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Finding a middle-ground: The native/non-native debate

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A B S T R A C T

Throughout the history of invasion biology, there has been long-standing and sometimes fierce debate on the perception and management of non-native species. Some argue that non-native species are universally undesirable for their unpredictability and their ability to at times dramatically disrupt native species and systems. Others argue for an approach that weighs a species' impact and role in a system before determining its desirability, irrespective of its identity. We suggest a middle-ground approach, one that does add extra caution about the desirability of non-native species relative to native species, but also bases perception and management decisions on the population stage of the non-native species and in relation to a wider range of conservation goals. In initial stages of introduction and establishment, we argue that a cautious approach is most prudent, one assuming the potential dangers of the new species in systems. In later stages of established populations, we argue that impact assessments will provide the soundest and more efficient management information, with origin and other available data included as part of the subsequent decision-making process. We explore and expand on these suggestions, and hope that the perspective presented respectfully contributes to finding a common ground in a long and polarized debate.

1. Introduction

Polarized debate is a feature of many major environmental issues. While properly informed debate is healthy, it should eventually lead to a new understanding or synthesis that provides a way forward. In this paper, we consider recent debate surrounding the focus on non-native species in conservation and management. We suggest the need for a middle-ground that recognizes the merit in both sides of the argument and prompts focus on the management implications of this recognition.

Perhaps no issue in conservation spawns as much emotional debate as the issue of managing non-native species. Depending on the context and perspective, non-native species may be villains, heroes, victims, or organisms just trying to survive. While invasive species management became a central conservation concern in the 1980s, there have been vigorous debates about the status and naming of non-native species starting in the late 19th century (see Coates, 2006). Those who defend the removal of non-native species have been accused of xenophobia and those who are more ambivalent are charged with biological homogenization. Both sides have merit. Gould (1998) articulated well how native species are really just species that arrived first, rather than species shaped by evolution to be the "best conceivable" for any particular place. Various other biologists and humanities scholars highlight the potential fallibility of a management logic based on claims to essentialism and authenticity (Warren, 2007). Meanwhile, non-native species often decrease biodiversity and alter ecosystem function in remarkable ways (e.g. Mooney and Hobbs, 2000). And while the vast majority of non-native species will not have major effects on ecosystem structure and function (Williamson, 1996) it is difficult to determine when, where and which species are going to be problematic, leading many to err on the side of precaution.

The most recent iteration of debate was sparked in July, 2011 in *Nature* Magazine (Davis et al., 2011; Simberloff, 2011a), and continued for months in various global discussion groups (i.e. EcoLog). Here Mark Davis and co-authors appealed against the native-versus-alien dichotomy exercised in much of the current conservation work. They argued that in a world of extreme change and novelty, it is more practical to shift focus from species origin to the effects species have on "biodiversity, human health, ecological services and economies." In a letter of response also published in Nature and signed by 141 prominent scientists, Simberloff (2011a,b) claims that Davis and co-authors have raised a straw man because land mangers only focus on problematic non-native

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species anyway, and that origin is a key indicator of species that are most likely to cause trouble.

Invasion biology has shifted its rhetoric in recent years to reflect a focus on species with the greatest impact (Pyšek et al., 2008). However, how much of this shift reflects a change in attitude toward non-native species, rather than just limited resources and political appeal, is unclear. This point sits at the center of much recent controversy. Without resource and methodological constraints, many, if not most, conservationists would still probably prefer to rid systems entirely of non-natives regardless of impact. Young and Larson (2011) found that while most invasion biologists do not demonize non-native species, more agree than disagree with the statement that "exotics are an unnatural, undesirable component of the biota and environment". Recognizing that this attitude toward non-native species exists and is widespread within the field helps contextualize Davis et al. (2011) and others.

In this paper, we attempt to find a middle ground in the native/non-native debate. We first highlight different non-native species management stances and their fundamental conservation goals, and explore management options with respect to these goals. Second, we present a framework that incorporates different approaches for new occurrences and introductions of non-native species versus established non-native and invasive species populations.

2. Management and research perspectives

2.1. The native/non-native dichotomy

Though most famously articulated by Elton (1958), the native/non-native distinction predates his oft-cited work. Chew and Hamilton (2011) trace the separation of 'native' and 'alien' species to Hewitt (H.C.) Watson in the early 19th century. Watson did not extend his definition into value judgments or conservation concerns; it took until the early twentieth century with Elton and his colleagues for the dichotomy to fully develop. The driving idea is that non-native species in a system – species whose presence in a region is attributable to human actions that enabled them to overcome fundamental biogeographical barriers (Richardson et al., 2011) – pose either a currently realized or a potential future threat to the native system and are therefore undesirable. The fear of future threat is based on examples in which non-native species appear benign or beneficial and have been managed accordingly, only to be found to have delayed or misunderstood negative impacts. In Germany, 51% of the 184 woody weed species took more than 200 years to become invasive (Kowarik, 1995).

Decades of accumulated anecdotes to this end have led to a conservative view among many ecologists, where the assumption is guilty until proven innocent (Ruesink et al., 1995; Simberloff, 2005). Most invasion biologists in the Young and Larson survey (2011) classified non-native species as inherently undesirable in natural systems. The common management application of this viewpoint is the removal of non-native species wherever possible and the absolute exclusion of non-native species in restoration and conservation practice. In California, for example, recent efforts have been made to remove non-native *Eucalyptus* trees. In some instances, *Eucalyptus* removal is based on efforts to manage local fire risk caused by trees that are known to be more-fire prone than native species (Simberloff, 2011b). However, in some cases, such as the Arastradero Perserve, CA, the girdling of a single, old mature tree with high cultural value, seemed to many to serve little purpose beyond removing a non-native tree species and caused much antipathy toward conservation aims (Dremann, 2004) Similarly, in the West Australian city of Perth, enhancement plans for a popular urban park included a proposition to cut down a group of innocuous non-native plane trees (*Plantanus* sp.) despite the local community's attachment to them. The proposal would have removed key sources of shade in the park and replaced them with native species known to potentially cause hayfever and allergic reactions (Trigger and Head, 2010).

Chew and Hamilton (2011) offer an interesting example of origin-based decision-making in an occurrence in Britain. Pool frogs, *Pelophylax lessonae*, are a common species across all of Europe thought to be descendent from a single Central European animal introduced to Britain in the 1800s. Genetic testing in 2005 found that a subspecies of the pool frog was descendent from Scandinavia, and was thus 'native' to Britain, not Central Europe. This subspecies, despite being ecologically interchangeable, morphologically similar, and able to freely interbreed with other (Central European) subspecies common to Britain, was given legal protection and released throughout regions of Britain in an effort to build its population. The logic behind decisions such as these demonstrates the assignment of an inherent value given to the native status of a species.

2.2. Questioning the dichotomy

An increasing number of scientists and practitioners are questioning the strict native/non-native dichotomy as a basis for management decisions. Proponents of this perspective emphasize the complexities of defining 'native' versus 'non-native', highlighting that often the definitions are purely a matter of temporal or spatial scale. This 'relativity' of native or non-native status has led some to suggest that there is a lack of scientific support for separating species based on their origin (e.g. Gould, 1998; Head, 2011), and thus it should be abandoned in favor of a purely impact-based determination of species control in a natural system (e.g. Brown and Sax, 2004; Warren, 2007; Chew and Hamilton, 2011).

A more contentious perspective goes further to highlight the desirability of some non-native species in systems to promote their active use in conservation and restoration planning. As some conservationists have shifted their focus from native biodiversity and historical fidelity, a higher emphasis has been placed on other ecological values such as biodiversity, ecosystem function, and resilience. Thus, the origin of a species is less relevant than its contribution to these values. This perspective stems from emerging examples of non-native species performing beneficial roles in novel communities, such as habitat provision (e.g. trees for bird species, such as pine in Australia for the endangered Carnaby's cockatoo (Valentine and Stock, 2008)), functional provision (e.g. native plant pollinators, such as non-native birds in Hawaii (Cox, 1983)), and nursing effects during succession (Lugo, 2004).

3. A suggested middle-ground

Most scientists and practitioners in conservation and restoration have opinions that fall between the two extreme perceptions of non-native species. Often for pragmatic reasons and/or due to resource constraints, managers have long tolerated the persistence of low-impact non-native species. Many scientists have also adopted this approach. As Simberloff (2011a,b) points out, "... most conservation biologists and ecologists do not oppose non-native species per se – only those targeted ... as threatening ecosystems, habitats or species". Similarly, Richardson et al. (2008) states that 'xenophobes' in invasion biology are on the fringe of the conservation movement, and that most invasion ecologists see the native/non-native classification as a continuum rather than absolute poles.

The extreme perspectives detailed above offer blanket generalizations about how to perceive and manage non-native species.

We, and many before us, argue that a single-perspective framework on the value of non-native species is a poor fit for the complexities of ecosystem management. We propose that considering different approaches at different stages of non-native species establishment may provide a formal middle-ground approach to the native/non-native debate. The stages of invasion have been schematized in many ways, most recently by Blackburn et al. (2011), and here we generalize these stages to represent the corresponding stages of non-native arrival, establishment, and spread (Fig. 1). Fundamentally different considerations come into play depending on whether a non-native species is in the transport or introduction phases versus whether it is in the establishment or spread phases.

In the initial phases of a new introduction, we suggest that decisions to exclude species based on their non-native status are wise given the unpredictability of species' behavior (Mack et al., 2000; Pyšek and Richardson, 2010). For already-established non-native populations, we argue that management decisions based on impact become more relevant and useful. Though origin can inform decision-making at this stage (as discussed later), weighing the benefits and drawbacks of controlling an individual species based on its impacts to a system relative to a range of conservation goals may lead to more effective and efficient management. This framework is in line with many strategic management plans (van Wilgen et al., 2011) and weed risk assessments that have long offered practical approaches to targeting non-native species (e.g. McGregor et al., 2011; Hulme, 2012).

3.1. Managing for transport and introduction

Given that many non-native species can and have become problematic, it seems prudent to predominantly rely on origin as a judgment tool in the case of unintentional introductions. In the Americas, non-native pests from Eurasia have inflicted billions of dollars of agricultural impact throughout the last two centuries (Coates, 2006). Foundational species such as the American chestnut have been nearly wiped out by a non-native fungal pathogen (Griffin, 2000). Waterways have been choked by non-native aquatic plants and invertebrates (e.g. Canadian water weed – *Elodea canadensis* – in the Thames River, though interestingly this has since become a relatively low-density population of non-noxious non-native species (Walker, 1912)). The enormous consequences that can result from the arrival, establishment, and spread of non-native species across geographical barriers have led to policies that aim to strictly control species entry points and rapidly respond to new detections; if applied effectively, these are likely some of the soundest policies to preserve conservation goals against further global species exchange. Many have pointed out that controlling arrival is the only way to prevent further issues with invasion, but that given entry by a new species, early detection and rapid eradication response are the most powerful tools at our disposal (Pyšek and Richardson, 2010). These policies should continue to be explicitly applied and strengthened for both inadvertent and deliberate introductions, including those for horticultural and land management purposes. An extension of this point-of-entry policy is manager response to the new appearance of a species within a reserve or locality. Populations of non-native species may be present on a large scale but not on the local scale. The general cautious response of removal or local eradication is still valid, particularly if a species has known invasive or noxious behavior in other localities.

However, decisions to locally control new species may be more complicated if the native status of a species is less clear. Much literature debating the definition of 'native' exists (e.g. Webb, 1985; Gould, 1998; Warren, 2007) and highlights that it is often a matter of temporal or spatial scale. For instance, a species can be native to a country, but not found in an individual region of that country. This becomes particularly important under the current reality of a rapidly changing global environment. It is well established that species migrate in response to changing climate and environmental conditions. Prevention of species movement through eradication of new propagules may potentially reduce the resilience of a species by reducing its capacity to respond to environmental change through migration and colonization (Walther et al., 2009). Additionally, overall resilience of a system to changing conditions may be impacted by preventing natural shifts in

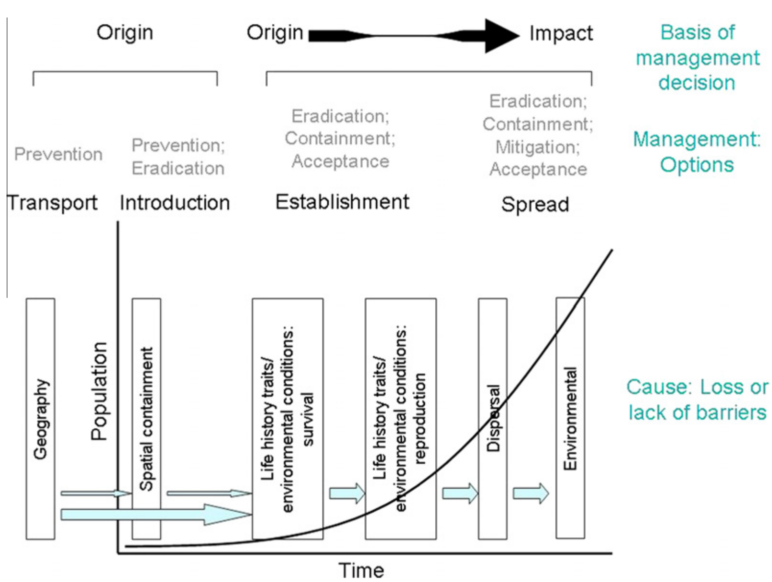

Fig. 1. Non-native species population density by time. Overlaying the graph are the categories of barriers to establishment and spread as delineated by population stage. For instance, to move from the establishment phase to the spread phase, a species must have life history traits that are able to overcome potential barriers to survival and reproduction caused by conditions in the new range. Management is advised by origin, impact, or a balance of the two dependent upon population stage and can include prevention (thwarting the occurrence of a species), eradication (extirpation of a species population within a management unit), containment (restriction of increase or spread of a species population), mitigation (reduction of a species population or offsetting population impacts), or acceptance (allowing or fostering persistence of a species population). Figure adapted from the invasion stages of Blackburn et al. (2011).

composition that occur through species colonization and spread (Harris et al., 2006; Millar et al., 2007). When assessing new arrivals, contextualization of the species' origin within multiple scales – temporal and spatial – can contribute to a better management response. For instance, recent attempts to map 'projected dispersal envelopes' based on biogeography and niche theory help define the regions where a species could be considered native under changing environmental conditions, irrespective of human involvement (Webber and Scott, 2011). The further development of this and other tools could help clarify some of the definitional confusion around native status.

Recently, questions on the value of new deliberate introductions have arisen from long-term considerations of environmental change and impacts to species and systems (Ewel et al., 1999). The introduction of species that deliver valuable services has been an important option throughout human land-management history. These questions are particularly important in a restoration context. Increasingly prevailing assumptions are being questioned and debate is ensuing about how best to restore an ecosystem that will be able to persist in the coming decades in the face of inevitable climate change (Broadhurst et al., 2008; McClanahan et al., 2008). Some argue that it remains prudent to prioritize local species and provenances, while others argue that it is better to either pick species on the basis of expected climate change, or to hedge bets and plant a variety of populations or species from different climate conditions to increase the chance that some will thrive in conditions of rapid change and uncertainty (Heller and Zavaleta, 2009). Individual species might also require intervention to survive climate shifts, particularly in highly fragmented landscapes; the merits and risks of assisted migration of species outside of their historical range is an ongoing topic of discussion in conservation (Ricciardi and Simberloff, 2009; Hewitt et al., 2011). These deliberate introductions are potentially pivotal in maintaining viable species populations against rapidly changing conditions, but there is large uncertainty in our ability to quantify and compare the benefits and harms of such management action.

Research for the deliberate introduction of species for other conservation or restoration purposes would have to be extensive and explore a range of scenarios, both likely and seemingly unlikely. As Ricciardi and Simberloff (2009) point out in their arguments against assisted migration, "contingency is the largest impediment to prediction". Genetic adaptation can increase the chance of invasiveness, shifting conditions can suddenly and dramatically favor a novel species, crossbreeding can dilute native species gene pools and result in new invasive hybrids, and synergistic relationships can cause unexpected indirect impacts. To deliberately introduce a species with any confidence in knowing its likely impacts, it is prudent to suggest that the justification of benefits should be great, alternative native species are considered, and the risk-analyses must be able to at least project a variety of scenarios that capture the complexity of the ecological context. Further research into sophisticated, yet widely applicable, techniques might be the pivotal development towards conserving many species and systems under rapidly changing conditions.

3.2. Managing for establishment and spread

There is a range of cultural and ecological reasons for considering established species separately, with origin becoming a relatively less important informer of management decision-making. An established species has had time to become embedded into the ecosystem and potentially more populous. Its removal may lead to unanticipated and undesirable impacts (Zavaleta et al., 2001), or involve more direct killing or use of toxic chemicals, a strategy that is alarming to some stakeholders and may have its own environmental impacts. Finally, an established population has had more time to become relevant to people's sense of place or to provide other cultural services that need to be considered in evaluation of the costs and benefits an invasive population.

Thus, criteria for choosing a species management option post-establishment (eradicating, controlling, containing, accepting, or even encouraging a particular population) should be more impact focused. It is widely acknowledged that the impact of a species will often be complex and include multiple ecological, cultural, and/or economic components (Andersen et al., 2004). Once a species is imbedded in a system, contextualizing management decisions within these components of impact, rather than focusing on whether the species is native or non-native, is important to form effective control strategies.

Here, we focus on the ecological aspects of impact by reviewing potential non-native species impacts to the ecological dimensions of biodiversity, ecosystem function, and resilience – three common goals in conservation and restoration projects (Society of Ecological Restoration International Science and Policy Working Group, 2004; Chapin et al., 2010a,b). For a discussion of more socio-cultural species impacts, see (Pejchar and Mooney, 2009). We emphasize that impact assessment must consider more than just the detrimental role the species may play. Non-native species often cause a range of negative, neutral, and positive impacts (Fig. 2). Though clear classification into any of these three categories is often difficult, the entire spectrum of impacts – defined within the appropriate spatial and temporal context – needs to be recognized for effective management. We address key considerations to understand impact 'to what' without explicitly outlining methodologies for measuring that impact (see Parker et al., 1999).

3.2.1. Understanding impacts to biodiversity

One of the most contentious debates about the negative effects of non-native species centers around their impact on native biodiversity (Davis, 2003; Gurevitch and Padilla, 2004). To address the question for an individual species or system, researchers and/or managers must clearly define the type of biodiversity of concern – richness (α: within site, β: between sites, or γ: over all sites) or some combination of abundance and richness captured in one of many diversity indices. Additionally, richness alone neglects to quantify impacts to abundance or distribution that might be critical in defining ecosystem biodiversity. Even those indices that measure both richness and relative abundances (e.g. Shannon-Weiner, Simpson, or Berger-Parker) do not capture all aspects of biodiversity concerns such as genetic diversity. There has been some work to develop reliable metrics to quantify the level and impacts of invasion (Catford et al., 2012), and these are a meaningful step towards establishing standard measurements of non-native species impact in a whole ecosystem context. One important consideration for continued development along these lines is the importance of uniqueness. Many parts of the world have high rates of local or regional endemism. If local or regional species diversity is maintained or increased after an invasion but at the cost of numbers or abundances of globally unique species and assemblages, then this is a net negative in overall conservation terms.

Though many impacts of non-native species on biodiversity have been shown to be negative (Vilà et al., 2011), there can be important biodiversity benefits of non-native species. Increasingly, there are observations that non-native species provide important resources, habitat or mutualisms for maintaining native species populations (Ewel and Putz, 2004), including listed threatened species (e.g. non-native honeysuckle as the preferred habitat of birds (Whelan and Dilger, 1992) and the invasive tree, tamarisk, as habitat for the threatened Southwestern Willow Flycatcher in the United States (Sogge et al., 2008). This is often the result of a decline in the abundance of native species that previously performed these supporting roles, and the cause of decline cannot always be

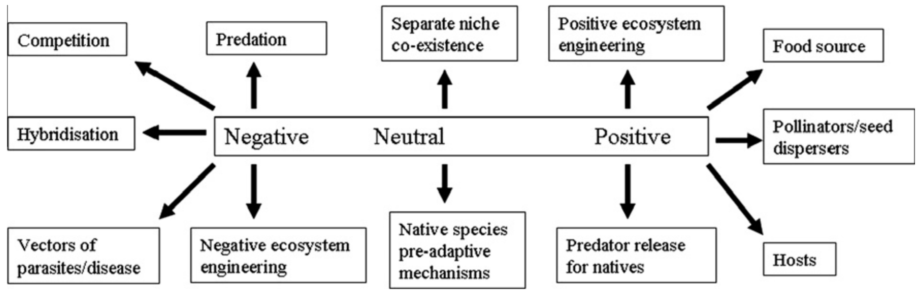

Fig. 2. Potential impacts of a non-native species on other species. Assigning these decisions involve both extensive knowledge of the impacted system as well as the assumption that impacts can be quantified into the three options shown. Adapted from Goodenough (2010).

attributed to the presence of non-native species. In cases where native species may depend on the presence of a new non-native, the simplistic solution of removing the non-native species may result in negative impacts.

3.2.2. Understanding impacts to ecosystem function

Ecosystem function is a synthetic framework for understanding the dynamic processes that occur in systems. Functions can encompass energy pathways (e.g. productivity, inter-trophic exchange rates, respiration, or decomposition rates), biotic–abiotic interactions (e.g. nutrient cycling, water cycling, or disturbance regimes), and biotic–biotic interactions (e.g. habitat provision, lowering invasibility, pollination). It is not an *a priori* truth that a non-native species population in a system will significantly alter existing function. If for instance, a non-native species replaces a native species that is functionally similar, such as the replacement of golden wattle by *Chrysanthemoides monilifera* in Australia (Weiss and Noble, 1984), overall ecosystem function will be maintained. On the other end of the spectrum, some individual species populations can play roles that fundamentally alter an entire system through one or multiple functional shifts (Crooks, 2002). These species are known as transformer species and are widely targeted for management and control because of the dramatic, often irreversible ecological changes resulting from their presence.

Most non-native species will subtly alter ecosystem functioning through the alteration of ecosystem processes such as nutrient and energy flows (Vitousek et al., 1987) or by altering system structure (Crooks, 2002). In many instances, multiple ecosystem functions are affected by a single non-native species. There are sometimes trade-offs, with one function potentially enhanced, and one degraded. In restored mine sites in the US Midwest, for instance, the overwhelmingly invasive non-native grasses provide good habitat for some bird species but due to their vegetative homogeneity, not others (Scott et al., 2002). Additionally, one single species may negatively alter functioning in one location, but neutrally or positively alter function in another. Spotted knapweed, considered responsible for poisoning plants and rerouting elk migrations is now being discussed for protection by the honeybee growers in Michigan and by butterfly conservationists in New York (Runk, 2011). There may be instances when different values and assessments will lead to eradication of a species in one location, control elsewhere, and tolerance in another, choices that are independent of the native/non-native distinction but rather dependent on the specifics of the landscape and its interaction with the non-native species. Because of the complexity of non-native species impacts, the ecosystem functions that are considered as key within the system of concern must be understood in order to quantify net impact. What is considered "key" is likely to be context-dependent and will vary among different elements of society. Hence, it may be hard to pin down: this is an often overlooked aspect of the entire debate on invasive species management.

3.2.3. Understanding impacts to resilience

Resilience is a complex term that has been defined in a number of ways throughout its 30+ years of use. If we use the most recent of these (e.g., Chapin et al. (2010a,b):

> "capacity of a social–ecological system to absorb a spectrum of shocks or perturbations and to sustain and develop its function, structure, identity and feedbacks as a result of recovery or reorganization in a new context."), origin of species can play multiple roles in this function. Non-native species have not evolved with the historical disturbance regime and may lower system resilience by being more susceptible to change than displaced native species: however, the converse can also be true. Additionally, some displaced species might play an important role in system recovery that is not filled by the non-native species.

Functionally dissimilar non-native species may become a force in the system that pushes it to a different state. Non-native grasses in woodland systems are well-known to interact with fire and ultimately lead to a state-change from woodland to grassland (D'Antonio et al., 1999). In instances such as these, the non-native species is both a driving force behind the disturbance as well as a force limiting the system's resilience to the disturbance. Once the state-change has occurred, the non-native species can function to increase the resilience of the new state. In the case mentioned above, the new grassland is difficult to restore to a woodland state because of the grasses' high resilience to further fire.

Conversely, the presence of some non-native species may increase a native system's resilience to disturbance and change. Many current disturbance regimes are not reflections of historical regimes. Altered fire regimes, clearing, grazing, and other human-induced disturbances have been introduced in many systems through the sustained interaction of humans with ecosystems. The impact of severe disturbance in Argentina has, for instance, been mediated by the presence of a non-native shrub, *Rosa rubiginosa*. It moves into highly degraded Argentine woodland systems and dramatically shortens recovery time by providing shelter to native seedlings from cattle grazing (De Pietri, 1992). Additionally, slow changes that are occurring globally such as climate change and atmospheric nutrient deposition are shifting the conditions in which systems must sustain their state and processes (Steffen, 2005). Non-native species that are adapted to these new changes may act to reinforce an ecosystem's structure, function, and processes against dramatic changes.

3.2.4. The continued utility of origin

The choice between using origin or impact as informative tools is not a one-or-the-other decision. We argue that it is more of a continuum, with origin playing a decreasing role as the non-native species becomes more embedded in the ecosystem. At more established stages, a fair assessment of the consequences of the non-native species can more adequately inform necessary management tactics such as control, mitigation, or acceptance. Still, knowing a species is non-native can guide impact assessment to some extent. The consequences of disjunctive evolution are that non-native species are more likely to be ecologically disruptive (Williamson and Fitter, 1996; Simberloff et al., 2011), an *a priori* understanding that encourages caution and careful monitoring not required for most native species. Additionally, the species behavior and traits in its native range can potentially predict behavior and traits in new ranges. Research has shown strong links between the geographic extent or abundance in the native range and the likelihood of a species becoming invasive in an introduced range (Goodwin et al., 1999).

Unpredictability of future behavior is a major factor limiting the adoption of impact assessment as the main or only guide in non-native species control. Experience has shown that despite our best efforts to understand impacts, even seemingly benign non-native species can swiftly and unexpectedly undergo population expansion that results in severe repercussions in the invaded system (Mack et al., 2000; Crooks, 2005). Therefore the benefits of a non-native species, though requiring quantification and consideration, may clearly need to be weighed against future detrimental effects arising after a lag phase. Here, origin can again be a potential guide as non-native species from climatically similar home ranges may potentially be assumed to have shorter lag times (Larkin, 2012). However, other considerations such as the potential for increasing propagule pressure may also determine the probability of a species experiencing a lag phase (Essl et al., 2012). Additionally, the relationship between non-native species populations and their impacts is an interactive process between the novel organism and the recipient system and is often inherently unpredictable and context-driven. Hence, there remain severe and inevitable limitations in our ability to predict the future and manage accordingly.

3.2.5. Further considerations in management decision-making

Beyond origin and impact, there are many considerations managers assess in the decision-making process. The impacts of the management action should be weighed against the impacts of the non-native species. Often control methods may themselves lead to ecosystem degradation: heavy use of chemicals may have adverse system impacts and thus undermine native species population survival, ecosystem function and resilience. Evidence of past impacts of pesticide and herbicide use is abundant, and chemicals such as the widely used glyphosate have been found to have long-term impacts on soil biota and chemistry (Araújo et al., 2003) while other herbicides that were touted to increase native plant diversity can reduce native diversity over the long-term (Rinella et al., 2009). Although modern chemicals are often considered less harmful and more specific, few are thoroughly field tested across a range of environments and the cumulative effects of multiple chemical applications is largely unknown. For example, recent findings show that systematic insecticides can lead to a dramatic loss of queens and can interfere in foragers' ability to navigate back to the hive (Stokstad, 2012). Additionally, increasing community disquiet with the heavy use of chemicals and toxins can place control programs at risk of discontinuation. For example in New Zealand, the poison 1080 is used extensively to control non-native mammal species, but is now the subject of an emotive popular campaign to stop its use (Winters, 2009). There is mounting evidence that the general public have very negative attitudes to the use of poisons and pesticides to control species (Bremner and Park, 2007).

In many cases, the probability of successful management may be unclear. Non-native species often respond positively to disturbance. If control methods cause continual disturbance, it may re-enforce non-native species propagation rather than diminish it. Similarly, removing a species without a clear plan for filling that niche often leaves a "weed-shaped hole" (Buckley et al., 2007). Sometimes what moves in and fills it can be worse. In the north and mid-west of the United States, efforts to remove knapweed often lead to a subsequent invasion by cheatgrass. Though both species are known to be conservation threats and poor forage material, cheatgrass is more flammable and has been shown to increase fire frequency in heavily invaded systems (Menakis et al., 2002).

Finally, management may be better served by focusing less on removal and more on ecological and evolutionary dynamics. At the moment, we often take snapshots of impacts and develop concomitant snapshot goals. However, when we look at longer timescales native species may be able to adapt to non-native species. In Puerto Rico, some abandoned pasture and coffee plantations initially fill in with non-native tree species. However, as the time since colonization increases, native species increase in importance, often out-competing the more shade-intolerant non-native species. The resulting mixed forest has been found to be equally resilient to hurricane damage as native forest (Lugo, 2004). A further example is the recent finding that some fauna species are adapting behaviorally or otherwise to the cane toad which is spreading across northern Australia. The poison secreted by the toad is lethal to many native species and has caused significant mortality, but in areas where toads have been common for some time, some native species numbers are increasing through either learned avoidance or rapid evolutionary responses (Shine, 2012).

4. Conclusion

In the past few decades, the language and understanding of ecology and conservation biology has moved from an almost exclusive focus on biodiversity, to a broader focus encompassing biodiversity, ecosystem function, and resilience. This distinction is important for understanding the issue of non-native species in light of conservation goals. From the perspective of traditional global conservation, the preservation of native biodiversity is the main driver behind management decisions. From the perspective of broader goals linked with managing complex socio-ecological systems, the maintenance of ecosystem function and resilience may shift management decisions in ways that require changes in procedures necessary to achieve biodiversity goals. Non-native species management decisions may involve similar trade-offs and complex considerations.

These trade-offs and complexities extend into socio-cultural issues (Richardson et al., 2008), with consideration of community interests and values, stakeholder goals, and economic constraints or repercussions playing just as large – or a larger – role in species control decision-making than ecological considerations. Often this can make impact assessments, decision criteria, and final decision-making difficult and value-charged. The challenge for modern invasion biology is to inform these management processes with relevant research. One avenue that needs further development is research into trade-offs: within ecological, conservation, and socio-cultural goals, and between them all. Additionally, further development of adaptive management techniques can offer a set of iterative decision-making tools. If properly implemented, many of the risks or uncertainties inherent in allowing non-native species to persist in a system or in removing them from a system in which they have been established long-term can be monitored and ameliorated through adaptive response of managers.

Young and Larson (2011) found that invasion biologists are relatively ambivalent about their advocacy role in policies. However, it is argued that environmental law is made powerful and legitimate by the science behind it (Tarlock, 1994), and there is some fear among scientists that their approaches and debates will have larger repercussions. Should scientists and managers begin to loosen their strict perspectives against invasive species, will regulatory agencies follow? Will they see it as an opportunity to reroute those resources, disregarding the careful consideration required to understand the long-term implications of allowing an invader to persist in an ecosystem? These questions highlight not that political fears should guide scientific direction, but that science should be carried out with careful planning, detail, and clear communication of findings, and that management applications should be cautious and closely follow scientific results. As noted by Gould (1998), "We have some ethical responsibility for the consequences of our actions." Current debate around the management of native and non-native species is essential for pragmatic application. However, finding a middle ground on which all sides of the debate can respectfully agree, rather than perpetuating the divisive debate on points of difference, is a vital process. We hope that this paper contributes to that process and that all sides will continue to reflect on new information and new context and its bearing on these questions.

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