The woman in the emergency ward of a Canadian hospital has no idea of her ultimate fate. Just a bad cold, she thinks—what a way to return from a trip to Asia. Within a week, the woman has died, a victim of severe acute respiratory syndrome (SARS). The nurse and doctor who took care of the woman, and a receptionist who handed the woman forms to fill out, will soon be in critical care.

SARS, a viral respiratory illness, is transmitted by person-to-person contact. First reported in Asia in February 2003, the illness spread over the next few months to more than two dozen countries in North America, South America, Europe, and Asia. During the SARS outbreak of 2003, a total of 8098 people worldwide became sick, according to the World Health Organization; of these, 774 died. In the United States, there were 192 infected individuals, all of whom recovered. Public health officials used isolation and quarantine measures to control the outbreak of this infectious disease.

But the story doesn’t end there. On 13 January 2004, the US Department of Health and Human Services banned import of civets—small catlike mammals related to the mongoose and native to Africa and the East Indies—whether

Invasive Species: The Search for Solutions
Cheryl Lyn Dybas

Understanding vectors, or modes of transport, is crucial to finding solutions to the problem of invasive species. Shipping is one vector of many related to transportation. Large commercial ships crisscrossing the Pacific Ocean are fitted with transponders that mark their locations as part of a weather-tracking program of the World Meteorological Organization (WMO). The tracking data, which are managed by the National Oceanic and Atmospheric Administration (NOAA), were used to generate this map of shipping patterns as part of a South Pacific Regional Environment Program (SPREP) exercise to determine regional risks for marine oil spills. Map created by Trevor Gilbert, formerly of SPREP and now at the Australian Maritime Safety Authority, from data courtesy of WMO and NOAA.
alive or dead. Wild animal traders, it turns out, show a higher incidence of exposure to the SARS virus. If humans can acquire infection directly from animals like civets, scientists think, SARS may have been introduced to new areas by multiple routes. The suspects implicated in this case? An almost infinitely complex web of interactions among humans, animals, and continents—and an exponentially increasing number of routes bringing them together in unprecedented numbers. The means? Planes, trains, ships, and automobiles.

Investigating invasions

The virus that causes SARS, called a coronavirus, is an invader: a species that is carried far from its natural home and flourishes elsewhere—and in some cases causes harm in its new environs. With SARS, as with many other infectious diseases, the study of invasive species has become critical to finding containment methods.

“The sciences of invasive species, ecology, infectious diseases, and population biology have great insights to offer each other,” said Richard O’Grady, executive director of the American Institute of Biological Sciences (AIBS). Gary Hartshorn, of the World Forestry Center in Portland, Oregon, and immediate past-president of AIBS, added, “This melding shows great promise for teasing apart the strands of questions like how invasive species and infectious diseases spread from one region to another, how they gain a foothold once they arrive, and what allows them to thrive in a new place.”

AIBS devoted its 2004 annual meeting, held in Washington, DC, 16–18 March 2004, to “Invasive Species: The Search for Solutions.” The conference brought together researchers from almost every field of biology to discuss how scientists might develop a better understanding of invasive species—and how humans might slow the spread of invaders, including the microbes responsible for infectious diseases, in a world where connections between people and distant lands are made at warp speed.

Conference plenary talks, panel sessions, and discussion groups addressed such topics as invasive plants, invertebrates, and microorganisms; freshwater and marine invasions; public health issues; prevention and remediation; education and invasive species; natural history collections and invasive species; national invasive species management plans; bioeconomics issues; international issues; and the design of National Ecological Observatory Network (NEON) initiatives for invasive species. More than 50 posters shed light on a range of subjects including the spread of aquatic nuisance species by river (Charles R. Berry, David Galat, and Mark Wildhaber, of South Dakota State University), the sale of nonnative crayfish species as bait (Michael G. McManus, Paul Horner, and Robert Distefano, from the Missouri Department of Conservation), a worldwide survey of pest ants (James K. Wetterer, of Florida Atlantic University), and the dispersal of invasive plant seeds by an invasive bird species (Nancy LaFleur, Margaret Rubega, and Jason Parent, from the University of Connecticut).

These investigations come not a moment too soon. “Since the first Europeans landed on North American soil, tens of thousands of nonnative plants, animals, and microorganisms have found their way to the United States,” according to a report from The Heinz Center, usually with human help, whether deliberate or accidental. Many of our crops, garden plants, and domesticated animals are natives of other lands. If these organisms stay within the bounds we have set for them, all is well. To paraphrase the poet Robert Frost, when it comes to nonnative species, good fences indeed make good neighbors.

But these species seldom comply with our demands. Plants and animals move about, helped in their efforts to colonize new territories by wind, flowing water, migrating birds, and—mostly—us. From pallets laden with the wares of global trade to the boots of farmers, which can track seeds from place to place, to the suitcases of the nefarious—like the man fined for carrying banned Chinese mitten crabs, an Asian delicacy, which can track seeds from place to place, to the suitcases of the nefarious—like the man fined for carrying banned Chinese mitten crabs, an Asian delicacy, these species indeed make good neighbors.
Identifying the problems

Nonnative species are referred to by many names: exotic, alien, nonindigenous, or introduced. When they spread aggressively, they’re called invasive. “They may cause diseases, compete for food or habitat, act as predators or parasites of native species, and threaten human health and economic well-being,” said plenary speaker Thomas Lovejoy, president of The H. John Heinz III Center for Science, Economics and the Environment in Washington, DC.

Whatever they’re called, these invaders cost the US public more than $137 billion each year. They come in the form of fire ants, zebra mussels, kudzu, nutria, Dutch elm disease, West Nile virus—a list so long we could easily designate an “invader of the week” for the foreseeable future. The Asian longhorned beetle, for example, which arrived in the United States in packing materials shipped from China, has the potential to wreak more havoc than gypsy moths, the chestnut blight, and Dutch elm disease combined, according to a 2002 report by The Heinz Center, The State of the Nation’s Ecosystems: Measuring the Lands, Waters, and Living Resources of the United States. By killing hardwood trees such as maple, birch, poplar, willow, elm, ash, and black locust, the beetle could cause losses of as much as $40 billion. Maple syrup making, commercial fruit harvesting, and lumbering are just a few of the industries that could be affected.

Whether by plane, train, ship, or automobile, and whether by good intention, bad intention, or “accidental tourism,” it’s clear that invasive species have arrived. “What are we going to do about them?” asked Representative Vernon J. Ehlers (R–MI), chair of the Environment, Technology, and Standards Subcommittee of the House Science Committee, who gave the conference’s opening remarks. “That old saw, an ounce of prevention is worth a pound of cure,” he said, “needs to be updated. How about one milligram of prevention is worth a thousand kilograms of cure?”

A possible answer linked every AIBS plenary talk, poster presentation, and discussion group: It’s all about vectors. Vectors are routes of transport for plants, animals, microorganisms, trade goods, and people. Ehlers’s one milligram of prevention, scientists believe, lies in developing an understanding not just of individual species but of how species in general are transported from one place to the next. Unless planes, trains, ships, and automobiles become part of the answer, even a thousand kilograms of cure won’t solve the problem.

“Vector management may be used to interrupt transfer of a particular target species,” write Gregory Ruiz and James Carlton in their 2003 book Invasive Species: Vectors and Management Strategies (Island Press), “but it can also be designed to prevent simultaneously the wholesale transfer of diverse assemblages (including both target and nontarget species), providing a powerful and efficient management approach.”
These ideas echo those of biologist Charles Elton, who almost 50 years ago wrote in his classic work, *The Ecology of Invasions by Animals and Plants* (Chapman and Hall, 1958), “It is not just nuclear bombs and wars that threaten us, though these rank very high on the list; there are other sorts of explosions... ecological explosions.” Ecological explosions, he believed, whether the potato blight of Ireland or the bubonic plague, “can be very impressive in their effects, and many people have been ruined by them, or died or forced to emigrate.” The word explosion, Elton said, was originally used to describe the barracking “of actors by an audience whom they [the actors] were no longer able to restrain by the quality of their performance.”

And so it is with invasive species.

Finding solutions

The hardest part of dealing with invasive species as an issue, said plenary speaker Ann Bartuska, of the US Department of Agriculture Forest Service, “is how little we have done about dealing with it—given how big it is, how clearly we know the impacts, how widespread it is, and how much it touches everyone in one way or another.”

In her talk, “Abating the Threat of Invasive Species: Linking Science and Policy,” Bartuska linked addressing invasive species to what she called “the fire issue.” In that case, she said, “we seem to have the political will and the public will to really take on fire [wildfire management] in a big way, and ‘big way’ meaning lots of money, lots of resources, and lots of focus on what is needed. But we don’t seem to be able to do the same thing with invasive species.... How do we make this problem that seems so huge and complex, that involves so many organizations and interests, that deals with multiple activities on all sorts of scales, from a very specific level to a global level; how do we bring all that together into a cohesive approach to the problem and begin to achieve solutions?”

Bartuska is in favor of an “early and often” strategy. “If you really want to address invasive species,” she said, “you want to get to them early and often, and not wait for an expansion to occur. This is the basis for our management of fire, to get to things before they get so out of hand that a fire becomes too costly and impossible to put out in many scenarios.” The answer, she believes, is in “looking at pathways and thinking more in terms of an integrated vector management approach rather than focusing on [individual] pests.... A lot of movement of goods and services across very large spaces is accelerating the potential movement of species. So if you wanted to address that movement, do you wait for it to jump an ocean or to jump into a country?” We need an effective early detection–rapid response system, said Bartuska. “This is where we really need to make the investment. Not species by species, case study by case study, but much more comprehensively.”

In his talk, “A Prescription for Plant Invasions: The Interaction of Attributes, Environment, and Circumstances,” plenary speaker Richard Mack of Washington State University spoke of a “bestiary of plant invasions that have occurred in the US, from purple loosestrife to Chinese tallow.” The invasion process, he said, is a multistage process: “an immigration phase, the survival of immigrants in a new range; a transient phase, in which many of these immigrants or their recent descendants perish and the population goes extinct, but some survive; a persistence stage, naturalizations in the case of plant examples; and a final stage in this process, the actual invasion.”

To address the problem of invasive species, Mack said, we need to “find commonality among the attributes of those species that have become invasive, then use this syndrome or syndromes in any other species proposed to be brought through customs declaration in airports: ‘sort of like what you see as you come to the country?’ We need an effective early detection–rapid response system, said Bartuska. “This is where we really need to make the investment. Not species by species, case study by case study, but much more comprehensively.”

Speaking about “Bioeconomic Risk Analysis of Invasive Vertebrates and Other Species,” David Lodge, of the University of Notre Dame, said most of our
Emerging infectious diseases have much in common with invasive species; in fact, the microbes responsible for disease outbreaks often spread by invading new host species or by conquering new territory. The vectors that move people and the microbes that infect them, transportation modes such as planes, trains, ships, and automobiles, are transporting infectious diseases in ever-increasing numbers. Abbreviations: CJD, Creutzfeldt-Jakob; E. coli, Escherichia coli; HIV, human immunodeficiency virus; VEE, Venezuelan equine encephalitis; V. cholerae, Vibrio cholerae. From the Centers for Disease Control and Prevention’s National Center for Infectious Diseases.
News about invasive species is not all bad. One reason for hope is the near-eradication of the invasive plant witchweed (Striga asiatica) from North Carolina. Through a several-decades-long commitment to fighting the spread of this invader, a veritable army of weed-pulling foot soldiers has been able to remove most of this alien weed, seen here lying dead between rows of corn. Photograph: US Department of Agriculture’s Animal and Plant Health Inspection Service.

and docked in San Francisco,” related Morse, “where the rats disembarked, carrying their infections with them. Globalization can be a very good thing, but there are careless by-products.”

Morse, in describing where these diseases come from, said, “In most cases, they are part of that great biodiversity of microbes in nature that find an opportunity to be introduced by various mechanisms into the human population. As the saying goes, ‘When the pig sneezes, the farmer may become infected.’ Viruses, for example, may have the capability just by luck, if you will, and biological chance to infect humans and spread well from person to person. Then there’s dissemination. No part of the world is more than a day or two away from any other part. So someone with SARS or anything else could get on a plane and be here tomorrow.”

We need improved surveillance, Morse said, early warning recognition, and the political will to assess and deal with invasive species. The fact that we don’t have these things, he believes, is responsible for “the microbes taking advantage of us.” Microbes know no country, they need no passports, and they don’t even need to be screened by the Department of Homeland Security. Microbes will hitch a ride on any means of conveyance, whether tires and wheel wells or human beings.

We don’t have to worry about whole continents being invaded, said Andrew Dobson, of Princeton University, in his plenary talk, “Zen, Parasites, and the Art of Alien Invasion.” “It’s essentially lots of little patches of you and me sitting out there—waiting to be invaded.”

Dobson related the tale of the first farm animals in England to contract foot and mouth disease. “It was at Burnside Farm up in the northeast,” he said. “The farm was owned by a man who had already been banned from farming in the neighboring county—and God knows what you have to do to be banned from farming—but he had moved across county lines and bought another farm.

“This outbreak then spread to other, neighboring farms, and then, as often happens, panic selling of pigs in the region managed to spread [the disease] throughout the rest of the United Kingdom. After the initial outbreak, it is essentially present throughout Britain and has had a number of cases reported from elsewhere in Europe. It had a major impact on movement of agriculture, what you could buy, what you could eat; a huge impact, billions of dollars.”

The pathogen infected cows and sheep, although not the pigs themselves, said Dobson. “But the size of this epidemic would have been half that size if we’d started [to work on it] one week earlier. So you could have had fewer dead cows, half the costs, and half the bad publicity. One week was all it took [to explode]. So that’s a bit scary.

“You not only want to know the detailed temporal dynamics of the disease,” said Dobson, “but how it spreads. Does the wind create asymmetries in the way it’s spread, for example, and what are the rates of spread, windborne over a local area?” Pathogen invasions can have effects that spread through the whole ecosystem and pose a major threat to human health. “On the other side, the sort of magical Zen side, is a nice thing about pathogens. Their absence in many invasive species gives those species a huge advantage. But it also potentially provides us with a new biological control mechanism that might be cheap to apply.”

As a species we are more skilled at changing the carrying capacity of the planet, said Lovejoy in his presentation, “Is the Top Beginning to Blow Off? Environmental Urgency and Biology’s Moment in History,” than any other species on Earth. “Leaf-cutting ants practice agriculture; beavers modify the landscape in their favor with dams. Then there’s us. What this raises is the big challenge of sustainability: How do you know it when you see it? How do you measure it? How do you deal with problems, which in the aggregate are obviously major problems but are made up of seemingly reasonable increments as they occur?”

If global change is viewed from that perspective, said Lovejoy, “I think we can state with fair authority that we are in the very first stages of what could be, but doesn’t have to be, the sixth great extinction in the history of life on Earth. And the cause of this is just a single species. That’s what’s different about this
extinction event. The thing that could be different [this time] is that we could stop it, because we are aware of what we’re doing.” What’s new in current discussions of how to better understand the impact of invasive species, Lovejoy said, “is the potential for synergies with the other ways in which we are affecting biological diversity, particularly synergies with the way we have modified the landscape.”

Our impact on the environment is on a scale that’s not easily reversed, Lovejoy believes. “There’s no easy solution. There is no global biological abracadabra. The solution is clearly multifactorial, and it’s tough, messy, and complex. I gave a speech in 1988 titled ‘Will Unexpectedly the Top Blow Off?’; another in 1995 called ‘Will Expectedly the Top Blow Off?’; and now in 2004, ‘Is the Top Beginning to Blow Off?’ And I think the answer is yes. The negative winds are nipping at the edges.”

We still hear that humans are speeding up a process that’s natural, in terms of invasive species, said James Carlton, of Williams College, in his talk, “Invasions in the World’s Oceans: How Much Do We Know, and What Does the Future Hold?” “In fact, what humans have done is not speed up the natural process at all,” said Carlton. “Invasions have occurred for tens and hundreds and millions of years on the surface of the earth, but what humans have done is radically different. We’re not simply speeding up what would happen anyway.” What we are doing is dissolving all temporal and spatial boundaries. In the natural world, Australia and England are not connected every 24 hours, stated Carlton. “The majority of the species we are concerned about would not, in fact, have arrived eventually.”

It’s hard to find a coastline in America that doesn’t have a signature invader, he said. In estuaries, bays, harbors, and other kinds of marine environments such as rocky shores, invasive species have gained a foothold. “But the question is on what scale have we been able to recognize invaders of the sea? I’ll argue that we have missed thousands of these species.” Vectors are numerous in the oceans, he explained. “They’ve served well to move species around for more than 500 years. Ocean-going ships are one of our number one vectors. There are ships that spend half their lives moving ballast water around, and half their lives bringing cargo back to port.” In ballast water and cargo are virtually unlimited opportunities for aquatic species of every description to hitch a ride to points known—and unknown.

Other vectors in the marine environment, said Carlton, include aquaculture, the saltwater aquarium industry, the bait industry, and marsh plants that are moved for restoration projects. “Some 5000 species could easily be in motion on any given day. In aggregate on a weekly basis, perhaps 15,000 different species. If one adds together all the vectors, that becomes a staggering number.”

Carlton’s advice is for biologists to “start reading the business section [of the newspaper], to get a sense of the scale of possible future invasions. If we can look at trade patterns, we might have a chance of getting more predictive,” because invasive species follow those patterns. In short, he said, “it’s all about understanding vectors. Invasions continue, but their Achilles’ heel is vectors.”

Cause for optimism?
Numbers of introduced species have increased. That fact has led to pessimism, said Daniel Simberloff, of the University of Tennessee, in “We Can Win This War! The Dangers of Pessimism about Introduced Species.” “In a century at most, the thinking goes, it will all be green [on Earth], but it’ll be the same nature everywhere. Maybe the best we can do is to slow the process down a little bit, people say.” Not so, he believes.

“[If you look at the dozens and dozens of successes] in eradicating invasive species, there are three key features: There have to be adequate resources devoted at the outset; there has to be commitment; and there have to be the resources to finish it. What often happens with eradication attempts that have failed—but could have succeeded—is that once the problem is diminished because the effort is working, the funding agency pulls the funding.”

Simberloff cited several cases in the United States in which “it was thought that a particular invasive species was no longer a problem...then the invasion really takes off, and the species becomes established. Eradication is an all-or-nothing phenomenon. You can’t have everyone on board for it except two people who think it won’t work and who decide they don’t want to eradicate. Clearly that doesn’t work.”

Witchweed in North Carolina is one example where eradication most likely will work, he said. “Witchweed is a famous federal–state eradication program. Over almost 50 years, witchweed has been reduced from 160,000 hectares to about 1500 hectares. It’s all in one little area in North Carolina now. Eventually, they’ll get it all, and it will be one of the triumphs of invasive species control. But it’s cost almost 300 million dollars. Conservation doesn’t have that kind of money. So it’s important to find these species early.

“There are so many cases where we could have eradicated them early and didn’t. The estimates have been far too pessimistic about how much effort that would take at the early stage.” Simberloff believes that successful future eradication efforts need very heavy use of person power.

“My main point is that in managing existing invasions, we’ve already won a lot of battles,” he said. “Without a lot of thought beforehand, we shouldn’t automatically assume [that] a species can’t be worked with and that we should just forget about it. On the eve of the eradication of smallpox, many, many people said it couldn’t be done. I think we could win a lot more of these battles, as long as we don’t let ourselves be hamstrung by pessimism.”

There are many vectors, Simberloff believes, and many coronaviruses, but there are also many witchweeds.

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