Union of Concerned Scientists
Citizens and Scientists for Environmental Solutions

THE SCIENCE OF INVASIVE SPECIES

An Information Update by the Union of Concerned Scientists

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Although the accelerating introduction and spread of invasive species is among the most serious of threats to global biodiversity, governments and many environmental groups have only begun to address the issue. The protection of biodiversity depends on bolstering the science of invasion biology, and ensuring that its findings quickly lead to more effective policies to reduce harmful impacts.

In response to the increasing severity of the threat, UCS is devoting a large portion of its overall conservation agenda to invasive species. This Information Update represents a kick-off of our new project. It is intended to provide a general overview of the science and conservation issues surrounding invasive species, including a look at:

- the nature and magnitude of the threat;
- the numbers of species involved and patterns in their spread;
- specific examples illustrating how invasive species arrive and their environmental impacts;
- their economic costs;
- the ways they are managed; and
- a number of current "hot" topics in invasion science.

A companion piece to follow (Part 2, Invasive Species Policy) will provide an overview of related policy. It will also review UCS's main policy goals. As with our work on climate change and other biodiversity issues, encouraging the use of credible science both in policymaking and in raising public awareness will be the cornerstone of our work.

Policymakers need to know that invasive species pose a major threat to native ecosystems and biodiversity as well as to economic prosperity. This and future updates will provide helpful background on the issues and information on how you can help influence major policy decisions on invasive species.

AN URGENT PROBLEM, A TIMELY RESPONSE FROM UCS

Biologists generally list five or six types of human-related "causes of extinction," of which habitat destruction is considered the greatest threat. Yet a growing chorus of experts point to invasive species as the second largest--and probably the fastest growing--threat to biodiversity in many ecosystems. For example, Wilcove et al. (1998) demonstrated that of 1,880 US species classified as imperiled, invasives played a major role in the listing of 49%. This was second only to habitat loss as a factor and was significantly higher than pollution, overexploitation, and disease combined. Loss of species is just one result of biological invasions--changes in ecosystem structure and function and increasing homogenization of unique regional biota are others.

But if the problem is so serious, why have we yet to build an effective approach to address the problem? Perhaps one reason lies in the issue's conceptual complexity. Invasive species often threaten biodiversity through complicated interactions, many taking place invisibly and over long periods of time. As Edward O. Wilson (1997) has noted, "Extinction by habitat destruction is like death in an automobile accident: easy to see and assess. Extinction by the invasion of exotic species is like death by disease: gradual, insidious, requiring scientific methods to diagnose."

Interestingly, neither the scientific community nor the conservation community (not to mention lawmakers, the public, and the media) has yet to agree on a single name for this topic. Species are described as alien, emerging, exotic, introduced, naturalized, noxious, nuisance, or nonindigenous. More colorful terms like biological pollution, green cancer, and biological wildfire describe their impact. Recently, usage of "invasive species" (or simply the shorthand "invasives") has become commonplace, but without a common definition.

At UCS, our focus is on protecting native species and ecosystems already or potentially at risk from biological invasions. We are not concerned with the nonindigenous organisms that neither spread nor cause environmental harm, and we recognize that economic harm is an important measure of damage for policymakers. For these reasons, we have adopted the definition recently put forward by the federal interagency National Invasive Species Council (NISC): "An 'invasive species' is "…a species that is 1) non-native (or alien) to the ecosystem under consideration **and** 2) whose introduction causes or is likely to cause economic or environmental harm or harm to human health" (NISC 2001). Although the term "invasive species" is most often applied to plants and larger animals, less well-studied microscopic and microbial species can also be invasive. Introductions can be either deliberate or unintentional and either legal or not.

The emerging invasive species crisis has received far less attention than is warranted. But recent progress in invasive species policy can be attributed in large part to scientists' involvement. Recognizing this, UCS recently launched a new project on this issue. We will advocate for specific policies that substantially reduce the introduction and spread of invasive species in the United States and decrease their impacts on native ecosystems and biodiversity. As an organization poised to affect US policy, our primary focus will be domestic. However, we recognize the role of the United States in global trade and we intend to take advantage of significant related opportunities. For example, we aim to discourage exports from the United States of species known to be invasive.

AN INTRODUCTION TO INVASION BIOLOGY

Humans have been transporting species, both intentionally and unintentionally, around the world for hundreds of years (Van Driesche and Van Driesche 2000). Early explorers, traders, and settlers released cattle, pigs, sheep, and goats to establish reliable food sources for shipping networks and islanders. The transport of livestock, crop plants and goods by colonists resulted in inadvertent introductions of many noxious weeds and pest insects while some agricultural species themselves became invasive. European rats colonized countless new ports, arriving as hitchhikers on sailing ships. Smallpox, measles, malaria, and diphtheria were among the many diseases that were spread to native peoples by European explorers.

Today, with modern, high-speed transport systems and extraordinarily complex global economic patterns, people are moving species at unprecedented rates across countless borders and ecosystems. For example, arrivals of seaworthy freight containers at the Port of Los Angeles, California increased from 20 in 1958 to 3.2 million in 1998 (USDA/APHIS 2000)--each a potential source of seeds, insects, diseases, and small organisms. The wooden packing material used to protect these goods may itself harbor damaging plant pathogens and insects. Worldwide, at least 7,000 species, ranging from cholera and botulism bacteria to invertebrates and fish, are probably in motion each day in the ballast water of tens of thousands of ships (Carlton 1999; McCarthy and Crowder 2000).

As a result of these historical and recent translocations, thousands of nonindigenous species now are present or established in new places, sometimes making up sizeable proportions of the biota. The Office of Technology Assessment (OTA) estimated that at least 4,600 nonindigenous species were established in the United States by 1990 (US

Congress 1993). Approximately 400 nonindigenous species are known in the estuaries along the Pacific, Atlantic, and Gulf coasts of the continental United States (Ruiz et al.1997). In just five northwestern states, a continuous influx of new plants between 1877 and 1997 has led to over 700 new weed species (INVADERS 1999). Historically, Hawaii had no native freshwater fish; now it has 52 non-native ones (Boydstun et al. 1995). Many US states that had no fish species in common before European settlement now share an average of 25 (Rahel 2000).

The means by which these species have moved around the globe varies by taxonomic group, by geographic region, and over time. Now, ballast water appears to be the single largest source of unintentional transfers of aquatic nonindigenous species throughout the world (Ruiz et al. 1997). For fish, deliberate introductions, e.g., for sport fishing, aquaculture, home aquaria, or biological control, account for more than 40% of the non-native fish species in the United States (Courtenay et al. 1984). About one-half of the several hundred plants now invading wildlands in the continental United States and Canada were imported for gardens (Marinelli 1996). While the major pathways of introductions are now well known, there is not yet any comprehensive understanding of the many and varied routes by which introductions occur (D'Antonio et al. 2001). A forthcoming publication on invasion vectors and pathways (Ruiz and Carlton, in press) should improve this situation.

The global movements of species--and their impacts--have been recognized for decades. By 1906 ornithologists had linked the introduction of the English house sparrow *(Passer domesticus*) to the decline of native bird species in Cambridge, Massachusetts. Yet the first major treatise on invasives did not come until the 1958 book, "The Ecology of Invasions by Animals and Plants." Author and ecologist Charles Elton concluded: "We must make no mistake: We are seeing one of the great historical convulsions in the world's flora and fauna."

The development of invasion biology as a separate field is more recent. IUCN added an Invasive Species Specialist Group to the Species Survival Commission in 1993. The number of scientific publications and conferences in this area has multiplied since the early 1990's, and the first issue of a journal devoted to the topic (*Biological Invasions*) was published in 1999.

But several of today's scientific tenets were clear to Charles Elton (Simberloff 2000a):

- Most introduced species do not survive. Indeed, most introduced species find neither a tolerable environment nor an available ecological niche. Successful establishment may also require multiple introductions. Of those species that do become established, only a limited number spread and become damaging. OTA found that of the more than 1,300 established, nonindigenous species in the US analyzed, approximately 15% caused "severe harm" to native ecosystems, species, or the economy (US Congress 1993).

- Invasive species are particularly devastating on islands, where unique floral and faunal species have evolved without selective pressures from large herbivores, carnivores, or pathogens. For example, introduced pigs and goats in Hawaii and other oceanic islands have decimated native flora by trampling and eating plants and rooting up soil, creating openings for nonnative plants and depressions where water and mosquito larvae collect. Predaceous tree snakes, rats, and mongooses, and diseases carried by introduced mosquitoes have also led to multiple species extinctions. Exotic plant species often outcompete endemic taxa or alter fire cycles.

- The impacts of invasive species are highly diverse and often difficult to quantify and compare. Some are economic, such as the clogging of drainage pipes by zebra mussels or damage to agricultural crops by a vast range of exotic pest species. They can directly affect ecosystems, severely reducing habitat structure and diversity. For example, by the late 1990s, massive infestations of water hyacinth (*Eichhornia crassipes*) covered approximately 90% of Lake Victoria's shoreline, depriving local (and, ironically, invasive) fish species and other organisms of oxygen and sunlight (Bright 1998). Or, invasive species can wipe out individual populations and species through direct competition or predation.

- It is difficult to predict which species will become invasive. For terrestrial vertebrates, mollusks, and fish, about as many deliberate as inadvertent introductions have turned out to be harmful (US Congress 1993). But this may be due as much to complacency regarding potential harm or to poor decision-making as to the inherent unpredictability of introductions. Increasing efforts have been made to list traits that contribute to an introduced organism's ability to spread (e.g., number of seeds produced and seed size; age at first reproduction), but only a few of these efforts have been very fruitful. Within a particular group of plants, for example, invasiveness has been correlated with early age at first reproduction, short intervals between large seed crops, and small seed size (Rejmanek and Richardson 1996). Thus far, though, the best predictor of invasiveness is whether or not the species has proven to be invasive elsewhere, especially under similar conditions (Reichard and Hamilton 1997; Wittenberg and Cock 2001). Changing the focus to such geographic or ecosystem considerations has led to important advances in predicting plant invaders (Daehler and Carino 2000).

Burgeoning research is adding to these first four tenets of invasion biology. For example, biologists no longer expect that undisturbed systems are safe from invasion (Lodge 1993). But the science is still young. For intentional introductions, research is needed on how to better evaluate risks and benefits, possible alternatives to introductions, what safeguards should accompany introductions, and how to better reduce negative impacts (Ewel et al. 1999). D'Antonio et al. (2001) flagged a broader group of 26 research questions, some of which they deemed needed answers within the next ten years or "it will be too late for many species or natural communities."

Another unknown is the relationship between global climate change and the spread of invasive species. Climate change could potentially favor invasive non-native species by either creating more favorable environmental conditions for them, e.g., increasing fire frequency (D'Antonio 2000), or by stressing native species to the point of being unable to compete against new invasives. In the Gulf of Maine, researchers believe that climate change and sustained overfishing are acting synergistically to favor introduced species (Harris and Tyrrell 2001). One potentially devastating possibility lies in the Pacific Northwest, where the current climate restricts the non-native balsam woolly adelgid (*Adelges piceae*)--a serious pest of fir trees--to low and middle elevations. If higher elevations warm, the adelgid might be able to reproduce and spread into higher elevations--just where subalpine fir (*Abies lasiocarpa*) is a major component of the forests (Franklin et al. 1992).

INVASIVE SPECIES' ECOLOGICAL IMPACTS

Whether introduced intentionally or accidentally, invasive species can: 1) prey on, parasitize, outcompete, or hybridize with native species to the point of extirpation or extinction, and 2) disrupt the function of native communities and ecosystems.

Examples of Population, Species, and Genetic Impacts

One well-known invasive species is the brown trout (*Salmo trutta*), first intentionally introduced from Europe to the United States in 1883 (US Congress 1993). Tolerant of a wide range of environments, the brown trout continues to be stocked for recreational fisheries in rivers and streams of the western United States. The species reproduces well in most of the places where it has been introduced and is known as a voracious predator, having depressed or eliminated many local trout, salamander, and frog populations--including the mountain yellow-legged frog (*Rana muscosa*), which has disappeared from over 90% of its historic range.

The zebra mussel (*Dreissena polymorpha*) is perhaps the most often cited example of inadvertent aquatic introductions. A native of eastern Europe, the zebra mussel colonized much of the European continent during the late 18th and early 19th centuries. In 1988, zebra mussels were first found in Lakes Erie and St. Clair, arriving in ship ballast water. By 1997, the zebra mussel had spread to waterways and lakes in 19 states. Zebra mussels will readily encrust nearly any hard surface, including shells of other organisms. As a consequence, both individual populations and entire species of native mussels are threatened (Williams et al. 1993).

Probably the most striking example of species impacts is found in Africa, where in the 1960's colonial authorities began stocking Lake Victoria with the aggressive Nile perch (*Lates niloticus*). This single species led to the disappearance of up to 200 native cichlid fish species--"the greatest single paroxysm of extinction ever recorded" (Bright 1998). Perhaps next in line for causing the highest number of extinctions is the rosy wolf snail (*Euglandia rosea*), introduced from North America into Hawaii and other large islands to control the previously introduced giant African snail (*Achatina fulica*). This effort at biological control was not only unsuccessful but also led to extinctions of at least 15 endemic snail species on the Hawaiian island of Oahu and 24 endemic snail species on the island of Mauritius (Stein and Flack 1996).

Another disastrous introduction--this time unintentional--occurred with the arrival of the brown tree snake (*Boiga irregularis*) on the island of Guam from the Admiralty Islands. It was first sighted in the 1950's. By the end of the 1960s, the snake had dispersed throughout the island. Overall, the brown tree snake has extirpated nine native bird species, and is probably a primary cause of the extirpations of five native lizard species and two of three bat species (Amand 2000). It is now but a plane ride away from both Hawaii and the US mainland, where single snakes have already been found. If viable populations become established, a new swath of extinctions will likely follow.

A host of invasive, or "emerging" infectious diseases affect fish, wildlife, domestic animals, and humans. Daszak et al. (2000) list 37 representative examples, all but ten of which are associated with high mortality rates, population declines, or possible extinctions. Avian malaria in Hawaii; amphibian chytridiomycosis in Australia and North and Central America; crayfish plague in Europe; and steinhausiosis, a disease of *Partula* snails, are among those having the most severe impacts on native biodiversity.

Invasive species can have genetic impacts as well, especially on animals. The loss of native fish due to hybridization between native and non-native species has been known for more than 20 years (Miller et al. 1989). Other types of hybrids also occur, e.g., between different nonindigenous species, between their ecotypes, and between previously isolated native species brought together by human activity (e.g., east and west coast species of *Spartina*, the salt marsh cordgrass).

Examples of Impacts on Ecosystem Structure and Function

First recognized in North America in 1889, cheat grass (*Bromus tectorum*), a native of Eurasia, probably arrived on the continent as a contaminant in shipments of grain seeds from Europe. It produces a litter that is slow to decompose and fills in the spaces between shrubs in arid rangeland systems. This results in a continuous cover of fine fuels that did not previously exist in these sites. Having now spread over 40 million acres of the western part of the continent, cheat grass has drastically increased the frequency of fires to a nearly annual cycle. This is turn has caused an almost complete loss of native woody species over large areas. Due to lack of cover and forage, songbirds and rodents abandon areas dominated by cheat grass; ultimately, predators of those species can no longer be sustained and the effected areas exhibit significantly reduced levels of species diversity.

Some of the most drastic ecosystem changes in the United States have involved plant pathogens. Chestnut blight (*Cryphonectria parasitica*) eliminated American chestnuts from an estimated 180 million acres in the eastern United States. Ten moth species that could live only on chestnut trees were among the animal casualties when new tree species became dominant. This and other invasive plant diseases have caused wave after wave of tree diebacks in North America. Currently an introduced microbe in the genus *Phytopthora* is causing the decline of most of the dominant forest hardwood species north of the San Francisco Bay along the California coast. The result will be large-scale ecosystem change.

The United States is not alone in experiencing ecosystem impacts. One of the more significant invasives in Europe is Leidy's comb jelly (*Mnemiopsis leidyi*) from the east coast of the Americas. The species was probably released from ballast waters around 1982 into the Black Sea, where it immediately set to foraging on zooplankton. Since nothing ate the Leidy's comb jelly, food webs in the Black Sea were severed, leading to the collapse of anchovy and other fisheries.

The virulent pathogen rinderpest was introduced from Asia to Africa in 1889. The disease front traveled 5,000 km in ten years, extirpating more than 90% of Kenya's buffalo population, which in turn effected a wide range of predators and caused local extinctions of the tsetse fly (Daszak et al. 2000). Some species' populations remain depleted or at risk. Rinderpest also wiped out most of the cattle in several regions, leading to widespread famine, staggering economic losses, and social unrest.

ECONOMIC IMPACTS

In perhaps the most comprehensive study of harmful nonindigenous species in the United States, the Office of Technology Assessment (US Congress 1993) found that between 1906 and 1991, 79 nonindigenous species caused documented losses of $97 billion. OTA estimated annual costs at several billion dollars, more in years when large-scale control programs were underway.

Pimentel et al. (2000) updated some of OTA's numbers and compiled the costs associated with a wider range of species. Their analysis "reveals that economic damages associated with nonindigenous species effects and their control amount to approximately $137 billion per year." This figure is universally cited but its accuracy is difficult to assess. Of necessity, many of the report's sources are in the gray literature. The total includes a wide mixture of actual expenditures, estimates of damage from already-present invasive species, and projections for potential invaders--some quite dated. However, the authors consider their total low since many intangible losses are not tallied, e.g., disruption of ecosystem services and aesthetic degradation. Even control costs may be underestimated because many programs rely on enormous amounts of volunteer labor.

UCS considers the following to be representative and careful estimates of economic damage:

- By 1994, documented cumulative losses to about 50% of the Great Lakes' large water users from zebra mussels were $60.2 million (Great Lakes Commission 1996).
- Leafy spurge, which infests several million acres in the upper Great Plains, causes an estimated annual economic loss of $130 million per year (Leitch et al. 1994).
- In 2000, $8.47 million in federal and state funds were spent to treat European gypsy moth infestations in seven northeastern states (USDA Forest Service 2000). The potentially more devastating Asian gypsy moth reached the United States twice in the 1990's. Eradication cost $25 million in the Pacific Northwest and $9 million in North and South Carolina (Wallner 1996).
- During the 1999-2000 fiscal year, more than $17 million in federal, state, and local funds were spent to treat mostly aquatic plants on almost 42,000 acres in Florida. The State's Bureau of Invasive Plant Management estimates that about $25 million will be needed in fiscal year 2001-2002 (Florida DEP 2000).

MANAGEMENT SOLUTIONS

The complex biology of invasive species often makes their impacts difficult to prevent or mitigate. Across the board, lessening the impacts of invasive species will ultimately require substantial investments in basic and applied scientific research.

Undoubtedly, the best point at which to control a potentially invasive species is prior to introduction. Unfortunately, US policy--which James T. Carlton has likened to "ecological roulette"--is no match for the pace of introductions. Now, only a small proportion of potentially damaging species are evaluated for invasiveness before import and then excluded if their risks are unacceptably high. Expanded screening of proposed imports is most often recommended as the way to cut risks. An Australian system for screening potentially invasive plants shows promise (Daehler and Carino 2000).

For inadvertent introductions, mitigation measures are key. Treating solid wood before it is used as packing material and sterilizing ships' ballast water while still on board are two examples. Although risk assessments for introduced species are primitive, scientists have prodded federal agencies to formally assess pathway-wide risks for high-risk routes of entry and then to require mitigation. Timber imports from Siberia and solid wood packing material have been evaluated this way.

As fundamental as prevention is, however, it is only part of the solution. Aiming for a standard of 'zero entry' has limited returns, especially if prevention efforts come at the expense of rapid response or essential long-term control of species already present. As both the impacts of invasive species and the failures of policy become clearer, land managers are paying more attention to controlling invasive species. This choice represents a fundamental shift in thinking about the levels of human intervention appropriate to "unmanaged" land and about the weight assigned to the risks of doing nothing.

Under the right circumstances, total eradication of an invasive species is possible (see "Hot Topics" below). If not, a range of methods may sometimes work to maintain species at low densities (Preston et al. 2000; Wittenberg and Cock 2001). Physical or mechanical controls include cutting or harvesting aquatic, riparian, and other plants; burning shrubs in grasslands; and excluding fish and mammals with fencing. Sterilization disrupts mating of the Mediterranean fruit fly (*Ceritítis capitata*) and limits the spread of grass carp (*Ctenopharyngodon idella*), a fish introduced to control aquatic weeds which itself became invasive.

Pesticides and other chemical controls are used to treat a wide variety of insects, pathogens, and vegetation and to bait insect and mammal traps. As the harm caused by invasive species has become more apparent, there has been a marked increase in managers' willingness to use herbicides, especially in areas once considered off limits such as preserves and wetlands. There is also a growing willingness to control emerging infectious diseases in wildlife. For example, domesticated dogs near the Serengeti National Park, mountain gorillas, and chimpanzees have been vaccinated against wild dog rabies, measles, and poliovirus, respectively (Daszak et al. 2000).

The more frequent use of such intense and ecologically risky interventions has been greeted with ambivalence, especially among the environmental community. In the most well-managed programs, precise application methods mean that the amount of herbicide applied per area can decline. Such efforts use chemical methods as only one of many possible tools in an "adaptive program" with carefully defined and highly specific management objectives (for example, see Tu et al. 2001).

An ever-expanding range of biological controls is also used. By 1998, for example, 73 biocontrol agents had been released on 36 weeds in the mainland United States (Zimmermann and Klein 2000) and in the mid-1990s 28 states operated their own biological control programs (US Congress 1995). Often biocontrol is considered the method of choice for widespread infestations and natural areas. Some agents appear safe and effective, obviating or reducing the need for additional control. Examples include the organisms used against alligatorweed (*Alternanthera philoxeroides*) in Florida and St. John's wort (*Hypericum perforatum*) in the western United States.

But biological control is highly controversial, especially when used against invasive species that are native elsewhere in the United States and where those species have close, non-invasive relatives nearby. Early attempts gave the strategy a deservedly poor reputation. For example, the Indian mongoose (*Herpestes javanicus*), when released in Hawaii to control rats, also preyed on several species of native birds. A European parasitoid fly (*Compsilura concinnata*)--introduced repeatedly to control 13 pest species in 30 states is decimating at least two species of native giant moths in the Northeast (Boettner et al. 2000). The second generation of biocontrol agents has been subjected to more rigorous tests of host-specificity, which proponents claim will prevent similar disasters (Knight 2001). Whether these tests are adequate and widely enough applied is still debated.

Regardless of the method, significant technical and policy issues remain. Attempts to control marine invaders are rarely made, for example. Control is often expensive and sometimes erratically funded, which allows invasives to spread and makes management more difficult. However, some successful control and eradication efforts have been quite inexpensive.

Modern control programs are frequently marked by their combinations of methods. For example local land managers and state officials have pioneered species-specific, precise ways to combine treatments. In one, nicknamed "hack and squirt," herbicide is applied only to the cambium of newly cut woody plants. The most promising methods combine monitoring and rapid response--to detect and treat new invasions early; information management--to select the sites, species, and methods that provide the best opportunities; and restoration methods--to fill gaps created by the removal of invaders and prevent their return.

Ecosystem management approaches are too new to have a clear track record in controlling invasive species. These entail subjecting large areas--and, in cases like the Everglades, entire ecosystems--to regular treatments that favor native species over invasive ones (Simberloff 2000b). Methods include regulating hydrology or changing fire regimes.

HOT TOPICS IN INVASION SCIENCE

In a number of areas, invasion biology is developing quickly, being re-interpreted, or proving controversial:

- What constitutes an "invasion?" Species that become invasive have survived a multi-step process of arrival, establishment, and spread. Now, scientists are teasing apart this sequence and investigating the forces that speed or slow different steps. The probability of establishment, for example, goes up with both the number of introductions attempted and the number of individuals released (Kolar and Lodge 2001). Recent population genetic studies reveal that some widespread populations of invaders represent not the result of a single event but multiple introductions from different sources (Kreiser et al. 2000).

- What makes ecosystems vulnerable to invasion? Surprisingly, some of the most biologically diverse "hotspots" are also among the most invaded. These include the most diverse portions of Californian riparian systems (Levine 2000) and the southeastern corner of Grand Staircase-Escalante National Monument in Utah (Stohlgren et al. 2001). But debates about what makes an area susceptible or resistant are only beginning to be resolved (Kaiser 2000).

- In what circumstances is eradication feasible? Eradication is perceived to be nearly impossible in most situations. But recent efforts suggest that, for a surprisingly large group of species and under the right conditions, it has untapped promise (Simberloff 2001). For example, mammal eradication, especially on islands and especially for herbivores, often works. Eradication of widespread plants is more difficult but not impossible with persistence. But elimination of small mammalian carnivores and snakes may require development of new technology.

- Under what circumstances is the use of transgenic organisms safe and effective? As biotechnology develops, some scientists hope for new ways to control invasive species for which there are few other options. But controversy is common in areas where issues related to invasive species and genetically modified organisms overlap. Recent debates involve: 1) the potential use of genetically modified (GM) Atlantic salmon in aquaculture where escapes of tens of thousands of fish per year are documented and when the genetic impacts of escaped farmed fish on rare wild populations are unclear (Canadian Parliament 2001; Naylor et al. 2000); 2) the first proposed field trials of a GM insect--caged populations of the pink bollworm (*Pectinophora gossypiella*)--itself a non-native pest of cotton; and 3) the emergence, in Canada, of naturally occurring herbicide resistant canola plants descended from GM parents (Ellstrand 2001).

- What should be done in those rare circumstances when invasive species provide valued ecosystem services or support threatened and endangered species? As native species continue to decline, increasingly difficult decisions will arise about which species to eradicate or control. For example, the endangered willow flycatcher has taken to nesting in introduced saltcedar trees (*Tamarix* spp.), which are destroying native wetland plant communities in the desert Southwest by monopolizing scarce water supplies. Some conservationists are concerned that killing the trees will leave the willow flycatcher with nowhere to nest (Knight 2001).

CONCLUSION

The specific examples of invasive, non-native species cited in this Information Update constitute only a minuscule fraction of the thousands threatening biodiversity throughout the world. Whether released intentionally or introduced inadvertently, invasive species have decimated individual populations, caused multiple extinctions, and altered the functioning of ecosystems. With the inevitable expansion of international trade in the coming decades, the threat of future introductions looms ominously over the past century's work to preserve native biological diversity.

A fundamental step in countering this threat is putting invasive species at the center of both public and private conservation efforts. Clearly, both prevention and control are essential components of any realistic strategy to solve the problem of invasive species.

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USEFUL WEBSITES AND LISTSERVES

U.S. Invasive Species Information System:
http://www.invasivespecies.gov/

Plant Conservation Alliance's Alien Plant Working Group:
http://www.nps.gov/plants/alien/

Center for Aquatic & Invasive Plants:
http://aquat1.ifas.ufl.edu

Global Invasive Species Programme:
http://jasper.stanford.edu/gisp/

Aliens-l, a listserve managed by IUCN's Invasive Species Specialist Group:
http://www.issg.org

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THE SOUND SCIENCE INITIATIVE

This Information Update was prepared for and distributed to UCS' Sound Science Initiative (SSI). SSI is an effective email-based vehicle for scientists to familiarize themselves and the public with environmental issues of global significance, with a special focus on climate change and loss of biological diversity. SSI also provides the tools for individuals to respond to and influence fast-breaking media and policy developments.

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