Risk Assessments, Blacklists, and White Lists for Introduced Species: Are Predictions Good Enough to Be Useful?

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The United States regulates deliberate species introduction by blacklists: any species not blacklisted may be imported. Half of invasive introduced species were deliberately introduced, yet most were not blacklisted, so this system is not working. White lists are also needed: no species can be deliberately introduced unless experts place it on a white list. The United States has not closed pathways for inadvertent introductions, which are regulated by international treaties. Risk assessments for introduced species have mostly targeted species as potential vectors for pathogens rather than as potentially invasive themselves. Although multilateral treaties mandate quantitative risk assessments for exclusions of species or goods that may carry them, biologists and economists can predict probabilities of invasiveness, and associated costs, only with enormous confidence limits. However, assessing risk can lead to insights on the likelihood of impact. The crucial decision will be to what extent the precautionary principle will be implemented. An added problem is that species established in parts of the United States (either native or introduced) have become invasive when introduced elsewhere in the United States. There is scant legal basis for preventing such introductions. To stem the flood of invasive species into and within the United States would require blacklists, a white listing procedure, and tighter regulation of pathways.

Key Words: blacklist, risk assessment, suminoe oyster, white list

The most efficient way to deal with introduced species is to keep them out in the first place, but the United States is not doing a very good job of exclusion. For instance, a team at the National Center for Ecological Analysis and Synthesis amassed data showing nearly linear increases of at least twofold over the twentieth century in established non-native species of insects, terrestrial vertebrates, plant pathogens, and mollusks (Fargione and Wolff 2001). This fact does not mean that the number of harmful species is increasing so rapidly, as the tens rule (Williamson and Fitter 1996) usually holds to a rough approximation: ca. 10 percent of established introduced species become harmful to the environment, human enterprises, or both. Such species are termed "invasive." However, 10 percent of a monotonically increasing number is still a monotonically increasing number.

It is notoriously difficult to estimate the economic cost of an introduced species, particularly when the damage is to indirect use values, such as ecosystem services, or non-use values, such as the existence of an intact ecosystem or an extraordinary evolutionary radiation (Naylor 2000). However, some damaging invaders are enormously costly. Widely bruited total cost estimates for all invasions of ca. US$137 billion annually for the United States (Pimentel et al. 2000) and more than US$336 billion annually for the United States, United Kingdom, Australia, India, South Africa, and Brazil together (Pimentel et al. 2001) have been criticized for many assumptions, but they are the first attempts to estimate total costs for entire nations and for the world, respectively, and they give a sense of the real scale of the problem caused by some subset of invaders. They also emphasize that the majority of the staggering costs

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are associated with a small minority of invaders. There are a few more detailed economic studies of particular invasions that give solid, comprehensive estimates, and these also suggest that costs can be enormous. Naylor (1996) assessed the costs of the introduced golden apple snail (*Pomacea canaliculata*) simply to rice yield, control costs, and replanting (there are other costs, such as environmental ones) in the Philippines as US$28–45 million annually, while Zavaleta (2000) valued ecosystem services lost to invasion by salt cedar (*Tamarix* spp.) in the United States as US$7.3–16.1 billion over a 55-year period.

A frequent complaint is that budgets and personnel for intercepting introduced species are woefully inadequate, and it is true that USDA APHIS (Animal and Plant Health Inspection Service) is understaffed even after some of its functions—such as border inspection and the Plum Island Animal Disease Center—have been transferred to the Department of Homeland Security. Despite this insufficiency, APHIS has kept out many species that would likely have become horrendous pests. APHIS keeps lists of intercepted species (see, e.g., USDA 1982, Dobbs and Brodel 2004), and these include hundreds of species known to be injurious elsewhere.

Adequate resources for inspection would help, but an even bigger problem than the resources for or technology of inspection is the regulations and laws that govern entry to the United States of deliberately introduced species or products that might inadvertently carry them. There are two basic laws; both are weak (Cox 1999, Peoples, McCann, and Starnes 1992). For animals, the chief exclusionary instrument is the Lacey Act of 1900. This Act, frequently amended by Congress, was originally written to help states enforce their own wildlife laws, and the section about introduced species was an afterthought, prohibiting a few species that were already in the United States, such as the house sparrow and starling, or that were famous for causing problems elsewhere, such as fruit bats. In addition to the indirect way in which this Act came to be associated with regulation of introductions, its key shortcoming is that it is a classic blacklist law: any species can be imported, subject to quarantine regulations, so long as it is not on a blacklist. Very few species have been added to the blacklist, and the law is more reactive than proactive. Further, although the Act as a whole was aimed at protecting wildlife (vertebrates), in practice the prohibited species are almost exclusively those that would affect agriculture or public health.

The plant analog to the Lacey Act is the Plant Protection Act (PPA) of 2000, which supersedes the Federal Noxious Weed Act (FNWA) of 1974 and incorporates its Federal Noxious Weeds list. This Act provides a similar blacklist to that of the Lacey Act, with a few species added each year; there are now ca. 100 listed plant species. Any species can be imported, subject to quarantine regulations, if it is not on the list. Although, as with the Lacey Act, the Act states that it will protect wildlife, in practice almost all listed species are potential agricultural pests. Also as with the Lacey Act, the PPA (like the earlier FWNA) is reactive rather than proactive. For instance, the first aquarium plant to be added to the list, the "killer alga" *Caulerpa taxifolia* (Meinesz 2001), was added to the list after this species was discovered in a bay in California. It is also worth noting that the PPA does not prohibit possession of listed species, just importation. Thus, for example, commercial concerns in Florida grow water hyacinth, a listed species, and ship it to Canada, despite the fact that there are myriad instances of confined introduced species escaping confinement or being deliberately released.

A final regulatory instrument with respect to deliberately introducing species to the United States is the Technical Advisory Group (TAG) of APHIS, which must approve introduction of plant-eating insects for biological control of weeds. Although TAG does reject some applications (for instance, it recently rejected a proposal to introduce a weevil to control pest thistles), it has historically been concerned primarily with damage to agriculture (artichokes, in the case of thistles) rather than species of no market significance. TAG members almost all belong to federal agencies and are intended to represent the interests of these agencies. There are no representatives of other stakeholders, such as ecologists, conservationists, or native plant societies. Also, TAG does not regulate introduction of insect-eating insects for biological control. For instance, two Asian lady beetles have recently been introduced to the eastern United States in attempts to control the

Asian hemlock woolly adelgid (Flowers, Salom, and Kok 2005) with no formal consideration by TAG or any similar body, despite the fact that there is already concern that introduced lady beetles affect native non-target species (Simberloff and Stiling 1996).

With respect to risk of inadvertent introduction of invasive species that may hitchhike on commercial goods or on other species, the United States relies on international treaties, particularly those of the World Trade Organization (WTO), as discussed below.

Species Introduced from Within the United States

The United States has a special problem with respect to excluding invaders: it is a huge nation, so an introduction of a species from one part to another—such as the salt marsh grass *Spartina alterniflora* from the east coast to the west coast—is just as likely to be invasive as if the species came from another nation, and many such introductions have caused grievous harm (Cox 1999). However, from a legal standpoint, if a species is native to any part of the continental United States, it can be deliberately taken anywhere within the continental United States (sometimes subject to quarantine laws to ensure that it is not carrying a pathogen that would harm agriculture).

Several states have attempted to sue or enact laws to prevent both deliberate and inadvertent invasions, but they are generally stymied, often by the Commerce Clause of the Constitution (see, e.g., Miller and Fabian 2004). The state laws for deliberate introductions are virtually all blacklist laws. For example, Maryland's law relies on a blacklist promulgated by the Secretary of Natural Resources. State options for excluding accidental invaders hitchhiking on goods or conveyances are severely limited by the Commerce Clause.

International Treaties and Quantitative Risk Assessments

Nowadays, in addition to our weak laws, a major culprit on introduced species is multilateral trade treaties, such as those of the World Trade Organization (WTO) [see Reaser et al. (2003) and Shine, Williams, and Burhenne-Guilmin (2005)]. In an era of bilateral arrangements between nations, any nation could simply refuse to accept a species, such as an ornamental plant, or a product that might inadvertently carry species, such as tiles or wooden packing material, on the grounds that such an import was too likely to lead to a harmful invasion.

Today, such decisions by signatory nations to multilateral treaties are subject to reversal by the adjucating bodies of the treaties (Simberloff 2005). An exclusion based on environmental grounds, such as a decision not to allow in some packing material that might carry a pest, can be appealed to the treaty organization on the grounds that the exclusion is really a covert form of economic protectionism. Furthermore, to defend the exclusion against such an appeal, a nation must present a quantitative risk assessment showing that the risk of harmful invasion is high. Other multilateral treaty organizations, such as the North American Free Trade Association (NAFTA), resemble WTO on this point. For instance, NAFTA requires a quantitative risk assessment to support any infringement of movement of goods on the basis that they could carry pathogens or environmental invaders. President Clinton's 1999 Executive Order 13112 on invasive species mandates quantitative risk assessment as the tool to judge suitability of a species proposed for introduction. Of course this aspect of the Executive Order is part and parcel of a general trend in the United States towards risk assessment in all regulatory matters (Simberloff 2005).

It is understandable that trade regulators seek quantitative, science-based risk assessments, for the sake of transparency and to prevent purely protectionist measures from masquerading as claims of environmental or economic risk. However, risk assessments for species to be deliberately introduced are in a very primitive state (Simberloff 2005). The confidence limits on the various aspects of these risk assessments are so large that it is far from clear that they are useful at all. On the one hand, if done properly, such risk assessments at least cause us to consider formally the various possible problems an introduced species might pose. On the other hand, given the staggering size of the confidence limits, a risk assessment for an introduced species can only be seen as pseudo-quantitative and might give the public a false sense of knowledge and security.

Four main features of introduced species make it extremely difficult to narrow the confidence limits of any risk assessment for a particular species (cf. Simberloff and Alexander 1998). The contrast with risk assessment for chemicals in the environment is striking. First, introduced species move of their own accord. Every species, including introduced species, has some means of autonomous dispersal. Chemicals may move in the environment, but not autonomously. Second, introduced species reproduce, just as all species do. Chemicals do not reproduce themselves. Third, introduced species interact with other species, including other species they have never been in contact with before, and these interactions may increase their impact, as when Japanese white-eyes are the main dispersers of the Atlantic shrub *Myrica faya* in the Hawaiian islands (Woodward et al. 1990), a case that will be discussed below. A chemical in the environment may interact with other chemicals, and such interactions may even increase its impact, but the sheer numbers of species and variety and complexity of their possible interactions means the uncertainty generated by interactions will be much greater for introduced species than for chemicals. Fourth, introduced species evolve, just as all species do, and the forces causing evolution include ones that are wholly random, such as mutation and recombination. Chemicals in the environment certainly change as they break down, but the pathways are far more constrained and predictable.

Among federal agencies, the Department of Agriculture (USDA), the Fish and Wildlife Service (FWS), the Environmental Protection Agency (EPA), and the interagency Aquatic Nuisance Species Task Force (ANSTF) have all applied risk assessment to introduced species, generally following the lead of the USDA generic process (Orr, Cohen, and Griffin 1993), described below. There are two basic kinds of risk assessments: those for particular species that may themselves become pests, and those for products (often species, like some species of timber, but also other materials, such as tiles and used tires) that may serve as pathways by which various hitchhiking species can invade. Most risk assessments for introduced species to date have been of species as pathways, rather than of species to be deliberately introduced that might be invaders in and of themselves. Sometimes a species poses both sorts of risks—for example, the black carp *Mylopharyngodon piceus* (Nico, Williams, and Jelks 2005).

In general, non-agricultural risks, like damage to natural areas, get little attention, and this is why the USDA has been most active among the federal agencies in using risk assessments. Usually the question being asked is whether a species can vector one or more other species that may become pests of agriculture, silviculture, or aquaculture (e.g., USDA 1991, 1992, Tkacz 2002), rather than whether a species may itself become invasive. Another problem is that the agencies presume that species proposed for introduction, or products that might carry them (like wooden packing material), are harmless, and they assess risk only when there is some strong prior reason to think there might be one.

I do not mean to imply that invasion biologists are not making progress, particularly on assessing risks of species that may be proposed for deliberate introduction (see, e.g., Kolar and Lodge 2002). There has been an explosion of research on introduced species over the past decade. However, impacts of introduced species are currently notoriously idiosyncratic and difficult to foresee (Cox 1999, Mack et al. 2000), so it is bad policy to rely on both our preliminary ideas about what might be risky and then risk assessment as a way of following up these ideas.

Another problem is that the quantification of risk achieved by the current process is an illusion (Simberloff and Alexander 1998, Simberloff 2005). Knowledge on most species is simply insufficient to enable more than educated guesses about the likelihood that a species will establish and impacts it might cause. To use the USDA generic process (Orr, Cohen, and Griffin 1993) to assess risk posed by a particular introduced species, risk assessors therefore must guesstimate the various probabilities as low, medium, or high. In the generic process, experts estimate probabilities (as low, medium, or high) that a species disperses, survives, establishes initially, and spreads, respectively, as well as probabilities of different levels (low, medium, or high) of economic, environmental, and perceptual consequences of establishment and spread.

Total risk of establishment is then scored by an ad hoc algorithm as the product of the independent probabilities of dispersal, survival, initial establishment, and spread. Total consequence of establishment is scored according to another ad hoc algorithm as the product of economic, environmental, and perceptual consequences. Total organism "risk potential" is then defined as the product of total risk of establishment and total consequence of establishment, this product scored according to yet another ad hoc algorithm.

If the risk assessment is of a pathway that might inadvertently introduce many species, rather than of a particular species, each component of the process is in principle applied to all those species that the assessors think might be transported in that pathway (cf. Andow 2003). Because there are so many species, and they may arrive by such idiosyncratic routes, risk assessment for an entire pathway poses a great challenge that has barely been addressed.

The single biggest problem with evaluating risk according to this algorithm or any other that I can imagine is simply the huge variety of sorts of impacts an introduced species can have (Cox 1999, Simberloff 2002). Some are obvious: introduced species can eat or parasitize or trample native species. Others are subtler; for instance, a major impact is that introduced species often hybridize with native species, causing a sort of genetic extinction (Rhymer and Simberloff 1996). Even if the matings are sterile and no genes are exchanged, the loss of reproduction can threaten the native species. Most of the biggest problems that introduced species cause are changes in the habitat that affect most of the species that live at a site. For example, plants may simply overgrow the native plants, or may generate enhanced fire regimes that native species are not adapted to (D'Antonio and Vitousek 1992), or may fertilize the soil, as N-fixers do (see, e.g., Asner and Vitousek 2005).

A tremendous complication is the phenomenon of invasional meltdown (Simberloff and Von Holle 1999), in which two or more introduced species facilitate one another so as to increase the probabilities of establishment and/or degree of impact of at least one invader. Often an introduced species remains quite innocuous in its new home until another introduced species invades, at which point the prior species becomes dramatically more problematic. Highly evolved pollination syndromes are an example. In south Florida, ornamental fig (*Ficus*) trees were common for at least a century, restricted to anthropogenic settings because they could not reproduce without their host-specific fig wasps. Recently, the fig wasp (*Parapristina verticillata*) of *Ficus microcarpus* invaded, and the latter is now spreading rapidly, including into natural areas (Kaufmann et al. 1991).

The impact of an exotic plant species is often exacerbated, or at least accelerated, by introduced animals that disperse its seeds. For example, seeds of the nitrogen-fixing *Myrica faya* in Hawaii are primarily dispersed by the introduced Japanese white-eye (Woodward et al. 1990), and also by introduced feral pigs and rats (Stone and Taylor 1984). In this case, there is a further interaction because the density of exotic earthworms under *Myrica* is two to eight times that under the native vegetation it is replacing (Aplet 1990). Exactly who is facilitating whom in this case is unclear, but the plant and the worms could be facilitating one another. In any event, the increased earthworm density with the spread of *Myrica* is helping to bury the nitrogen in the *Myrica* leaves in the soil and increasing rates of nitrogen-cycling. This impact on the nitrogen regime is leading to invasion by exotic plants that were unable to thrive in the nitrogen-poor volcanic soil.

Yet another phenomenon complicating risk assessment for introduced species is that an invader often remains innocuous and restricted in its new environments for decades or longer, then undergoes a rapid population explosion to become a raging pest (Crooks and Soulé 1996). The fig tree *Ficus microcarpus* in Florida waiting for its pollinating wasp to arrive is an excellent example cited previously. Perhaps the most dramatic time lag is that of a Japanese fungus, *Entomophaga maimaiga*, released in the United States in 1910–1911 to control the gypsy moth. After being unrecorded for 79 years, it surfaced again in 1989 and is now having a major impact on gypsy moth populations in the northeastern United States (Hajek, Humber, and Elkinton 1995).

Why a lag has occurred is sometimes obvious (e.g., the case of the fig and fig wasp in Florida) but is often mysterious. New mutations are frequently invoked but have rarely been documented. Another common explanation for sudden population explosion of a hitherto harmless introduced species is a subtle change in the biotic or abiotic environment. How many invasions entail lags is unknown, but the documentation of some well-studied cases suggests that any assessment of impact of an invasive species is subject to rapid change.

The fact that invasion biologists cannot produce credible quantified risk assessments has severe consequences, as risk assessment becomes ever more dominant in regulatory circles. In an era in which free trade is a religion, it is not shocking that the WTO has shown itself to be relentlessly hostile to exclusions claimed on environmental grounds, including those aimed at excluding introduced species. A recent case is informative (Victor 2000). A Canadian exporter wished to ship frozen trout to Australia. Australia banned them on the grounds that they might inadvertently vector parasites that could affect Australian fish. This is not a fatuous concern; whirling disease, which has eliminated rainbow trout fishing from large parts of the American West, got to the United States from Europe in frozen rainbow trout imported to Pennsylvania from Sweden (Bergersen and Anderson 1997). However, Canada appealed the exclusion, and the WTO sustained the appeal and ruled against Australia on two grounds: (i) Australia could not produce a quantitative risk assessment, and (ii) Australia does not subject other imports to the same high safety standards it wanted to impose on salmon.

Risk Assessment Failure in Practice: A Telling Example

An example of many of the problems besetting attempts to assess risk from an introduction comes from the recent introduction of the Asian suminoe oyster *Crassostrea ariakensis* to the Chesapeake Bay (National Research Council 2004, Simberloff 2005). Because populations of the native eastern oyster *Crassostrea virginica* had declined greatly, the state of Virginia proposed introducing the suminoe oyster. This pathway had been tried previously with another Asian oyster, *Crassostrea gigas*, which not only failed to generate commercially adequate populations but also introduced the pathogen MSX, which ravaged remaining populations of the eastern oyster (National Research Council 2004).

Through 2002, the state of Maryland opposed releases as too risky to the environment. The seafood industry advocated fast release despite controversy over risks and benefits, so the National Research Council (NRC) was asked in 2002 to render an opinion. The NRC advocated a thorough risk assessment but cautioned that "development of a quantitative risk assessment model for evaluating risks associated with…management options would require a great deal of additional research that could take many years to complete" (NRC 2004). The NRC restricted its published report (NRC 2004) to an enumeration of risk categories, including both the oyster as potential pathway (e.g., introducing new pathogens) and the oyster as invasive pest in its own right (e.g., competing with native species).

The NRC noted that it would be impossible to limit dispersal of the suminoe oyster if it were introduced to the Chesapeake Bay, and further emphasized a great risk of illegal plantings, including of reproductively viable diploids (the test oysters were to be artificially produced sterile triploids). The heart of the chapter in the NRC report on risk listed management procedures that might lessen certain risks, but the report did not try to quantify risk.

The NRC could not produce even this "quick and dirty" qualitative risk assessment quickly enough for major stakeholders. When Robert Ehrlich became governor in January 2003, Maryland's stance changed dramatically, and in advance of the NRC report the state pursued its own program to introduce the suminoe oyster to the Chesapeake Bay. The Virginia Seafood Council urged rapid field trials, and with Maryland now unopposed, the NRC was asked for a preliminary report before completing its study.

In early 2003, the NRC issued a preliminary letter report listing risks of the proposed field trials, including the likelihood that fertile diploids would be released, and concluded that there was currently inadequate scientific information on which to base an assessment of risks of the introduction, a statement repeated in the final report (NRC 2004).

However, shortly after the NRC preliminary opinion, the Virginia Marine Resources Commission allowed the field test to proceed, and suminoe oysters were distributed in the Chesapeake Bay and elsewhere. Thousands have escaped to the wild from ruptures of mesh bags, spillage during transfers, and because of equipment damage during Hurricane Isabel (Smith 2004). Now the U.S. Army Corps of Engineers plus Virginia and Maryland agencies are doing a 1-year environmental impact assessment (rather than the 5-

year study recommended by the NRC) on risks associated with introducing fertile diploid *C. ariakensis* (Blankenship 2004).

The types of risks the NRC considered show just how variegated and complicated the possibilities are. Introduced oysters have many of the same sorts of effects as zebra mussels; these are summarized by Ruesink et al (2005). Of course, in many instances, introduced oysters are more or less replacing native oysters and the ecological functions they served. This is the goal of the suminoe oyster introduction, although the emphasis there is much more on commercial production then ecosystem function. By suspension feeding, oysters filter huge amounts of water and thereby influence energy flow and nutrient cycling at the scale of estuaries. There are very few data on impact on biogeochemical cycles, but they must be huge. Oysters release inorganic nutrients into the water, which probably enhances phytoplankton productivity, and there is also a major buildup of organic matter near reefs. Some reefs of introduced oysters do not really replace native oysters, but constitute new structures, such as some reefs of *Crassostrea gigas* in Willapa Bay, Washington. The ecosystem impacts in such cases must be enormous.

Hitchhikers on introduced oysters are legion (Ribera Siguan 2003), and these are not only pathogens. Some hitchhikers have also produced whole new structural habitats that house a new community. For example, *Caulacanthus ustulatus*, an Asian turf-forming red alga, has been introduced with *C. gigas* and forms monocultures in the intertidal in the Azores and at Elkhorn Slough, California (Ruesink et al. 2005).

In addition to the fact that the NRC (2004) continually stressed (i) that there was not nearly enough information to do a valid risk assessment in less than five years and (ii) that they could not even attempt to quantify risks, it is interesting to point out that even this group of experts, who tried hard to think of every possible contingency, did not think of everything. Two protist parasites in the genus *Bonamia* are strongly suspected of having devastated *C. ariakensis* being grown off North Carolina (*Bay Journal* 2004). Where they came from is unknown, but native mollusk hosts are suspected. The concern now is that the infected *C. ariakensis* in North Carolina could spread the parasite to *C. ariakensis* (and perhaps to other species) in the Chesapeake Bay and beyond. Neither the NRC nor anyone else I am aware of suggested this possibility. Another unforeseen problem is that *C. ariakensis* is far more susceptible than the native *C. virginica* to predation by blue crabs (*Callinectes sapidus*), possibly to the extent of preventing *C. ariakensis* from attaining sufficient densities to support fishery restoration (Bishop and Peterson 2006).

A More Rational and Effective Process for Limiting Introduced Species

If a particular species, like the small Indian mongoose (Laycock 1966), has proven invasive in most places where it has been introduced, it is a good bet that it will be invasive if introduced to yet another site. Obviously such a species should be blacklisted. Beyond this limited dictum—a species invasive in one site is likely to be invasive in others (Lonsdale 1999)—invasion biologists have great difficulty making firm assessments of the probability that a deliberately introduced species will become invasive. Similarly, for pathways, if many pests have been inadvertently introduced by the same pathway, such as in ballast water on vessels moving from the Caspian region to North America (Ricciardi and MacIsaac 2000), one can guess that the pathway is likely to transport others, but it is currently impossible to say just what degree of usage of a pathway will be associated with what probability of introducing a new invader in a given time period.

As observed above, almost all federal and state legislation so far relies on blacklists of particular species. But these blacklists alone have not sufficed. They are largely reactive rather than proactive. Often species have been blacklisted only after they have been introduced.

The proactive approach to blacklisting a species, using a formal risk assessment, has rarely been tried, but it seems unlikely to work well because various treaties require quantified risk assessments and, as shown above, ecologists simply cannot adequately quantify risk, for three main reasons: (i) the endeavor is quite new, (ii) the possible impacts are myriad and complicated, and (iii) there are inherently unpredictable aspects of species, such as evolution. I emphasize that invasion biologists are making progress. With limited groups of species, such as pines (Rejmanek and

Richardson 1996, Grotkopp, Rejmanek, and Rost 2002) and woody plants in general (Reichard and Hamilton 1997), they have had some success using decision trees and discriminant analysis to separate post facto which species have become invasive and which have not. But there are not many such efforts, and there are always species whose traits suggest that they should not be invasive, but that are.

For pathways for inadvertent introductions, the situation is even worse. We can identify certain pathways as having carried many invaders in the past, but we can in no way quantify the risks associated with those pathways today.

What is needed for deliberate introductions is both blacklist and white list laws. That is, there are certainly some species that should never be allowed in (those on the blacklist). For example, knowing the huge damage the small Indian mongoose has caused wherever it has established introduced populations, we would be foolish even to consider it for introduction. It must be blacklisted.

But, in addition, no species, no matter how innocuous it may appear, should be able to be imported unless it is approved (that is, put on a white list), and it should not be approved unless it is subjected to serious expert scrutiny. The burden should be shifted from the government to the party that wants to introduce the species, to show it is likely to be harmless, rather than the government having to show it has a high probability of being harmful. The fact that a risk assessment cannot be quantified should play a minuscule role in a white-listing decision.

With respect to pathways that carry unplanned introductions, we have to recognize that we cannot quantify the risks associated with them, but that certain ones have repeatedly introduced pests in the past and will very likely do so again unless constricted.

Finally, contingencies of history have rendered a huge swath of the North American continent all one nation, encompassing many different sorts of ecosystems that have evolved in isolation from one another. The result is that introductions within the United States can be every bit as damaging as introductions from outside our borders. This happenstance of history should not govern how we regulate movement of species or products that might carry them. In short, if we are to avoid an ever-increasing cost of biological invasions, there must be limits on interstate transport of species and interstate pathways that carry them.

References

Andow, D.A. 2003. "Pathways-Based Risk Assessment of Exotic Species Invasions." In G.M. Ruiz and J.T. Carlton, eds., *Invasive Species: Vectors and Management Strategies*. Washington, D.C.: Island Press.

Aplet, G.H. 1990. "Alteration of Earthworm Community Biomass by the Alien *Myrica faya* in Hawaii (USA)." *Oecologia* 82(3): 414–416.

Asner, G.P., and P.M. Vitousek. 2005. "Remote Analysis of Biological Invasion and Biogeochemical Change." *Proceedings of the National Academy of Sciences* 102(12): 4383–4386.

Bay Journal. 2004. "2nd Strain of *Bonamia* Parasite Found, May Pose Threat to *ariakensis*." *Bay Journal* 14(1): 7.

Bergersen, E.P., and D.E. Anderson. 1997. "The Distribution and Spread of *Myxobolus cerebralis* in the United States." *Fisheries* 22(8): 6–7.

Bishop, M.J., and C.H. Peterson. 2006. "When r-Selection May Not Predict Proliferation of an Introduced Species: Relative Susceptibility of a Non-Native Oyster to Predation." *Ecological Applications* (in press).

Blankenship, K. 2004. "Scientists Urge Officials to Proceed Slowly with *ariakensis*." *Bay Journal* 14(1): 1, 6–7.

Cox, G.W. 1999. *Alien Species in North America and Hawaii*. Washington, D.C.: Island Press.

Crooks, J., and M.E. Soulé. 1996. "Lag Times in Population Explosions of Invasive Species: Causes and Implications." In O.T. Sandlund, P.J. Schei, and A. Viken, eds., *Proceedings, Norway/UN Conference on Alien Species*. Trondheim, Norway: Directorate for Nature Management and Norwegian Institute for Nature Research.

D'Antonio, C.M., and P.M. Vitousek. 1992. "Biological Invasions by Exotic Grasses, the Grass/Fire Cycle, and Global Change." *Annual Review of Ecology and Systematics* 23: 63–87.

Dobbs, T.T., and C.F. Brodel. 2004. "Cargo Aircraft as a Pathway for Entry of Nonindigenous Pests into South Florida." *Florida Entomologist* 87(1): 65–78.

Fargione, J., and B. Wolff. 2001. University of Minnesota, Minneapolis. Personal communication.

Flowers, R.W., S.M. Salom, and L.T. Kok. 2005. "Competitive Interactions Among Two Specialist Predators and Generalist Predator of Hemlock Woolly Adelgid, *Adelges tsugae* (Homoptera: Adelgidae), in the Laboratory." *Environmental Entomology* 34(3): 664–675.

Grotkopp, E., M. Rejmanek, and T.L. Rost. 2002. "Toward a Causal Explanation of Plant Invasiveness: Seedling Growth and Life-History Strategies of 29 Pine (*Pinus*) Species." *American Naturalist* 159(4): 396–419.

Hajek, A.E., R.A. Humber, and J.S. Elkinton. 1995. "Mysterious Origins of *Entomophaga maimaiga* in North America." *American Entomologist* 41(1): 31–42.

Kaufmann, S., D.B. McKey, M. Hossaert-McKey, and C.C. Horvitz. 1991. "Adaptations for a Two-Phase Seed Dispersal System Involving Vertebrates and Ants in a Hemiepiphytic Fig (*Ficus microcarpa*: Moraceae)." *American Journal of Botany* 78(7): 971–977.

Kolar, C.S., and D.M. Lodge. 2002. "Ecological Predictions and Risk Assessment for Alien Fishes in North America." *Science* 298(5596): 1233–1236.

Laycock, G. 1966. *The Alien Animals*. Garden City, NY: Natural History Press.

Lonsdale, W.M. 1999. "Concepts and Synthesis: Global Patterns of Plant Invasions, and the Concept of Invasibility." *Ecology* 80(5): 1522–1536.

Mack, R.N., D. Simberloff, W.M. Lonsdale, H. Evans, M. Clout, and F.A. Bazzaz. 2000. "Biotic Invasions: Causes, Epidemiology, Global Consequences, and Control." *Ecological Applications* 10(3): 689–710.

Meinesz, A. 2001. *Killer Algae* (with new postscript). Chicago: University of Chicago Press.

Miller, M.L., and R.N. Fabian (eds.). 2004. *Harmful Invasive Species: Legal Responses*. Washington, D.C.: Environmental Law Institute.

National Research Council. 2004. *Nonnative Oysters in the Chesapeake Bay*. Washington, D.C.: National Academy Press.

Naylor, R.L. 1996. "Invasions in Agriculture: Assessing the Cost of the Golden Apple Snail in Asia." *AMBIO* 25(7): 443–448.

____. 2000. "The Economics of Alien Species Invasions." In H.A. Mooney and R.J. Hobbs, eds., *Invasive Species in a Changing World*. Washington, D.C.: Island Press.

Nico, L.G., J.D. Williams, and H.L. Jelks. 2005. *Black Carp: Biological Synopsis and Risk Assessment of an Introduced Fish*. Bethesda, MD: American Fisheries Society.

Orr, R.L., S.D. Cohen, and R.L. Griffin. 1993. "Generic Non-Indigenous Species Pest Risk Assessment Process (for Estimating Pest Risk Associated with the Introduction of Non-Indigenous Organisms)." Animal and Plant Health Inspection Service, U.S. Department of Agriculture, Beltsville, MD.

Peoples, Jr., R.A., J.A. McCann, and L.B. Starnes. 1992. "Introduced Organisms: Policies and Activities of the U.S. Fish and Wildlife Service." In A. Rosenfield and R. Mann, eds., *Dispersal of Living Organisms into Aquatic Ecosystems*. College Park, MD: Maryland Sea Grant College.

Pimentel, D., L. Lach, R. Zuniga, and D. Morrison. 2000. "Environmental and Economic Costs of Non-Indigenous Species in the United States." *BioScience* 50(1): 53–65.

Pimentel, D., S. McNair, J. Janecka, J. Wightman, C. Simmonds, C. O'Connell, E. Wong, L. Russel, J. Zern, T. Aquino, and T. Tsomondo. 2001. "Economic and Environmental Threats of Alien Plant, Animal, and Microbe Invasions." *Agriculture, Ecosystems, and Environment* 84(1): 1–20.

Reaser, J.K., B.B. Yeager, P.R. Phifer, A.K. Hancock, and A.T. Gutierrez. 2003. "Environmental Diplomacy and the Global Movement of Invasive Alien Species: A U.S. Perspective." In G.M. Ruiz and J.T. Carlton, eds., *Invasive Species: Vectors and Management Strategies*. Washington, DC: Island Press.

Reichard, S.H., and C.W. Hamilton. 1997. "Predicting Invasions of Woody Plants Introduced into North America." *Conservation Biology* 11(1): 193–203.

Rejmanek, M., and D.M. Richardson. 1996. "What Attributes Make Some Plant Species More Invasive?" *Ecology* 77(6): 1655–1661.

Rhymer, J., and D. Simberloff. 1996. "Extinction by Hybridization and Introgression." *Annual Review of Ecology and Systematics* 27: 83–109.

Ribera Siguan, M.A. 2003. "Pathways of Biological Invasions of Marine Plants." In G.M. Ruiz and J.T. Carlton, eds., *Invasive Species: Vectors and Management Strategies*. Washington, D.C.: Island Press.

Ricciardi, A., and H.J. MacIsaac. 2000. "Recent Mass Invasion of the North American Great Lakes by Ponto-Caspian Species." *Trends in Ecology and Evolution* 15(2): 62–65.

Ruesink, J., H.S. Lenihan, A. Trimble, K.W. Heiman, F. Micheli, J.E. Byers, and M. Kay. 2005. "Introduction of Non-Native Oysters: Ecosystem Effects and Restoration Implications." *Annual Review of Ecology, Evolution, and Systematics* 36: 643–689.

Shine, C., N. Williams, and F. Burhenne-Guilmin. 2005. "Legal and Institutional Frameworks for Invasive Alien Species." In H.A. Mooney, R.N. Mack, J.A. McNeely, L.E. Neville, P.J. Schei, and J.K. Waage, eds., *Invasive Alien Species: A New Synthesis*. Washington, D.C.: Island Press.

Simberloff, D. 2002. "Ecological and Economic Impacts of Alien Species: A Phenomenal Global Change." In R. Claudi, P. Nantel, and E. Muckle-Jeffs, eds., *Alien Invaders in Canada's Waters, Wetlands, and Forests*. Ottawa: Natural Resources Canada.

____. 2005. "The Politics of Assessing Risk for Biological Invasions: The USA as a Case Study." *Trends in Ecology and Evolution* 20(5): 216–222.

Simberloff, D., and M. Alexander. 1998. "Assessing Risks to Ecological Systems from Biological Introductions (excluding genetically modified organisms)." In P. Calow, ed., *Handbook of Environmental Risk Assessment and Management.* Oxford: Blackwell.

Simberloff, D., and P. Stiling. 1996. "How Risky Is Biological Control?" *Ecology* 77(7): 1965–1974.

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

Smith, P. 2004. "Work on Oyster Experiment Report Begins." *Jacksonville Daily News* (Jacksonville, NC), December 1, p. 1.

Stone, C.P, and D.D. Taylor. 1984. "Status of Feral Pig Management and Research in Hawaii Volcanoes National Park." *Proceedings of the Hawaii Volcanoes National Park Natural Science Conference* 5: 106–117.

Tkacz, B.M. 2002. "Pest Risks Associated with Importing Wood to the United States." *Canadian Journal of Plant Pathology* 24(2): 111–116.

U.S. Department of Agriculture. 1982. "List of Intercepted Plant Pests: Fiscal Years 1980–1981." USDA/APHIS/PPQ, APHIS 82-8. U.S. Department of Agriculture, Washington, D.C.

____. 1991. "Pest Risk Assessment of the Importation of Larch from Siberia and the Soviet Far East." Miscellaneous Publication No. 1495, Forest Service, U.S. Department of Agriculture, Washington, D.C.

____. 1992. "Pest Risk Assessment of the Importation of *Pinus radiata* and Douglas-Fir Logs from New Zealand." Miscellaneous Publication No. 1508, Forest Service, U.S. Department of Agriculture, Washington, D.C.

Victor, D.G. 2000. "Risk Management and the World Trading System: Regulating International Trade Distortions Caused by National Sanitary and Phytosanitary Policies." *Incorporating Science, Economics, and Sociology in Developing Sanitary and Phytosanitary Standards in International Trade* (National Resource Council). Washington, D.C.: National Academy Press.

Williamson, M., and A. Fitter. 1996. "The Varying Success of Invaders." *Ecology* 77(6): 1661–1666.

Woodward, S.A., P.M. Vitousek, K. Matson, F. Hughes, K. Benvenuto, and P.A. Matson. 1990. "Use of the Exotic Tree *Myrica faya* by Native and Exotic Birds in Hawai'i Volcanoes National Park." *Pacific Science* 44(1): 88–93.

Zavaleta, E. 2000. "Valuing Ecosystem Services Lost to *Tamarix* Invasion in the United States." In H.A. Mooney and R.J. Hobbs, eds., *Invasive Species in a Changing World*. Washington, D.C.: Island Press.