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How might science misdirect policy? Insights into the threats and consequences of invasive species

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Abstract Humans frequently introduce novel organisms (e.g., non-native species and, more recently, genetically modified organisms) into ecosystems for economic or biological purposes. However, prior to this, risk analysis is an inherent part of the decision about which species to release. In this contribution we draw upon our experience with non-native species to illustrate two ways in which science can potentially misdirect policy and management of novel organisms. The first involves scientific error, and the challenges in evaluating risk in complex systems. For example, predicting the ecological impact of an evolutionary novel organism on its proposed new ecosystem carries substantial uncertainty, which, depending on how it is explained or framed, can result in different policy outcomes. The second category involves potential biases amongst scientists. As a result of their training scientists may be inclined towards particular opinions that are not necessarily shared by the larger public. Moreover, differences in values also exist among scientists due to different cultures. Examples include a predisposition among scientists against non-native species which can result in an overstatement of perceived risks, as well as an under-appreciation of potential benefits. We illustrate how both scientific and epistemological error can result in sub-optimal policy. Scientists as experts can, and should, express their personal positions, but these should be clearly distinguished from scientific analyses.

Keywords Exotic species · Conservation · Biases · Policy

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1 Introduction

Non-native species represent a range of threats to native ecosystems and human well-being. They can provoke extinctions of native species, particularly on islands and in fresh water ecosystems (Mooney and Hobbs 2000; Sax and Gaines 2008), alter the functioning of native ecosystems, and may carry alien pathogens that can endanger native species and human health (Daszak et al. 2000; Vitousek et al. 1996). Moreover, by damaging important crops and interfering with industrial activities, non-native species are responsible for annual economic losses, in the order of $US billions in the USA (Pimentel et al. 2005). As a result, governmental agencies and non-governmental organizations are frequently mandated—or have chosen—to carry-out the difficult task of preventing their introduction and minimizing negative impacts and conducting risk assessment analyses of these species (Lodge et al. 2006).

Management efforts to control or eradicate non-native species after establishment are costly and because of this tend to focus on particularly damaging species. Importantly, non-native species that initially appear relatively benign can sometimes become invasive after years or even decades (Holt et al. 2005). As a result of such unpredictable outcomes, a common perception among biologists is that all non-native species are potentially invasive, and thus undesirable (Krajick 2005) in part because it is often economically or biologically impractical to eradicate non-native species once they have become firmly established. Of course, non-native species can also make up a large fraction of agriculturally important species (Ewel et al. 1999) and in some cases can even provide conservation benefits (Schlaepfer et al. 2011).

A biological feature that distinguishes non-native from native species is that the former have not co-evolved with other species in the recipient ecosystem (although they may have evolved with closely related species in their home range). As discussed below this may partly explain the propensity of some non-native species to become invasive. There is a parallel between non-native species and genetically modified organisms (GMOs) in that both are evolutionarily novel species. The objective of this paper is therefore to consider whether any lessons learned from the field of invasion biology might be applicable to risk evaluation, including the release of GMOs.

2 Assessing risk

A common definition of risk is the following:

$$\text{Risk} = \text{Exposure} \times \text{Hazard}.$$

In the context of biological invasions, a question that is asked before an intentional introduction is whether the introduced species could at some point become invasive. The risk assessment equation can thus be reformulated as the probability that an introduced organisms becomes established as a self-sustaining population, and that they have an "impact":

$$\begin{aligned}\text{Risk (Invasive)} \\ &= \text{Probability (Self-sustaining populations)} \\ &\quad \times \text{Undesirable Impact.}\end{aligned}$$

In discussing how risk can misdirect policy, it is necessary to focus on the two right-hand components of the risk assessment equation. First, there is the scientific challenge and uncertainties surrounding the evaluation of the probability of a species becoming established as a self-sustaining population and second, we discuss the challenges, and potential biases that science can bring, when estimating impact. Impact can consist of objective measures such as economic costs, but also subjective components such as aesthetics and personal values. Importantly, biases among scientists can also influence the type of investigation into evolutionarily novel organisms, which can in turn affect public perception of these species. We illustrate this point below by briefly reviewing how biases against non-native species have led scientists to focus on the negative consequences of non-native species, at the expense of their potential benefits. Finally, we speculate how these lessons can be applied to GMOs and potentially result in more objective risk evaluation for this socially contentious issue.

2.1 Assessing exposure

In the context of risk-assessment, "exposure" corresponds to the probability of a non-native species establishing a self-sustaining population. Scientists have used a variety of approaches to try and predict which species were likely to eventually become established in a new area and subsequently become invasive. One approach consists of contrasting invasive and non-invasive congeners and seek some behavioral or life-history characteristic that might help explain why one group becomes invasive. While some character traits may emerge as statistically significant from such analyses (high reproductive potential, high dispersal ability, neo-philia, etc.) they rarely provide sufficient predictive power to be useful. The limitations of this approach can be seen by considering *Rattus*, a genus of small mammals that contains three of the most invasive species in the world, the black rat *R. rattus*, the Norway rat *R. norvegicus*, and the Pacific rat, *R. exulans* (Pascal 2010). Yet the same genus contains more than 60 other species, many of which are locally distributed, endemic, and rare. Species that are already known to be problematic in some part of the world are statistically likely to become invasive in other parts. It is more difficult, however, to know which of the remaining species might suddenly and expectedly cause harm.

An alternative approach to predicting invasive potential has been to consider the evolutionary mismatches that can arise when two species encounter one another (Schlaepfer et al. 2005). Each organism has evolved traits adapted to its recent native environment. How such traits will affect the fitness of a native organism when it is confronted with a novel species or sudden change in environmental conditions may be the key to predicting how species will fare in the future. For example, the extraordinary proliferation of cane toads *Bufo marinus* after its intentional introduction into Australia may be due to the presence of its paratoid gland, which contains defensive bufo-toxins against potential predators. There are no native toads in Australia and native amphibians do not have paratoid glands or similar defensive toxins (Tyler 1994). Thus, cane toads carried with them an evolutionarily novel defense which few local predators could initially overcome (Crossland and Azevedo-Ramos 1999; Phillips et al. 2003). In the absence of predation pressure, resources that otherwise would have been dedicated to avoiding predators can instead be shunted into dispersal, growth, and reproduction.

An evolutionary perspective can also be instructive when assessing the susceptibility of entire ecosystems to non-native species. Indeed, scientists have been able to confirm empirically that certain biogeographic regions are more prone to invasions than others. Species encountered on islands, for example, have frequently evolved in the absence of vertebrate predators. As a result, such taxa are expected to be particularly vulnerable to the introduction of mammalian or reptilian predators. Indeed, there is widespread agreement that some of the best documented species extinctions caused by non-native species have occurred in insular habitats, such as islands and lakes islands (Davis 2009). For example, the introduction of the brown tree snake *Boiga irregularis* to the island of Guam has resulted in the extinction of several endemic species and sub-species of birds and reptiles from the island (Rodda et al. 1997).

One objective of this study is to investigate how agricultural practices can affect biodiversity (i.e., species richness) in agricultural landscapes. An evolutionary perspective may help to predict how native, non-target species can be affected by GMOs, such as modified plants that produce *Bacillus thuringensis* (*Bt*) toxins. Little theory or quantitative data exists to guide risk re GMOs and therefore it might be instructive to draw lessons from introduced non-native species, given the parallels between these two groups of organisms. *Bt* is toxic to invertebrates, and its primary purpose is to limit plant herbivory. Existing evidence suggests that GMO plants do not differ in any noticeable way from their non-modified counterparts, except for the introduced trait (see other chapters in this issue). One may speculate that non-target organisms, drawn to plant cues that normally correlate with adaptive outcomes (such as using the plant as a suitable oviposition site, herbivory, pollination) may also fall into the evolutionary trap that the altered plant now represents (Schlaepfer et al. 2002, 2005). Therefore, a better understanding of how preferences and decision-making rules evolve in response to novel situations will help predict the likelihood that target and non-target species learn to avoid *Bt* plants.

2.2 Assessing undesirable impact

The second component of risk assessment is to evaluate the effect of a non-native species. It has long been recognized that not only a small fraction of introduced species become established and have an effect that is considered harmful (Davis 2009; Williamson and Fitter 1996). In fact, many non-native species contribute to human economic well being, agricultural production (Ewel and Putz 2004) and can potentially contribute to conservation objectives (Rodriguez 2006; Schlaepfer et al. 2011). Clearly both the "positive" and "negative" effects must be integrated into any cost-benefit analyses when deciding whether and how to manage non-native species. Because of the subjective nature of this assessment, biases and misguided advice can easily slip into policy analysis and recommendation, with the potential consequences of misdirecting management or control efforts.

Several authors have argued that there persists a bias against non-native species among scientists (e.g., Davis 2009; Gurevitch and Padilla 2004; Stromberg et al. 2009). Such bias is reflected in the assumptions commonly made regarding intrinsic and instrumental values, the vernacular used when describing the species and in the types of studies conducted (Sagoff 2005). Prejudice can also be seen in examples where notions of change and harm are conflated. Changes in a population's distribution, behavior, ecological requirements or gene frequency are often assumed to be undesirable and this is reflected in the language chosen. Comments similar to the following are common in the literature:

> By flowing to other plant populations, genes from GMOs may contaminate the gene pools of nearby species.

> The introduction of GMOs threatens healthy ecosystems.

These sentences sound like scientific statements, but they are actually pseudo-scientific statements, a kind of hybrid language in which values are cloaked in scientific discourse. Contrast these two statements with the following more value-neutral versions:

> Genes from GMOs may flow to other crops.

> The introduction of GMOs may affect ecosystems.

The fact that changes will occur should not automatically be viewed as harm or departure from what is "natural", particularly if there are reasons to believe that such changes represent an adaptive response to changing selective pressures that will allow populations to persist without human assistance. Below is an example of the type of statement that is often made by scientists when arguing that harm is being produced.

> Our findings suggest Bt corn could possibly affect the composition and functions of soil microbial communities.

The appropriate scientific response to both these statements should be, "And, so what is the problem?" The possibility that Bt corn could possibly affect rhizosphere and soil communities is communicating almost nothing of value. The replacement by one species by another, or one genotype by another will, without question, cause some effects. The issue is not whether change will occur, because it always will, but whether we should consider that change as harm. One might also ask whether the changes are harmful beyond what might be expected as a consequence of normal agricultural practice. As we illustrate in the next section, such biases can potentially lead to misguided policy decisions.

3 A case study of how entrenched negative perceptions may have led to bad policy

Salt cedar (*Tamarix* spp.) is a non-native deciduous shrub that has become relatively common in riparian areas throughout the southwestern United States as a result of human-induced habitat disturbance and changes in hydrology (Stromberg et al. 2009). Initial reports suggested that salt-cedar trees were drawing down water tables and removing habitat for native riparian species, including the federally endangered southwestern willow flycatcher (*Empidonax traillii extimus*). As a result, millions of US dollars were spent controlling salt-cedar by mechanical removal, herbicides, and a bio-control agent (herbivorous beetle, *Diorabda elongata*) (DeLoach et al. 2006).

Scientists over the years have sustained a negative perception of Tamarix by, among other things, (1) citing outmoded sources; (2) inferring causation from correlative studies; (3) applying conclusions beyond the scope (domain) of the studies; and (4) emphasizing findings that present the species as an extreme or unnatural agent of change (Stromberg et al. 2009). A recent review, however, has suggested that many of the undesirable changes to the water table and displacement of native biota attributed to salt cedar were exaggerated or unfounded (Stromberg et al. 2009). As a result, an alternative interpretation, espoused by an increasing number of scientists, is that Tamarix is simply responding to human-induced changes to the ecosystems hydrology. By perpetuating an incorrect view that Tamarisk was a driver of change, scientists may have favored management options that were costly, environmentally harmful, and ineffective. Ironically, management plans to control or reduce Tamarisk may have permanently altered the ecological state of many riverbeds (e.g., soil compaction by vehicles involved in the mechanical removal of trees) which may hinder an eventual restoration to a more native-like ecosystem. More generally, it may be unwise to remove non-native species based on untested hypotheses (Hager and McCoy 1998) and before adequately considering the broader ecological and evolutionary consequences of such actions (Courchamp et al. 2003).

4 Summary

A fundamental challenge in managing evolutionarily novel organisms such as non-native species and GMOs is that risk assessment analyses must contend with both scientific uncertainty and social biases. With a few notable exceptions, it remains difficult to predict the ecological impact of these organisms. Furthermore, biases against or for certain groups of organisms may lead scientists to pursue questions that seek essentially to confirm preconceived notions about their impacts. Scientists, as experts, can, and should, express their personal positions, but that should be clearly distinguished from our scientific analyses.

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