EXOTIC INVASION

In 1982, a carnivorous jellyfish, *Mnemiopsis leidyi,* suddenly showed up in the Black Sea, where it had never been seen before. The jellyfish found an abundant food supply of anchovy eggs and larvae in this Eurasian sea. By 1988, the invader had devoured so many juvenile fish that commercial catches had declined by 90%. By 1992, it had migrated again, this time to the eastern Mediterranean, where it continued to eat up fisheries. Until it showed up in Eurasia, *Mnemiopsis leidyi* lived only in the western Atlantic Ocean, primarily in the Chesapeake Bay, where its population has been limited by natural predators. So how did it travel thousands of miles from home? Like increasing numbers of other exotic (or nonnative) species, it was carried abroad by international trade, hitchhiking in ballast water.

Today, exotic species are booming in population around the world, destroying forests, rangelands, and valuable crops. Some invaders carry exotic diseases that kill native plants. Others endanger human health by introducing parasites and pathogens. Still others overrun their new habitats, frequently forcing native species into extinction. And once exotics take hold in an environment, they can be extremely difficult to eliminate.

Biological invaders are especially a problem in Europe, North America, Australia, and other regions with sophisticated economies. "Most introductions probably now take place in developed nations, where most international trade occurs," says Stanford University ecologist Peter Vitousek. For example, about 24% of Canada's plant species and 46% of New Zealand's plant species are nonnative, while only about 3% of Egypt's plant species and 1% of Tanzania's plant species are exotics.

Exotic weeds, traveling as seeds hidden in soil, arrive in ports on farming equipment and other products. Exotic insects hitchhike across borders on timber, in agricultural produce, and in nursery products. Diseases that kill fish and other seafood arrive in aquaculture stock. Mosquitoes that can spread malaria, dengue fever, and other diseases travel on cars, planes, railway cars, and trucks. And travelers returning from abroad often smuggle in exotic fruits and vegetables.

But these interlopers don't always sneak in. For example, in the 1940s, the U.S. Department of Agriculture gave Japanese kudzu seeds to farmers in the Southeast for erosion control. Since then, the plant has become a notorious nuisance, spreading rapidly throughout the region, covering millions of acres. And the Australian tree *Melaleuca quinquenervia,* originally imported to serve as a windbreak and soil stabilizer in the Florida Everglades, has run wild, pushing out native plants. Ecologists estimate that the tree is spreading at a rate of 15,000 acres per year.

Coastal and aquatic ecosystems, in particular, have been harmed by exotic species that stow away on merchant ships. In port, an empty ship takes water into its hold for ballast to provide extra weight, making it ride lower in the water and giving it greater stability on the open sea. But ballast water is frequently rich with aquatic creatures including plankton, larval fish, waterfleas, clams, mussels, sea slugs, toxic algae, and jellyfish. During a transoceanic trip lasting a few weeks, numerous species can survive in ballast water. When the ship enters a new port, the ballast water is dumped and, if its new environment is similar to its native one, an exotic species can establish itself.

In the future, exotic invasions will probably increase significantly in countries with growing economies and thriving overseas trade, says Vitousek. "There hasn't been much trade between Africa and Latin America, for example. So as that trade increases in the future, species introductions are likely to get worse in developing regions."

Estuaries and Islands

Of the places most harmed by exotic species, oceanic islands top the list. Many oceanic islands are on important trade routes, and some have large ports. Furthermore, oceanic islands usually host a

narrower range of species than continental ecosystems, making them more vulnerable to invasions. As a classic example, before people colonized Hawaii, there were no small mammals or reptiles to eat the islands' birds, which had never adapted methods of escaping or avoiding such predators. Then the small, voracious Indian mongoose was introduced to control rats (which, in turn, had been introduced to Polynesia by European colonists) in sugar cane fields. The mongoose, a generalized predator, began eating huge numbers of birds along with the rats, and many Hawaiian bird species collapsed.

In the aquatic realm, freshwater and saltwater ports have borne the brunt of biological invasions, mostly introduced by ballast water. Biological invasions are exacerbated when exotics spread from freshwater ports into rivers and inland lakes. In the United States, a notorious example is the zebra mussel (*Dreissina polymorpha*), an exotic species from the Black Sea, which was introduced to the U.S. Great Lakes by ballast water in 1986. Within a few years, the mussel species was carried throughout the Great Lakes and into rivers by barges, and into smaller lakes by recreational boaters. The mussel reproduces at an extraordinary rate, disrupting ecosystems and clogging industrial and utility pipes, at a cost that could reach hundreds of millions of dollars over a decade. The zebra mussel has spread as far south as Louisiana and southeast as far as Tennessee, and there is a chance it could eventually reach the U.S. west coast, according to zoologist Thomas Dietz of Louisiana State University in Baton Rouge, who says that "in spot checks of boats entering California, officials have identified zebra mussels, and a few times the mussels have been alive."

Human Health

Human pathogens hitchhike on a variety of products brought across borders. Animals imported for research may carry diseases that can be transferred to humans. For example, seven people in Marburg, Germany, died after handling blood and tissue from African green monkeys that had been imported from Uganda for use in vaccine research. The tissue contained the organism now known as the Marburg virus. Tropical fruit can harbor dangerous bacteria, including salmonella. Lizards and reptiles imported as pets from tropical regions can also spread salmonella; in fact, salmonella has become a serious health problem in Florida due to people legally importing iguanas as pets.

Disease-carrying mosquitoes travel on all kinds of vessels, even surviving in airplane wheel bays on international flights, according to an Australian study conducted by R.C. Russell of the University of Sydney that was published in the 1987 *Bulletin of the World Health Organization.* In fact, in recent years, international trade and travel have been implicated in numerous epidemics of infectious diseases including rabies, tuberculosis, dengue, and cholera.

In the United States, the Asian tiger mosquito (*Aedes albopictus*) is a potentially dangerous exotic disease carrier, first introduced from Japan in the mid-1980s, probably via used tires. The mosquito, which can spread dengue and yellow fever, lays its eggs in the water that collects in tires. It attacks more hosts than any other mosquito, including many mammals, birds, and reptiles, so it can potentially spread disease organisms among species. This mosquito is found in 21 states in the United States, though the spread of dengue or yellow fever is unlikely here due to the nation's excellent system of health monitoring, experts say. However, in September 1996, a North Carolina man was infected with and died of the Eastern equine encephalitis virus, also carried by this species.

Ballast water, as well, can carry human pathogens. From polluted harbors and bays, ship ballast can carry the *Vibrio* cholera, concealed in plankton, to estuaries around the world. The virulent El Tor cholera strain, which causes intestinal disease with symptoms of severe diarrhea, was probably carried by ballast water from Asia to Latin America in 1991, and then spread to Mobile Bay, Alabama, where it was found in oysters in closed shellfish beds. Fortunately, no humans were infected with the cholera bacterium at that time.

Ship ballast also carries toxic algae that could infect shellfish and harm people who eat them. Shellfish such as clams, mussels, oysters, and scallops filter toxic plankton from the water, accumulating the toxins in their tissues to levels that are potentially lethal to people. Human deaths are quite rare, though. Far more often, the toxins cause severe diarrhea, short-term memory loss, and respiratory problems when they are aerosolized by the surf. In recent years, the number of the toxic blooms in U.S. coastal waters has grown significantly. But whether toxic algae from ballast water have been introduced in U.S. waters is unclear. It is difficult to determine why blooms are growing in number, because they could be caused by foreign algae, or by once low-profile native species stimulated by pollution of coastal waters, climate change, or other factors, says Donald Anderson, a biologist at the Woods Hole Oceanographic Institution on Cape Cod, Massachusetts. However, according to a 1993 Australian study published in *Phycologia*, two species of toxic dinoflagellates probably were introduced to Australian waters from Japan via ballast water.

Focused National Policies

Most governments have been rather disorganized and unfocused in their response to exotics, ecologists say, with the two notable exceptions of Australia and New Zealand. With strong traditions of protecting their unique flora and fauna, Australia and New Zealand have been "more aggressive in trying to stop invasions because they have a much stronger dislike of exotic species" than the United States or European nations, says Kevin Lafferty, a marine biologist at the University of California in Santa Barbara.

New Zealand, for example, established a "user pays" system requiring importers to pay for risk assessments of exotic introductions. As part of a user fee, importers must also help pay for costs of inspection, surveillance, and enforcement against any violators of exotic species regulations.

New Zealand intensively inspects arriving foreign passengers, baggage, and goods, and treats each incoming aircraft with insecticide. New Zealand's program against exotics also comprises public education campaigns, which include thorough questioning of travelers at airports and other entry points. When exotics manage to enter the countries and become nuisances, Australia and New Zealand attack them with powerful weapons, including pesticides and biological controls.

For generations, farmers around the world have successfully controlled harmful insects by releasing biological controls, including predators, parasites, or pathogens. But some forms of biological control have proven disastrous, such as releases of generalized predators like the Indian mongoose, which eat the target species along with many other species. Once the predator is introduced, it is often impossible to control the negative effects that may come along with the beneficial ones. Now some scientists are concerned about a calicivirus—a hemorrhagic disease virus—released as a biological control to kill rabbits in Australia. The European rabbit *Oryctolagus cuniculus* was brought to Australia from Spain in 1859 and soon proliferated. Now there are about 300 million rabbits plaguing the continent, eating up crops, forests, and pasture, competing with livestock for food, and contributing to soil erosion.

Australian resource managers already employ integrated pest management to kill rabbits. Rabbit warrens are blasted and removed, rabbits are killed by poisoning, fumigating, and shooting, and biological controls such as myxomatosis (a viral disease that kills up to 90% of the rabbits it infects) and rabbit fleas attack the animals. But these methods were not enough to control the animals. So in October 1996, the Australian government intentionally released a rabbit calicivirus at 280 sites, intending to kill a sizable fraction of the nation's rabbit population with rabbit calicivirus disease (RCD). During the summer of 1997, New Zealand may also release the rabbit calicivirus.

Virologists and veterinarians criticized the Australian government for releasing a pathogen that could infect foxes and other species that eat rabbits, or that could mutate and jump to other species, as has been argued by Alvin Smith of the College of Veterinary Medicine at Oregon State University in Corvallis. But according to the Commonwealth Bureau of Resource Sciences, the calicivirus affects only European rabbits. Many native and introduced species in Australia and New Zealand, including foxes, dogs, marsupials such as the tammar wallaby, and the New Zealand lesser short-tailed bat, were tested for possible infection. None of the species developed RCD, which results in coma and death within 36 hours of infection. Also, a health study of people exposed to the calicivirus in Australia showed no evidence of humans becoming infected. In Europe and China, people have been in contact with calicivirus-infected rabbits for 10 years, with no reports of illness.

Over the next four years, the Agriculture and Resource Management Council of Australia and New Zealand will monitor the calicivirus's effects on European rabbits and other species. It will be a year before the council knows how animal populations are affected.

Although Australia sometimes uses controversial methods to get rid of exotics, at least it has a focused national agenda to cope with invaders, ecologists say. In contrast, in the United States "there is no national policy to deal with biological invasions," says Don C. Schmitz, alien plant coordinator for the Florida Department of Environmental Protection in Tallahassee. After decades of inadequate monitoring of exotics, information is scattered among 20 federal agencies and numerous state and local agencies, which pay little attention to each others' strategies and wait too long to eliminate species that enter the country, he says. "We're not sure what needs to be done to stop invasive species," says Schmitz.

In the United States, most of the responsibility for halting biological invasions belongs to two agencies. Under the Lacey Act of 1900, the U.S. Fish and Wildlife Service requires a special permit to import a certain number of foreign wild fish, wildlife, and some plants that could pose threats. But the agency regards few species as threatening, says Florida State University ecologist Daniel Simberloff, and the agency doesn't address unintentional importation of species.

Under the Federal Noxious Weed Act of 1974 and the 1939 Federal Seed Act, the Department of Agriculture's Animal and Plant Health Inspection Service (APHIS) primarily regulates species that pose a threat to agriculture and forestry. But the agency usually does not address species that harm natural resources or create a nuisance outside the agency's specialties. As a result, APHIS inspectors focus on species that cause direct economic harm to crops and forests, while generally ignoring species that cause widespread ecological harm, says Schmitz. Critics argue that the APHIS has a very limited blacklist of prohibited species. For example, there are 93 noxious weed species on the APHIS blacklist, though more than 750 additional noxious weeds could be listed, according to a comprehensive 1993 Office of Technology Assessment (OTA) report, *Harmful Non-Indigenous Species in the United States.*

Purple loosestrife, for example, is an unlisted exotic weed that smothers vast wetland acreage in the United States, particularly in the Midwest, according to Simberloff. But because purple loosestrife does not directly harm commercial forestry or agriculture, it can be brought into the country.

The APHIS and the U.S. Customs inspection offices are not staffed to search more than a tiny fraction of the shipments that come into the country, says Phyllis Windle, project director for the OTA report and now a consultant on exotic species issues. For example, there are only eight APHIS inspectors for both the Charleston, South Carolina, seaport—one of the largest in the United States—and Charleston's international airport. At the seaport, inspectors particularly watch for pests such as beetles, borers, termites, and weevils that tunnel into wood crating, and for seeds carried in dirt caked on tractors and other equipment, says APHIS officer Frances Jowyk. Inspectors keep a close eye on any container from the Mediterranean area, which has a high population of snails that eat other gastropod and mollusk species. They also look out for containers from Central and South America, which can harbor African honey bees (*Apis mellifera scutellata*, also known as "killer bees").

Furthermore, once a noxious weed enters the United States, the APHIS does little to stop its spread, says Schmitz. Part of the problem is a minuscule budget to manage a gigantic problem. In fiscal year 1997–1998, Congress appropriated only $408,000 to the APHIS to eradicate 45 noxious weeds across the nation.

Federal agencies don't move quickly enough once exotic creatures are found in the United States, says Schmitz. "You have to deal with invaders as you would a war. Invaders make beachheads and you meet those beachheads and eradicate them. You need SWAT teams for exotics. Instead, agencies ask for funds that they'll use two or three years from now."

The United States, moreover, lacks a formal education program to prevent exotic introductions, says Windle. Public education is a very important component of a strategy to stop invasions, because large numbers of exotics enter countries illegally with travelers. At Los Angeles International Airport during one week of May 1990, the APHIS, California regulators, and county officials performed "blitz" inspections of all baggage on 153 overseas flights targeted from a total of 490 flights, according to the OTA report. The inspections intercepted 667 lots of prohibited fruits and vegetables, among other restricted products. "I often hear people saying that they've brought exotic fruits and vegetables into the country," says Windle. "People aren't getting the message."

Growing Consensus

The international community has few agreements addressing the monitoring and control of the full spectrum of exotic species. One exception is the 1951 International Plant Protection Convention. Signed by 98 nations, this agreement was designed to prevent the introduction and spread of plant pests, and to undertake efforts to eradicate such exotics, but its goals have been met only sporadically, depending on each signatory's ability to control agricultural pests. Another exception is a series of international agreements preventing illegal export of endangered species. But generally "keeping nuisances out of countries has been the job of national governments," says Simberloff, not the role of international treaties.

At the Earth Summit in Rio de Janeiro in 1992, however, 165 nations signed the United Nations Convention on Biodiversity, which calls on governments

to "[p]revent the introduction of, control, or eradicate those alien species which threaten ecosystems, habitats, or species." This is a tall order, some say, that will be extremely difficult to fill. Today, the treaty lacks both a monitoring program for most exotic species and legal mechanisms to enforce controls over such exotics.

The treaty's sole initiative toward controlling exotics does not have the authority of international law. In 1995, the parties to the convention met in Jakarta, Indonesia, to agree on a plan of action to implement the treaty in regard to marine and biological diversity. This plan, called the Jakarta Mandate, offers guidance on controlling exotic species in the marine environment, though it is not legally binding, says David Downes, senior attorney with the Center for International Environmental Law in Washington, DC. Among other initiatives, the Jakarta Mandate encourages ships to dump ballast water from the previous port at sea and then replace it with offshore ocean water. Organisms from the open ocean are unlikely to survive when discharged into estuaries.

The United States has similar guidelines. In 1990, Congress passed a law requiring ships to dump ballast water before they enter the Great Lakes. Then in 1996, Congress passed a law that establishes voluntary guidelines on ballast water for ships that enter all U.S. waters. If, after three years, voluntary compliance is inadequate, then the ballast guidelines will be made mandatory.

In July 1996, parties to the biodiversity convention met in Trondheim, Norway, to discuss the issue of exotic species, but no further guidelines were issued. In Trondheim, scientists spoke of the need for more information about the status of exotic species, potential international legal mechanisms, and early warning systems.

In the United States, 537 ecologists, agricultural officials, and environmental experts have signed a letter to Vice President Al Gore, asking him to form a special commission on exotics. Schmitz says that he and a handful of colleagues have asked for a meeting at the White House, hoping to deliver the letter personally.

In 1993, a similar group asked for a national program. Since then, "biological invasions by pest and nuisance species . . . have continued almost unabated," says the 1997 letter to Gore. "We are losing the war against invasive exotic species, and their economic impacts are soaring." Attempts by federal, state, and local agencies to stop exotics have been "piecemeal, ad hoc, and reactive."

The true extent of the exotic-species problem seems impossible to gauge, because it changes constantly. Each day, species are being introduced into ecosystems worldwide, both intentionally and accidentally. Global markets continue to be pried open by international trade agreements, creating more opportunities for the transport of invaders. As a result, designing monitoring and regulatory systems for exotics on an international scale is a Sisyphean job. Nevertheless, national governments and the international community must be more effective in slowing the introductions of exotic species before the new global economy does irreparable damage to the global environment.

John Tibbetts