

Strangers in Our Midst

The Problem of Invasive Alien Species

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Invasive alien species—non-native species that become established in a new environment then proliferate and spread in ways that damage human interests—are now recognized as one of the greatest biological threats to our planet's environmental and economic well-being.¹

Most nations are already grappling with complex and costly invasive-species problems: Zebra mussels (*Dreissena polymorpha*) from the Caspian and Black Sea region affect fisheries, mollusk diversity, and electric-power generation in Canada and the United States; water hyacinth (*Eichornia crassipes*) from the Amazon chokes African and Asian waterways; rats originally carried by the first Polynesians exterminate native birds on Pacific islands; and deadly new disease organisms (such as the viruses causing SARS, HIV/AIDS, and West Nile fever) attack human, animal, and plant populations in temperate and tropical countries. For all animal extinctions where the cause is known, invasive alien species are the leading culprits, contributing to the demise of 39 percent of species that have become extinct since 1600.² The 2000 IUCN Red List of Threatened Species reported that invasive alien species harmed 30 percent of threatened birds and 15 percent of threatened plants.³ Addressing the problem of these invasive alien species is urgent because the threat is growing daily and the economic and environmental impacts are severe.

A key question is whether the global reach of modern human society can be matched by an appropriate sense of responsibility. One critical element of this question is the definition of "native," a concept with challenging spatial and temporal dimensions. While every species is native to a particular geographic area, this is just a snapshot in time, because species are constantly expanding and contracting their ranges, sometimes with human help. For example, Britain has nearly 40 more species of birds today than were recorded 200 years ago. About a third of these are deliberate introductions, such as the Little Owl (*Athene noctua*), while the others are natural colonizations that may be taking advantage of climate change.⁴

An invasive alien species is not a "bad" species but rather one "behaving badly" in a particular context.

According to one view, local biological "enrichment" by non-native species always harms native species at some level, so any introduction should be regarded, at least in principle, as undesirable. An opposing view is that because species are constantly expanding or contracting their range, new species—especially those that are beneficial to people, such as crops, ornamental plants, and pets—should be welcomed as "increasing biodiversity" unless they are clearly harmful. According to this perspective, in the case of British birds noted above, only those introduced by people and that are causing ecological or economic damage, such as pigeons, are considered to be invasive.

All continental areas have suffered from invasions of alien species, losing biological diversity as a result, but the problem is especially acute on islands in general and for small islands in particular. The physical isolation of islands over millions of years has favored the evolution of unique species and ecosystems, so islands often have a high proportion of endemic species. The evolutionary processes associated with isolation have also meant that island species are especially vulnerable to predators, pathogens, and parasites from other areas. More than 90 percent of the 115 birds known to have become extinct over the past 400 years were endemic to islands.⁵ Most of these evolved in the absence of mammalian predators, so the arrival of rats and cats carried by people has had a devastating impact.

Island plants are also affected. For example, the tree *Miconia calvescens* replaced the forest canopy on more than 70 percent of the island of Tahiti over a 50-year time span, starting with a few trees in two botanical gardens. Some 40–50 of the 107 plant species endemic to the island of Tahiti are believed to be on the verge of extinction primarily due to this invasion.⁶ Introduced animals also can affect plants. For example, goats introduced on St. Clemente Island, California, have caused the extinction of eight endemic species of plants and have endangered eight others.⁷

An invasive alien species is not a "bad" species but rather one "behaving badly" in a particular context, usually due to inappropriate human agency or intervention. A species may be so threatened in its natural range that it is given legal protection, yet it may generate massive ecological and other damage elsewhere.

The degradation of natural habitats, ecosystems, and agricultural lands (through loss of vegetation and soil and pollution of land and waterways) that has occurred throughout the world has

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made it easier for non-native species to become invasive, opening up new possibilities for them. For all of these reasons, and others that will become apparent below, the issue of invasive alien species is receiving growing international attention.

The Vectors: How Species Move Around the World

The natural barriers of oceans, mountains, rivers, and deserts have provided the isolation that has enabled unique species and ecosystems to evolve. But in just a few hundred years, these barriers have been overcome by technological changes that helped people move species vast distances to new habitats, where some of them became invasive. The growth in the volume of international trade, from US\$192 billion in 1960 to almost \$6 trillion in 2003,⁸ provides more opportunities than ever for species to be spread either accidentally or deliberately.

Some movement seems accidental, or at least incidental, in that transporting the species was not the purpose of the transporter. For example, ballast water is now regarded as the most important vector for transoceanic movements of shallow-water coastal organisms, dispersing fish, crabs, worms, mollusks, and microorganisms from one ocean to another. Enclosed water bodies like San Francisco Bay are especially vulnerable. The bay already has at least 234 invasive alien species, causing significant economic damage. California has one of the toughest ballast water laws in the nation, requiring ships from foreign ports to exchange their ballast water 200 miles from the California coastline, but enforcement remains spotty at best.

Ballast water may also be important in the epidemiology of waterborne diseases affecting plants and animals. One study measured the concentration of the bacteria *Vibrio cholerae*—which cause human epidemic cholera—in the ballast water of vessels arriving to the Chesapeake Bay from foreign ports, finding the bacteria in plankton samples from all ships.⁹

Other invasives are hitchhikers on global trade. For example, the Asian long-horned beetle (*Anoplophora glabripennis*) is one of the newest and most harmful invasive species in the United States. Originating in northeastern Asia, it finds its way to the United States through packing crates made of low-quality timber (that which is too infested for other uses). The number of insects found in materials imported from China increased from 1 percent of all interceptions in 1987 to 20 percent in 1996.¹⁰ Outbreaks were reported in and around Chicago as early as 1992, in Brooklyn in August 1996, and in California in 1997. The beetle finds a congenial home among native maples, elders, elms, horse chestnuts, and others. The U.S. Department of Agriculture predicted that if the beetle becomes established, it could denude Main Street, USA, of shade trees, affect lumber and maple sugar production, threaten tourism in infested areas, and reduce biological diversity in forests.¹¹

Another dangerous trade-related species for North America is the Asian gypsy moth (*Lymantria dispar*), which was first reported in the United States in 1991, entering as egg masses attached to ships or cargo from eastern Siberia. The caterpillars of this species are known to feed on more than 600 species of trees, and as moths, the females can disperse themselves

over long distances. Scientists fear that this species could cause vastly more damage than the European gypsy moth, which already defoliates 1.5 million hectares of forest per year in North America.

With almost 700 million people crossing international borders as tourists each year, the opportunities for them to carry potential invasive species, either knowingly or unknowingly, are profound and increasing. Many tourists return with living plants that may become invasive, or carry exotic fruits that may be infested with invasive insects that can plague agriculture back home. Travelers may also carry diseases between countries, as apparently happened with the SARS virus. Tourism is considered an especially efficient pathway for invasive alien species on subAntarctic islands such as South Georgia. Visitors to the island reached 15,000 in 1999. Part of the problem is that many tourists are visiting similar islands on the same trip, increasing the chances of a seed, fruit, or insect being carried, more than would be expected from a single landing of a few people who spend an extended time on one island.¹²

Many species are introduced on purpose but have unintended consequences. One example of purposeful introduction gone wrong is the extensive stocking program that introduced African tilapia *Oreochromis* into Lake Nicaragua in the 1980s, resulting in the decline of native populations of fish and the imminent collapse of one of the world's most distinctive freshwater ecosystems. The alteration of Lake Nicaragua's ecosystem is likely to have effects on the planktonic community and primary productivity of the entire lake—Central America's largest—destroying native fish populations and likely leading to unanticipated consequences.¹³

Sport fishers have also had an influence, importing their favorite game fish into new river systems, where they can have significant negative impacts on native species. For example, the northern pike (*Esox lucius*) has invaded rivers in Alaska and is replacing native species of salmon. While the northern pike occurs naturally in some parts of Alaska, it was introduced to the salmon-rich south-central area in the 1950s, probably by a fisherman who brought it to Bulchitna Lake. Flooding in the 1980s subsequently spread the pike into the streams of the Susitna and Matanuska river basins. Pike have now occupied at least a dozen lakes and four rivers in some of the richest salmon and trout habitat in the Pacific Northwest. Rainbow trout are an even greater threat. Originating in western North America, they have been introduced into 80 new countries, often with devastating impacts on native fish.

Pets are also a problem. Domestic cats can plunder ecosystems that they did not previously inhabit. On Marion Island in the sub-Antarctic Indian Ocean, cats were estimated to kill about 450,000 seabirds annually.¹⁴ Exotic pets may escape—or be released when they have outlived their novelty—and become established in their new home. Stories of crocodiles in the Manhattan's sewer system are probably fanciful, but many former pets are becoming established in the wild. For example, Monk parakeets (*Myiopsitta monachus*), descended from former pets that were released possibly in the 1960s, have invaded some 76 localities in 15 U.S. states.¹⁵ Native to southern South America, they are the only parrots that build their own nests,

some of which support several hundred individuals and have separate families living in different chambers. Some believe that they soon will become widespread throughout the lower 48 states, posing a significant threat to at least some agricultural lands by feeding on ripening crops. And Burmese pythons (*Python molurus*) have become established in Everglades National Park, where they reach a very large size and prey on many native species, even alligators.

Pet stores often advertise invasive species that are legally controlled. For example, the July 2000 issue of the magazine *Tropical Fish Hobbyist* recommended several species of the genus *Salvinia* as aquarium plants, even though they are considered noxious weeds in the United States and prohibited by Australian quarantine laws.

The globalization of trade and the power of the Internet offer new challenges, as sales of seeds and other organisms by mail order or over the Internet pose new and very serious risks to the ecological security of all nations. Controls on harvest and export of species are required as part of a more responsible attitude of governments toward the potential of spreading genetic pollution through invasive species. Further, all receiving countries want to ensure that they are able to control what is being imported. Virtually all countries in the world have serious problems in this regard, an issue that some countries are calling "biosecurity."

The Science of Understanding Invasions

Biodiversity is dynamic, and the movement of species around the world is a continuing process that is accelerating through expanding global trade. By trying to identify which species are especially likely to become invasive, and hence harmful to people, ecologists are improving the quality of invasion biology as a predictive science so that people can continue to benefit from global biodiversity without paying the costs resulting from species that later become harmful.

Previous examples indicate the characteristics that can make a species invasive. For instance, coastal ecosystems are frequently invaded by microorganisms from ballast water for three main reasons. First, concentrations of bacteria and viruses exceed those reported for other taxonomic groups in ballast water by 6 to 8 orders of magnitude, and the probability of successful invasion increases with inoculation concentration. Second, the biology of many microorganisms combines a high capacity for increase, asexual reproduction, and the ability to form dormant resting stages. Such flexibility in life history can broaden the opportunity for successful colonization, allowing rapid population growth when suitable environmental conditions occur. And third, many microorganisms can tolerate a broad range of environmental conditions, such as salinity or temperature, so many sites may be suitable for colonization.¹⁶ Insects are a major problem because they can lay dormant or travel as egg masses and are difficult to detect. The African tilapia introduced to Lake Nicaragua adapted well, because they are able to grow rapidly; feed on a wide range of plants, fish, and other organisms; and

form large schools that can migrate long distances. Further, they are maternal mouth brooders, so a single female can colonize a new environment by carrying her young in her mouth.¹⁷ Rapid growth, generalized diet, ability to move large distances, and prolific breeding are all characteristics of successful invaders.

It is not always simple, however, to distinguish a beneficial non-native species from one at significant risk of becoming invasive. A non-native species that is useful in one part of a landscape may invade other parts of the landscape where its presence is undesirable, and some species may behave well for decades before suddenly erupting into invasive status. The Nile Perch (*Lates niloticus*), for example, was introduced to Lake Victoria in the 1950s but did not become a problem until the 1980s, when it was a key factor in the extinction of as many as half of the lake's 500 species of endemic fish, attractive prey for the perch.¹⁸ That said, ecologists over the past several decades have agreed on some broad principles for guiding risk assessment. First, the probability of a successful invasion increases with the initial population size and with the number of attempts at introduction. While it is possible for a species to invade with a single gravid female or fertile spore, the odds of doing so are very low. Second, among plants, the longer a non-native plant has been recorded in a country and the greater the number of seeds or other propagules that it produces, the more likely it will become invasive. Third, species that are successful invaders in one situation are likely to be successful in other situations; rats, water hyacinth, microorganisms, and many others fall into this category. Fourth, intentionally introduced species may be more likely to become established than are unintentionally introduced species, at least partly because the vast majority of these have been selected for their ability to survive in the environment where they are introduced. Fifth, plant invaders of croplands and other highly disturbed areas are concentrated in herbaceous families with rapid growth and a wide range of environmental tolerances, while invaders of undisturbed natural areas are usually from woody families, especially nitrogen-fixing species that can live in nitrogen-poor soils.¹⁹ And sixth, fire, like disturbance in general, increases invasion by introduced species. So ecosystems that are naturally prone to fire, such as the fynbos of South Africa, coastal chaparral in California, and maquis in the Mediterranean,²⁰ can be heavily invaded if fire-liberated seeds of invasive species are available. (These are all shrub communities adapted to cool, wet winters and hot, dry summers, where fire is a regular phenomenon. They are also rich in species: Fynbos have about 8,500 species that include many endemic *Proteaceae*; chaparral have about 5,000 species; and maquis have 25,000—of which about 60 percent are endemic to the Mediterranean region.²¹)

Other ecological factors that may favor nonindigenous species include a lack of controlling natural enemies, the ability of an alien parasite to switch to a new host, an ability to be an effective predator in the new ecosystem, the availability of artificial or disturbed habitats that provide an ecosystem the aliens can easily invade, and high adaptability to novel conditions.²²

It is sometimes argued that systems with great species diversity are more resistant to new species invading. However, a

Invasive Alien Species and Protected Areas

Protected areas are widely perceived as being devoted to conserving natural ecosystems. Ironically, protected areas are in fact heavily damaged by invasive alien species, and many protected-area managers consider this their biggest problem. Some examples:

- Galapagos National Park, a World Heritage site, is being affected by numerous invasive alien species, including pigs, goats, feral cats, fire ants, and mosquitoes.
- Kruger National Park, South Africa's largest, has recorded 363 alien plant species, including water weeds that pose a serious threat to the park's rivers.
- In the Wadden Sea, a biosphere reserve and Ramsar site protected by the Netherlands, Germany, and Denmark, the Pacific oyster has invaded, having escaped captive management. It is disrupting tourism because of its sharp shells. It has also carried with it numerous other invasive alien species.
- The Wet Tropic World Heritage Area of North Queensland, Australia, is infested by numerous invasive alien species, of which the worst is the pond apple from

Florida, which has invaded creeks and riverbanks, wetlands, melaleuca swamps, and mangrove communities. Feral pigs, another invasive species, help to spread the species. The pond apple is now rare in its native range in the Florida Everglades.

- Everglades National Park in Florida, another World Heritage site, is threatened by the invasion of melaleuca from Queensland, demonstrating that species that may behave well in their natural habitat can be a serious problem when they invade somewhere else.
- Tongariro National Park, New Zealand, is also a World Heritage site, but a third of its territory has been infested by heather, a European plant deliberately introduced into New Zealand by an early park warden in 1912 in an attempt to reproduce the moors of Scotland.

These are just a few examples among many that could be cited that demonstrate that even the most strictly protected areas can be extremely vulnerable to invasion by non-native species.

study in a California riparian system found that the most diverse natural assemblages are in fact the most invaded by non-native plants, and protected areas worldwide are heavily invaded by non-native plants and animals.²³ Dalmatian toadflax (*Linaria dalmatica*) is invading relatively undisturbed shrub-steppe habitat in the Pacific Northwest, wetland nightshade (*Solanum tampicense*) is invading cypress wetlands in central and south Florida, and garlic mustard (*Alliaria officinalis*) is often found in relatively undisturbed systems in the northern parts of North America.

This work helps resolve the controversy over the relationship between biodiversity and invasions, suggesting that the scale of investigation is a critical factor. Theory suggests that non-native species should have a more difficult time invading a diverse ecosystem, because the web of species interactions should be more efficient in using resources such as nutrients, light, and water than would fewer species, leaving fewer resources available for the nonnative species. But even in well-protected landscapes such as national parks, invaders often seem to be more successful in diverse ecosystems. Even though diversity does matter in fending off invasives, its effects are negated by other factors at larger scales. The most diverse ecosystems might be at the greatest risk of invasion, while losses of species, if they affect community-scale diversity, may erode invasion resistance.²⁴

The Economic Impacts of Invasion

One reason invasive alien species are attracting more attention is that they are having substantial negative impacts on numerous economic sectors, even beyond the obvious impacts on agriculture

(weeds), forestry (pests), and health (diseases or disease vectors). The probability that any one introduced species will become invasive may be low, but the damage costs and costs of control of the species that do become invasive can be extremely high (such as the recent invasion of eastern Canada by the European brown spruce longhorn beetle (*Tetropium fuscum*), which threatens the Canadian timber industry).

Estimates of the economic costs of invasive alien species include considerable uncertainty, but the costs are profound—and growing (see Table 1).

Most of these examples come from the industrialized world, but developing countries are experiencing similar, and perhaps proportionally greater, damage. Invasive alien insect pests—such as the white cassava mealybug (*Phenacoccus herreni*) and larger grain borer (*Prostephanus truncates*) in Africa—pose direct threats to food security. Alien weeds constrain efforts to restore degraded land, regenerate forests, and improve utilization of water for irrigation and fisheries. Water hyacinth and other alien water weeds that choke waterways currently cost developing countries in Africa and Asia more than US\$100 million annually. Invasive alien species pose a threat to more than \$13 billion of current and planned World Bank funding to projects in the irrigation, drainage, water supply, sanitation, and power sectors.²⁵ And a study of three developing nations (South Africa, India, and Brazil) found annual losses to introduced pests of \$138 billion per year.²⁶

In addition to the direct costs of managing invasives, the economic costs also include their indirect environmental consequences and other nonmarket values. For example, invasives may cause changes in ecological services by disturbing the operation of the hydrological cycle, including flood control

Table 1 Indicative Costs of Some Invasive Alien Species (in U.S. Dollars)

Species	Economic Variable	Economic Impact
Introduced disease organisms	Annual cost to human, plant, and animal health in the United States	\$41 billion per year ^a
A sample of alien species of plants and animals	Economic costs of damage in the United States	\$137 billion per year ^b
Salt cedar	Value of ecosystem services lost in western United States	\$7–16 billion over 55 years ^c
Knapweed and leafy spurge	Impact on economy in three U.S. states	Direct costs of \$40.5 million per year; indirect costs of \$89 million ^d
Zebra mussel	Damages to U.S. industry	Damage of more than \$2.5 billion to the Great Lakes fishery between 1998–2000; ^e \$5 billion to U.S. industry by 2000 ^f
Most serious invasive alien plant species	Costs 1983–1992 of herbicide control in England	\$344 million per year for 12 species ^g
Six weed species	Costs in Australia agroecosystems	\$105 million per year ^h
Pinus, Hakeas, and Acacia	Costs on South African floral kingdom to restore to pristine state	\$2 billion total for impacts felt over several decades ⁱ
Water hyacinth	Costs in seven African countries	\$20–50 million per year ^j
Rabbits	Costs in Australia	\$373 million per year (agricultural losses) ^k
Varroa mite	Economic cost to beekeeping in New Zealand	An estimated \$267–602 million over the next 35 years ^l

^aP. Daszak, A. Cunningham, and A. D. Hyatt, "Emerging Infectious Diseases of Wildlife: Threats to Biodiversity and Human Health," *Science*, 21 January 2000, 443–49.

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

^cE. Zavaleta, "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 DC: Island Press, 2000).

^dD. A. Bangsund, F. L. Leistriz, and J. A. Leitch, "Assessing Economic Impacts of Biological Control of Weeds: The Case of Leafy Spurge in the Northern Great Plains of the United States," *Journal of Environmental Management* 56 (1999): 35–43; and D. A. Bangsund, S. A. Hirsch, and J. A. Leitch, *The Impact of Knapweed on Montana's Economy* (Fargo, ND: Department of Agricultural Economics, North Dakota State University, 1996).

^eP. C. Focazio, "Coordinated Issue Area: Aquatic Nuisance, Non-Indigenous, and Invasive Species," *Coastlines* 30, no.1 (2001): 4–5.

^f"Coatings to Repel Zebra Mussels," U.S. Army Construction Engineering Research Laboratory fact sheet, <http://www.cecer.army.mil/facts/sheets/FL10.html>.

^gM. Williamson, "Measuring the Impact of Plant Invaders in Britain," in S. Starfinger, K. Edwards, I. Kowarik, and M. Williamson, eds., *Plant Invasions: Ecological Mechanisms and Human Responses* (Leiden, Netherlands: Backhuys, 2000), 57–70.

^hA. Watkinson, R. Freckleton, and P. Dowling, "Weed Invasions of Australian Farming Systems: From Ecology to Economics," in C. Perrings, M. Williamson, and S. Dalmazzone, eds., *The Economics of Biological Invasions* (Cheltenham, UK: Edward Elgar, 2000), 94–116.

ⁱJ. Turpie and B. Heydenrych, "Economic Consequences of Alien Infestation of the Cape Floral Kingdom's Fynbos Vegetation," in Perrings, Williamson, and Dalmazzone, *ibid.*, pages 152–82.

^jS. Joffe and S. Cook, *Management of the Water Hyacinth and Other Aquatic Weeds: Issues for the World Bank* (Cambridge, UK: Commonwealth Agriculture Bureau International (CABI) Bioscience, 1997).

^kP. White and G. Newton-Cross, "An Introduced Disease in an Invasive Host: The Ecology and Economics of Rabbit Carcivirus Disease (RCD) in Rabbits in Australia," in Perrings, Williamson, and Dalmazzone, note h above, pages 117–37.

^lR. Wittenberg and M. J. W. Cock, eds., *Invasive Alien Species: A Tool Kit of Best Prevention and Management Practices* (Wallingford, UK: Global Invasive Species Programme and CABI, 2001).

Source: J. A. McNeely.

and water supply, waste assimilation, recycling of nutrients, conservation and regeneration of soils, pollination of crops, and seed dispersal. Such services have current-use value and option value (the potential value of such services in the future). In the South African fynbos, for example, the establishment of invasive tree species—which use more water than do native species—has decreased water supplies for nearby communities and increased fire hazards, justifying government expenditures equivalent to US\$40 million per year for both manual and chemical control.²⁷

Customs and quarantine practices, developed in an earlier time, are inadequate safeguards against the rising tide of species that threaten native biodiversity.

Many people in today's globalized economy are driven especially by economic motivations. Those who are importing non-native species are usually doing so with a profit motive

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and often seek to avoid paying for possible associated negative impacts if those species become invasive. The fact that these negative impacts might take several decades to appear make it all the easier for the negative economic impacts to be ignored. Similarly, those who are ultimately responsible for such "accidental" introductions (for example, through infestation of packing materials or organisms carried in ballast water) seek to avoid paying the economic costs that would be required to prevent these "accidental," but predictable, invasions. In both cases, the potential costs are externalized to the larger society, and to future generations.

Responses

Customs and quarantine practices, developed in an earlier time to guard against diseases and pests of economic importance, are inadequate safeguards against the rising tide of species that threaten native biodiversity. Globally, about 165 million 6-meter-long, sealed containers are being shipped around the world at any given time. This number is far larger than custom officers can reasonably be expected to examine in detail. In the United States, some 1,300 quarantine officers are responsible for inspecting 410,000 planes and more than 50,000 ships, with each ship carrying hundreds of containers. While they intercept alien species nearly 50,000 times a year, it is highly likely that at least tens of thousands more enter the country uninspected each year. In Europe, inspection at the port of entry is also desperately overextended, and once a container enters the European Union, no further border inspections are done. This is a recipe for disaster.

Instead, a different set of strategies is now needed to deal with invasive species. These include prevention (certainly the most preferable), early eradication, special containment, or integrated management (often based on biological control). Mechanical, biological, and chemical means are available for controlling invasive species of plants and animals once they have arrived. Early warning, quarantine, and various other health measures are involved to halt the spread of pathogens.²⁸

The international community has responded to the problem of invasive alien species through more than 40 conventions or programs, and many more are awaiting finalization or ratification.²⁹ The most comprehensive is the 1992 Convention on Biological Diversity, which calls on its 188 parties to "prevent the introduction of, control, or eradicate those alien species which threaten ecosystems, habitats, or species" (Article 8h).³⁰ A much older instrument, one that is virtually universally applied, is the 1952 International Plant Protection Convention, which applies primarily to plant pests, based on a system of phytosanitary certificates. Regional agreements further strengthen this convention. Other instruments deal with invasive alien species in specific regions (such as Antarctica), sectors (such as fishing in the Danube River), or vectors (such as invasive species in ballast water, through the International Maritime Organization). The fact that the problem continues to worsen indicates that the international response to date has been inadequate.

On the national level, some legal measures can offer very straightforward methods of preventing or managing invasions.

For example, to deal with the problem of Asian beetle invasions, the United States now requires that all solidwood packing material from China must be certified free of bark (under which insects may lurk) and heat-treated, fumigated, or treated with preservatives. China might reasonably issue a reciprocal regulation, as North American beetles are a hazard there.

The nursery industry is by far the largest intentional importer of new plant taxa. Issuing permits for imported species is a good way for the agencies responsible for managing such invasions to keep track of what is being traded and moved around the country. Some people believe that it is impossible to issue a regulation containing a list of permitted and prohibited species, at least partly because the ornamental horticulture industry is always seeking new species. But the Florida Nurserymen and Growers Association recently identified 24 marketed species on a black list drawn up by Florida's Exotic Pest Plant Council and decided to discourage trade in 11 of the species (the least promising sellers in any case).³¹

Sometimes nature itself can fight back against invasive alien species, at least when they reach plague proportions. For example, the zebra mussels that have invaded the North American Great Lakes with disastrous effects are now declining because a native sponge (*Eunapius fragilis*) is growing on the mussels, preventing them from opening their shells to feed or to breathe. The sponge has become abundant in some areas, while the zebra mussel population has fallen by up to 40 percent, although it is not yet clear whether the sponges will be effective in controlling the invasive mussels in the long term.³²

Biological control—the intentional use of natural enemies to control an invasive species—is an important tool for managers. Some early efforts at biological control agents had disastrous effects, such as South American cane toads (*Bufo marinus*) in Australia, Indian common mynahs (*Acridotheres tristis*) in Hawaii, and Asian mongooses (*Herpestes javanicus*) in the Caribbean. Not only did these species not deal with the problem species upon which they were expected to prey, but they ended up causing havoc to native species and ecosystems. On the other hand, biological control programs are now much more carefully considered and in many cases are the most efficient, most effective, cheapest, and least damaging to the environment of any of the options for dealing with invasives that have already arrived.³³ Examples include the use of a weevil (*Cyrtobagous salviniae*) to control salvinia fern (*Salvinia molesta*), another weevil (*Neohydronomus affinis*) to control water lettuce (*Pistia stratiotes*), and a predatory beetle (*Hyperaspis pantherina*) to control orthezia scale (*Orthezia insignis*) that threatened the endemic national tree of Saint Helena (*Commidendrum robustum*).³⁴

Those seeking to use viruses or other disease organisms to control an invasive species need to understand ecological links. When millions of rabbits died after the intentional introduction of the myxomatosis virus in the United Kingdom, for example, populations of their predators, including stoats, buzzards, and owls, declined sharply. The impact affected other species indirectly, leading to local extinction of the endangered large blue butterfly (*Maculina arion*) because of reduced grazing by rabbits on heathlands, which removed the habitat for an ant species that assists developing butterfly larvae.³⁵ But the use of the

myxoma virus in conjunction with 1080 poison on the Phillip Island in the South Pacific successfully eradicated invasive rabbits, allowing the recovery of the island's vegetation (including the endemic *Hibiscus insularis*).³⁶

At small scales of less than one hectare, it appears possible with current technology to eradicate invasive species of plants through use of herbicides, fire, physical removal, or a combination of these, but the costs of eradication rise quickly as the area covered increases. With the right approach and technology, invasive alien mammals can be eradicated from islands of thousands of hectares in size. Rat eradication from islands of larger than 2,000 hectares has been successful, and large mammals have been removed from much bigger ones than that, primarily by hunting and trapping.

Environmentally sensitive eradication also requires the restoration of the community or ecosystem following the removal of the invasive. For example, the eradication of Norway rats from Mokoia Island in New Zealand was followed by greatly increased densities of mice, also alien species. Similarly, the removal of Pacific rats (*Rattus exulans*) from Motupao Island, New Zealand, to protect a native snail led to increases of an exotic snail to the detriment of the natives. And on Motunau Island, New Zealand, the exotic box-thorn (*Lycium ferocissimum*) increased after the control of rabbits. On Santa Cruz Island, off the west coast of California, removing goats led to dramatic increases in the abundance of fennel (*Foeniculum vulgare*) and other alien species of weeds. Thus reversing the changes to native communities caused by non-native species will often require a sophisticated understanding of ecological relationships. It is now well recognized that eradication programs are only the first step in a long process of restoration.³⁷ Sometimes native species become dependent on invasive ones, causing dilemmas for managers. For example, giant kangaroo rats (*Dipodomys ingens*) in the American West continually modify their burrow precincts by digging tunnels, clipping plants, and other activities. This chronic disturbance to soil and vegetation sometimes promotes the establishment of invasive species of plants that were originally imported as ornamentals from the Mediterranean so that they constitute a very large proportion of the vegetation on giant kangaroo rat territories. They have significantly larger seeds than do native species so are favored by the grain-eating kangaroo rats.³⁸ Because the kangaroo rats depend on non-native plant species for food and the non-native plant species depend upon the kangaroo rats to disturb their habitat continually, the relationship is mutualistic. This strong relationship may also inhibit population growth of native grassland plants that occupy disturbed habitats but have difficulty competing with nonnative weeds for resources. This mutualism presents an intractable conservation management dilemma, suggesting that it may be impossible to restore valley grasslands occupied by endangered kangaroo rats to conditions where native species dominate.

High-tech management measures are also being tried. For example, Australian scientists are planning to insert a gene known as "daughterless" into invasive male carp (*Cyprinus carpio*) in the Murray-Darling River, the country's longest, thereby ensuring that their offspring are male. The objective is to release

them into the wild, sending wild carp populations into a decline and making room for the native species that are being threatened by the invasive European carp.³⁹ Using genetic modification can help eradicate an invasive alien species, but if the detrimental gene is released into nature and starts to flourish, many other species could be negatively affected. Thus the precautionary approach needs to be applied to control techniques as well as to introductions.

The problems of invasive alien species are so serious that actions must be taken even before we can be "certain" of all of their effects. However, mechanical removal, biocontrol, chemical control, shooting, or any other approach to controlling alien invasive species needs to be carefully considered prior to use to ensure that the implications have been fully and carefully considered, including impacts on human health, other species, and so forth. A public information program is also needed to ensure that the proposed measures are likely to be effective as well as socially and politically acceptable. Many animal-rights groups oppose the killing of any species of wildlife, for instance, even if they are causing harm to native species of plants and animals. The recent controversy surrounding the population of mute swans in the Chesapeake Bay is a good example.⁴⁰

Conclusions

Ecosystems have been significantly influenced by people in virtually all parts of the world; some have even called these "engineered ecologies." Thus, a much more conscious and better-informed management of ecosystems—one that deals with non-native species—is critical.

In just a few hundred years, major global forces have rendered natural barriers ineffective, allowing non-native species to travel vast distances to new habitats and become invasive alien species. The globalization and growth in the volume of trade and tourism, coupled with the emphasis on free trade, provide more opportunities than ever for species to be spread accidentally or deliberately. This inadvertent ending of millions of years of biological isolation has created major ongoing environmental problems that affect developed and developing countries, with profound economic and ecological implications.

Because of the potential for economic and ecological damage when an alien species becomes invasive, every alien species needs to be treated for management purposes as if it is potentially invasive, unless and until convincing evidence indicates that it is harmless in the new range. This view calls for urgent action by a wide range of governmental, intergovernmental, private sector, and civil institutions.

A comprehensive solution for dealing with invasive alien species has been developed by the Global Invasive Species Programme.⁴¹ It includes 10 key elements:

- *An effective national capacity to deal with invasive alien species.* Building national capacity could include designing and establishing a "rapid response mechanism" to detect and respond immediately to the presence of potentially invasive species as soon as they appear, with sufficient funding and regulatory

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support; as well as implementing appropriate training and education programs to enhance individual capacity, including customs officials, field staff, managers, and policymakers. It could also include developing institutions at national or regional levels that bring together biodiversity specialists with agricultural quarantine specialists. Building basic border control and quarantine capacity and ensuring that agricultural quarantine, customs, and food inspection officers are aware of the elements of the Biosafety Protocol are other ways to deal with invasive alien species on a national level.

- *Fundamental and applied research at local, national, and global levels.* Research is required on taxonomy, invasion pathways, management measures, and effective monitoring. Further understanding on how and why species become established can lead to improved prediction on which species have the potential to become invasive; improved understanding of lag times between first introduction and establishment of invasive alien species; and better methods for excluding or removing alien species from traded goods, packaging material, ballast water, personal luggage, and other methods of transport.

The problems of invasive alien species are so serious that actions must be taken even before we can be “certain” of all their effects.

- *Effective technical communications.* An accessible knowledge base, a planned system for review of proposed introductions, and an informed public are needed within countries and between countries. Already, numerous major sources of information on invasive species are accessible electronically and more could also be developed and promoted, along with other forms of media.
- *Appropriate economic policies.* While prevention, eradication, control, mitigation, and adaptation all yield economic benefits, they are likely to be undersupplied, because it is difficult for policymakers to identify specific beneficiaries who should pay for the benefits received. New or adapted economic instruments can help ensure that the costs of addressing invasive alien species are better reflected in market prices. Economic principles relevant to national strategies include ensuring that those responsible for the introduction of economically harmful invasive species are liable for the costs they impose; ensuring that use rights to natural or environmental resources include an obligation to prevent the spread of potential invasive alien species; and requiring importers of such potential species to have liability insurance to cover the unanticipated costs of introductions.
- *Effective national, regional, and international legal and institutional frameworks.* Coordination and cooperation between the relevant institutions are necessary to address possible gaps, weaknesses, and inconsistencies and to promote greater mutual support among the many international instruments dealing with invasive alien species.
- *A system of environmental risk analysis.* Such a system could be based on existing environmental impact assessment procedures that have been developed in many countries. Risk analysis measures should be used to identify and evaluate the relevant risks of a proposed activity regarding alien species and determine the appropriate measures that should be adopted to manage the risks. This would also include developing criteria to measure and classify impacts of alien species on natural ecosystems, including detailed protocols for assessing the likelihood of invasion in specific habitats or ecosystems.
- *Public awareness and engagement.* If management of invasive species is to be successful, the general public must be involved. A vigorous public awareness program would involve the key stakeholders who are actively engaged in issues relevant to invasive alien species, including botanic gardens, nurseries, agricultural suppliers, and others. The public can also be involved as volunteers in eradication programs of certain nonnative species, such as woody invasives of national parks for suggested actions that individuals can take.
- *National strategies and plans.* The many elements of controlling invasive alien species need to be well coordinated, ensuring that they are not simply passed on to the Ministry of Environment or a natural resource management department. A national strategy should promote cooperation among the many sectors whose activities have the greatest potential to introduce them, including military, forestry, agriculture, aquaculture, transport, tourism, health, and water-supply sectors. The government agencies with responsibility for human health, animal health, plant health, and other relevant fields, need to ensure that they are all working toward the same broad objective of sustainable development in accordance to national and international legislation. Such national strategies and plans can also encourage collaboration between different scientific disciplines and approaches that can seek new approaches to dealing with problems caused by invasive alien species.
- *Invasive alien species issues built into global change initiatives.* Global change issues relevant to invasives begin with climate change but also include changes in nitrogen cycles, economic development, land use, and other fundamental changes that might enhance the possibilities of these species becoming established. Further, responses to global change issues, such as sequestering carbon, generating biomass energy, and recovering degraded lands, should be designed in ways that use native species and do not increase the risk of the spread of non-native invasives.

What Can an Individual Do?

While the problem of invasive alien species seems daunting, an individual can make an important contribution to the problem, and if thousands of individuals work toward reducing the spread of invasive aliens, real progress can be made. Here are some steps that can be taken:

- Become informed about the issue.
 - Grow native plants, keep native pets, and avoid releasing non-natives into the wild.
 - Avoid carrying any living materials when traveling.
 - Never release plants, fish, or other animals into a body of water unless they came out of that body of water.
 - Clean boats before moving them from one body of water to another, and avoid using non-native species as bait.
 - Support the work of organizations that are addressing the problem of invasive alien species.
- *Promotion of international cooperation.* The problem of invasive alien species is fundamentally international, so international cooperation is essential to develop the necessary range of approaches, strategies, models, tools, and potential partners to ensure that the problems of such species are effectively addressed. Elements that would foster better international cooperation could include developing an international vocabulary, widely agreed upon and adopted; cross-sector collaboration among international organizations involved in agriculture, trade, tourism, health, and transport; and improved linkages among the international institutions dealing with phytosanitary, biosafety, and biodiversity issues and supporting these by strong linkages to coordinated national programs.

Because the diverse ecosystems of our planet have become connected through numerous trade routes, the problems caused by invasive alien species are certain to continue. As with maintaining and enhancing health, education, and security, perpetual investments will be required to manage the challenge they present. These 10 elements will ensure that the clear and present danger of invasive species is addressed in ways that build the capacity to address any future problems arising from expanding international trade.

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