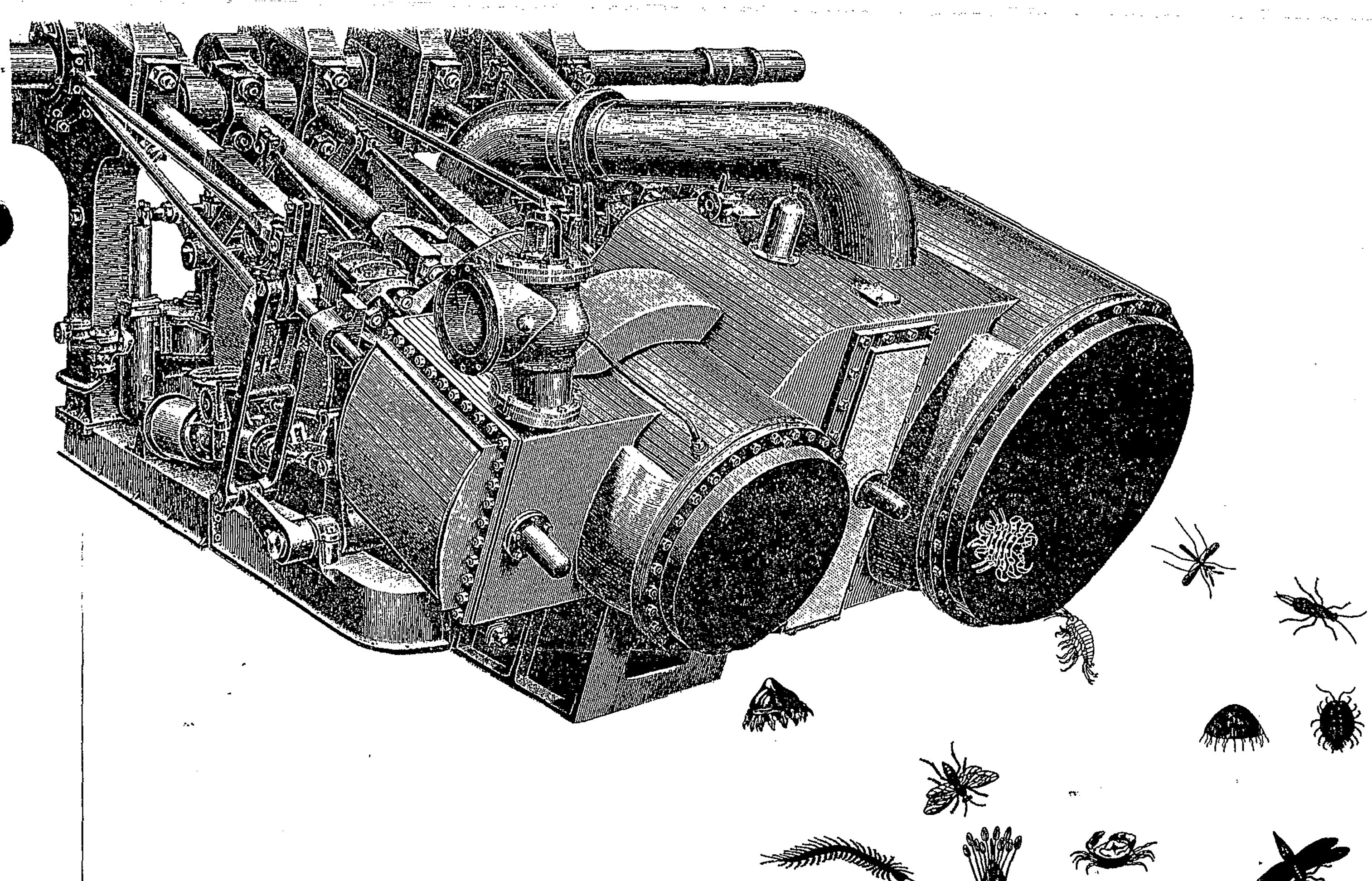
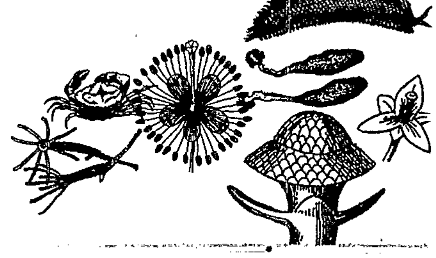


**Bioinvasion, the spread of non-native "exotic" species, may be the least visible and least predictable of all the major dimensions of ecological decline. It is also one of the most dangerous, because exotics often create pressures for which there is no local evolutionary precedent: native species simply may not be adapted to live with the invaders. The result, increasingly, is widespread suppression of natives and sometimes extinction. As a threat to global biological diversity, bioinvasion may now be surpassed only by the broadest category of environmental decline, habitat loss.**

**Some exotics are released intentionally—trees for plantations, for example, or fish for aquaculture. But many of the worst invasions have been accidents. Industry and trade are continually leaking weeds, forest pests, aggressive crabs, predatory jellyfish, and all sorts of other invasive organisms out into the world's natural spaces. Sometimes even the intentional releases go wild, and spread far beyond their appointed ranges.**

**In this article, adapted from Chapter 7 of *Life Out of Bounds: Bioinvasion in a Borderless World*, Chris Bright explores the realm of the biotic spill—and the growing threat of biological pollution.**



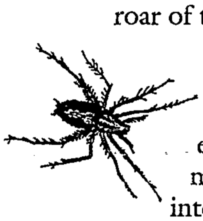
# CRAWLING OUT OF THE PIPE

## The hazardous waste that makes more of itself

by Chris Bright

The convulsions have ebbed away but left a low-grade infection, incurable and subject to flare-up. This is the victim: the Black Sea, where Ovid passed his exile, where the Byzantine Empire rose and gave way to the Crusaders, the Golden Horde, and the Ottoman Turks. These are the waters stained by the terrible pogroms of Stalin and Hitler, caressed by generations of Russian elite on holiday.

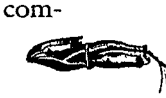
And all that time, along the Atlantic coast of the Americas, constellations of little luminescent blobs were drifting along, here and there, out beyond the roar of the surf. This is the pathogen: the Leidy's comb jelly *(Mnemiopsis leidyi)*, a widespread species but nothing special. Until one day in the early 1980s, when a ship enroute from—who knows?—New York, maybe, or Caracas, sailed up the Bosporus, into the Black Sea, and squirted the jelly out of its ballast water tanks.



Leidy's comb jelly eats the myriad tiny animals known collectively as zooplankton. And since nothing in the Black Sea would eat the jelly, it launched one of the most intense biological invasions ever recorded in a marine ecosystem. By late 1988, a single cubic meter of Black Sea water could contain as many as 500 jellies, most of them probably smaller than your thumb. If all of the jellies could have been hauled out of the sea that fall and weighed, the take would have come to between 900 million and 1 billion tons—at least 10 times the total world fishery catch for that year. But the anchovies and other fish that make up the sea's traditional catch had largely disappeared. The Black Sea had been poisoned by ballast water, one of the most common forms of marine pollution today—and one of the most dangerous.

Despite its apparent stability, a big ship doesn't sail simply by virtue of its design, any more than an airplane flies simply because it has wings. Keeping a ship upright takes ballast water—lots of it. Moving that water in and out of the cavernous tanks designed to hold it is as critical a part of the nautical routine as managing the rudder or the engines. Ballast water must be taken on when cargo is unloaded, or as fuel is consumed, or to provide extra stability in heavy weather, or sometimes to make the ship ride low enough to pass under a bridge. And for every reason that it's pumped aboard, there's a corresponding reason for pumping it out—taking aboard cargo, making the ship ride high enough to move into a shallow harbor, and so on. The ballast capacity of a big tanker can exceed 200,000 cubic meters—enough to fill 2,000 Olympic-sized swimming pools—and its pumps can move that water at rates as high as 20,000 cubic meters an hour. That's not gentle suction. Most ballasting is done around harbors, in shallow water, and ships sometimes scour the bottom as they're ballasting up. In the resultant turmoil, the slurry gushing into the tanks may contain hundreds of cubic meters of sediment—along with any small creatures that happen to be in the water, the mud, or on nearby harbor pilings.

The tanks of a large ship may come to support a chaotic but more-or-less permanent living community. A large ballast tank can only be emptied com-





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pletely by opening it up, and that is only done during dry-dock overhaul, which on a well-maintained vessel might occur every three to five years. Routine use always leaves plenty of room for biological activity. In one recent survey of large ships reporting no ballast on board, the burden of unpumpable water and sediment in their "empty" tanks averaged 157.7 metric tons—enough to fill perhaps a dozen dump trucks.

Ballast water is a soup stocked from harbors all over the world. The holes in ballast intake grates are usually about a centimeter wide. That's probably plenty of room for most marine organisms in larval form—most fish larvae, for instance, are small enough to pass through. Sometimes the grates fall off, allowing much larger creatures to enter. In April 1995, for example, the tanks of a ship that had come into Baltimore harbor from the eastern Mediterranean were found to contain more than 50 healthy mullet from 30 to 36 centimeters long.

But some of the most significant stowaways are microscopic: in 1991, ballast discharge from ships arriving in Peruvian ports from South Asia is thought to have unleashed the first cholera epidemic that the Western Hemisphere had seen for more than a century. The outbreak may have infected several million people and killed 10,000 of them. Ships outbound from Latin America were found to have cholera-laden ballast upon arrival in ports in Australia and the United States. In 1992, as the epidemic gained momentum in South America, more cases of imported cholera were observed in the United States than in any year since surveillance for that disease began.

There are more than 28,700 vessels in the world's major merchant fleets and they make up by far the largest part of the world's trading infrastructure. About 80 percent of the world's commodities travel by ship for at least part of the journey to their consumers, and the volume of seaborne trade is climbing steadily upward. From 1970 to 1996, the trade nearly doubled (it climbed from 10,654 billion ton-miles, the standard industry measure, to 20,545 btm). Through its ballast systems, the world merchant fleet has in effect superimposed a second set of currents on the world's oceans, and these meta-currents are far more efficient at transporting life over long distances than are the natural ones. On any day, the meta-currents are moving perhaps 3,000 different species of every conceivable ecological function: green plant, pathogen, parasite, herbivore, carnivore, scavenger. And in harbor after harbor, the same species are appearing over and over again—the same crabs and clams, the same worms, sometimes even the same fish. The world trading system is creating an extra-geographical marine biota. (See table, page 25.)

In the Black Sea, the process was so traumatic partly because the native biota was already so sick. Over the previous several decades, the sea had grown steadily more polluted from fertilizer run-off and the raw sewage of some 170 million people. This nutrient-rich pollution was feeding clouds of algae, which were robbing the water of light and burning up oxygen as they decayed. The Black Sea is naturally anoxic (oxygen-poor) to begin with. For millennia, rafts of plant material would sweep in from the Danube and the other tributary rivers, consuming the oxygen as they rotted, and leaving only a film of aerated water riding a vast anoxic pool—the largest such pool on earth. The algae had begun to suffocate that upper layer of life. The algae were also shading out the huge shallow-water seagrass beds that had once functioned as the sea's "lungs"—and as prime habitat for fish, crustaceans, sponges, and many other creatures. But zooplankton eat algae—and zooplankton were just about all that remained of the sea's battered immune system. Then the jelly ate virtually all the zooplankton. Algae and jelly were almost the only living things in the water. At its peak, the jelly alone accounted for 95 percent of the sea's entire wet weight biomass.

By the mid-1990s, the jelly was showing signs of having exhausted its larder. Its Black Sea population has declined, but by 1992 it had invaded the Sea of Marmara, below the Bosporus, and it has turned up farther south, in the Aegean as well. Eventually, it might infest much of the Mediterranean coastline. Shipping could also take it north, up the great European rivers that run into the Black Sea, and into the Baltic. Neither the Mediterranean nor the Baltic are in robust health and we have no way of knowing how either would cope with an *M. leidyi* infection. In the meantime, several jellyfish native to the Black Sea have established themselves in the Chesapeake Bay on the U.S. East Coast, and in San Francisco Bay on the West Coast.

Despite their capacity for havoc, most ballast-water invaders don't get much press. To the news media and probably to the public in general, marine pollution usually means oil spill. The 1989 Exxon Valdez spill in Alaska's Prince William Sound, for example, attracted major media coverage for months. But what about the spill that is spreading through the Sound today? In December 1997, the U.S. Fish and Wildlife Service announced that it had discovered four new species of zooplankton in the Sound, where they had been released from tanker ballast. The plankton appear to have come from East Asia via San Francisco Bay. Scientists are concerned that the invaders may develop a taste for the same foods that are needed by the Dungeness crab, an important fishery species. As more and more Alaskan oil is pumped, some scientists fear that ballast releases like these could become a general threat to the state's fisheries. The biotic spills, in other words, could become a far greater danger to Alaskan coasts than the oil spills. After all, oil spills may be a grave environmental insult, but they eventually go away. Biotic spills do not.

Biotic spills have been a major ecological side-effect of commerce for centuries, but ballast water is a fairly recent variation on the theme. Keeping a ship afloat by pumping some of the ocean into it was an innovation made possible by motorized pumps and metal hulls. By the turn of the century both of these technologies were well established and ballast tanks had become common. The first known ballast water invasion dates from the same era: a Chinese species of plankton, *Biddulphia sinensis*, appeared in the North Sea.

Earlier generations of sailors shoveled ballast into their ships: rocks, earth, scrap metal, any other heavy portside debris—along with the resident beetles, earthworms, sandfleas, and seeds. Ballast was supposed to be dumped and collected at specific sites around harbors. By the last century, botanists knew that these "ballast points" were good places to prospect for exotic flora. Some of those plants have since gone prospecting on their own. Alligator weed *(Alternanthera philoxeroides)*, an aggressive South American plant that flourishes both in water and on land—and that is naturally resistant to herbicides—grew out of the ballast heaps near Newcastle, Australia, about 50 years ago. It is now choking irrigation ditches and natural waterways all along the coast of New South Wales, and unless it is controlled, experts fear it could spread around the country. Animals emerged from the heaps as well. One of the most common snails on the Northeast coast of the United States may have arrived on the shores of the New World in shovelfuls of ballast: the European periwinkle *(Littorina littorea)*. In the late 19th century it exploded, zebra-mussel fashion, along the intertidal zone and rearranged (in ways no longer entirely clear) shoreline and marsh ecology from Newfoundland to New Jersey.

The wooden hulls of sailing vessels also had enormous biological potential. Seaweeds and barnacles colonized the surface, creating mobile habitat for

## Caught Up in the Meta-Currents

Almost every kind of marine organism is riding the shipping routes in ballast tanks . . .

| | |
|---|---|
| Outbound from Europe | The zebra mussel, a **shellfish** native to the Caspian Sea region, is rearranging the ecology of many North American waterways. |
| | The ruffe, a European **fish**, is established in the Great Lakes and is beginning to outcompete the yellow perch and walleye—native fish with an economic value of $90 million annually. |
| | A Mediterranean **fan worm** now forms a kind of living carpet over parts of the floor of Port Phillip Bay, on the southeastern coast of Australia, to the detriment of the local scallop fishery. |
| . . . from the Americas | The Leidy's comb jelly, a **jellyfish** native to the western Atlantic coast, devastated the Black Sea fisheries. |
| | The American razor clam, a **shellfish** native to the North American Atlantic coast, has established itself along the western and northern European coasts. |
| | A **bristle worm** from the North American Atlantic coast now constitutes 97 percent of the biomass of the large bottom-dwelling species in the Vistula lagoon, on the Polish coast. |
| . . . from East Asia | The Chinese mitten **crab** and an Asian **clam** have invaded San Francisco Bay. |
| | At least eight East Asian **copepods** are living on the Pacific coast of the Americas. |
| | A **starfish** from the Northwestern Pacific has invaded the Tasmanian coast; it is threatening local shellfish industries and endangering the native spotted handfish—which could become the first known marine fish to go extinct during the historic era (although there have likely been undocumented extinctions). |
| | Poisonous dinoflagellate "red tide" **plankton**, native to the waters off Japan, occasionally shut down oyster farms along the southeast coast of Australia. |
| | Various **seaweeds** native to the Japanese coast are established in the waters off Tasmania and along both coasts of the United States. |
| . . . from South Asia | The Indian bream, a **fish**, is established in western Australia. |
| | Another **fish**, the Indo-Pacific goby, is established in Nigeria, Cameroon, and the Panama Canal. |
| | A **crab** native to the Indo-Pacific and established in the eastern Mediterranean has now appeared in the waters off Cuba, Venezuela, Colombia, and Florida. |
| . . . from Australia | An Australian **barnacle** is outcompeting native barnacles over stretches of European coast. |

For sources, see chapter 7 of *Life Out of Bounds*.

fish, shrimp, crabs, and other little animals. The resultant fouling communities, teeming with all sorts of life, could be more than a meter thick. Specialized boring molluscs called shipworms took up residence inside the hulls, and their continual gnawing opened up little caverns that also became home to other travelers. As early as the 16th century, shipworms were regarded as so serious a problem that the British Admiralty ordered English ships to stay clear of those South American waters deemed most heavily infested with them.

Today, solid ballast is a thing of the past and hull fouling communities are much sparser, thanks to toxic antifouling paints, high sailing speeds, and port times often measured in hours instead of months. But this ancient pathway of invasion has not been closed entirely. A modern hull can offer well over a hectare of surface (easily 3 acres) below the water line, so even a light encrustation could be substantial enough to innoculate a harbor. And some species of seaweed are now resistant to the copper-based toxins in the antifouling paints. Recent fouling introductions include the Mediterranean mussel *(Mytilus galloprovincialis)*, which was discovered in Hong Kong in 1983, and the Asian brown seaweed *Undaria pinnatifida*, which is apparently spreading along the Pacific coast of South America, the Atlantic coast of Europe, and the Australian coast by riding on ships' hulls.

Probably the richest fouling communities these days are riding on a kind of vessel that didn't exist during the days of sail: semisubmersible oil drilling platforms, which are towed from one seabed oil field to another. Our thirst for oil is dispersing various species of fish, sea anemonies, crabs, barnacles, and algae—but not necessarily the same ones that rode the tall ships. Oil drilling is usually done off shore, so the platforms are moving open-ocean species, rather than the estuary and near-shore creatures most frequently found on ships.

The ship itself remains a complicated nexus of invasion routes, both ancient and modern. Apart from hull surface and ballast tank, exotic species stowaway in bilges (the ship's "storm sewers"), sea chests (the ports leading to the ballast tanks), nets, chain lockers—and in some places an ancient mariner would never dream of. In the U.S. Pacific Northwest, a series of portside infestations of the Asian strain of the gypsy moth *(Lymantria dispar)* were detected in 1991 and apparently eliminated over the course of the ensuing year. (The gypsy moth, a widespread Eurasian insect, is a serious exotic pest of broadleaf forest in eastern North America. Thus far, only the European strain of the moth has established itself in North America; the Asian strain is much more mobile and therefore much more dangerous.) The pathway of invasion, it turned out, was the lighting aboard grain carriers coming in from East Asia. The ships' lamps produced light of a wavelength that strongly attracted the moths, and the fast crossing times—so important in reducing hull fouling—helped insure the moths' safe arrival. No doubt, there are other shipboard pathways that haven't yet been discovered because we haven't yet traced an invader back through them.

The trading network is injecting exotics deep within the continents as well. A major leap in invasion potential involves containers, those big metal boxes that have revolutionized the freight industry over the past couple of decades. Containers are nearly ubiquitous. They move by ship, train, and truck—in fact, the trailers of many trucks *are* containers. They can be stacked for weeks or even months in ports or railyards, allowing plenty of time for pests to enter. They offer a safe haven to anything that manages to get inside, since they are very difficult to inspect. They are rarely cleaned between shipments, and they may not be unpacked until they are hundreds of kilometers from their ports of entry. Containers have integrated sea and land transit. They have ruptured the ancient pattern of ship-borne invasion, in which exotics simply made their way inland from ports.

The overwhelming share of world shipping volume is in bulk commodities, like grain or oil. Materials of this sort can't be containerized, but almost everything else can be. And increasingly, it is. In 1995, the most recent year for which figures are available, world container traffic had reached 135 million TEUs ("twenty-foot equivalent units"—because containers come in several sizes, total volume is measured by an abstract unit rather than by the absolute number of containers). As a share of total shipping volume, container traffic is growing steadily; it has risen from a mere 1.6 percent in 1980 to 6.4 percent by the end of 1996—a fourfold increase. And the container is becoming a major means of linking developing world economies with their industrialized trading partners: by 1996, slightly over half of world container volume was passing through the ports of developing countries.

Containers have been identified as significant pathways for insects, weed seeds, slugs, and snails. One of the most dangerous exotics known to be using this pathway is the Asian tiger mosquito (*Aedes albopictus*), an extremely aggressive biting pest. In Asia, this mosquito is a major vector of dengue fever, an excruciating disease that gets its common name from the pain it inflicts: "break-bone fever." Dengue infects about 560,000 people each year and kills 23,000. The mosquito can carry at least 17 other viral diseases, including various forms of encephalitis and yellow fever.

For decades, the Asian tiger mosquito had been a common pest throughout much of the Indo-Pacific region, from Madagascar all the way to Hawaii. Then in the mid-1980s, it embarked on its version of world conquest. It is currently known to have established itself in the southeastern United States, Brazil, southern Europe, South Africa, Nigeria, New Zealand, and Australia. It may have been a factor in the 1986 yellow fever epidemic in Rio de Janeiro, in which about 1 million people were infected. In 1991, it was discovered in the midst of a yellow fever outbreak in Nigeria. Around the same time, it was a suspected vector in several encephalitis epidemics in Florida. Researchers fear that the continued spread of the mosquito could substantially increase the disease burden of both the developed and developing worlds. Even where the diseases it carries are already well established, its arrival could be trouble. In the Caribbean, for example, dengue fever is primarily a disease of the cities because the virus still lacks an efficient rural vector—a role this mosquito could readily play.

The vector of this vector, it turns out, is the containerized used tire. Millions of used tires are traded internationally every year—some to make recycled rubber products or asphalt, but most as fuel for powerplants, cement kilns, and so forth. A tire with a little water in it is ideal mosquito habitat—and have you ever tried to empty a wet tire completely? Unless you puncture it, you can't. Within the peculiar contours of one of the world's most common objects, fluid dynamics and gravity will defeat your every maneuver.

A more recent container-borne invader is the Asian longhorn beetle *(Anoplophora glabripennis)*. Since 1996, this wood-boring insect from China has turned up in more than 30 warehouses all over the United States and has succeeded in launching small infestations around Chicago and New York City. The beetle will attack a wide range of broadleaf trees, injuring or killing them by boring through their sapwood. Counter-attack is very difficult, since the beetle spends most of its life inside the tree, where it cannot be reached by pesticides and may often go undetected until the damage is done. At present the only method of control consists of cutting, chipping, and burning every tree known or suspected of being infested. U.S. foresters have no way of knowing what the beetle would do if it were to establish itself in the country permanently, but it is conceivable that some native American maples could join the list of trees currently threatened or rendered functionally extinct by exotic pests. (See table, page 28.) The beetle travels in untreated wood pallets and packing material. Over China's strenuous objections, the U.S. government has now imposed emergency restrictions on this type of packing—a move that could affect up to one-half of China's $63 billion worth of annual exports to the United States.

It is apparently a universal dimension of culture, the essential human enterprise, to be riddled with hundreds of these accidental thoroughfares, which have conveyed other organisms far beyond their natural ranges. This biotic mixing has exercised a profound influence on landscape and seascape, yet the results have often gone unnoticed. During the last century, for example, wooden-hulled ships apparently brought a tiny, wood-boring crustacean (the isopod *Sphaeroma terebrans*) to the Atlantic coasts of the Americas from the Pacific. *S. terebrans* has spread throughout the Atlantic mangrove communities—the fringe of stilt-rooted trees common along tropical and warm temperate shores. It attacks and kills mangrove root tips, thereby controlling the trees' seaward spread. According to James Carlton, a professor at Williams College in Connecticut and the world's preeminent authority on marine exotics, *S. terebrans* has "virtually 'reset' the seaward history" of the western Atlantic's mangrove ecosystems.

In the coastal communities they dominate, mangroves knit sea and shore together. They buffer the coasts from surf. Their roots shelter rich communities of fish, crabs, and many other marine organisms. Birds, mammals, and reptiles live in the branches above. *S. terebrans* doesn't seem to have doomed the western Atlantic mangrove communities, but as with the European periwinkle farther north, the little isopod's invasion is a change at once enormous and very subtle. What difference does it make? As far as the ecology is concerned, there may never be a definitive answer—it all depends on the era in which the question is asked, and what else is happening in the mangroves. But think about *S. terebrans* as a cultural phenomenon: our forebears inadvertently rescripted the functioning of a vast (if very narrow) ecosystem, and we have lived with the invasion for a century or so. Yet apparently, the change remained completely invisible until Carlton discovered it.

Many biotic spills have spread a similar stain—vast but very hard to read. In Europe, for example, a fungal pathogen of North American crayfish was accidentally released into Italian waters around 1860 and is inexorably erasing the native crayfish from that continent. Probably very few Europeans know that the crayfish in their streams are largely exotic North American species, introduced because they are resistant to the fungus. This remedy, incidentally, is a further injury to the patient: without the North American crayfish, the epidemic might have reduced the native crayfish to remnant populations and then run out of steam for lack of victims. But the plague now has a permanent host in the North American crayfish, and the beleaguered native species must now face exotic competitors as well as the exotic disease.

Canals have been highly efficient corridors of invasion, when they connected bodies of water that

# INFECTED FORESTS

A sampler of North American trees and the exotics that are threatening them.

**1892** The white pine blister rust (*Cronartium ribicola*) is introduced from Europe in infected nursery stock. The rust has eliminated some stands of whitebark pine (*Pinus albicaulis*), which is native to the Rocky Mountains. The pine is vulnerable to the rust over its entire range.

**1904** The chestnut blight (*Cryphonectria parasitica*) arrives in shipments of Asian chestnut nursery stock. The blight has completely suppressed the American chestnut (*Castanea dentata*), formerly a keystone species in most of the deciduous forests east of the Mississippi. The chestnut is now "functionally extinct."

**1923** The fungus now known as the Port-Orford-cedar root disease (*Phytophthora lateralis*) arrives in shipments of Asian conifer nursery stock. The disease is killing the Port-Orford cedar (*Chamaecyparis lawsoniana*), which is native only to northern California and southern Oregon. The cedar may be vulnerable over its entire range, at least at lower elevations.

**1920s** The hemlock woolly adelgid (*Adelges tsugae*) is discovered on the West Coast. This Asian insect infests and kills Canadian hemlock (*Tsuga canadensis*), a major component of the eastern coniferous forests. The die-back is especially severe in the U.S. Northeast but the hemlock may be vulnerable over its entire range. (A recently-discovered Japanese ladybug, which appears to prey exclusively on the adelgid, may eventually ease the threat. The ladybug is being released as a bio-control agent.)

**1920s?** The beech scale complex, consisting of a scale insect (*Cryptococcus fagisuga*) and one or two fungi (*Nectria* spp.), is introduced on European beech nursery stock. The disease has killed over half the trees in some northeastern stands of American beech (*Fagus grandifolia*); the full extent of the threat is not known.

**1930** The Dutch elm disease, a complex consisting of a European bark beetle (*Scolytus multistriatus*) and the fungus *Ophiostoma ulmi*, probably from Asia, arrives in shipments of veneer logs from Europe. The disease has caused the functional extinction of the American elm (*Ulmus americana*), native to the East and Midwest.

**1967** The butternut canker (*Sirococcus clavigignenti-juglandacearum*), a fungus of unknown origin but almost certainly exotic, is discovered in Wisconsin. The fungus has completely eliminated some populations of butternut (*Juglans cinerea*), a sparsely-distributed tree native to the East and Midwest. The tree is threatened throughout its range.

**1976** The dogwood anthracnose (*Discula destructiva*), a fungus of unknown origin but probably exotic, is discovered in Washington state. The disease is killing off the Pacific dogwood (*Cornus nuttallii*), native to the West Coast, and the eastern dogwood (*C. florida*), native to the East and Midwest. The course of the epidemic cannot be predicted, but in the Southeast, at least, the fungus' sensitivity to heat limits its effects on the eastern dogwood.

Primary source: Faith Thompson Campbell and Scott E. Schlarbaum, *Fading Forests: North American Trees and the Threat of Exotic Pests* (New York: Natural Resources Defense Council, 1994).

had previously been distinct. The barriers thus breached may not even be noticed by terrestrial, canal-building vertebrates, but the view looks very different from the water. In the U.S. Northeast, the Erie canal, completed in 1823, broke through the hump of land geographers call the Allegheny Divide. For over 10,000 years, since the retreat of the glaciers, the divide had separated what is now the Great Lakes Basin from coastal rivers like the Hudson. More than a score of exotic fish and molluscs have arrived in the Hudson drainage through the canal. The Suez Canal, a conduit for 20 percent of world maritime traffic, rejoined the Red Sea to the Mediterranean in 1869, after some 20 million years of separation. Thus far, nearly 300 exotics are thought to have found their way into the Mediterranean through the Suez, including the Red Sea jellyfish (*Rhopilema nomadica*), which now produces mass summertime swarms along the sea's eastern coast. A harbinger, perhaps, of what the Leidy's comb jelly may do if it makes its way down from the north.

If you know what to look for, you can read the results of past ambitions, conflicts, and blunders large and small in the landscape around you. Around some European cities, for instance, you can still find the remnants of various "siege flora"—the growing remains of the meals, bedding, and forage of beseiging armies of the past. Military movements have triggered more spectacular invasions too: the brown tree snake *(Boiga irregularis)* is thought to have arrived on the Pacific island of Guam in U.S. military transports around 1950. The brown tree snake has eaten 12 of the island's 14 land bird species into extinction in the wild, and several lizard and bat species as well.

Many industries—some of them still with us, some largely forgotten—have left an enormous biotic legacy in the form of invasion. Some 500 exotic plant species growing around the French city of Montpellier, for instance, have been attributed to wool imports; for centuries, wool scouring was an important local industry. It was the oyster industry, about a century ago, that inadvertently released the North American Atlantic cordgrass onto the coast of the Pacific Northwest, in shipments of oyster "seed." In its new range, the cordgrass has converted extensive tracts of tidal mudflats—essential for many bird and fish species—into much less productive marsh. A failed soap-making industry helped the highly invasive Chinese tallow tree into the forests and wetlands of the U.S. Southeast. (The tree's seeds can be made into soap; unfortunately, since the tree is also beautiful, there is another pathway through which it moves: horticulture). The failed enterprise that has probably left the greatest biotic scar was the tragic attempt to produce silk in Massachusetts by importing the gypsy moth.

Today, the invasion potential of trade and industry is expanding radically in several dimensions at once. In terms of volume, speed, trade routes, and the variety of organisms involved, the modern trading system dwarfs anything previous eras have seen. Take volume first: at the turn of the century, a substantial ship might have a capacity of 3,000 tons; by World War II, 10,000-ton ships were common; today, ships are often 150,000 to 250,000 tons and the largest vessels exceed 600,000 tons. The sheer increase in size may help explain why ballast water invasions seem to have gone from a dribble to a torrent somewhere in the 1970s or early 1980s.

For many types of organisms, greater speed may be more important than greater volume, since the shorter the time in transit, the higher the odds of survival. For ships, the quantum leap in speed actually occurred in the latter half of the last century. In 1851, the William T. Coleman California Line was billing its *Syren*—"The A 1 Extreme Clipper Ship"—as capable of sailing from San Francisco to Boston (via Cape Horn) in 100 days, and from Calcutta to Boston in 96 days. It would have taken the *Syren* four to six weeks to cross the Atlantic. The transition from sail to steam cut that time in half: by the turn of the century, steamers were crossing the Atlantic in only two weeks. Land transportation underwent a revolution at about the same time. By the 1870s, North America had been girded by rail and it was possible to travel from one coast to the other in a couple of days. The rail system included ubiquitous water towers—an essential part of transportation infrastructure in the steam age. Rail and water offered an unprecedented opportunity to fisheries authorities, who were eager to flood the continent's waters with their favorite fish. Stock could be moved rapidly over great distances and the fish tanks topped up whenever locomotive boilers were refilled. Soon drainages all over the United States were feeling the plunge of exotic fingerlings.

Air traffic, of course, represents another quantum leap in speed, and air cargo is a rapidly expanding sector in the trade network. Air cargo traffic is growing at about 7 percent a year (in terms of ton-kilometers). In 1989, only three airports received more than a million tons of cargo; by 1996, that number had risen to 13. Many organisms that would die or be detected during a shipboard crossing can travel easily by air, including human pathogens. Anyone infected with cholera who boarded the *Syren* in Calcutta would have been very sick long before reaching Boston. But cholera and many other diseases are bound to travel undetected on dozens of air routes.

Because the world trading system is so large and complex, the pathways within it are in a continual state of flux. Like vessels in some sort of global capillary network, they are constantly growing and constantly withering away, only to rebuild themselves elsewhere. As developing countries trade increasingly

among themselves, it is likely that whole new sets of pathways will open up—between India and Africa, for example, or Latin America and Southeast Asia. The geographical shifting, along with the complexity of the pathways themselves, gives the "ecology" of the world trading system a kind of demented complexity, like a Rube Goldberg drawing. Who would have thought, prior to the early 1980s, that rubber recycling would be instrumental in spreading a mosquito? Or that manufacturers of a certain kind of light were unwittingly increasing the pest risks to North American coniferous forest?

What is true of the trading system in general is also true of many industries in particular. The forest products industry is a prime example of the trend. The movement of forest products has always entailed serious ecological risk—a shipment of veneer logs, for example, brought the Dutch elm disease to North America. (See table, page 28.) But those risks have increased enormously as the trade in raw wood products continues to grow, both in volume and in the number of trade routes involved. From 1970 to 1994, the most recent year for which figures are available, export volumes of raw logs increased 21 percent (to 113.4 million cubic meters). Trade in sawnwood nearly doubled (to 108 million cubic meters). Among the countries that have substantially increased their raw log exports in recent years are China, Ghana, Papua New Guinea, the Solomon Islands, Russia, New Zealand, and Chile. Bigger importers include China, Korea, Taiwan, and a number of African countries.

What the logs contain besides wood is anybody's guess. At a conference on the dangers of raw wood imports in 1996, a former Oregon Department of Agriculture inspector recalled opening up the hatches of a wood chip carrier that had just arrived from Brazil and watching "a cloud of insects" escape. According to many experts, North America would risk a disaster of epochal proportions if lumber companies in the U.S. Pacific Northwest succeed in weakening federal regulations on importing raw logs. Relaxing the regulations would make it easier to feed the region's overcapacity sawmills, but it would also greatly increase the odds of hundreds of new forest pests eventually making their way into western North America.

Some mill owners, for instance, have been promoting the idea of importing Siberian logs. (Strictly speaking, it is already legal to do this, but no company has found an economical way to handle the required treatment procedures, which involve debarking, heating, then storing the logs in sanitary conditions until shipment.) A U.S. Forest Service inventory of organisms associated with Siberian larch, a major timber species in eastern Russia, turned up 175 species of arthropods (insects and their relatives), nematodes, and fungi, including a Eurasian spruce bark beetle *(Ips typographus)* that occasionally explodes in outbreaks lethal to millions of trees in its native range. Thus far, U.S. inspectors have found this beetle nearly 200 times in incoming shipments of European and Asian goods. In 1993, an infestation was detected around Erie, Pennsylvania and eradicated. Weakened regulations would presumably increase the likelihood of the beetle establishing itself in North America. And the results, according to the Forest Service, could be "as disastrous for North American spruce as the Dutch elm disease was to elms."

But not all biologically dirty industries are as large as the forestry sector. Some small industries are playing out-sized roles as biopolluters—horticulture, for example. (See table, page 32.) About 60 percent of the worst plant invaders of North American natural areas are still being grown and sold by the North American nursery industry. One global survey of woody plant invasions found that in the 624 cases in which the origin of the invasion could be ascertained, 59 percent came from botanical gardens, landscaping, or other amenity purposes. In addition to escaped garden plants, horticulture releases a large number of weeds, insects, slugs, and pathogens. Historic nursery trade contributions to North America include the chestnut blight, the white pine blister rust, and the beech bark disease complex. (See table, page 28.)

The pet trade, the animal equivalent of horticulture, is another major conduit of invasion. The domestic cat, for example, is a formidable and now a nearly universal predator. Cats—many of them gone wild—appear to be a serious stress on bird populations in Europe and North America and on small mammal populations in Australia. There are plenty of other ex-pets out there as well. Consider the booming reptile trade. In Florida, the trade has introduced about 20 species of exotic lizards, some of which prey on native lizards. Florida may eventually become home to breeding populations of exotic pythons; since no big constrictors are native to the state, local birds and other potential prey species may not be adapted to cope with them. In Hawaii, escaped chameleons are competing with native birds for insects. And perhaps the most popular reptile in the U.S. pet trade, a native North American turtle called the common slider *(Trachemys scripta)*, has attracted the attention of animal breeders in various developing countries; common sliders are now sliding into the rivers of Panama, Malaysia, and Thailand.

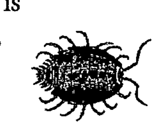
But by far the most ecologically disruptive sector of the pet industry is the aquarium trade. In increasing numbers, aquatic plants, snails, shrimp, fish, and various other denizens of hobby aquariums are finding their way into natural waters. Some escape from breeding facilities; others are offered their freedom by soft-hearted but misguided owners who have tired of their charges. The results have really put the industry on the map. Hydrilla, a popular aquarium plant from South Asia, escaped from a culture facility in Florida in the early 1950s and is now a premier aquatic weed throughout the Southeast, as well as on much of the West Coast. Hydrilla is clogging more than 40 percent of Florida's rivers and lakes.

Various species of aquarium fish—and the collection includes a substantial share of the world's tropical freshwater fish—are rapidly approaching cosmopolitan status. Such standard ornamentals as guppies and swordtails, both native to Central America, can now be found in tropical ponds and streams all over the world, especially near cities. Some highly disturbed but relatively clean habitats, like the canal systems of central Florida or the streams on the Hawaiian island of Oahu, have in effect become giant natural aquaria; aquarium species now dominate.

Healthy aquarium fish command a good price and efficient transport makes it possible to sell to distant markets, so breeders have set up shop throughout the warm regions of the world. If it's beautiful and breeds easily, it has a good chance of making a new life in the southeastern United States, Thailand, Malaysia, India, and various places in between. In the United States, 65 percent of the exotic fish species that are completely foreign to the country arrived through the aquarium trade. And new ones are establishing themselves all the time. At the time of writing, the latest addition is an Asian eel that has taken up residence in ponds near the Chattahoochee River, a major southeastern river. Like the Asian walking catfish that has invaded Florida, the eel is an efficient predator that can breathe both air and water, and it's capable of moving overland from one pool to another.

The aquarium trade is spreading fish pathogens as well. For example, at least 42 diseases have been identified in aquarium fish awaiting shipment into Australia. In that country and in other parts of the world, some of these pathogens have escaped into the wild; a few apparently owe a nearly worldwide distribution to this industry. Some ecologists speculate that escaped aquarium pathogens may be a factor in global amphibian decline.

New industries will doubtless create new pathways, or expand old ones. In Europe and North America, for example, the resurgence of interest in herbal medicine is likely to result in more medicinal plant invasions. Herbal medicine was probably one of the pathways that spread purple loosestrife. (See table, page 32.) A plant in more recent vogue is Saint John's wort *(Hypericum perforatum)*; herbalists credit it as an antidepressant; natural areas managers know it as a serious weed.



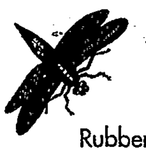
A set of new pathways may emerge from bioremediation, the increasingly common practice of using living things to clean up contaminated sites. In its most common form, bioremediation involves the release of bacteria to break down large organic chemicals (such as petroleum derivatives) into smaller, more benign compounds that will dissipate more readily into the environment. (The bacteria used are not pathogens—they don't cause diseases.) This kind of bioremediation is effective and cheap; it's expected to reduce clean-up costs on sites contaminated primarily by organic chemicals by a factor of 10. The U.S. Environmental Protection Agency has concluded, for example, that if bioremediation had been used to clean up the Exxon Valdez spill, the cost would have come in under $250 million, instead of the actual $2.5 billion. Most bacteria used in bioremediation belong to very widespread groups, but our understanding of bacterial distribution is not highly developed, and in the process of cleaning up oil spills, we may create some bacterial spills.

Spills of a very different sort are likely to result from phytoremediation, a form of bioremediation that uses certain plants to draw up soil contaminants. The process involves sowing a suitable plant on a contaminated area, allowing the "crop" to mature, and then cutting or uprooting it. The contaminant-laden plants can then be treated as toxic waste. Phytoremediation is used primarily to clean up metals such as lead, zinc, or chromium. Sometimes it's even possible to recover usable amounts of metals from the contaminated harvest. The process has been used to clean up radioactive contamination too. The oilseed crop, Indian mustard *(Brassica juncea)*, for example, is being used in Ukraine to pull strontium and cesium out of soils contaminated by the Chernobyl disaster.

There are apparently a large number of plants that can "hyperaccumulate" metals, especially in the tropics. In the flora of Cuba alone, for example, one botanist has identified 80 species that concentrate nickel. Some geneticists, not content with these naturally-occurring forms, are searching hyperaccumulating bacteria for metal-hungry genes, which they can then splice into plants. One group has created a transgenic form of *Arabidopsis thaliana* (a plant commonly used in genetic experiments) that absorbs mercury and exhales a faint mercurial plume into the air. Transgenic or not, a metal-laden plant could make a formidable invader. Hyperaccumulation has survival value: it tends to make plant tissues toxic or unpalatable to insects and pathogens. In the continual war with the insects, plants with this internal "armor" could well have an edge over more edible native competitors.

In terms of immediate social effect, the most important set of pathways involves the growing movement of humanity itself, which is increasingly stirring the world's human pathogens into a single, integrated, microbial system. No previous era has experienced such an uproar of human movement. Every week, about 1 million people move between the developed and the developing worlds; every day, about 2 million people cross an international border. Travel and tourism is now the world's biggest industry, in terms of its annual receipts, which amount to more than $3.4 trillion. World air passenger traffic—the best single indicator of long distance travel—is increasing at about 6 percent per year. By 2000, the civilian world air fleet will be moving more than 1.7 billion passengers annually, 522 million of them on international flights.

People infected with serious communicable diseases are presumably moving through this system all the time. Doubtless, many of them have no idea they're infected. In the United States, for example, there are about 1,000 new cases of malaria every year, and nearly all of the victims apparently pick up the disease while traveling. The infectious potential of an airplane is not simply a matter of quick transit—it's also the result of close confinement within the plane, especially for respiratory infections. Consider this: every hour, the average pair of human lungs takes in roughly 833 liters of air, or 83 percent of a cubic meter. A really big plane, like a 747, can carry about 400 people, who would have a collective respiration rate of around 333 cubic meters per hour. The maximum cabin volume of a 747 is 876 cubic meters (but that's empty volume—before people come on board). Airplane ventilation systems admit small amounts of fresh air at fairly rapid intervals, but it may take 30 minutes or so to flush cabin air completely. Given the amount of breathing that is going on in the cabin,



## GARDEN VARIETY MONSTERS

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| Rubber Vine | Introduced from Madagascar as an ornamental and possible rubber source into northern Australia at the turn of the century. This plant now infests some 350,000 square kilometers of tropical Queensland, where it chokes out native grassland and forest, smothering trees up to 30 meters high. |
| *Clematis vitalba* | This ornamental vine from northern Europe had escaped from gardens in New Zealand by the 1930s. It is doing to that country's forests what rubber vine is doing to northern Australia. When a stand of smothered trees collapses, clematis blankets the resulting tangle, forming mats over a meter thick and preventing any regeneration. |
| Water Hyacinth | A South American aquatic plant introduced during the 19th century into the southern United States, Africa, and southern Asia. Its original use was often as a pool ornament; subsequent uses have included fodder, green manure, biogas production, and wastewater treatment. But given the number of lakes and rivers that have disappeared beneath it, many water managers would be glad to get rid of it without using it at all. |
| Purple Loosestrife | This European wetland plant probably first reached North America at the end of the 18th century in wool imports and solid ship ballast; during the 19th century it was imported for ornamental and probably for medicinal purposes. It has now overrun more than 600,000 hectares of North American temperate and boreal wetland, where it has eliminated native vegetation and ruined the waterfowl forage base. |
| Knotweeds | Bamboo-like plants from east Asia introduced into Europe and North America during the 19th century as ornamentals and, in Europe, for game forage. On both continents, knotweeds are outcompeting native riverside vegetation and choking off water courses. |
| Saltcedars or Tamarisks | Scrubby, Asian trees introduced into the western United States beginning in the early 19th century, primarily as ornamentals but also for erosion control along rivers. Today they infest more than 600,000 hectares along rivers and streams, forming dense thickets of little wildlife value and often eliminating surface water. In the U.S. Southwest, saltcedars may now absorb a greater quantity of water than is used by all the cities of southern California combined. |
| Miconia | A beautiful tree from the American tropics, miconia is a favorite in tropical botanical gardens all over the world. But the tree casts dense shade that excludes other vegetation. Its seedlings reach sexual maturity in only a few years, then produce millions of seeds of their own. In French Polynesia, miconia is smothering virtually all of the territory's major islands. On Tahiti, where it is known as "the green cancer," miconia has displaced more than two-thirds of the native forest, and is threatening 25 percent of the island's native wildlife species. |

For sources, see chapter 6 of *Life Out of Bounds*.

that leaves plenty of time for little clouds of microbes to move from one set of lungs to another. So an airplane that takes off with one infected passenger may well arrive with several. And if a crew member is infected, then several plane-loads of people could be exposed before the disease is discovered. In 1993, an investigation by the U.S. Centers for Disease Control and Prevention uncovered a case in which tuberculosis had been transmitted through one flight attendant to 23 other crew members in this fashion.

Permanent migration, like tourism, has reached unprecedented levels. Every year, some 110 million people immigrate to another country. In addition to these "standard" immigrants, the stream of international refugees and internally displaced persons has increased almost every year since the end of World War II. Since the beginning of this decade alone, their number has grown by more than 60 percent, from about 30 to 48 million. Many of these people end up in camps or shantytowns that are among the world's most miserable and disease-ridden places.

In general, the world we are traveling through seems to be getting sicker. Over the past two decades, some 30 "new" diseases have emerged—diseases like AIDS, Ebola, and the "flesh-eating" streptococcus. At the same time, several of humanity's oldest and deadliest scourges—malaria, cholera, and tuberculosis, for example—may be gathering strength. This resurgence of infectious disease is driven by a complex of environmental and social forces. Water-borne diseases like cholera lurk in the open, untreated sewers used by some 1.7 billion people, mostly in the rapidly growing slums of Third World cities. Other pathogens are spreading because their vectors are on the move—creatures like the Asian tiger mosquito. And a growing number of pathogens—all three of the ancient diseases just mentioned, for example—have evolved drug resistant strains. (Another reason for the resurgence, however, may be the fact that some 2.5 billion people, about 40 percent of the global population, don't have access to essential drugs at all.) Infectious diseases kill about 16.4 million people every year; that's about a third of all human mortality.

Human movement is the common denominator within much of this complex: it makes every local misery a global concern. Take the mosquito-vectored disease, yellow fever, for example. Yellow fever has two strongholds: the forests of Latin America and the west African countryside. In 1992, for the first time in a quarter-century, the African reservoir of the disease reached east, into Kenya. Many experts fear that the Kenya epidemic is the beginning of a new conquest. Kenya is a favorite destination for Indian emigrants; there is, consequently, a considerable amount of air traffic between the two countries. Yellow fever is not yet present in Asia and the Indian population is wholly unvaccinated against it. Some experts regard an Indian epidemic as all but inevitable—especially since another favorite destination of Indian emigrants is . . . Latin America.

Travel not only spreads diseases, it can intensify them. It used to be, for example, that on any particular Caribbean island, there was only one type of dengue fever, but travel and trade are mixing the forms of the disease. Infection with multiple strains of dengue produces dengue hemorrhagic fever (DHF), a condition that is far more likely to be fatal than ordinary dengue. Globally, the incidence of DHF has increased nearly tenfold, to 260,000 cases per year, since 1986. Such overlapping infections may open up whole new dimensions of public ill-health. One reason AIDS kills much faster in Africa than it does in other parts of the world may be that so many of its victims are also infected with malaria. Malaria (another mosquito-borne disease) is already infecting 225 million people a year and killing 2 million of them. Perhaps one side-effect of its resurgence will be an increase in the death toll from AIDS.

Medieval Arabian scholars were able to map the path of the Black Death. From its origin in the central Asian steppes, it followed the trade routes overland to the Crimean peninsula of the Black Sea, then sailed to Byzantium and on to the great cities of the eastern Mediterranean. Those chroniclers were watching a particularly horrible form of biotic mixing on a continental level. At the end of the 15th century, as the Age of Discovery opened, the biotic turmoil began to unfold on a global level, as the European biota spilled out over much of the earth. Gradually, over the ensuing centuries, various creatures from other regions were pulled into the flux—South American potatoes, Australian eucalypts, North American salmonids. Today, we have inaugurated a new era of ecological chaos. There is no longer any single predominating current, nor is there any type of organism that we can say with assurance is exempt from movement. Just about anything could be transported anywhere. Who will be able to map the plagues of the next millennium?

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Chris Bright is senior editor of WORLD WATCH and a research associate at the Worldwatch Institute. *Life Out of Bounds: Bioinvasion in a Borderless World* was published by W.W. Norton & Company in October 1998 for the Worldwatch Environmental Alert Series. It can be ordered through the Institute web site, www.worldwatch.org, or by calling (800) 555-2028.