two or more management actions to directly support decision making, i.e. were in category A (Fig 3). The majority of research articles (74%, 270/361) were in category B, i.e analysed results of one management action and then made post-hoc recommendations about whether the action was suitable or not. The remaining few research articles (4%, 13/361) were in category C, making no explicit link between research and management. Multinomial logistic regression again confirmed these observed trends, with less than 1% relative yearly changes in all categories.

Is reintroduction biology supporting reintroduction practice?

Throughout its two-decade history, the science of reintroduction biology has repeatedly been encouraged to better support reintroduction practice [34-37,17-18]. The publication frequency of reintroduction-related studies continues to increase, making more and more scientific evidence available to support reintroduction practice. However, this is not in itself an indication of better application: reintroduction science will not improve simply by producing more data [17]. Rather, it requires both scientific learning through experiments, prediction and monitoring, and true integration into reintroduction practice, allowing managers to identify the actions that are most likely to achieve their objectives.

In this regard, our assessment shows that in spite of frequent calls, reintroduction biology is not reaching its full potential in providing the evidence base to support management decisions. For example, resource-demanding and technically challenging metapopulation and ecosystem studies continue to represent only a small proportion of the reintroduction literature. This practical complexity reinforces the need for clear *a priori* thinking; in this regard, it is encouraging to find an increasing proportion of studies focus on answering *a priori* hypotheses. However, whether this latter trend represents a specific improvement of reintroduction biology, or reflects the more general tendency to move away from descriptive studies, particularly in higher-profile peer-reviewed journals, cannot be discerned.

Perhaps the most important of our results is that over the last two decades there has been no appreciable increase in the proportion of studies that provide direct support for management decisions, by explicitly comparing alternative actions. In many such cases, managers and decision makers might be presented with evidence, but it is left to them to translate such information into a management decision. Only a fifth of the studies we reviewed directly compared two or more possible actions (or treatment groups), either through predictive modelling prior to any practical implementation, or from interpretation of data from field monitoring or deliberate manipulation as part of the reintroduction. This limitation is likely driven by practical constraints. Many reintroductions focus on highly endangered species, where the potential for learning is limited by small sample sizes and difficulties in replication. However, these limitations reinforce, rather than diminish, the need for a strong theoretical basis for recovery plans, and make the alternative trial-and-error approach even more risky [38]. Where active comparison of management actions via experiments is still considered too risky and learning is limited by other practical constraints such as small sample sizes, predictive modelling *a priori* and passive adaptive management [39] can still provide guidance. In general, explicit consideration of multiple actions, including “doing nothing” options, can make even studies that directly assess only one action more relevant for management.

To summarise our findings, some encouraging trends are visible in the reintroduction literature: more studies are explicitly addressing *a priori* hypotheses. However, reintroduction biology still has great scope to better support reintroduction practice: broader-scale metapopulation and ecosystem-level studies are still rare, and most importantly, few studies explicitly focus on assisting the choice among alternative management actions, which is the ultimate requirement of decision making. The key to filling this gap is currently represented by a small set of more recent studies that illustrate clearly how to embed conservation science into practice by developing clear *a priori* questions that are immediately relevant to management, explicitly comparing two or more management actions [23,40-43]. An example is given in Box 1. We acknowledge that each article in our review was treated equally, regardless of its scale and the number of institutions involved, and that our inferences might have been different to some extent if these factors were taken into account.

Changes still need to occur in *what* reintroduction biology researches (expanding to a broader range of questioning spanning establishment to ecosystems) and in *how* it responds to management needs (by directly embedding within decision making). By targeting uncertainties that are relevant for management, explicitly comparing the expected outcomes of alternative actions, and managing adaptively rather than by trial-and-error, reintroduction biology can best provide the scientific evidence needed to maximise the success of reintroduction practice.

Box 1 – The benefits of reintroducing ecosystem engineers back into the Australian environment for the management of wildfire [44]**.**

As in other parts of the world, wildfires are a natural occurrence in the Australian environment and have shaped the life-history traits of floral and faunal communities [45]. In Australia, burning has been used by indigenous peoples as a traditional ecological management tool for millennia; however uncontrolled wildfires are becoming more frequent and intense, causing enormous economic, social and environmental damage [44]. Australian terrestrial mammals such as the bilby (*Macrotis lagotis*), the numbat *(Myrmecobius fasciatus)*, the woylie *(Bettongia ogilbyi)* and the boodie *(Bettongia lesueur)* (Fig 4a) are considered ecosystem engineers as they alter leaf litter accumulation and breakdown. Australia has seen a dramatic decline in small terrestrial mammals, and the loss of these species, particularly fossorial species, has been hypothesised as altering wildfire behaviour through increased leaf litter accumulation. Leaf litter is a hugely combustible material that, when in abundance, can facilitate the spread and intensity of fire [44,46]. An experimental study by Hayward et al. (2016) aimed to determine whether this loss of ecosystem engineers did lead to an increase in leaf litter and therefore an increase in fire intensity and rate of spread. The study was conducted at three Australian Wildlife Conservancy restoration sites where previously extinct fossorial species had been reintroduced into large, exotic-predator-free fenced areas. At these sites, a pair-wise, fence-line comparison was replicated (where outside fence-line represented locations with no reintroduced species). The paired sites inside and outside the fenced areas otherwise had similar vegetation and fire regimes, and data were collected on animal digging pits, leaf litter accumulation and bare ground cover. The McArthur Mk5 Forest fire behaviour model which predicts the probability of a fire starting, rate of spread, and intensity, based on environmental parameters was also applied to these sites. Results showed a significant decrease (24% (95% CI 6–43) in leaf-litter mass inside the fenced areas (in the presence of reintroduced mammal ecosystem engineers) compared to outside (no reintroduced mammal ecosystem engineers) at all the three sites (Fig 4b). The fire-behaviour model also predicted that flame height would be much higher outside (1.41m) of the fenced areas compared to inside (0.37m) and that fire spread would be much faster outside fenced (0.18 km h^{-1}) areas compared to inside (0.12 km h^{-1}), equating to a 74% reduction in flame height and a 33% reduction in the rate of fire spread.

This is an example of an experimental study that explicitly tests the outcomes of more than one management alternative (reintroduction of native fossorial species or absence of these species) and answers an ecosystem-level question by highlighting the beneficial impact of these management actions on ecosystem function and restoration.

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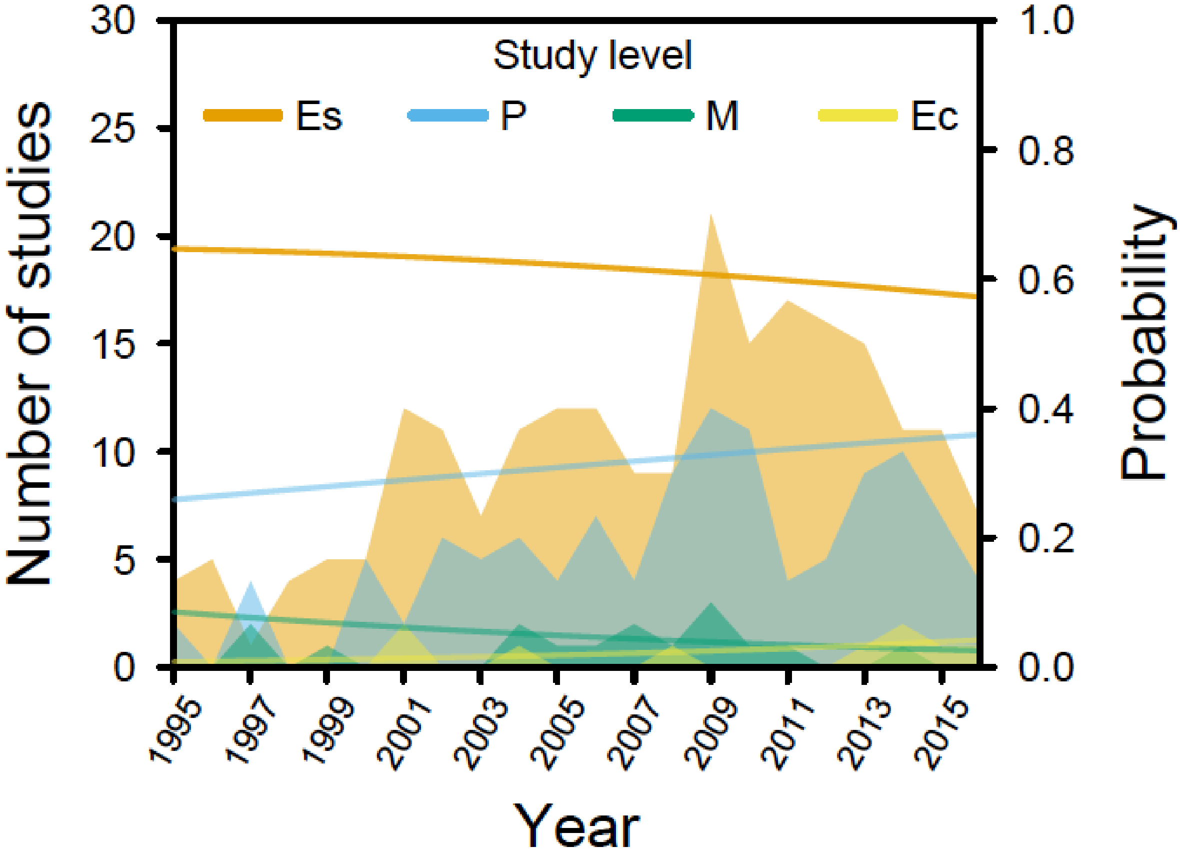
Figure captions

Figure 1. Temporal trend in the level of question addressed (Es=establishment, P=persistence, M=metapop, Ec=ecosystem). Shaded areas are the number of studies in each category each year. Lines are the mean probability of a study falling in each category in a given year, as predicted by multinomial logistic regression.

Figure 2. Temporal trend in the treatment of *a priori* hypotheses (yes/no). Shaded areas are the number of studies in each category each year. The solid line indicates the mean probability of a study addressing a priori hypotheses in a given year, as predicted by logistic regression (the shaded area indicates the 95% confidence interval).

Figure 3. Temporal trend in the level of comparison of management alternatives (explicit/implicit/none). Shaded areas are the number of studies in each category each year. Lines are the mean probability of a study falling in each category in a given year, as predicted by multinomial logistic regression.

Figure 4. (Panel a) Native Australian mammalian ecosystem engineers; (top left) The bilby (*Macrotis lagotis*), (top right) the numbat *(Myrmecobius fasciatus,* (bottom left) the woylie *(Bettongia ogilbyi)* and (bottom right) the boodie *(Bettongia lesueur)* are considered ecosystem engineers which have the potential to reduce fire intensity and spread due to the alteration of leaf litter accumulation and breakdown where these species (and others) are present (Panel b). Photo credits: Bilby and Boodie - Wayne Lawler/Australian Wildlife Conservancy, Numbat and Woylie - Rohan Clarke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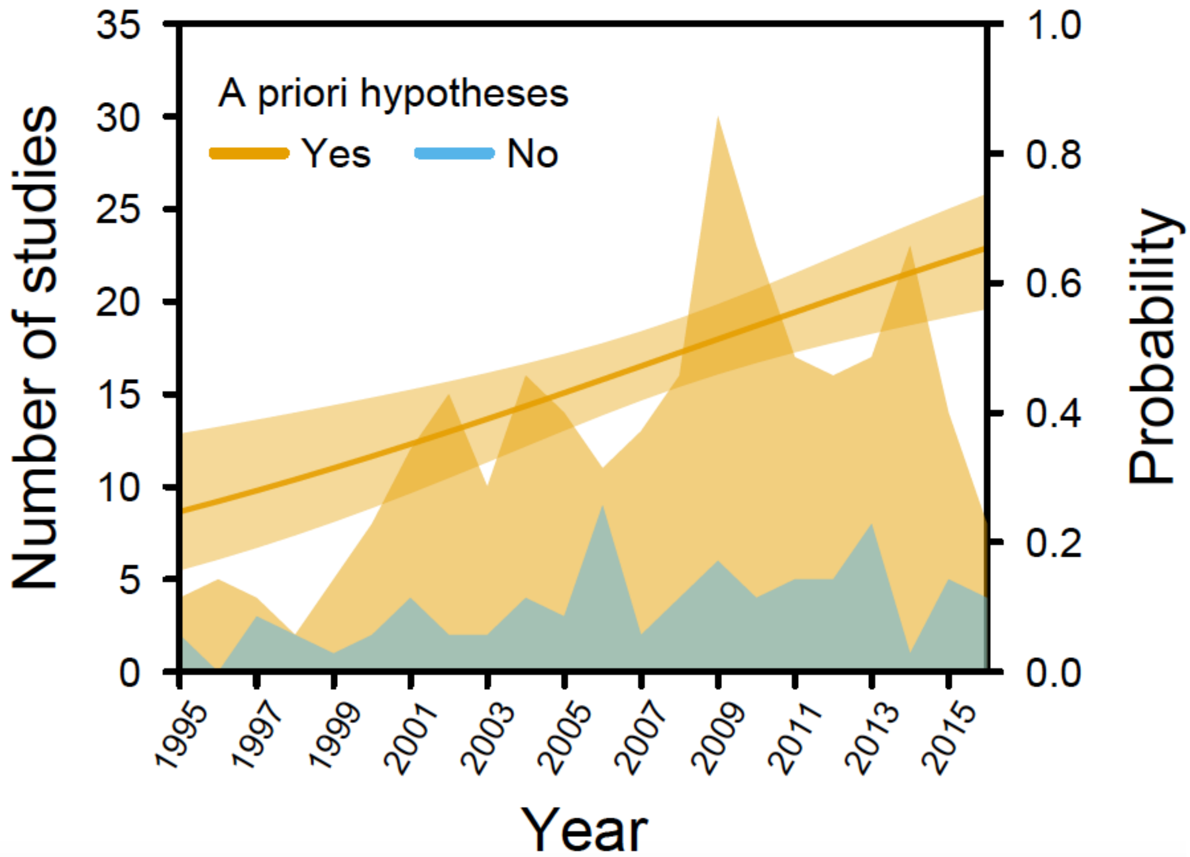
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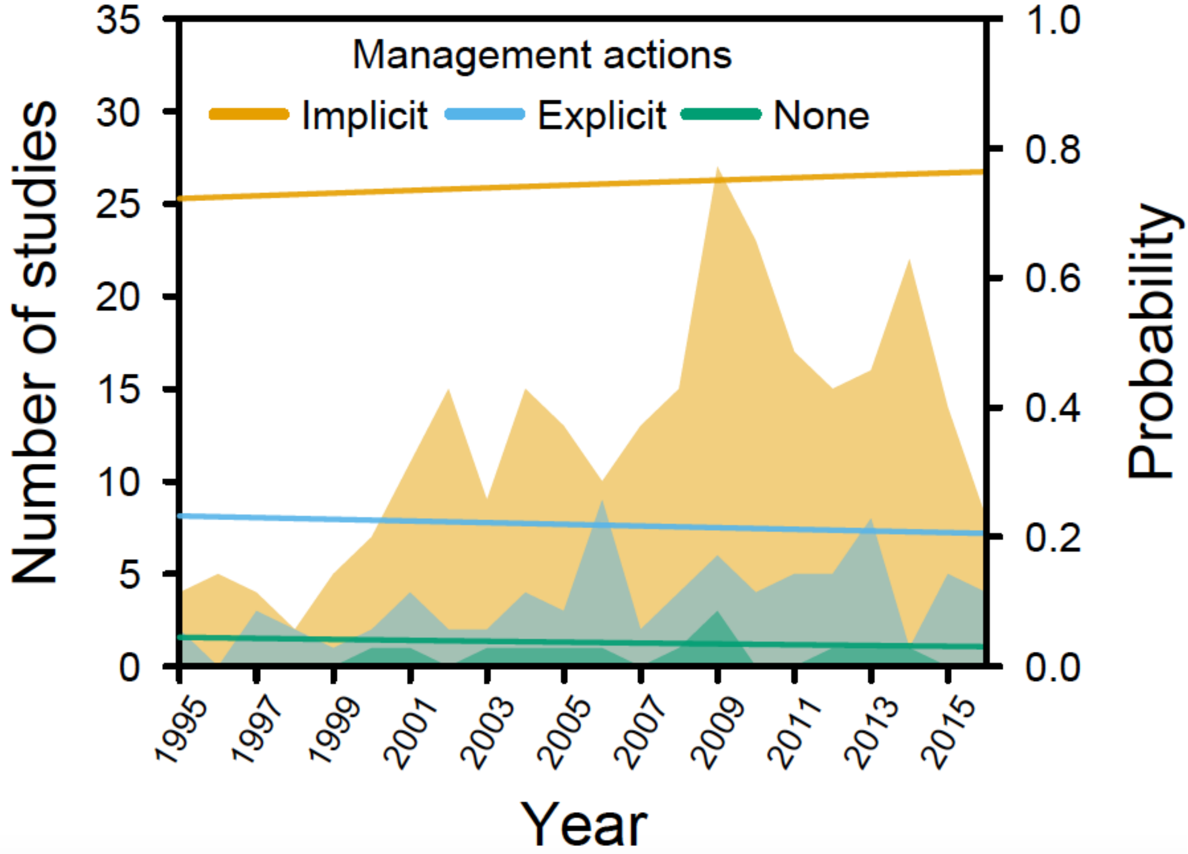
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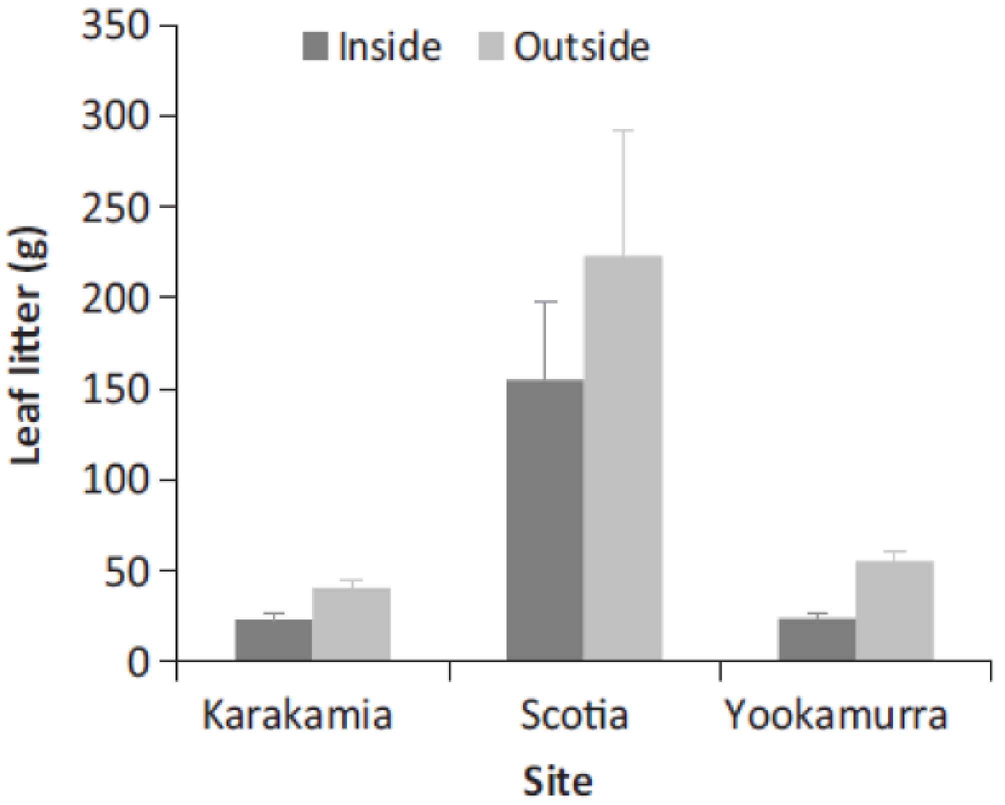
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