
Nonindigenous Species: Ecological Explanation, Environmental Ethics, and Public Policy

DAVID M. LODGE* AND KRISTIN SHRADER-FRECHETTE†

*Department of Biological Sciences, University of Notre Dame, Notre Dame, IN 46556, U.S.A.,
email lodge.1@nd.edu

†Department of Philosophy, University of Notre Dame, Notre Dame, IN 46556, U.S.A.

Abstract: *The public is getting a mixed message from ecologists, other scholars, and journalists on the topic of nonindigenous species. Misunderstandings and tension exist regarding the science, values, environmental ethics, and public policy relevant to invasive species, which are the subset of nonindigenous species that cause economic or environmental damage. Although there is a natural background rate at which species invasions occur, it is much lower than the current human-induced rates at which species are being moved around the globe. Contrary to some recently voiced opinions, the fact that some species invasions occur without human assistance does not confer acceptability on all species invasions. Also, despite claims to the contrary, the reductions of native biodiversity caused by nonindigenous species are large and well documented. Even if that were not true, an emphasis on species numbers alone as a metric for the impact of nonindigenous species does not adequately incorporate the high value many humans place on the uniqueness of regional biota. Because regional biota are being homogenized by species invasions, it has become an appropriate and official public policy goal in the United States to reduce the harm done by invasive species. The goal is not, however, a reduction of numbers of nonindigenous species per se, as recently claimed by some authors, but a reduction in the damage caused by invasive species, including many sorts of environmental and economic damage. A major challenge remaining for ecology, environmental ethics, and public policy is therefore the development of widely applicable risk-assessment protocols that are acceptable to diverse constituencies. Despite apparent disagreements among scholars, little real disagreement exists about the occurrence, effects, or public-policy implications of nonindigenous species.*

Especies No Nativas: Explicación Ecológica, Ética Ambiental y Política Pública

Resumen: *El público está recibiendo un mensaje confuso de ecologistas, otros académicos y periodistas sobre el tema de especies no nativas. Existen malos entendidos y tensión en relación con la ciencia, los valores, la ética ambiental y las políticas públicas relevantes a las especies invasoras, que son un subconjunto de las especies no nativas que causan daños económicos o ambientales. Aunque existe una tasa natural a la que ocurren invasiones, es mucho más baja que las actuales tasas, inducidas por humanos, a las que especies son movidas alrededor del mundo. Al contrario de algunos autores recientes, el hecho de que algunas invasiones de especies ocurren sin asistencia humana no le confiere aceptabilidad moral sobre todas las invasiones de especies. También, a pesar de recientes afirmaciones de lo contrario, las reducciones de biodiversidad nativa debido a especies no nativas son notables y están bien documentadas. Aún si no fuera verdad, el énfasis sólo en el número de especies como una medida del impacto de especies no nativas no incorpora adecuadamente el alto valor que muchos humanos reconocen en la singularidad de la biota regional. Debido a que la biota regional está siendo homogeneizada por invasiones de especies, la reducción del daño causado por especies invasoras se ha convertido en una política pública apropiada y oficial en los Estados Unidos. Sin embargo, la meta no es la reducción de especies no nativas, en sí, como afirman algunos autores recientes, sino una reducción de los impactos dañinos de las especies invasoras, incluyendo muchos tipos de daño económico y ambiental. Por lo tanto, un reto mayor para la ecología, la ética ambiental y la política*

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pública es el desarrollo de protocolos de evaluación de riesgos ampliamente aplicables que sean aceptables para electores diversos. A pesar de aparentes desacuerdos entre académicos, existe poco desacuerdo real acerca de la ocurrencia, el impacto o las implicancias en política pública de las especies no nativas.

Introduction

Most ecologists and farmers need little convincing that many nonindigenous species cause major changes in ecosystems and crop production. Farmers and ranchers, for example, lose about \$13 billion per year to invasive plants, many of which are nonindigenous (Westbrooks 1998). To ecologists and others, nonindigenous species in general are also known as alien or exotic species—species that did not previously exist in a given region. Nonindigenous species that spread and cause ecological or economic harm are called weeds by farmers and invasive species by ecologists (for other definitions see Davis & Thompson 2000; Richardson et al. 2000). A recent, crude estimate of the annual cost imposed by invasive species on the United States is \$138 billion (Pimentel et al. 2000); because the study considered only a subset of invasive species and excluded many indirect and non-market costs, it is certainly an underestimate. It has thus become a shared goal of many constituencies in the United States and many other countries to reduce the occurrence and impact of invasive species (Mack et al. 2000; National Invasive Species Council 2001).

Considerable misunderstanding about this issue has been promulgated in the popular press, which tends to magnify misunderstandings (or differing emphases) among scholars. For example, a recent issue of the *New York Times* had an article entitled “Alien Species Often Fit in Fine, Some Scientists Contend” (Derr 2001), which followed by a few pages an article documenting the devastating impact on California forests of nonindigenous oak blight fungus (Woodson 2001). The public is getting a mixed message, and some ecologists have contributed to the confusion.

Confusion and tension about nonindigenous species is understandable because science, conflicting value systems, environmental ethics, and public policy have begun to intersect strongly on this issue. Value judgments are made about whether the invasive species-induced changes described by ecologists are good or bad. Sometimes value judgments are made and reported by scientists themselves, with no distinction made between the changes in the natural world that they have documented and the judgments they make about the acceptability of such changes. As citizens, scientists are just as entitled as anyone else to make such judgments, but not under the banner of scientific credibility. When ecologists or

others confuse normative judgments with descriptions of environmental change, the role of science in public policy development is compromised. Different people, of course, will make such judgments differently, or at least weigh them differently against competing goals. What is harm for one person may be good for another. The history of fisheries management, for example, is replete with examples of now-regretted species introductions and conflation of descriptions of fish stocks with judgments about how humans should manage fisheries (Rahel 1997). In general, the pathways that move species among biogeographic regions within continents and that transport species among continents are often associated with economic activity and trade globalization that benefit millions worldwide.

Thus, two strongly supported and often competing goals—increasing economic activity and protecting the environment from invasive species—should be balanced by public policy. Given the critical expertise that ecologists possess on the environmental impacts of invasive species, they must be more careful both in communicating scientific knowledge and in making clear when value judgments are passed on scientific results. Ecologists are in a unique position to contribute to risk analyses of nonindigenous species. But ecologists must recognize that such risk analyses will—and should—include values, inferences, and goals in addition to largely scientific claims about protecting ecosystems from invasive species.

Here we address some of the major sources of confusion surrounding nonindigenous species. We select topics that have been highlighted by recent technical and popular publications. The topics are ordered roughly from those that are more purely scientific to those that explicitly integrate scientific information into public policy. We hope our treatment of these topics will illuminate some of the central issues surrounding nonindigenous species and make clear that existing misunderstandings are tangential to the important public policy challenges about which there is little real disagreement among scientists and policymakers.

The Naturalness of Species Invasions

Flannery (2001:345–347) suggests that lions and elephants could be reintroduced into North America to re-

place those that disappeared 13,000 years ago. Ancient North American lions were apparently the same species that exist on the plains of Africa today. The elephants would replace the ecologically similar mammoths and mastodons that once were part of a speciose herbivorous megafauna. Without these herbivores, with which North American native plants co-evolved, some native plants can barely reproduce and cannot thrive (Barlow 2001). Turning away from those species that became extinct and instead thinking about species that arrived in North America, Flannery (2001:141) notes that "had the creosote bush arrived [from Argentina] last century rather than 10,000 years ago, it would doubtless be proclaimed the most noxious weed ever to have invaded North America."

The perspective that emerges from these and many other observations about the biogeographic history of life on Earth is that the supposed balance of nature is much more complicated than previously thought (Pickett et al. 1992) and that "... biological invasions are natural and, more important, necessary for the persistence of life" (Botkin 2001). Even if the arrival of humans was responsible for the extinction of the North American megafauna in the last few thousands of years, extinctions and invasions of biota characterized Earth long before humans existed (Flannery 2001). Even on the scale of years and decades, species ranges change (Lodge 1993). And as Botkin (2001) points out, invasions of new habitats allow the long-term persistence of species, as populations in old habitats are extirpated in the face of environmental change. Thus, it is true that species invasions are natural and that the very definition of "non-indigenous" sometimes hinges on what time frame is being considered.

However, at least three important qualifications must be added to any claims about the naturalness of species invasions or the time frames involved. The first qualification is scientific, the second a consideration of public policy, and the third ethical. First, although humans are, of course, as natural as any other species, in recent centuries human influence has increased far more dramatically than that of any other species. The human-induced rate not only of species extinction but also of species invasion has increased exponentially, in concert with the exponential growth of the human population over the last few hundred years. In addition, in more recent decades, global human travel and commerce have increased disproportionately relative to the increase in the sheer number of humans. Combined, these factors have produced burgeoning rates of nonindigenous species in every ecosystem that has been monitored (e.g., Cohen & Carlton 1998). Although species invasions are natural, both the rate of their occurrence and the distances traversed by species now exceed by orders of magnitude those of only a few hundred years ago (Cohen & Carlton 1998; Williamson 1996).

Second, rational disagreement exists about the temporal benchmarks for ecological conservation or restoration. The U.S. National Park Service's pre-European benchmark is not as "arbitrary" as Botkin (2001) suggests, however. The arrival of Europeans in North America marked an ecologically significant time of rapid increase in human population, travel, and commerce. It was the beginning of an enormous increase in the rate of arrival of nonindigenous species. Clearly, any such benchmarks would differ for other continents, and whether the National Park Service's benchmark is appropriate for other U.S. agencies and applications should be the topic of scientifically informed public-policy discussions.

Third, some writers, such as Sagoff (1999, 2000), presuppose that whatever is natural (e.g., species invasions) is morally acceptable, an example of the naturalistic fallacy (Moore 1951). This presupposition is obviously false, as murder, auto accidents, and species extinctions are all natural or normal, but clearly they are neither moral nor acceptable. Moore (1951) reasoned that what "is" the case never provides grounds for what "ought to be" the case: descriptive claims never provide sufficient grounds for normative claims. Yet Sagoff (2000) assumes that the undesirable effects of both native and invasive species are morally acceptable when he writes that "no one has shown that exotics are more likely than natives to be harmful" and when he claims that "native cousins [of exotics] . . . are as bad or worse." Even if Sagoff (2000) is right (as he surely is) that some native species are as harmful to human goals as some nonindigenous species, this fact does not provide grounds for condoning increased unevaluated introductions of nonindigenous species. Sagoff (2000) uses these statements to arrive at the illogical conclusion that it is ethically acceptable to allow invasive species to add to the harmful effects already caused by some natives. Instead, an ethically defensible conclusion is that both native species and nonindigenous species should be managed with respect to what is both humanly and ecologically desirable.

Overall, then, the fact that some biological invasions have occurred throughout the history of life does not mean that contemporary invasions are an inappropriate target for management. Rather, the dramatically accelerating rate of invasion in recent centuries and decades requires management toward explicitly articulated goals.

Effects of Nonindigenous Species

For both prehistorical periods (Wilson 1992; Flannery 2001) and recent periods (Mack et al. 2000; Sala et al. 2000), the dramatic effects of species invasions on other species and ecosystems are extremely well documented. Thus, Sagoff (2000) is wrong in asserting that little evidence exists for invasive species-caused extinctions of native species, as Simberloff and Strong (2000) point

out. Invasive species are at least partially responsible for the extinction or imperiled status of 49% of the extinct or imperiled species in the United States (Wilcove et al. 1998). Similar situations exist in ecosystems around the globe, with invasive species among the top five causes of loss of native biodiversity in every ecosystem that has been studied (Sala et al. 2000). In the lakes of the world, invasive species are perhaps the greatest cause of species extinctions (Lodge 2001). Many details remain to be learned about the effect of many individual invasions (Parker et al. 1999), but no reasonable doubt exists that invasive species cause both local and global losses of native biodiversity.

Some recent authors, including ecologist Michael Rosenzweig as quoted in the *New York Times* article already mentioned, have been interpreted as casting doubt on the impact of nonindigenous species on biodiversity. With an analysis based on species-area relationships, Rosenzweig (2001) argues convincingly that if all continents suddenly were united, the resulting extreme effects of invasive species would decrease global species diversity (species number). Two other aspects of the study by Rosenzweig (2001), though, have been interpreted in such a way as to dampen environmental concerns (Derr 2001). Rosenzweig (2001) writes that the invasion-caused decrease in global biodiversity would apply only in the "short term." By this he means that over the long term (assuming no other causes of biodiversity loss), evolution would again increase biodiversity on the "New Pangaea." He assumes that the past speciation rate would apply in the future and that the situation of decreased biodiversity would be corrected on a time scale measured in millions of years. For at least four reasons, we do not think this analysis is relevant to public policy concerns about invasive species.

First, self-correction on a scale of millions of years is not reassuring in the context of public policy made on a scale of years to decades. All of recorded history encompasses only a few thousand years. It is ethically suspect to suggest that the loss of biodiversity now should be accepted because it will be corrected later. That presupposes that the value of biodiversity in the short term is zero, an ethical argument that would not be accepted for the loss of anything else that people value—a child or property—even if the correction occurred within a person's lifetime.

Second, the inference about the gravity of the short-term harm of extinctions is incomplete. Not only is it presupposed that the value of biodiversity per se is zero, but it is also presupposed that the economic, aesthetic, and other environmental damages that would occur as a result of loss of species over the short term are inconsequential.

Third, the inference about short-term damage and long-term correction is premised on a scientifically doubtful promissory note: using species-area relationships to draw

precise conclusions about long-term species gains. Not only is such re-speciation doubtful because, as Rosenzweig (2001) acknowledges, there are many additional forces causing species extinctions worldwide, but the species-area relationship, applied hypothetically to a New Pangaea, may itself be too rough a generalization to be reliable in a real-world situation (Connor & McCoy 1979; Dunn & Loehle 1988; Barkman 1989; Shrader-Frechette & McCoy 1993). Thus, even on Rosenzweig's own terms, it is not obvious that evolution would lead to a recovery in biodiversity.

Fourth, the observation by Rosenzweig (2001) and Gido and Brown (1999) that local species diversity would increase on both short and long (evolutionary) time scales hinges on the definition of diversity. As defined by these studies, species diversity increases because both nonindigenous and native species are included in their sums of species, whereas in most environmentally oriented discussions, species diversity and biodiversity are used to refer to native species only. Another way to describe this effect, though, is biotic homogenization (McKinney & Lockwood 1999; Rahel 2000) the obliteration of regional differences in flora and fauna. A focus on total species diversity at the local scale, including nonindigenous species, ignores the basis of the fear of the Homogocene that is shared by many in society, not just environmentalists: the high value placed on the uniqueness of regional biota. There is no controversy among scientists that nonindigenous species cause extinctions of native species. But if the distinction between native and nonindigenous species diversity is not kept clear by ecologists, environmentalists, and journalists, confusion can easily arise in discussions of public policy, and the values held by different groups will not be appropriately considered.

The other aspect of the study by Rosenzweig (2001) that might easily be misrepresented is that, as Rosenzweig (2001) himself points out (but incompletely), biodiversity loss at the level of species is only one of the important effects of nonindigenous species that justifies alarm. Others include much larger reductions in the lower (genetic diversity) and higher (generic) levels of biodiversity, changes in ecosystem function, changes in the ecosystem services provided to humans, aesthetic changes to landscapes, direct damage to industries, damage to crops and forests, and the spread of diseases of humans, such as HIV and West Nile virus (e.g., Mack et al. 2000).

Value Judgments about Nonindigenous Species

Any characterization that any or all nonindigenous species are good or bad is a value judgment, not science (Rosenzweig 2001; Slobodkin 2001). Thus, the very definition of *invasive species* offered in the first paragraph of our es-

say—hinging as it does on “harm”—depends on value judgments, which is why so many misunderstandings have developed around nonindigenous species. The unavailability of such value judgments also reveals why development of policy for invasive species should depend on much more than scientific expertise.

Sagoff (2000), for example, clearly misunderstands U.S. Executive Order 13112 (www.invasivespecies.gov) to target all nonindigenous species for elimination (Simberloff & Strong 2000). As a result, Sagoff (2000) attacks a straw man. Instead, as the definitions in the executive order and recommendations in the U.S. National Invasive Species Management Plan (National Invasive Species Council 2001) make clear, the goal of the U.S. government is to reduce the impact of invasive species (including those species that are “likely” to cause harm), not all nonindigenous species. In deciding which nonindigenous species are invasive, value judgments from many societal constituencies are required.

It is clear that some nonindigenous species in North America fit the definition of invasive: they spread quickly and everybody recognizes their damage (e.g., Dutch Elm disease, cheatgrass [*Bromus tectorum*], gypsy moth [*Lymantria dispar*], West Nile virus). For a second group of species, the potential for spread and harm is uncertain; as a result, for example, no one is advocating in favor of the many unintentional species introductions in ballast water. For such species, prudence and even a weak form of the precautionary principle would dictate using cost constraints determined by society to help prevent their introduction. For yet a third group of species, such as nonindigenous salmon in areas of native salmon harvest, constituencies are divided. Some stand to gain economically from them or otherwise favor deliberate introductions, whereas other groups oppose them on economic or environmental grounds. In such cases, the same species is classified as invasive by one group and beneficial by another group. Sagoff (2000) discusses two such species, zebra mussels (*Dreissena polymorpha*) and kudzu (*Pueraria lobata*), but emphasizes effects that he sees as beneficial while downplaying or ignoring effects of both species that are unanimously seen as negative (e.g., pipe clogging and extirpation of native mussels by zebra mussels, overgrowth of trees and crops by kudzu). The challenge, then, as outlined in the National Invasive Species Council (2001) is to devise fair processes for adjudicating competing claims. The key question is whether, on balance, a nonindigenous species is likely to cause more harm than good to society (see section on Risk Analysis of Nonindigenous Species).

The value judgment by Sagoff (2000) that “. . . no one has shown that exotics are more likely than natives to be harmful” may be true, but it is not relevant to any discussion about preventing the introduction of invasive species. By definition, society already has the native spe-

cies, and thus it does not have the option of preventing their arrival. The public policy goal is and should be to prevent adding harmful species (National Invasive Species Council 2001).

Sagoff’s claim about the relative harm caused by native and nonindigenous species is also of dubious relevance to efforts at control or eradication of already established species. Neither the National Management Plan (National Invasive Species Council 2001) nor any of the proponents of aggressive response to invasive species is arguing against responses to harmful native species. Native species have been and are the frequent targets of farmers (native weed species), public health officials (native diseases), and wildlife managers (undesirable native species). Native species are often difficult targets for control, however, because they often have broad ranges and high levels of abundance. Otherwise, they are unlikely to be perceived as harmful. In contrast, rapid efforts at eradication or control are essential if the harmful effects of newly discovered invasive species are to be kept to a minimum. Thus, it is useful, at least in the public policy arena, to maintain a distinction between native species and nonindigenous species that spread quickly (cf. Davis et al. 2001). For invasive species, the stakes are higher than for most other forms of pollution because once a species is established and has begun to spread, the introduction is irreversible.

Risk Analysis of Nonindigenous Species

As suggested in the previous section, one of the greatest public policy challenges is the development of accurate, precise, generally applicable, and widely accepted risk-analysis protocols that are capable of distinguishing invasive species from the larger pool of nonindigenous species (National Invasive Species Council 2001). As even Sagoff (2000) argues, there are “. . . good reasons to try to keep out . . . organisms known to be dangerous.” But a focus only on those species *known* to be dangerous is too narrow, and raises an ethical issue critical to the development of risk-analysis protocols.

Sagoff (2000) errs in presupposing that a sufficient condition for the control of nonindigenous species—that the species is known to be dangerous—is also a necessary condition. This approach ignores the fact that other conditions, such as the likelihood that a nonindigenous species will cause serious environmental or economic damage, may also provide sufficient grounds for avoiding the introduction of that species. If there is no reasonable benefit likely to arise from an invading organism, then even if the organism is not known to be dangerous (because its effects are uncertain), it might not be reasonable to take the chance that its effects are benign. For example, if a potential food has no nutritional

or pleasurable value, then even if the food is not known to be dangerous (because its effects are uncertain), one would not eat the food, precisely because the effects are uncertain and there would be little reason to risk detrimental effects in the absence of benefits.

Sagoff (2000) makes another ethical error in assuming that what you don't know can't hurt you. He claims that "if exotic species typically damaged ecosystems, ecologists could readily distinguish between the ecosystems that had been invaded and harmed" and those that were not. In a previous section, we pointed to the abundant evidence (contrary to Sagoff) of the effects of nonindigenous species on native biodiversity and ecosystems (e.g., Mack et al. 2000; Sala et al. 2000). Nevertheless, we grant that the impact of nonindigenous species, even those that may be invasive, has often not been detected for many reasons. Three important reasons are that appropriate studies have not been attempted; that effects often develop over many years; and that it is often difficult to distinguish the effects of nonindigenous species from those of many other simultaneous, natural, and anthropogenic effects on ecosystems. Because of the difficulty in tracing a causal chain back to its origins, ecologists often do not know precisely which of several factors may have induced a given change. But their inability to trace a complex causal chain is not grounds for denying the causal chain. It is clear that some nonindigenous species are harmful and that what we don't know can hurt ecosystems, contrary to Sagoff's assumption.

The existence of ignorance and uncertainty poses a serious challenge to risk analysis of all sorts. For example, risk assessors know there are factors other than ionizing radiation that cause double-strand breaks in DNA. Just because they cannot distinguish radiation-induced DNA breaks from nonradiation-induced DNA breaks does not mean radiation has caused no breaks. Likewise, one often cannot easily determine what caused a particular cancer in a given case, so one must resort either to an empirically determined dose-response curve or a probabilistic model. Yet this failure to attain deterministic knowledge of cancer causation in an individual case provides no grounds for denying either that the cancer rate, statistically speaking, has been increasing or that various pollutants exhibit a statistical dose-response relationship. To assume otherwise would be to encourage further cancer deaths and to fall victim to the flawed assumption that whatever is not easily distinguishable does not exist.

Therefore, the inability to distinguish invasive species-induced damage to ecosystems from other causes of damage does not prove there is no damage induced by nonindigenous species. Rather, with both DNA and nonindigenous species, the difficulties of tracing the causal chains reveal that one may need statistical techniques or experiments to determine the probability of damage from one cause relative to that of another. The assump-

tion that only deterministic evidence of harm reveals a problem is erroneous and dangerous in both contexts.

Despite the continued existence of substantial uncertainty in predicting which nonindigenous species are likely to be invasive, ecologists are making rapid strides in developing statistical approaches appropriate for risk assessments (Groves et al. 2001). A meta-analysis has revealed that many recent statistical studies have identified characteristics of species and introduction events that correlate significantly with the success or failure of introductions (Kolar & Lodge 2001). For example, the probability of plant invasiveness correlates positively with vegetative reproduction and low variability in seed crop and negatively with seed size and length of the juvenile period. The probability of bird invasiveness correlates negatively with body mass and positively with migratory behavior (Kolar & Lodge 2001). Both qualitative assessments (e.g., Ricciardi & Rasmussen 1998) and quantitative assessments (e.g., Reichard & Hamilton 1997) of a variety of aquatic and terrestrial taxa are paving the way for screening mechanisms for prevention and control efforts that will reduce future harm to society by invasive species. Although the accuracy of some existing screening protocols is high, much scientific work remains to improve their precision (Smith et al. 1999) and to improve the metrics for making different sorts of benefit and harm (environmental and economic) commensurable so that competing claims can be adjudicated fairly in risk analysis (Shogren 2000).

Conclusion

The anthropogenic rate of species invasions far exceeds the natural background rate and is accelerating. No matter what the rate, the naturalness of invasions does not constitute an argument for their acceptability. The increase in nonindigenous species-induced rates of extinction of native species on both local and global scales is a fact. Furthermore, the rates of loss of genetic diversity and of generic diversity and the rates of increase in biotic homogenization are all higher than the species-extinction rates. Combined with the many other negative effects of invasive species, these facts constitute a strong rationale for better policies to decrease the occurrence and impact of invasive species. Although progress has been made toward risk-screening protocols that incorporate different values about the benefits and harm of species, many challenges remain for ecologists, environmental ethicists, and public policymakers. Little real disagreement exists about the scientific understanding of nonindigenous species. The major challenges lie in adjudicating among sometimes conflicting constituencies with respect to the benefits and harm of nonindigenous species, especially when these can be predicted only in probabilistic terms.

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