Journal of Agricultural and Environmental Ethics (2005) 18: 215–236
DOI 10.1007/s10806-005-1500-y

MARK SAGOFF

DO NON-NATIVE SPECIES THREATEN THE NATURAL ENVIRONMENT?

(Accepted in revised form October 31, 2004)

ABSTRACT. Conservation biologists and other environmentalists confront five obstacles in building support for regulatory policies that seek to exclude or remove introduced plants and other non-native species that threaten to harm natural areas or the natural environment. First, the concept of "harm to the natural environment" is nebulous and undefined. Second, ecologists cannot predict how introduced species will behave in natural ecosystems. If biologists cannot define "harm" or predict the behavior of introduced species, they must target all non-native species as potentially "harmful," an impossibly large regulatory task. Third, loss of species richness may constitute harm to an environment, but introduced organisms typically, generally, and significantly add to species richness in ecosystems. If species richness correlates with desirable ecosystem properties, moreover, such as stability and productivity, as some ecologists believe, then introduced organisms, by increasing species richness, would support those desirable properties. Fourth, one may plausibly argue that extinction constitutes environmental harm, but there is no evidence that non-native species, especially plants, are significant causes of extinction, except for predators in certain lakes and other small island-like environments. Fifth, while aesthetic, ethical, and spiritual values may provide a legitimate basis for invasive species policy, biologists often cite concepts such as "biodiversity" and ecosystem "health" or "integrity" to provide a scientific justification. To assert that non-native species threaten biodiversity or undermine ecosystem health, however, may be to draw conceptual entailments or consequences from definitions of "biodiversity" and "integrity" that arbitrarily exclude non-native species or make the presence of exotic species a *per se* indicator of decline.

KEY WORDS: Biodiversity, ecosystems, invasive species, plant breeding

Science writer Baskin (2002, p. 464) has described a "conflict between those who make a living introducing, growing, or selling exotic plants and the biologists and land managers who spend an increasing proportion of their time trying to keep a handful of these plants from advancing aggressively across natural areas." To address this conflict, members of the seed and nursery trades, conservationists, plant breeders, and others meeting in St. Louis in 2001 and in Chicago the next year issued the St. Louis Declaration on Invasive Plant Species (2001) and the Chicago Botanic Garden Invasive Species Policy (2002).

The St. Louis Declaration recognizes that "a small proportion of introduced plant species become invasive and cause unwanted impacts to natural systems and biological diversity..." The Chicago policy, citing purple loosestrife and Japanese honeysuckle as examples, stated, "Invasive plants... pose an enormous threat to our native plants, animals and ecosystems." Therefore, "When species are determined to present a risk of becoming invasive, they will be removed from the collection and destroyed."

1. HISTORICAL BACKGROUND

Since the early days of the Republic until recently, the introduction, cultivation, and domestication of exotic plants appeared to be an unmitigated good. Thomas Jefferson wrote in 1790, "The greatest service which can be rendered any country is to add a useful plant to its culture" (Glass, 1944). President John Quincy Adams established a national policy that held for more than 150 years. He declared, "The United States should facilitate the entry of plants of whatever nature whether useful as a food for man or the domestic animals, or for purposes connected with... any of the useful arts" (Hyland, 1977).

Since 1898, the US Department of Agriculture (USDA) has avidly supported the introduction of plants from around the world. Between 1900 and 1930, USDA sponsored more than 50 international expeditions to gather germplasm (Kloppenberg, 1998, p. 157). By 1933, the Department had brought more than 100,000 foreign plant species into the United States (Lemmon, 1968; Whittle, 1970; Healey, 1975; Hyland, 1977). In 1905, in response to Mendelian genetics, the secretary of the American Breeders Association wrote, "Never before was there apparent greater reason for pushing the work of plant introduction... This work must continue that we may have all the needed wild forms and all forms heretofore or henceforth improved in foreign lands" (quoted in Kloppenberg, 1998, p. 157).

With the passage of the Lacey Act in 1900, society enacted tough legislation to protect crops and other cultivated plants from threats posed by wild organisms that lurk in "nature" – for example, pathogens, pests, and predatory animals. The Lacy Act prohibits the importation of any "wild animal or bird" the Secretary of Agriculture considered a possible agricultural nuisance. Laws that followed, such as the Plant Pest Act, the Plant Quarantine Act, and the Noxious Weed Act, were similarly motivated by an attempt to police the boundary between the wild and the cultivated, between the natural and the domesticated. Enabled by legislation, governmental agencies and programs, such as the Centers for Disease Control (CDC) and the Animal and Plant Health Inspection Service (APHIS), detect, track, and combat naturally occurring pathogens and pests that damage or threaten to harm human health or agricultural production.

Historically, the policy goal has been to protect crops and other domesticated plants from threats posed by wild species, not to protect – as the St. Louis Declaration intends – wild species and natural areas from threats posed by cultivated and other introduced plants (Allen, 2001; Dowdell, 2002). As Baskin observes, the direction of the invasion has changed. Conservationists now emphasize the threat non-native plants and animals – including domesticated varieties – pose to wild or natural systems. "Horticultural professionals now recognize that some garden escapees can become pests" by invading natural environments (Baskin, 2002).

No statute instructs agencies to protect natural ecosystems from introduced plants. The legal basis for this policy is found in other documents. The Invasive Species Management Plan (National Invasive Species Council, 2001) seeks "to lessen the impact of invasive species on natural areas." It states, "The protection of agriculture has been, and continues to be, the primary focus of Federal efforts to prevent invasions of non-native species, but damage to natural areas is increasing in priority." Similarly, Presidential Executive Order 13112 (1999) instructs agencies to minimize the ecological impacts of non-native species. The Convention on Biological Diversity (Section 8h) requires steps to "Prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species" (GISP, 1999).

No one questions the urgency of protecting human safety and health from disease-causing organisms and other pests, native or exotic. No one doubts the importance of protecting domesticated environments – such as gardens and farms – from weeds and other pests that invade from the surrounding natural world. Everyone endorses the missions of agencies such as the CDC and APHIS to protect human health, agriculture, and other specific and well-defined economic interests from damage by pathogens, weeds, and other pests. Conservation biologists and other environmentalists, pointing out how costly invasive species can be to human health and agriculture, seek to build support for a different goal, i.e., to exclude and combat introduced species that may "become invasive and cause unwanted impacts to natural systems and biological diversity," again to quote the St. Louis Declaration.

Environmentalists have to overcome five obstacles to build public support for policies that target for exclusion or elimination non-native species that harm or threaten to harm the natural environment. First, the concept "harm to the natural environment" must be given a scientific and legal definition; otherwise, the values in question will depend on personal preference. Second, given the difficulty both of defining "harm" to natural systems and of predicting how an introduced species will behave in its new habitat, policy makers may have to target all non-native species as potentially harmful, an impossibly huge regulatory task. Third, if introduced species as a general rule decrease species richness, this may harm the ecosystems they colonize. Introduced species, however, generally increase – and only in exceptional cases decrease – species richness in natural ecosystems. Fourth, society plainly regards extinction as an instance of environmental harm; however, no evidence shows that non-native species, other than predators in tiny island-like ecosystems such as lakes, are more likely than native species or species in general to be significant factors in extinction. Finally, the belief that non-native species diminish biodiversity and impair ecosystem health or integrity should not rely on stipulative definitions, for example, on concepts of biodiversity that exclude non-native species or concepts of health that make their presence a *per se* indicator of environmental decline.

2. THE PROBLEM OF DEFINING "HARM TO THE ENVIRONMENT"

A fascinating and growing literature debates many ways to define "invasive" and cognate terms such as "native," "exotic," and "naturalized" species (Rejmanek et al., 2002). Richardson et al. (2000, p. 93) deplore the "confusion... concerning the terms 'naturalized' and 'invasive' and their associated concepts." Shrader-Frechette (2001) argues that as a result of this confusion, "ecologists debating various accounts of community structure and ecological explanation do not even make logical contact with each other." Colautti and MacIsaac (2004, p. 136) observe, "Problems with invasion terminology reflect a more general dilemma in ecology: the 'non-operational' or casual use of important terms and concepts." Carlton (2004) has said of the concept of ecological invasion, "It has utilitarian value for the three Ps, the public, the press, the politicians, the government world, and in that context, operates I think in a very powerful way. It's not a scientific concept at the moment and that's a caution for everyone."

This paper does not attempt to comment on the literature that grapples with the difficulty, perhaps the impossibility, of bringing a scientific consensus behind definitions of such elusive concepts as "invasive," "naturalized," "native," and "exotic." This essay instead asks whether, on any plausible understanding of these concepts, ecologists can (1) develop an operational and non-question-begging definition of "harm" to natural environments and (2) by using this definition of "harm," show that non-native species are more likely to cause harm than native species or than species selected at random. Ecosystems constantly change, of course, and non-native species are often responsible for many of those changes. The problem is to explain which of the many effects associated with non-native species are harmful and why.

According to a National Research Council (2002, p. 97) study, "There are few guidelines or widely accepted protocols for measuring the impact of an invader." Investigators (e.g., Parker et al., 1999) have listed the kinds of environmental effects that can be associated with introduced non-native species – genetic effects (exotic species may hybridize with natives and otherwise exert evolutionary pressures); population and community effects (exotic species may add to the number of species but decrease populations of native biodiversity); and ecosystem effects (exotic species often alter productivity, nutrient cycling, succession, etc.). What is needed is a concept of environmental harm that can be used to determine which of these changes – and therefore which of the species responsible for them – harm natural environments.

If one defines as "harm" any significant change a non-native species causes, the statement that non-native species harm ecosystems represents a tautology. Every significant change a non-native species causes would be defined as harmful – but what justifies that definition? To make a case against introduced species, scientists must rely not on *a priori* stipulation but on empirical evidence and argument. This might consist in a showing that in a random sample of ecosystems and given a non-question-begging definition of "harm," non-native species in fact are more harmful than native species or than species on average or in general.

It is not obvious that biologists can identify any trait of behavior or morphology that (1) distinguishes established non-native from native species in order (2) to explain why the non-native species could be more "harmful" in general than native ones. If one group of ecologists determines and lists on the basis of historical evidence in randomly selected environments those established species that are native and those that are not, a second group of biologists, by observing how these species look, behave, or relate to each other or to the environment, might not be able to tell which list is which. According to Davis and Thompson (2001), the attempt to discriminate between the traits of native and established non-native species has "proved to be a largely unrewarding enterprise." No biologist may be able to tell by examining living organisms in a place which are naive and which are not. "In the United Kingdom, about equal numbers of native and alien plants are expanding their ranges, and an analysis of their traits shows that these two groups are effectively indistinguishable" (Davis and Thompson, 2001).

One might suppose that "an organism introduced into a new region leaves behind its natural predators, competitors, and parasites, its chances of reproductive success increase'' relative to native species (Withgott, 2004). This Enemy Release Hypothesis (ERH) might distinguish native from non-native species. The hypothesis has been disconfirmed by both case studies and scientific tests. Clay (1995; see also Chew and Laubichler, 2003) found that non-native grasses in the United States have, on average, more pathogen species than co-occurring native grasses. Vermeij (1996) adds, ''Moreover, evidence from marine as well a terrestrial invasions implies that invaders quickly establish interactions with new hosts and parasites, which may impose new population controls and selective regimes on the invaders themselves.'' A recent literature review summarizes, ''community studies imply that non-indigenous species (NIS) are no less affected by enemies than native species in the invaded community'' (Colautti et al., 2004, p. 721).

One can look for places – Guam is often cited – in which an introduced predator has decreased local biodiversity. Sites selected on neutral grounds or at random – and thus that support a scientific argument – reveal on the contrary positive relationships between native and exotic species richness (Londsdale, 1999; Stohlgren et al., 1999; Levine, 2000). According to Houlahan and Findlay (2004, p. 1132), in a scientific sample of wetlands, ''Exotic species were no more likely to dominate a wetland than native species, and the proportion of dominant exotic species that had a significant negative effect on the native plant community was the same as the proportion of native species with a significant negative effect.'' In addition, ''There was no evidence to support the hypothesis that exotic species are more able to dominate invaded communities because they have fewer natural enemies than native plants'' (1135).

Conservationists have shown that ecosystems constantly change and that non-native species, like native ones, often contribute to these changes. What are lacking, however, are criteria that enable scientists to determine in randomly selected ecosystems if non-native species as a rule cause more harm than native ones or than species in general. On any non-question-begging conception of ''harm,'' non-native species in a random or otherwise scientific sample of ecosystems may be no more harmful – perhaps less harmful – than native organisms.

3. TWO SIDES TO EVERY STORY

The Chicago Invasive Species Policy (2002) lists purple loosestrife and Japanese honeysuckle among the worst weeds that infest natural areas. Yet purple loosestrife – although its beautiful flower is often seen – has not been shown to have baneful ecological effects, according to a literature review (Anderson, 1995) and an experimental study (Treberg and Husband, 1999).

Ecologists "traced the history of purple loosestrife and its control in North America and found little scientific evidence consistent with the hypothesis that [it] has deleterious effects… Loosestrife was initially assumed to be a problem without actually determining whether this was the case… there is currently no scientific justification for the control of loosestrife…" (Hager and McCoy, 1998; cf. Farnsworth and Ellis, 2001; Whitt et al., 1999; Morrison, 2002; but for a contrary argument, see Blossey et al., 2001).

Honeysuckle was introduced by the USDA to improve habitat for birds and small mammals. "The consistently high flower and fruit reproduction of the Amur honeysuckle suited it well for wildlife habitat improvement," Luken and Thieret (1996, p. 20) report. These authors (p. 23) add that honeysuckle may still "serve valuable ecological functions (for example, nutrient retention, carbon storage, and animal habitat improvement," in disturbed areas, where it is commonly found. McNeely (2001) summarizes, "While many resource managers perceive the plant as an undesirable element, gardeners and horticulturists consider it an extremely useful plant. Thus the 'noxious invasive' of one group is the 'desirable addition' of other groups."

Some commentators refer to the costs of controlling a species (control costs) as a measure of the harm that species does (e.g., Pimentel et al., 2000). Control costs may be used as a measure of harm when people spend their own money. If a governmental agency spends other people's money to remove loosestrife or honeysuckle, however, the connection between benefits and costs is less apparent. Government agencies may seek huge budgets for invasive species programs; they may then cite these "control costs" to justify the expense. The Forest Service spent billions to fight forest fires, to the detriment of the health of forests. Experience has shown that the costs of government programs are not reliable measures of their benefits.

One may suspect there are two sides to nearly every invasive species story; if so, general conclusions can be difficult to draw. For example, biologists have praised the work of the zebra mussel in clearing the water column and restoring native grasses in aquatic systems (Morton, 1996; Munawar et a1., 2001; Ojaveer et al., 2002). Holland et al. (1995) identified the mussel as the principal reason that eutrophication abated in Lake Erie, while others have noted similar effects in other lakes and rivers (e.g., Strayer et al., 1999). According to Gurevith and Padilla (2004, p. 471), "no species have gone extinct as a result of the introduction of zebra mussels." Were it native, the zebra mussel might be hailed as a savior not reviled as a scourge.

Many public officials consider oriental bittersweet to be a noxious invasive species, but crafters who make wreaths and floral arrangements from the dried vines and berries prefer it to native varieties. In Hawaii, an apple snail created a valuable new crop (escargot) and damaged an old one

(Cowie, 1995). A chameleon that is protected as an endangered species in East Africa is considered an invasive pest in Hawaii, where it was introduced as a pet (Loope et al., 1999). The Nile perch and tilapia introduced into Lake Victoria displaced many endemic cichlids but produced a successful commercial fishery. In Lake Victoria, "total fish production and its economic value rose considerably" (WRI, 2000, p. 21). Of Lake Victoria, Williamson (1996, p. 25; cf. Goldschmidt, 1996; Balirwa, 1995) has written, "In biological and environmental terms, this invasion has been a disaster. In terms of feeding the growing human population round the lake, it is a success. There is no way to reconcile the conflict of these views."

4. TARGETING EVERY ALIEN

More than a century ago, Gray (1879) argued that invasive species have no biological properties other than their invasiveness that distinguish them from other species. Accordingly, biologists have no way to predict how an introduced plant will behave in its new habitat, for example, whether or to what extent it will spread. Gray could "discern nothing in the plant itself that would give it an advantage." Gray reasoned that to ask why weeds are weeds – "so pertinacious and aggressive" – was to ask a loose, rhetorical question, "for any herb whatever when successfully aggressive becomes a weed; and the reasons for the predominance may be almost as divers as the weeds themselves."

Since Gray's time, ecologists have not developed more reliable ways to predict if and when an organism will spread, how it may evolve to become competitive, and what impacts it may have on the larger ecosystem (Shrader-Frechette, 2001). As Simberloff (1997, p. 329; cf. Hobbs and Humphries, 1995) has written, "Virtually every specialist in invasion biology who has examined the matter concludes that aspects of the ecological impact of a NIS are inherently unpredictable." He adds that "many scientists argue that every species should be considered a potential threat to biodiversity and sustainability if it were to be introduced." Information at a level of detail and specificity needed to assess potential invasiveness is unavailable for most species (Mack et al., 2000). "The effects of introduced species are so poorly understood and the record of predicting which ones will cause problems is so bad that one can question how much credence to place in a risk assessment" (Schmitz and Simberloff, 1997). "There is so much contingency involved among organisms that we regard as invasive, that their study has to be essentially a case by case analysis," Wagner (1993, p. 1) has written. "No two situations are alike."

Executive Order 13112 defines as "invasive" any "species that is (1) non-native (or alien) to the ecosystem under consideration and (2) whose introduction causes or is likely to cause economic or environmental harm or harm to human health'' (http://www.invasivespecies.gov/). Long before President Clinton signed Executive Order 12113, agencies such as APHIS and the CDC targeted organisms that cause or are likely to cause economic harm or harm to human health. These agencies have limited and thus legitimate missions because both scientists and the public understand the concepts of harm to human health and economic harm. Epidemiologists know how to plot the spread of disease organisms through human populations; entomologists can predict the proliferation of insect pests in crops.

Ecologists often remind us that they do not seek to exclude or target every non-native species but only those that cause or are likely to cause harm (Simberloff and Strong, 2000). Yet these scientists have no settled understanding or definition of ''environmental harm.'' They concede that even if they had such an understanding or definition, they would not have any way to tell which introduced species are likely to become harmful. They are no more able than Asa Gray to predict which organisms that can colonize a place will spread and to what effect.

Society looks to ecology for advice about how to respond to invasive species. How should ecologists respond to their uncertainty about how to define ''environmental harm'' and their inability to predict which species may cause it? They could advise society to fund fully the missions of agencies such as the CDC and APHIS that apply predictive sciences such as epidemiology and entomology to battle pests and pathogens that threaten human health and other well-defined economic interests. Alternatively, ecologists could advise society to devote scarce resources to programs to prevent ''environmental harm'' – an utterly vague notion – in spite of their inability both to define the concept and to assess the risk a species may cause it.

Ecologists could argue that what they do not know may hurt us and that we disregard their ignorance to our peril. In the absence of criteria to define ''harm to the environment'' and of methods to predict it, no non-native organism can be ''proven innocent'' (Ruesink et al., 1995). Accordingly, ecologists say that ''states must adopt rigorous white lists, despite the difficulties of doing so'' (Schmitz and Simberloff, 1997). A ''white list'' or ''guilty until proven innocent'' approach insists that ''every proposed introduction be viewed as potentially problematic until substantial research suggests otherwise'' (Simberloff, 1996). Prominent researchers have written, ''*Every* proposed introduction must receive the scrutiny currently reserved for species known to have caused harm elsewhere'' (Schmitz and Simberloff, 1997). Remarks like these create the impression that conservationists are not particularly interested in sustaining the missions of agencies like APHIS and the CDC, which deal with organisms that affect human health and agricultural corps. Instead, they appear to support a different and in some ways a competing agenda – namely, a *carte blanche* against all alien species in natural environments.

5. INTRODUCED ORGANISMS AND SPECIES RICHNESS

Ecologists have argued that species richness supports valuable ecosystem properties. "Recent experiments have shown increasing net primary productivity (NPP) and nutrient retention in ecosystems as the number of plant species increases," one study asserts (Hooper and Vitousek, 1997, p. 1312; cf. Waide et al., 1999). Species diversity, according to many accounts, positively affects ecosystem functioning, for example, "diversity can be expected, on average, to give rise to ecosystem stability" (McCann, 2000, p. 232; Schwartz et al., 2000; Cottingham et al., 2001; Hector et al., 2001; Loreau et al., 2001; Kinzig et al., 2002; Lawler et al., 2002). Thus one could argue that non-native invaders – if they crowd out other species and thus decrease overall species richness – may in that way harm the environment.

To evaluate the effect of introduced species on species richness, however, is to encounter a puzzling phenomenon. Both ecological theory and observation confirm that "invasions may actually increase total species richness" (Parker et al., 1999, p. 8). Plants introduced by humans have increased the overall diversity of flora in regions, such as central Europe, over the centuries (di Castri, 1989). McNeely (2001, p. 173) observes that cities "are greatly enriched by invasive species of plants. For example, London has some 2100 species of flowering plants and ferns growing wild while the rest of Britain has no more than 1500 species, and Berlin has 839 native species of plants and 593 invasives" (cf. Kowarik, 1990; McNeely, 1995). Davis (2003) notes that introductions have increased the diversity of plants in California by 20%; this increase is representative of North America generally (BONAP, 1999).

"With regard to biological diversity," Huston (1994, p. 318) has written, "invasions potentially lead to an increase in species richness, as invading species are added to the species gene pool." Sax et al. (2002, p. 774) have observed a "highly consistent, approximately twofold, increase in the species richness of plants on oceanic islands" owing to plant introductions and invasions. Historically about 2000 plant species existed in the wild in New Zealand; fewer than 10 are known have become extinct. An additional 2000 exotic species have migrated to New Zealand, doubling plant biodiversity on that island (Sax et al., 2002, p. 768). Likewise, in Hawaii, "the native flora consists of about 1100 species – and an additional 4600 exotic plants have been identified there...." (Vitousek, 1990, p. 8). According to Eldredge and Miller (1995), "the richness of freshwater fishes on oceanic islands has increased dramatically following the introduction of nonnative species, for example, by 800% on Hawaii.''

In the past, many ecologists believed that a given environment contains only a limited number of niches so that when a newcomer arrives, it is likely to expropriate a native creature (MacArthur, 1972; cf. McKinney and Lockwood, 1999). Many ecologists, however, now question a niche-based perspective and suggest that the number of species that can reach a site may be the principal factor that limits the number that can take hold there (Tilman, 1997; Hubbell, 2001). There is no ''absolute upper limit to the number of coexisting species'' (Fox et al., 2000, p. 198). According to Cornell and Lawton (1992), ''opportunities always exist for the invasion of appropriately adapted species into unoccupied niches, and the subdividing of existing niches.'' Species richness at the local and regional level increases with immigration intensity ''so that community richness reflects the diversity of a regional pool of potential colonists'' (Ricklefs, 1987; Loreau and Mouquet, 1999, p. 431; Srivastava, 1999). Globalization makes the ''regional pool of potential colonists'' world-wide. Rosenzweig (2001, p. 365) concludes that ''local diversities are headed for much higher steady states... The observed local increases are stepping stones to that result.''

Do exotic species increase or decrease the species richness of natural environments? If in any scientific (e.g., random) sample of ecosystems introduced organisms generally, overwhelmingly, and typically increase species richness, and if species richness supports desirable ecosystem properties, then one could argue these organisms benefit those systems. Vermeij (1996, p. 7) explains, ''In the absence of invasions, communities and the species interactions comprising them may stagnate.'' Critics (e.g., Pollan, 1994) argue that the case against non-native species rests not on scientific studies but on selected examples, such as the predations of the tree snake in Guam. Conservationists who deplore the spread of non-native species cite ''poster'' aliens, such as honeysuckle and loosestrife, the presence of which they do not like. Examples, of course, are not arguments. Yet examples like these constitute the principal argument for a ''guilty until proven innocent'' or a ''white list'' approach to non-native species.

6. EXOTICS AND EXTINCTION

Conservationists often state that ''invasive plants, animals, and fungi are second only to habitat loss and degradation in endangering native plant species'' (Reichard and White, 2001). If introduced plants and other non-native species contribute significantly to the incidence of extinction, they may be said in that way to harm the environment, for example, by decreasing biodiversity at the global scale. On the other hand, invasion, adaptive radiation, and hybridization have been important factors in increasing the number of species in the world – indeed, if one thinks back far enough, volcanic islands such as Hawaii and the Galapagos owe virtually all their biodiversity to invasions at different times and from different places. Genetic engineering, moreover, provides the ability to scientists to custom design as many kinds of novel species and ecosystems as one could imagine, if what is valued is genetic variety within and between communities, however that variety is produced (Forcella, 1984).

That invasive species constitute the second leading cause of extinction is a dictum so often repeated that one may assume that it rests on evidence. This is not the case. As Gurevich and Padilla (2004, p. 470) have carefully shown, "available data supporting invasion as a cause of extinctions are, in many cases, anecdotal, speculative and based upon limited observation."

While examples of faunal extinctions of endemic species have been observed on a few islands – the predations of the brown tree snake in Guam is the much-cited instance (Jaffe, 1994) – it is doubtful that a single clear example can be found in which an introduced plant has acted as the principal cause of an extinction. It is intuitively plausible to suppose that on small islands, predatory and parasitic animals could eliminate those creatures they prey upon. It is much harder to build even a plausible prima facie argument to support the idea that plants, especially domesticated or cultivated ones, could be significant factors in extinction.

A paper by Wilcove et al. (1998) is often cited to support the idea that invasive species are major factors in extinction. These authors, however, did not attempt to measure or quantify the importance or significance of the five kinds of stressors they studied as causes of extinction – "habitat destruction, the spread of alien species, overharvest, pollution (including siltation), and disease." As the authors noted, the five categories are not exclusive; they therefore treated each kind of stressor, whether it made a minimal or major difference, as if it were an equal factor in causing extinction. "Nor did we try to distinguish between major and minor threats to each species because such information was not consistently available."

Wilcove et al. cited two studies that identify "leading" or "primary" threats to imperiled species to support the view exotic species (as compared with native ones, for example) are significant factors in extinction. In one study, Schemske et al. (1994), after sifting through an immense amount of US Fish and Wildlife Service data, identify the primary causes of endangerment for 98 US plant species protected under the Endangered Species Act. These authors report that alien species constitute a significant problem for about 11% of these plants, the same level of threat associated with off-road vehicles. In the second study, Richter et al. (1997), report an opinion poll in which many respondents chose exotics among other factors from a list of possible "leading" sources of stress. Richter et al. caution, "Our results must be interpreted in light of their resting in expert opinions rather than on published reports."

Although introduced plants and other organisms, except for predators in a few lakes and other tiny island-like ecosystems, are rarely significant causes of extinction, they may lead to changes in the populations of native species, causing some to increase and others to decrease. That introduced species affect the populations of native ones in either direction does not show that they are harmful, however, or that they are more likely than native ones to be important factors in extinction. Indeed, invasion may help avoid extinction, since species endangered in one place often survive in another (Burda, 1998).

Aquatic invaders in ocean and estuarine systems are seldom culprits in extinction. In a study of the heavily invaded San Francisco Estuary, Cohen and Carlton (1995) report that, "no introduction in the Estuary has unambiguously caused the extinction of a native species." Since the Suez Canal opened in 1869, the Red Sea and the Mediterranean, which were separated for millions of years, have freely exchanged biota. Even though "over 250 species, 34 new genera, and 13 new families have moved into the Mediterranean Sea from the Red Sea, yet there has only been one documented extinction" (Mooney and Cleland, 2001). The Panama Canal, completed in 1914, allowed the free exchange of fish between the Chagres River on the Atlantic slope and the Rio Grande on the Pacific slope. The rivers on both sides of the Isthmus became much more species rich as a result of this experiment, as fish from each river invaded the other. Surveys taken at the completion of the Canal and again in 2002 reveal that after about 90 years not a single species in these rivers has become extinct (Smith et al., 2004).

In the continental United States, invasive organisms, particularly plants, have not been major factors in causing extinction. Kudzu has not, "to our knowledge, caused any native species to go extinct, though it has certainly caused some to decline" (Simberloff and Strong, 2000). Davis (2003) writes that "there is no evidence that even a single long-term resident species has been driven to extinction... because of competition from an introduced plant species." In fact, "there are surprisingly few instances in which extinctions of resident species can be attributed to competition from new species." Vermeij (1996, p. 6) agrees. "The evidence so far points to the conclusion that invaders often cause extinction on oceanic islands and in lakes, but rarely in the sea or on large land masses."

7. TAUTOLOGY

While metaphorical borrowings from oncology may endow the term "invasion" with much of its political impact – invasive species are said to spread aggressively across natural areas – Elton (1958), who developed the concept, had military analogies in mind (Davis et al., 2001). Biologists have also written that exotic species "pollute" (McKnight, 1993), "meltdown" (Simberloff and Von Holle, 1999), "harm" (Ehrenfeld, 1999, p. 11), "disrupt" (NRC, 1997, p. 325), and "destroy," and "degrade" (Schmitz and Simberloff, 1997) natural ecosystems. Insofar as these terms refer to aesthetic, moral, or spiritual judgments, they may legitimately enter into political debate and policy discussion. Normative terms such as these figure constantly, however, in the scientific literature of conservation biology and invasion ecology. Is this simply an example of political advocacy parading as empirical science? Is there a scientific or empirical – as well as an aesthetic and spiritual – basis for the assumption that non-native species are, indeed, pernicious in their effects on natural areas and environments?

Biologists frequently assert in their scientific writing that invasive species constitute a "threat to biodiversity" (Simberloff, 1999) or "threaten the existence of community-level biodiversity" (Simberloff, 2003, p. 180). According to the US Geological Survey, non-native plants pose "a long-term threat to biodiversity, ecosystem stability, and the balance of nature on which all species depend" (USGS, 2003). Have any of these statements been tested – can they be tested – empirically? To construct empirical studies, one would have to start with definitions of terms such as "invasive species," "biodiversity," and "ecosystem stability." One could then study randomly selected environments to see if, indeed, the presence of invasive species correlates empirically with a loss of biodiversity, decline in ecosystem stability, integrity, health, or function, or any scientifically defined concept.

According to historian Takacs (1996; cf. Sarkar, 2002) and ecologists he interviewed, the concept of biodiversity, like that of invasion, appeals to political and social values but has no scientific meaning. Takacs reports that Walter Rosen coined the term "biodiversity" while planning "The National Forum on BioDiversity" in 1986, to bring political attention to the goal of protecting species. How is this goal and with it the protection of biodiversity to be served by a campaign against non-native species? If non-native species are rarely causes of extinction and generally increase species richness, why should ecologists believe they threaten rather than enhance biodiversity?

The reason that ecologists believe that non-native species threaten biodiversity appears to consist in stipulation, i.e., in word play. Many ecologists define the term "biodiversity" to exclude organisms that colonized a place with human assistance, i.e., to exclude non-native species. For example, Sala et al. (2000) write, "Our definition [of biodiversity] excludes exotic organisms that have been introduced..." If the concept *biodiversity* excludes introduced (including cultivated and engineered) species, non-native organisms logically can detract from but never augment biodiversity. That non-native species harm biodiversity expresses a conceptual truism not an empirical fact. By analogy, antiquarians may define the concept *housing* to exclude in old cities any building constructed after 1950. They could then argue that any newer building, even if it functions the same way as older buildings in providing shelter and the like, should be excluded or removed, because it threatens or competes with housing.

Similarly, ecosystem integrity and related concepts are generally defined in a way that makes the presence of non-native species a per se indicator of ecosystem decline (Angermeier and Karr, 1994). "Because the mere presence of an invader usually lowers the biotic integrity score, their [sic] use can be circular" (Parker et al., 1999, p. 10). No ecologist has proposed a non-question-begging definition of "biodiversity" or ecosystem "integrity" for which scientific studies have shown that non-native species generally or as a rule harm biodiversity or damage ecosystem integrity. The concept of a "scientific study" does not refer to a list of examples, such as Guam and Lake Victoria, selected to support a thesis. Rather than drawing general conclusions from pre-selected and biased examples, as the literature often does, a scientific study would consider a sample of species or sites selected randomly or on neutral grounds.

There are three impediments to scientific studies in invasion biology. First, fundamental concepts, such as "invasion" and "biodiversity" have political, social, and normative significance, but no scientific meaning. Second, the indictment of non-native species is based on lists of selected examples, rather than on the investigation of random samples or samples determined on independent grounds. Third, ecologists have not shown that non-native species, once established in an ecosystem, behave in general any differently than native ones. To tell whether a species is native or alien, ecologists must rely on historical, such as paleoecological, evidence; there is no study that demonstrates that established alien and native species can be distinguished on the basis of the activity or properties of living organisms. In other words, if one group of ecologists, on the basis of historical evidence, lists those species established at a site that are native and those that are alien, a second group of ecologists, who inspect the sites and the activity in them but have no knowledge of their history, could not tell which list was which. Nor can ecologists detect which sites are more or less invaded – the systems do not appear to have any different qualities as ecosystems – except by historical research. If a group of ecologists on the basis of paleobiological research determined which of a random sample of ecosystems were relatively invaded and which relatively pristine, another group of ecologists could not without historical information tell which list was which. They could identify the systems that were damaged or harmed only if they knew which systems were invaded. Thus, ecological damage is a conceptual not a causal result of the presence of introduced species.

In order to test empirically whether non-native species harm ecosystems or threaten biodiversity, one would have to start with concepts of environmental "harm" (or "degradation," "contamination," "damage," and so on) and "biodiversity" that make no reference to non-native species. In other words, one must define *harm* or *biodiversity* in ways that do not logically entail that alien species cause harm or diminish biodiversity. Consider an example. According to McNeely (2001, citing Jacobs, 1975), "Lake Nakuru was transformed from an ecosystem of very low diversity (a large population of flamingos, two species of algae and a few invertebrate species) to one of much higher diversity (including 30 species of fish-eating birds) after the introduction of a fish, *Tilapia grahami*, to control mosquitoes." Is the introduced fish, which caused many changes in ecosystem structure, invasive? Did it harm the ecosystem? Did it cause biodiversity to diminish, say, if the population of the mosquito declined? For every Lake Victoria that sees a decrease in species richness because of an invader, there may be a thousand or a million ecosystems in which alien species add to biodiversity, ecosystem integrity, stability, resilience, and so on. We do not know. Because there are no established non-question-begging concepts of "invader," "biodiversity," "ecosystem integrity," "stability," "resilience," or "harm to the environment," there is no conceptual basis for scientific research on invasive species.

ACKNOWLEDGEMENTS

The author gratefully acknowledges research support from the National Science Foundation (EVS 0326154) and from the Illinois-Missouri Biotechnology Alliance. The views expressed are those of the author alone.

REFERENCES

Allen, William, "Invasive Plants Get Attention at Botanical Workshop," *St. Louis Post Dispatch* December 3 (2002).

Anderson, M. G., "Interactions Between Lythrum Salicaria and Native Organisms: A Critical Review," *Environmental Management* 19 (1995), 225–231.

Angermeier, P. L. and J. R. Karr, "Biological Integrity Versus Biological Diversity as Policy Directives: Protecting Biotic Resources," *BioScience* 44(10) (1994) 690–697.

Balirwa, J. S., "The Lake Victoria environment: Its fisheries and wetlands – a review," *Wetlands Ecology and Management* 3 (1995), 209–224.

Baskin, Y., "The Greening of Horticulture: New Codes of Conduct Aim to Curb Plant Invasions," *BioScience* 52 (2002), 464.

Blossey, B., L. C. Skinner, and J. Taylor, "Impact and Management of Purple Loosestrife (Lythrum salicaria) in North America," *Biodiversity and Conservation* 10 (2001), 1787–1807.

BONAP, *Invasive Species Database Search* (*http://www.bonap.org*). The Biota of North America Program (Universiy of North Carolina, Chapel Hill, NC, 1999).

Burda, R. I., "Examples of Invasions by Threatened Native Species in Anthropogenous Ecotypes," in U. Starfinger et al. (eds.), *Plant Invasions, Ecological Mechanisms and Human Responses* (Backhuys, Leiden, 1998), 299–306.

Carlton, J., "Invasions in the World's Oceans: How Much Do We Know, and What Does the Future Hold?" (2004). Lecture delivered at the March 2004 meeting of the American Institute of Biological Sciences. Recorded and available on line at: http://aibs.digiscript.com/presentation/index.cfm?media_id = 13542

Chew, M. K. and M. D. Laubichler, "Natural enemies – Metaphor or Misconception?," *Science* 301 (2003), 52–53.

Chicago Botanic Garden Invasive Species Policy, (2002) Available on line at: http://www.mobot.org/invasives/Download%20PDF/CBG_Proceedings.pdf

Clay, K., "Correlates of Pathogen Species Richness in the Grass Family," *Canadian Journal Botany* 73 (1995), S42–S49.

Cohen, A. N. and J. T. Carlton, *Nonindigenous Aquatic Species in a United States Estuary: A Case Study of the Biological Invasions of the San Francisco Bay and Delta. A Report for the United States Fish and Wildlife Service, Washington, DC and The National Sea Grant College Program Connecticut Sea Grant Program*. Available on line at: http://nas.er.usgs.gov/publications/sfinvade.html

Colautti, R. I. and H. J. MacIsaac, "A Neutral Terminology to Define Invasive Species," *Diversity and Distributions* 10 (2004), 135–141.

Colautti, Robert I., Anthony Ricciardi, Igor A. Grigorovich and Hugh J. MacIsaac, "Is Invasion Success Explained by the Enemy Release Hypothesis?" *Ecology Letters* 7(8) (2004), 721–733.

Cornell, H. V. and J. H. Lawton, "Species Interactions, Local and Regional Processes, and Limits to the Richness of Ecological Communities: A Theoretical Perspective," *Journal of Animal Ecology* 61 (1992), 1–12.

Cottingham, K. L., B. L. Brown and J. T. Lennon, "Biodiversity may Regulate the Temporal Variability of Ecological Systems," *Ecological Letters* 4 (2001), 72–85.

Cowie, R. H., "Identity, Distribution and Impacts of Introduced Ampullariidae and Viviparidae in the Hawaiian Islands," *Journal of Medical and Applied Malacology* 5 (1995), 61–67.

Davis, M. A., K. Thompson, and J. P. Grime, "Charles S. Elton and the Dissociation of Invasion Ecology from the Rest of Ecology," *Diversity and Distributions* 7(2001), 97–102.

Davis, M. A., "Biotic Globalization: Does Competition from Introduced Species Threaten Biodiversity?"*BioScience* 53 (2003), 481–489.

Davis, M. A. and K. Thompson, "Invasion Terminology: Should Ecologists Define their Terms Differently than others? No, not if we want to be any help!" *ESA Bulletin* 82 (2001), 206.

di Castri, F., "History of Biological Invasions with Special Emphasis on the Old World," in J. A. Drake, H. A. Mooney, F. di Castri, R. H. Groves, F. J. Kruger,

M. Rejmánek, and M. Williamson (eds.), *Biological Invasions: A Global Perspective***.** Scope 37 (John Wiley and Sons, Chichester, UK, 1989).

Dowdell, Jennifer, "An Unlikely Alliance: Professionals Counter alien Plant Invasions with a United Front," *Landscape Architecture* March (2002).

Ehrenfeld, D. W., "Adulusian Bog Hounds," *Orion* Autumn (1999), 9–11.

Eldredge, L. and S. Miller, "How Many Species are there in Hawai'i?" *B. P. Bishop Museum Occasional Papers* 41 (1995), 3–18.

Elton, C. S., *The Ecology of Invasions by Animals and Plants* (Methuen and Co., Ltd, London, UK, 1958).

Executive Order. 1999. No. 13112. Invasive species. http://www.invasivespecies.gov/laws/execorder.shtml

Farnsworth, E. J. and D. R. Ellis, "Is Purple Loosestrife (Lythrum salicaria) an Invasive Threat to Freshwater Wetlands? Conflicting Evidence from Several Ecological Metrics," *Wetlands* 21 (2001), 199–209.

Forcella, F., "Ecological Biotechnology," *Bulletin of the Ecological Society of America* 65 (1984), p. 434.

Fox, J. W., J. McGrady-Steed, and O. L. Petchey, "Testing for Local Species Saturation with Nonindependent Regional Species Pools," *Ecology Letters* 3 (2000), 198–206.

Glass, P., 1944. "Jefferson and Plant introduction," *National Horticultural Magazine* 23 (1994), 127–31.

Global Invasive Species Program (GISP), *International Convention on Biodiversity*. Available on line at: http://jasper.stanford.edu/gisp/Init.htm (1999).

Goldschmidt, T., *Darwin's Dreampond: Drama in Lake Victoria* (MIT Press, Cambridge, MA, 1996).

Gray. A., "The Pertinacity and Predominance of Weeds" *The American Journal of Science and Arts*, vol XVIII; reprinted in Ronald L. Stuckey (eds.), *Essays on North American Plant Geography From The Nineteenth Century* (Arno Press, New York, 1978).

Gurevitch, J. and D. K. Padilla, "Are Invasive Species a Major Cause of Extinctions?" *Trends in Ecology and Evolution* 19(9) (2004), 470–474.

Hager, H. A. and K. D. McCoy, "The Implications of Accepting Untested Hypotheses: A Review of the Effects of Purple Loosestrife (Lythrum salicaria) in North America," *Biodiversity and Conservation* 7 (1998), 1069–1079.

Healey, B. J., *The Plant Hunters* (Scribner's, New York, 1975).

Hector, A., J. Joshi, S. P. Lawler, E. M. Spehn, and A. Wilby, "Conservation Implications of the Link between Biodiversity and Ecosystem Functioning," *Oecologia* 129 (2001), 624–628.

Hobbs R. J. and S. E. Humphries, "An Integrated Approach to the Ecology and Management of Plant Invasions," *Conservation Biology* 9 (1995), 761–770.

Holland, R. E., T. H. Johengen, and A. M. Beeton, "Trends in Nutrient Concentrations in Hatchery Bay, western Lake Erie, before and after *Dreissena polymorpha*," *Canadian Journal of Fisheries and Aquatic Science* 52(6) (1995), 1202–1209.

Hooper, D. U. and P. M. Vitousek, "The Effects of Plant Composition and Diversity on Ecosystem Processes," *Science* 277 (1997), 1302–1305.

Houlahan, J. E. and C. S. Findlay, "Effect of Invasive Plant Species on Temperate Wetland Plant Diversity," *Conservation Biology* 18(4) (August) (2004), 1132–1138.

Hubbell, S. P., *The Unified Neutral Theory of Biodiversity and Biogeography* (Princeton University Press, Princeton, NJ, 2001).

Huston, M. A., *Biological Diversity: The Coexistence of Species on Changing Landscapes* (Cambridge University Press, Cambridge (UK), 1994).

Hyland, H. L., "History of US Plant introduction," *Environmental Review* 4 (1977), 26–33.

Jacobs, J., "Diversity, Stability and Maturity in Ecosystems Influenced by Human Activities," in W. H. Van Dobben and R. H. Lowe-McConnell (eds.), *Unifying Concepts in Ecology*. (Junk, The Hague, 1975), 187–207.

Jaffe, M., *And No Birds Sing: The Story of an Ecological Disaster in a Tropical Paradise* (Simon and Schuster, New York, 1994).

Kinzig, A. P., S. W. Pacala, and D. Tilman (eds.), *The Functional Consequences of Biodiversity: Empirical Progress and Theoretical Extensions* (Princeton University Press, Princeton, NJ, 2002).

Kloppenburg, J. R., Jr., *First the Seed: The Political Economy of Plant Biotechnology* (Cambridge University Press, New York, 1988), 1492–2000.

Kowarik, I., "Some Responses of Flora and Vegetation to Urbanization in Central Europe," in H. Sukopp, S. Mejny and I. Kowarik (eds.), *Urban Ecology: Plants and Plant Communities in Urban Environments* (SPB Academic Publishing, The Hague, 1990), 45–74.

Lawler, S. P., J. J. Armesto, and P. Kareiva, "How Relevant to Conservation are Studies Linking Biodiversity and Ecosystem Functioning?" in A. P. Kinzig, S. W. Pacala, and D. Tilman (eds.), *The Functional Consequences of Biodiversity: Empirical Progress and Theoretical Extensions* (Princeton University Press, Princeton, NJ, 2002), 294–320.

Lemmon, K., *The Golden Age of Plant Hunters* (Phoenix House, London, 1968).

Levine, J. M., "Species Diversity and Biological Invasions: Relating Local Process to Community Pattern," *Science* 288 (2000), 852–854.

Lonsdale, W. M., "Global Patterns of Plant Invasions and the Concept of Invasibility," *Ecology* 80 (1999), 1522–1536.

Loope, L. L., F. G. Howarth, F. Kraus, and T. K. Pratt, "Newly Emergent and Future Threats of Alien Species to Pacific Landbirds and Ecosystems," in J. M. Scott, S. Conant, and C. van Riper III (eds.), *Proceedings of Symposium on Threats to Pacific Landbirds and Endangered Ecosystems*, *Hilo*, *Hawaii*, *May1–2*, *1997*. Cooper Ornithological Society, Studies in Avian Biology (1999).

Loreau, M. and N. Mouquet, "Immigration and the Maintenance of Local Species Diversity,"*American Naturalist* 154 (1999), 427–440.

Loreau, M., S. Naeem, P. Inchausti, J. Bengtsson, P. Grime, A. Hector, D. U. Hopper, M. A. Huston, D. Raffaelli, B. Schymidt, D. Tilman, and D. A. Wardle, "Biodiversity and ecosystem functioning: Current knowledge and Future Challenges," *Science* 294 (2001), 804–808.

Luken, J. O. and John W. Thieret, "Amur Honeysuckle, its fall from Grace," *BioScience* 46(1) (1996), 18–24.

MacArthur, R. H., *Geographical Ecology: Patterns in the Distribution of Species*. (Harper and Row, New York, 1972).

Mack, R. N., D. Simberloff, W. M. Lonsdale, H. Evans, M. Clout, and F. A. Bazzaz, "Biotic Invasions: Causes, Epidemiology, Global consequences and Control," *Ecological Applications* 10 (2000), 689–710.

McCann, K., "The Diversity-stability Debate. 2000," *Nature* 405 (2000), 228–233.

McKinney, M. L. and J. L. Lockwood, "Biotic Homogenization: A Few Winners Replacing Many Losers in the Next Mass Extinction," *TREE* 14 (1999), 450–453.

McKnight, B. N. (ed.), *Biological Pollution: The Control and Impact of Invasive Exotic Species* (Indiana Academy of Sciences, Indianapolis. IN, 1993).

McNeely, J. A., ''The great reshuffling: How alien species help feed the global economy,'' IUCN Web Page; on line at: http://www.iucn.org/biodiversityday/introduction.html (2001).

McNeely, J. A., ''Cities, Nature, and Protected Areas: a General Introduction,'' Paper presented to *Symposium on Natural Areas in Conurbations and on City Outskirts, Barcelona, Spain, 25–27 October* (1995).

Mooney, H. A. and E. E. Cleland, ''The Evolutionary Impact of Invasive Species.'' *Proceedings of the National Academy of Sciences of the United States, 98, 10, 5446*. http://www.pnas.org/cgi/content/full/98/10/5446 (2001).

Morrison, J. A., ''Wetland Vegetation before and after Experimental Purple Loosestrife Removal,'' *Wetlands* 22(1) (2002), 159–169.

Morton, B., ''The Aquatic Nuisance Species Problem: A Global Perspective and Review,'' in Frank D'itri (ed.), *Zebra Mussels and Other Aquatic Nuisance Species* (Ann Arbor Press, Ann Asrbor, MI, (1996). http://sgnis.org/publicat/papers/9615_1.pdf.

Munawar, M., I. F. Munawar, R. Dermott, H. Niblock, and S. Carou, ''Is Lake Erie a resilient ecosystem?'' *Aquatic Ecosystem Health and Management* 5(1) (2001), 79–93.

National Invasive Species Council, *National Invasive Species Management Plan*. Available on line at: http://www.invasivespecies.gov/council/nmp.shtml (2001).

National Research Council (NRC), *Predicting Invasions of Nonindigenous Plants and Plant Pests*. Board on Agriculture and Natural Resources, Board on Life Sciences (National Academy of Science, Washington, DC, 2002).

National Research Council (NRC), *Nature and Human Society: The Quest for a Sustainable World* (National Academy Press, Washington, DC, 1997).

Ojaveer, H., E. Leppäkoski, S. Olenin, and A. Ricciardi, ''Ecological Impact of Ponto-caspian invaders in the Baltic Sea, European inland waters and the great lakes: An inter-ecosystem comparison,'' in E. Leppäkoski, S. Gollsch, and S. Olenin (eds.), *Invasive Aquatic Species of Europe* (Kluwer Academic Publishers, Dordrecht, 2002).

Parker, I. M., D. Simberloff, W. M. Lonsdale, K. Goodell, M. Wonham, P. M. Kareiva, M. H. Williamson, B. Von Holle, P. B. Moyle, J. E. Byers, and L. Goldwasser, ''Impact: Toward a Framework for Understanding the Ecological Effects of Invaders,'' *Biological Invasions* 1(1) (1994), 3–19.

Pimentel, D., L. Lach, R. Zuniga, and D. Morrison, ''Environmental and Economic Costs Associated with Non-indigenous Species in the United States,'' *BioScience* 50(1)(January) (2000), 53–65.

Pollan, M., ''Against Nativism,'' *New York Times Magazine* May 15 (1994), 52–55.

Reichard Sarah H. and Peter White, ''Horticulture as a Pathway of Invasive Plant Introductions in the United States,'' *Bioscience* 51(2) (2001), 103–113.

Rejmanek, M., D. M. Richardson, M. G. Barbour, M. J. Crawley, G. F. Hrusa, P. B. Moyle, J. M. Randall, D. Simberloff, and M. Williamson, ''Biological Invasions: Politics and the Discontinuity of Ecological Terminology,'' *ESA Bulletin* 83 (2002), 131–133.

Richardson, D. M., P. Pysek, M. Rejmanek, M. G. Barbour, F. D. Panetta, and C. J. West, ''Naturalization and Invasion of Alien Plants: Concepts and Definitions,'' *Diversity and Distributions* 6 (2000), 93–107.

Richter B. D., D. P. Braun, M. A. Mendelson, and L. L. Master, ''Threats to Imperiled Freshwater Fauna,'' *Conservation Biology* 11 (1997), 1081–1093.

Ricklefs, R. E., ''Community Diversity: Relative roles of Local and Regional Processes,'' *Science* 235 (1987), 167–171.

Rosenzweig, M., ''The Four Questions: What does the Introduction of Exotic Species do to Biodiversity?'' *Evolutionary Ecology Research* 3 (2001), 361–367.

Ruesink, J. L., I. M. Parker, M. J. Groom, and P. Kareiva, ''Guilty Until Proven Innocent: Reducing the Risks of Non-Indigenous Species Introductions,'' *Bioscience* 45(7) (1995), 465–477.

Sala, O. E. et al., ''Global Biodiversity Scenarios for the year 2100,'' *Science* 287 (2000), 1770–1774.

Sarkar S., ''Defining 'Biodiversity': Assessing Biodiversity,'' *Monist* 85 (2002), 131–155.

Sax, D. F., S. D. Gaines, and J. H. Brown, ''Species Invasions Exceed Extinctions on Islands Worldwide: A Comparative Study of Plants and Birds,'' *American Naturalist* 160 (2002), 766–783.

Schemske D. W., B. C. Husband, M. H. Ruckelshaus, C. Goodwillie, I. M. Parker, and J. G. Bishop, ''Evaluating Approaches to the Conservation of Rare and Endangered Plants,'' *Ecology* 75 (1994), 584–606.

Schmitz, D. C. and D. Simberloff, ''Biological Invasions: A Growing Threat,'' *Issues in Science and Technology* 13:4 (Summer) (1997), 33–41. Available on line at http://www.nap.edu/issues/13.4/schmit.htm

Schwartz, M. W., C. A. Brigham, J. D. Hoeksema, K. G. Lyons, M. H. Mills, and P. J. Van Mantgem, ''Linking Biodiversity to Ecosystem Function: Implications for Conservation Ecology,'' *Oecologia* 122 (2000), 297–305.

Shrader-Frechette, K. S., ''Non-indigenous Species and Ecological Explanation,'' *Biology and Philosophy* 16(4) (2001), 507–519.

Simberloff, D., ''Impacts of Introduced Species in the United States,'' *Consequences* 2(2) (1996). Available on line at http://www.gcrio.org/CONSEQUENCES/vol2no2/article2.html

Simberloff, D., ''Nonindigenous Species – A Global Threat to Biodiversity and Stability,'' in Peter H. Raven and T. Williams (eds.), *Nature and Human Society: The Quest for a Sustainable World*, Committee for the Second Forum on Biodiversity, National Academy of Sciences and National Research Council, Washington, DC (1997), On line at: http://books.nap.edu/books/0309065550/html/329.html

Simberloff, D., ''Confronting Introduced Species: A Form of Xenophobia?'' *Biological Invasions* 5 (2003), 179–192.

Simberloff, D. and D. R. Strong, ''Exotic Species Seriously Threaten Our Environment,'' *Chronicle of Higher Education* 47(2) (2000), B20.

Simberloff, D. and B. Von Holle, ''Positive Interactions of Nonindigenous Species: Invasion Meltdown?'' *Bioloical Invasions* 1(1) (1999), 21–32.

Smith, S., G. Bell, and E. Bermingham, ''Cross-Cordillera Exchange Mediated by the Panama Canal Increased the Species Richness of Local Freshwater Fish Assemblages,'' *Proceedings of the Royal Society of London B* (2004), online. See: http://www.journals.royalsoc.ac.uk.

Srivastava, D. S., ''Using Local-Regional Richness Plots to Test for Species Saturation: Pitfalls and Potentials,'' *Journal of Animal Ecology* 68 (1999), 1–16.

St. Louis Declaration on Invasive Plant Species, Missouri Botanical Garden (2001), Available on line at: http://www.mobot.org/invasives/findingsN.html

Stohlgren, T. J., D. Binkley, G. W. Chong, M. A. Kalkhan, L. D. Schell, K. A. Bull, Y. Otsuki, G. Newman, M. Bashkin, and Y. Son, "Exotic Plant Species Invade Hot Spots of Native Plant Diversity," *Ecological Monographs* 69 (1999), 25–46.

Strayer, D. L., N. F. Caraco, J. J. Cole, S. Findlay, and M. L. Pace, "Transformation of Freshwater Ecosystems by Bivalves," *BioScience* 49 (1999), 19–27.

Takacs, D., *The Idea of Biodiversity: Philosophies of Paradise* (The Johns Hopkins University Press, Baltimore, MD, 1996).

Tilman, D, "Community Invasibility, Recruitment Limitation, and Grassland Biodiversity," *Ecology* 78 (1997), 81–82.

Treberg, M. A. and B. C. Husband, "Relationship Between the Abundance of Lythrum salicaria (purple loosestrife) and Plant Species Richness along the Bar River, Canada," *Wetlands* 19 (1999), 118–125.

US Geological Survey (USGS), *Invasive Plant Species*. CINDI: Center for Integration of Natural Disaster Information, (2003), Available on line at: http://cindi.usgs.gov/invasives.html

Vermeij, G., "An Agenda for Invasion Biology," *Biological Conservation* 78 (1996), 3–9.

Vitousek, P. M., "Biological Invasions and Ecosystem Processes; Towards an Integration of Population Biology and Ecosystem Studies," *Oikos* 57 (1990), 7–13.

Wagner, W. H., "Problems with Biotic Invasives: A Biologist's Viewpoint." in B. N. McKnight (ed.), *Biological Pollution: The Control and Impact of Invasive Exotic Species* (Indiana Academy of Science, Indianapolis, 1993).

Waide, R. B., M. R. Willig, C. F. Steiner, G. Mittelbach, L. Gough, S. I. Dodson, G. P. Juday, and R. Parmenter, "The Relationship Between Productivity and Species Richness," *Annual Review of Ecology and Systematics* 30 (1999), 257–300.

Whitt, M. B., H. H. Prince, and R. R. Cox, Jr., "Avian use of Purple Loosestrife Dominated Habitat Relative to Other Vegetation Types in a Lake Huron Wetland Complex," *The Wilson Bulletin* 111 (1999), 105–114.

Whittle, T., *The Plant Hunters* (Chilton Book Co, Philadelphia, 1970).

Wilcove, D. S., D. Rothstein, J. Dubow, A. Phillips, and E. Losos, "Quantifying Threats to Imperiled Species in the United States," *BioScience* 48 (1988), 607–615.

Williamson, M., *Biological Invasions* (Chapman & Hall, London 1996).

Withgott, J., "Are Invasive Species Born Bad?" *Science* 305(5687) (2004), 1100–1101, 20 August.

World Resources Institute (WRI), *World Resources 2000–2001: People and ecosystems: The fraying web of life*. United Nations Development Programme, United Nations Environment Programme, World Bank, World Resources Institute. Washington, DC (2000), Available on line at: http://pdf.wri.org/wr2000_chapter1_box1.9_lakevictoria.pdf

Institute for Philosophy and Public Policy
University of Maryland
College Park, MD
USA
E-mail: msagoff@umd.edu