The Consequences of Harmful Non-Indigenous Species 2

Chapters 2 and 3 examine basic aspects of non-indigenous species (NIS)----their effects, how many there are, and how they get here. Technologies to deal with harmful NIS, including decisionmaking methods and techniques for preventing and managing problem species, are covered in chapters 4 and 5. Chapters 6, 7, and 8 assess what various institutions at the Federal, State, and local levels do, or fail to do, about NIS. Finally, chapters 9 and 10 place NIS in a broader context by examiningtheir relationships to genetically engineered organisms, to international relations, to other prominent environmental issues, and to choices regarding the future of the nation's biological resources.

WHAT'S IN AND WHAT'S OUT: FOCUS AND DEFINITIONS

Although considerable benefits accrue from the presence of many NIS in the United States, others have caused significant harm. This report's goal is to identify where and how such problems arise, and how these problems can be avoided or minimized. This "problem-oriented" approach requires that beneficial introductions get limited attention throughout the assessment. They are summarized only briefly in this chapter. The emphasis is on harmful NIS, encompassing terrestrial and aquatic ecosystems and also most types of organisms (figure 2-l). An important consideration is whether a species can establish free-living populations beyond human cultivation and control. Non-indigenous species within this category-those living beyond human management--cause most harmful effects.

Figure 2-l-Scope of Study

Species Central to the Assessment (to be given full consideration)	Species Not Central to the Assessment (to be *considered only when they raise important ecologlcal or economic issues)*
Potentially or already harmful non-indigenous species: • not yet in the United States (e.g., certain weedy bromegrasses) • in the United States, but in a captive or managed state (e.g., some tilapia in aquiculture) **Potentially or already harmful non-indigenous species established as free-living populations in the United States:** • of non-U.S. origin (e.g., zebra mussel) • originating in one area of the United States, but non-indigenous in another (e.g., certain salt marsh grasses on the West Coast) • feral species (e.g., wild hogs)	**Beneficial non-indigenous species:** • of non-U.S. origin not yet in the United States (e.g., new crops) ■ of non-U. S. origin presently in the United States in a captive (e.g., elephants), managed (e.g. alfalfa), or free-living state (e.g., several earthworms) ■ originating in one area of the United States, but non-indigenous in another (e.g., Pacific salmon in the Great Lakes) ■ except those also having the potential to escape and/or cause harm **Indigenous species, including those:** ■ naturally expanding their ranges into the United States (e.g., Old World blackheaded gull) ■ previously extirpated, but presently being reintroduced (e.g., Californian condors) ■ stocked or planted within their natural ranges (e.g., southern-pine plantations) naturally occurring hybirds between indigenous species (e.g., grey wolf/coyote hybrids) **Species of unknown origin (e.g., dogwood anthracnose)** **Bioengineered orgnisms (e.g., transgenic fish) -- but central in chapter 9** **Structural pests (e.g., cockroaches)** **Human diseases (e.g., swine flu)**

NOTE: When the word "species" occurs above, "subspecies" and "recognized variants" may be substituted. Our emphasis is species-level issues first, then subspecies and variants in decreasing priority. See index for species' scientific names.

SOURCE: Office of Technology Assessment, 1993.

Definitions

Finding:

Terms and definitions pertaining to NIS differ greatly among various laws, regulations, policies, and publications, making direct comparisons misleading. A need exists for uniform definitions to ensure accurate assessments of problems and consistent applications of policies.

Movements of people and cargo across the Earth provide routes by which species spread to new locales. ''Exotic, ' ''alien," ''introduced, " "immigrant, " ''non-native,' and "non-indigenous' have all been used to refer to these species. No universally accepted or standard terminology exists.

OTA has chosen "non-indigenous" as the most neutral, inclusive, and unambiguous term. OTA's definition of non-indigenous (box 2-A) avoids some common sources of confusion. It sets spatial limits based on a species' ecology rather than on national or State boundaries. Other definitions of non-indigenous and related terms, like exotic, vary greatly as to whether they include only species foreign to the United States, or additionally incorporate species of U.S. origin

Box 2-A–Terms Used by OTA

- Non-indigenous-The condition of a species being beyond its natural range or natural zone of potential dispersal; includes all domesticated and feral species and all hybrids except for naturally occurring crosses between indigenous species.
- Indgigenous-The condition of a species being within its natural range or natural zone of potential dispersal; excludes species descended from domesticated ancestors.
- **Feral-Used to describe free-living plants or animals, living under natural selection pressures, descended from domesticated ancestors.**
- *Natural* range-The geographic area a species inhabits or would inhabit in the absence of significant human influence.
- *Natural zone of potential* dispersal-The area a species would disperse to in the absence of significant human influence.
- *Introduction-All* or **part of the process** by which a non-indigenous species is imported to a new locale and is released or escapes into a free-living state.
- Established-The condition of a species that has formed a self-sustaining, free-living population at a given location.

OTA's definitions of "indigenous" and "non-indigenous" are based on species' ecology rather than on national, State, or local political boundaries. Thus, if **a** species' natural range is only in west Texas, it would be non-indigenous when imported to east Texas. A species is indigenous to its entire natural range, even to areas it previously but no longer occupies due to human influence.

The definition of "natural range" incorporates the idea of a "significant human influence." This acknowledges that species can have natural ranges even when affected by humans so long as humans are not a *major* determinant oft he range. The concept of "natural zone of potential dispersal" incorporates naturally occurring expansions and contractions of species ranges. For example, a shore bird that shifts naturally overtime from being an "accidental" visitor to the United States to being a breeding resident would be indigenous.

Domesticated and feral species and their variants are all non-indigenous. They are products of human selection and lack natural ranges. For similar reasons, all hybrids except for naturally occurring crosses between indigenous species are also non-indigenous.

OTA will explicitly indicate where this report's discussion is limited to species non-indigenous to the United States rather than to all non-indigenous species. Similarly, the terms "indigenous" and "non-indigenous" also can apply to subspecies, recognized variants, and other biological subdivisions beneath the level of species. Uses in these contexts also will be clearly identified.

SOURCE: Office of Technology Assessment, 1993.

living beyond their natural ranges (48,92). OTA's definition also does not include arbitrary time limits. Some definitions classify as native or indigenous all species established in the United States by a certain date, commonly before European settlement (53). Under other definitions, NIS eventually become ' 'naturalized' after a certain period has elapsed (97).

Several important categories of organisms are comprised wholly or in part of NIS. Experts estimate that at least half of U.S. weeds are non-indigenous to the country (19). A similarly large proportion of economically significant insect pests of agriculture and forestry is non-indigenous: 39 percent (67). Federal laws restrict or prohibit importation of plants and animals considered to be "noxious weeds' and "injurious wildlife' '2—species that are all non-indigenous.

Other Efforts Under Way

Several efforts related to this assessment are under way or were recently completed.[3] Passage of the Nonindigenous Aquatic Nuisance Prevention and Control Act of 199@ created the interagency Aquatic Nuisance Species Task Force. This task force is required to develop a program to prevent, monitor, and control unintentional introductions of non-indigenous aquatic nuisance species and to provide for related public education and research. A draft of the program was released for public comment November 12, 1992, and is expected to be presented to Congress in 1993 (14). The task force also is conducting a review of policies related to the intentional introduction of aquatic species. The task force's activities parallel, to some extent, portions of OTA's study.

DO WE KNOW ENOUGH TO ASSESS THE SITUATION?

Finding:

The information on NIS is widely scattered and often anecdotal. It emphasizes species having negative effects on agriculture, industry, or human health. The numbers and impacts of harmful NIS in the United States are chronically underestimated, especially for organisms lacking such economic or health effects.

Information Gaps

Although much information on NIS exists, overall it is widely scattered, sometimes obscure, and highly variable in quality and scientific rigor. No governmental or private agency keeps track of new NIS that enter or become established in the country, unless they also are considered a potential pest to agriculture or forestry or a human health threat, and even these databases are not comprehensive. Summary lists of NIS do not exist for most types of organisms (7,33,43,72,79). This gap is especially large for non-indigenous insect and plant species, which number in the thousands in the United States (ch. 3) (33,43). It also plagues attempts to quantify the numbers and effects of plant pathogens, since the origin of most is unknown (72). Even for known NIS, the effects of many have never been studied, especially those without clear economic or human health impacts. Information on effects is similarly lacking for the numerous as-yet-undetected NIS that many of OTA's contractors and advisory panelists believe are already established in the country.

Because of the poor documentation, presently available information provides an incomplete picture of NIS in the United States. Consequently, whatever we do know about harmful NIS surely

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1 ''Noxious weeds'' are defined under the Federal Noxious Weed Act of 1974, as amended (7 U. S.C.A. 2801-2814) as ''any living stage (including but not limited to, seeds and reproductive parts) of any parasitic or other plant of a kind, or subdivision of a kind, which is of foreign origin, is new to or not widely prevalent in the United States, and can directly or indirectly injure crops, other useful plants, livestock, or poultry or other interests of agriculture, including irrigation or navigation or the fish or wildlife resources of the United States or the public health. "

2 ''Injurious wildlife'' is defined under the Lacey Act (1900), as amended (16 U, S.C.A. 667 *et seq.)* as *several* named species *"ad* such other species of wild mammals, wild birds, fish (including mollusks and crustacean), amphibians, reptiles, or the offspring or eggs of any of the foregoing which the Secretary of the Interior may prescribe by regulation to be injurious to human beings, to the interests of agriculture, horticulture, forestry, or to wildlife or the wildlife resources of the United States. "

3 The Hawaii Office of the Nature Conservancy in collaboration with the Natural Resources Defense Council released The *Alien* Pest *Species Invasion in Hawaii: Background Study and Recommendations for Interagency Planning in* July 1992 (60). This report examines the causes, consequences, and solutions to harmful NIS in Hawaii, A report on NIS in Minnesota was issued by the Minnesota Interagency Exotic Species Task Force in April 1991 (53). In addition, the National Research Council (NRC) approved the concept for a broad study of science and policy issues related to marine NIS in 1991. The study was not undertaken, however, because of inadequate funding.

4 Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990, as amended (16 U. S.C.A. 4701-475 1).

Table 2-l—Groups of Organisms Covered by OTA's Contractors[a]

Category examined by contractor	Number of species analyzed for summary of NIS consequences	Percent of total known U.S. NIS analyzed per category by OTA's contractors
Plants-free-living plants and algae dwelling on land and in fresh water; excludes those under human cultivation	—[c]	—c
Terrestrial/ vertebrates-free-living vertebrate animals dwelling on land (birds, reptiles, amphibians, mammals); excludes strictly domesticated species	125 NIS of foreign or U.S. origin	65%
Insects-insects and arachnids (ticks, mites, spiders)	1,059 NIS of foreign origin from 149 taxonomic families	53%
Fish-free-living finfish that dwell for all or part of their lives in fresh water	111 NIS of foreign or U.S. origin	88%
Mollusks-snails, bivalves, and slugs living on land, in fresh water, and in estuaries	88 NIS of foreign origin	97%
Plant pathogens-viruses, bacteria, fungi, nematodes, and parasitic plants that cause diseases of plants	54 NIS of foreign origin from selected host plants (potato, rhododendron, citrus, wheat, Douglas fir, kudzu, five-needled pines, chestnut)	23%

[a]Major categories not covered include: exclusively marine plants and animals; organisms causing animal diseases (viruses, bacteria, etc.); worms; crustaceans (crayfish, water fleas); free-living bacteria and fungi,
[b]See figures 2-2, 2-4, and 2-5.
[c]contractor could not quantitatively analyze effects of non-indigenous plants because of the large numbers of species (>2,000)" and lack of previous summary material.

SOURCES: Summarized by OTA from: J.C. Britton, "Pathways and Consequences of the Introduction of Non-Indigenous Fresh Water, Terrestrial, and Estuarine Mollusks in the United States, " contractor report prepared for the Office of Technology Assessment, October 1991; W.R. Courtenay, Jr., "Pathways and Consequences of the Introduction of Non-indigenous Fishes in the United States," contractor report prepared for the Office of Technology Assessment, September 1991; K.C. Kim and A.G. Wheeler, "Pathways and Consequences of the Introduction of Non-Indigenous Insects and Arachnids in the United States," contractor report prepared for the Office of Technology Assessment, December 1991; C.L. Schoulties, "Pat hwaysand Consequences of the Introduction of Non-Indigenous Plant Pathogens in the United States," contractor report prepared for the Off ice of Technology Assessment, December 1991; S.A. Temple and D.M. Carroll, "Pathways and Consequences of the Introduction of Non-Indigenous Vertebrates in the United States," contractor report prepared for the Office of Technology Assessment, October 1991.

underestimates their numbers and the magnitude of their effects. Even from this baseline estimate, however, a picture emerges of current and impending problems that require action. OTA's approach is to provide such a baseline estimate.

OTA's Approach for Chapters 2 and 3

To attempt a quantitative analysis, OTA asked experts to assess the numbers of known NIS in the country, what their effects have been, and how they entered or spread within the nation. The OTA contractors categorized impacts of established NIS by type (harmful, beneficial, neutral, or unknown); nature of effect (economic, ecological, and other); and magnitude (high, medium, low). Six reports were prepared, one each for plants, terrestrial vertebrates, insects, fish, mollusks, and plant pathogens (table 2-l). This selection, while covering most important terrestrial and freshwater organisms, is not all-inclusive. It reflects a balance between comprehensiveness and feasibility. For example, no identifiable expert could summarize information on all aquatic invertebrate animals (e.g., mollusks, worms, crustaceans, etc.), in part because many groups are only poorly known.

In preparing background reports, the contractors reviewed available publications, surveyed or interviewed numerous other experts, and incorporated their own judgments. Their resulting summaries are the most complete and up-to-date available. Chapters 2 and 3 draw on these background summaries, additional published information, and additional expert opinions to develop a broad overview of harmful NIS in the United States. The effects of NIS-both beneficial and harmful are covered in this chapter. Chapter 3 examines the pathways by which NIS enter and spread in the United States, their rates of arrival, and current numbers in the country.

BENEFITS OF INTRODUCTIONS

Finding:

Cultivation of non-indigenous crops and livestock is the foundation of U.S. agriculture. NIS also play a key role in other industries and enterprises, many of which are based on the U.S. market for biological novelty, e.g., ornamental plants and pets.

NIS are essential to many U.S. industries and enterprises. Their benefits are great, and include economic, recreational, and social effects.

Almost all economically important crops[5] and livestock in the United States are of foreign origin (43). Non-indigenous plants have a similarly important role in horticulture and include such familiar horticultural mainstays as iris *(Iris* spp.), forsythia *(Forsythia* spp.), and weeping willow *(Salix* spp.) (26). Many plants used to prevent erosion are also non-indigenous, such as Bermuda grass *(Cynodon dactylon)* and lespedeza (*Lespedeza* spp.) (93). Importation of new species and strains continues for the development of new varieties for agriculture, horticulture, and soil conservation (65).

Non-indigenous insects also have important functions in agriculture. The European honey bee *(Apis mellifera)* forms the basis for the U.S. apiculture industry, providing bees to pollinate orchards and many other agricultural crops. Non-indigenous organisms of many types have beneficial uses as biological control agents, frequently for control of non-indigenous pests. Insects and pathogens of plants and animals are most commonly used for control of weeds and insect pests. For example, a rust fungus *(Puccinia chondrillina)* was successfully introduced into California to control skeletonweed *(Chondrilla juncea)* in 1975 (72). Fish have been introduced in some places to control aquatic weeds, mosquitoes, gnats, and midges (23). Some consider the introduction of barn owls (Tyto *alba)* to Hawaii to control mice and rats a success, although the use of land-dwelling vertebrates for biological control has generally caused great environmental damage (79).

A number of fish and shellfish cultured in the growing aquiculture industry are non-indigenous. Virtually the entire West Coast oyster industry is based on the Pacific oyster *(Crassostrea gigas), originally* from Japan. Fish species of *Tilapia,* from Africa and the Middle East, are now commonly grown throughout the United States (10), and shrimp farmers in southeastern and other regions of the country commonly raise Pacific white shrimp *(Penaeus vannamei),* a shrimp originally from Asia.

Sport fishing often means fishing for non-indigenous fish. The rainbow trout *(Oncorhynchus mykiss),* striped bass *(Morone saxatilis),* and varieties of largemouth bass *(Micropterus salmoides),* although indigenous to the United States, have been widely introduced beyond their natural ranges for fisheries enhancement (10). A frequently stocked sport fish, the brown trout *(Salmo trutta),* originated in Europe. The Great Lakes salmon fishery is based on species indigenous to the Pacific coast of North America. Additional fish have been introduced to provide forage for game fish. Sport fishing not only provides recreational opportunities, but also stimulates the development of related businesses,

[5] Crops originating in the United States include cranberry (*Vaccinium macrocarpon*), pecan (*Carya illinoensis*), tobacco (*Nicotiana tabacum*), and sunflower (*Helianthus annuus*).

such as boat rentals, charter fishing, and sales of fishing equipment and supplies (10).

Some of the most widely hunted game species, such as the chukar partridge *(Alecloris chuckar)* and ring-necked pheasant *(Phasianus colchieus),* originated outside of the United States (95). Sizable businesses exist to provide supplies and services for recreational hunting (79). Some non-indigenous big-game animals, like Sika deer (Cervus *nippon)* from Asia and South African oryx (Oryx *gazella gazella), are* grown on private ranches for hunting, and also to satisfy the growing market for "exotic" game meats (81). Non-indigenous fur-bearing animals support both the trapping industry and fur-bearer farms (79).

Most pet and aquarium industries are based on domesticated and other NIS, including cats, dogs, hamsters, goldfish, snakes, turtles, and chameleons. These animals are valued by owners for companionship, protection, and recreation. A number of non-indigenous animals, such as the African clawed frog *(Xenopus laevis), are* used in biomedical fields for experimental work or testing (79).

Restoration of habitats degraded by pollution, mining, and other human disruptions sometimes includes planting stress-tolerant NIS. Several trees, like the ginkgo from China *(Ginkgo biloba), are* common in urban landscaping, where few indigenous species can grow. Some non-indigenous sport fish serve a similar role in reservoirs and other artificial habitats less hospitable to indigenous species. Efforts to remedy environmental contamination from oil or other substances sometimes involve the release of non-indigenous microbes that accelerate contaminant degradation (88). Certain microbes help make nutrients available to plants through nitrogen fixation. These microbes also have been widely transferred and released around the world.

Paradoxically, introductions of NIS are increasingly seen by some conservationists as a means to preserve certain endangered and threatened species that cannot be saved in their native habitats (79). Some conservationists have even suggested that introduction of large ungulates from Africa onto the American plains may be some species' best chance at survival (74).

WHEN NON-INDIGENOUS SPECIES CAUSE PROBLEMS

Despite the clear benefits of many NIS, numerous others continue to cause great harm in the United States. Many are familiar. They range from nuisances like crabgrass *(Digitaria* spp.), dandelions *(Taraxacum officinale),* and German cockroaches *(Blattella germanica),* to species annually costing millions of dollars to agriculture and forestry, such as the Mediterranean fruitfly, or medfly *(Ceratitis capitata),* and the European gypsy moth *(Lymantria dispar).* Some pose human health risks, such as the African honeybee *(Apis mellifera scutellata)* and the imported fire ant *(Solenopsis invicta, S. richteri).* Still others, like the paper bark tree *(Melaleuca quinquenervia)* and zebra mussel *(Dreissena polymorpha),* threaten widespread disruption of U.S. ecosystems and the displacement or loss of indigenous plants and animals.

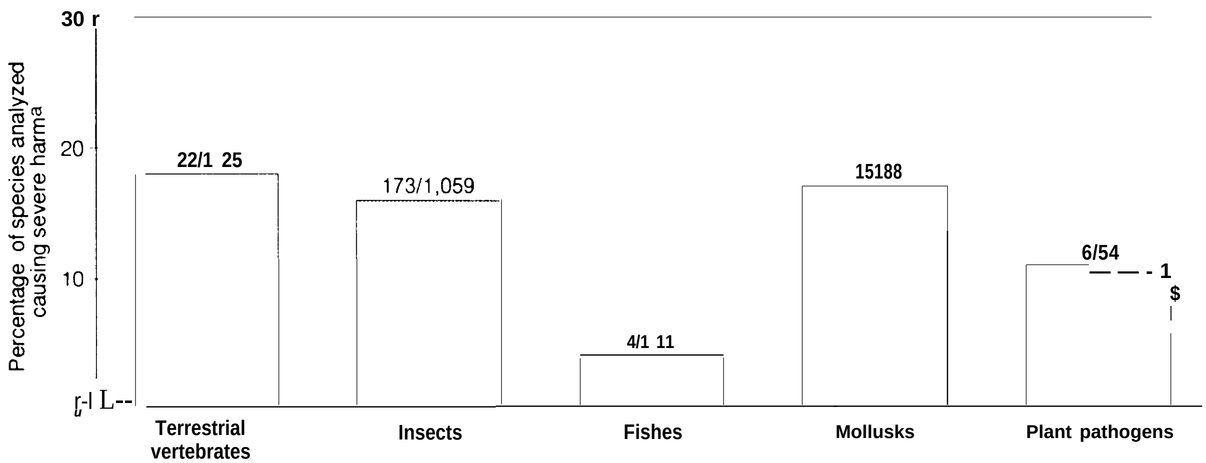
A Major Consideration: High Negative Impacts Are Infrequent

Finding:

A minority of the total NIS cause severe harm. However, such high-impact NIS occur in almost all regions of the country. Individually and cumulatively, they have had extensive negative impacts in the United States.

Relatively few NIS cause great harm. Estimates range from 4 to 19 percent of the NIS analyzed by OTA's contractors, depending on the type of organism (figure 2-2). Included here are NIS that are significant and difficult-to-control pests of agriculture, rangelands, or forests; seriously foul waterways, irrigation systems, and power plants; cause wide-scale disruption of indigenous ecosystems; or threaten indigenous species with extinction. At least 200 well-known, high-impact NIS presently occur in the United

Figure 2-2—How Frequent Are High-Impact Non-Indigenous Species?[a]



[a]Species judged by OTA's contractors as causing severe economic or environmental harm. Numbers Of severely harmful and total species are listed above each bar.

SOURCES: Summarized by OTA from: J.C. Britton, "Pathways and Consequences of the Introduction of Freshwater, Terrestrial, and Estuarine Mollusks in the United States," contractor report prepared for the Office of Technology Assessment, October 1991; W.R. Courtenay, Jr., "Pathways and Consequences of the Introduction of Non-Indigenous Fishes in the United States," contractor report prepared for the Office of Technology Assessment, September 1991; K.C. Kim and A.G. Wheeler, "Pathways and Consequences of the introduction of Non-Indigenous Insects and Arachnids in the United States," contractor report prepared for the Office of Technology Assessment, December 1991; C.L. Schoulties, "Pathways and Consequences of the Introduction of Non-Indigenous Plant Pathogens in the United States," contractor report prepared for the Office of Technology Assessment, December 1991; S.A. Temple and D.M. Carroll, "Pathways and Consequences of the Introduction of Non-Indigenous Vertebrates in the United States," contractor report prepared for the Office of Technology Assessment, October 1991.

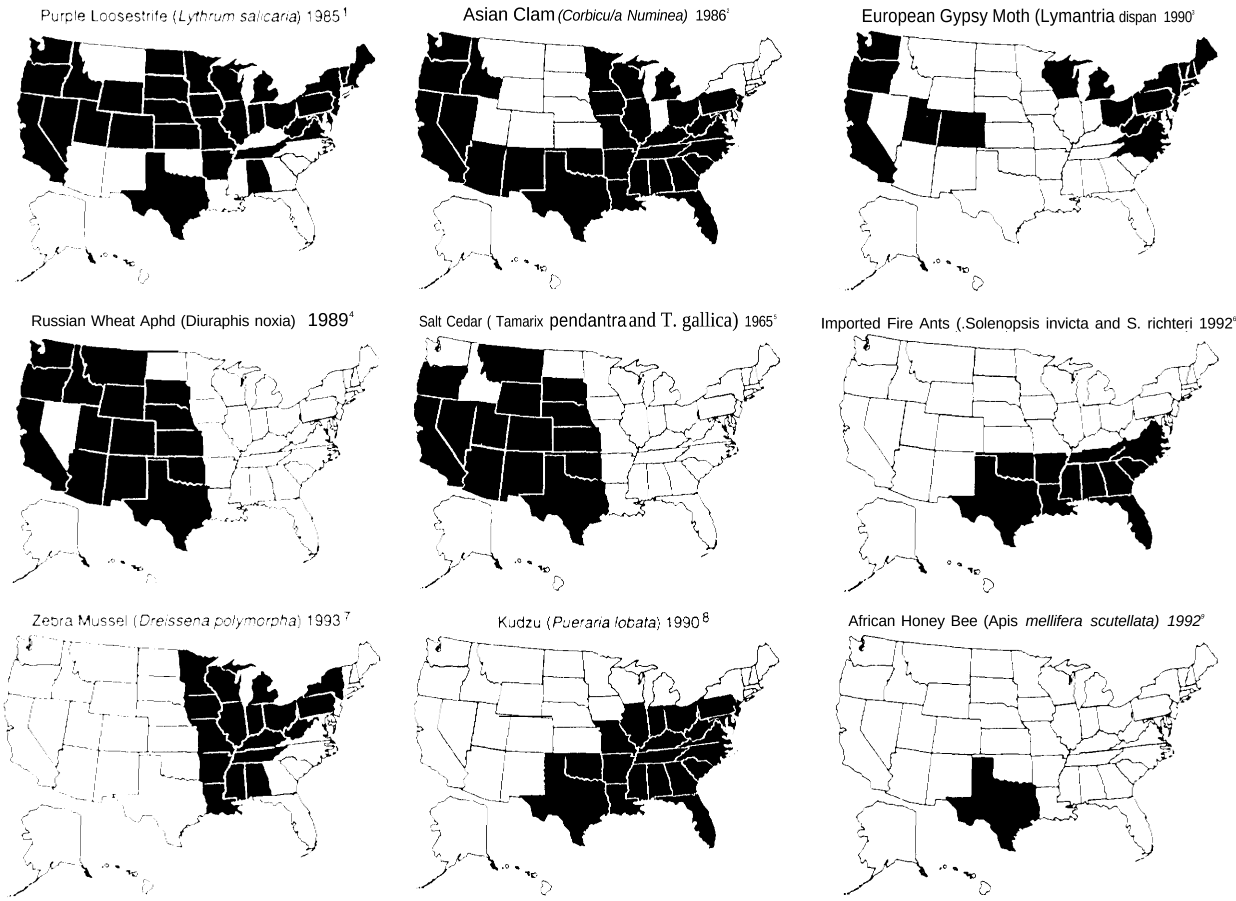
States (7,10,33,72). Even though relatively few NIS are highly damaging, they occur in almost all regions of the country (figure 2-3). Moreover, the summed impacts of even one disastrous species can be substantial. Estimated U.S. losses from 1987 to 1989 attributable to the Russian wheat aphid *(Diuraphis noxia)* alone exceeded *$600* million (1991 dollars) (8).

Time Lags and Unknown Effects Are Common

Effects of many NIS remain undetected for extended periods following their establishment. Such time lags can reflect an initial period during which a species' population is too small to cause noticeable impacts. Over time, changing environmental conditions cause some previously rare NIS to become abundant and cause harmful effects. Other previously benign NIS become problems after additional NIS enter the country. For example, an Asian fig plant *(Ficus microcarpa)* widely planted as an ornamental in Florida only became a pest about 45 years after introduction, when its natural pollinator-a fig wasp *(Parapristina verticillata)-was* introduced (50). Similarly, at least a decade elapsed between establishment of the Asian clam *(Corbicula fluminea)* and appearance of its harmful effects; 12 years for chestnut blight *(Cryphonectria parasitica) (see* 'Forestry' below); and 4 years for the cereal leaf beetle *(Oulema melanopus) (7,33,72).*

Some harmful species are mistakenly thought to have neutral consequences until other effects are detected. Thus, in many cases, ''neutral' NIS are better characterized as having unknown effects. Unknown effects and time lags are common for NIS affecting non-agricultural areas, since these tend to be poorly studied. OTA's contractors found between 6 and 53 percent of the NIS examined had neutral or unknown effects (figure 2-4). Given that time delays are common, some of these eventually will cause harmful impacts.

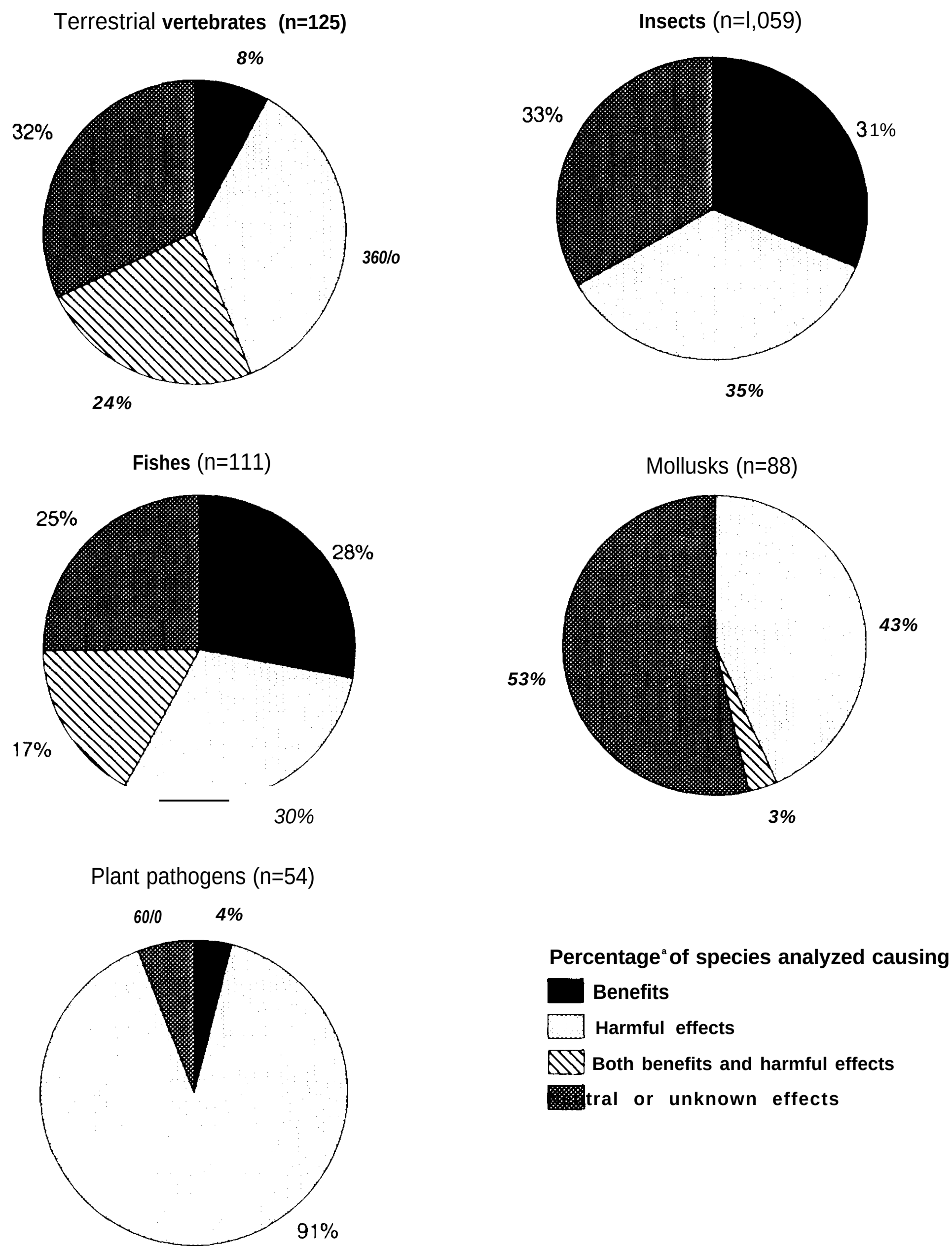
Figure 2-3—State by State Distribution of Some High-Impact **Non-Indigenous Species**



SOURCES:

1. **D.Q. Thompson, R.L. Stuckey, E.B. Thompson, "Spread, Impact, and Control of Purple Loosestrife (Lythrum salicaria in North American Wetlands" (Washington, DC: U.S. Department of the Interior Fish and Wildlife Service, 1987).**
2. **Clement L. Counts, Ill, 'The Zoogeography and History of the Invasion of the United States by** *Corbicula Fluminea* **(Bivalvia: Corbiculidae),"** *American Malacological Bulletin,* **Special Edition No. 2, 1986, pp. 7-39.**
3. **P.W. Schaefer and R.W. Fuester, "Gypsy Moths: Thwarting Their Wandering Ways,"** *Agricultural Research, vol. 39, No. 5, May 1991, pp. 4-11;* **M.L. McManus and T. Mclntyre, "Introduction," The Gypsy Moth.'** *Research* **Toward Integrated** *Pest Management, C.C.* **Deane and M.L, McManus (eds.) Technical Bulletin No. 1584 (Washington, DC: U.S. Forest Service, 1981), pp. 1-8; T. Eiber, "Enhancement of Gypsy Moth Management, Detection, and Delay Strategies,"** *Gypsy Moth News, No.* **26, June 1991, pp. 2-5.**
4. **S.D. Kindler and T.L. Springer, "Alternative Hosts of Russian Wheat Aphid" (Homoptera: Aphididae),** *Journal of Economical Entomology,* **vol. 82, No. 5, 1989, pp. 1358-1362.**
5. **T.W. Robinson, "Introduction, Spread and Area! Extent of Saltcedar (Tamarix) in the Western States," Studies of Evapotranspiration, Geological Survey Professional Paper 491-A (Washington, DC: U.S. Government Printing Office, 1965).**
6. **V.R. Lewis et al., "Imported Fire Ants: Potential Risk to California,"** *California Agriculture,* **vol. 46, No. 1, January-February 1992, pp. 29-31; D'Vera Cohn, "Insect Aside: Beware of the Fire Down Below, Stinging Ants From Farther South Have Begun to Make Inroads in Virginia, Maryland,"** *Washington Post,* **June 2, 1992, p. B3,**
7. **U.S. Department of the Interior, Fish and Wildlife Service, briefing delivered to the Senate Great Lakes Task Force, May 21, 1993.**
8. **Anonymous,** *National Geographic Magazine,* **'Scourge of the South May be Heading North," vol. 178, No. 1, July 1990.**
9. **M.L. Winston, "Honey, They're Herel Leaning to Cope with Africanized Bees,"** *The Sciences,* **vol. 32, No. 2, March/April 1992, pp. 22-28.**

Figure 2-4-Reported Effects of Non-Indigenous Species in the United States



[a] percentages do not always total 100% due to rounding!

SOURCES: Summarized by OTA from: J.C. Britton, "Pathways and Consequences of the Introduction of Freshwater, Terrestrial, and Estuarine Mollusks in the United States," contractor report prepared for the office of Technology Assessment, October 1991; W.R. Courtenay, Jr., "Pathways and Consequences of the Introduction of Non-Indigenous Fishes in the United States," contractor report prepared for the Office of Technology Assessment, September 1991; K.C. Kim and A.G. Wheeler, "Pathways and Consequences of the Introduction of Non-Indigenous Insects and Arachnids in the United States," contractor report prepared for the Office of Technology Assessment, December 1991; C.L. Schoulties, "Pathways and Consequences of the Introduction of Non-Indigenous Plant Pathogens In the United States," contractor report prepared for the Office of Technology Assessment, December 1991; S.A. Temple and D.M. Carroll, "Pathways and Consequences of the Introduction of Non-Indigenous Vertebrates in the United States," contractor report prepared for the Office of Technology Assessment, October 1991.

How Problems Arise

NIS problems have several origins. Some NIS introduced for beneficial purposes unexpectedly produce harmful consequences. Many other harmful species arrived or spread within the country unintentionally. A complicating factor is that numerous NIS cause both beneficial and harmful effects.

POOR CHOICES: INTENTIONAL INTRODUCTIONS THAT GO AWRY

Many harmful introductions probably would not have occurred had the damage they caused been anticipated in advance. But little advance evaluation of potential harmful effects was performed for many NIS intentionally released in the past. Even when advance evaluations have been performed, however, they often have done a poor job of anticipating effects. Scientists generally agree that predicting the role and effects of a species in a new environment is extremely difficult (56). Each introduction creates a novel combination of organism and environment. Detailed information about both is necessary to anticipate the result, and such information usually is lacking.

Nevertheless, some continue to use a simplistic approach to evaluating introductions. An erroneous concept still widely applied by fisheries managers is the ‘‘vacant niche. ’ This concept holds that some ecological roles may not be filled in a community, and species can be selectively introduced to fill these voids. Application of this approach to natural communities is inappropriate both because few species can fit the narrow ecological vacancies identified by managers, and because it is virtually impossible to predetermine the role a species will assume after it has been released (28). Numerous examples exist where a species’ ecological role was mistakenly understood before its release. For example, many insect parasites and predators introduced to Hawaii for biological control of pests unexpectedly expanded their diets to include indigenous species (29).

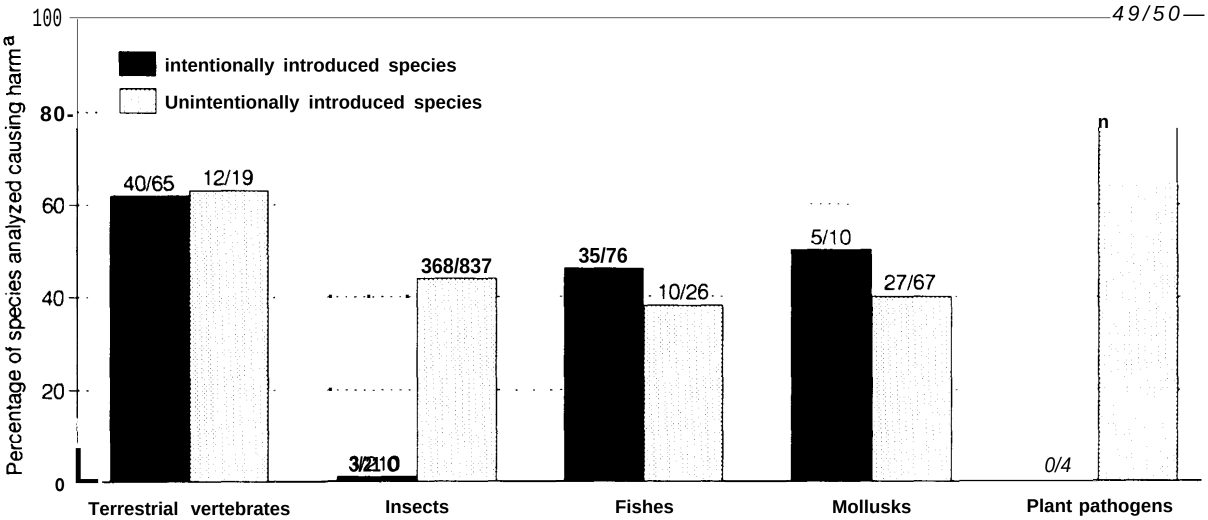
DON SCHMITZ

Kudzu (Pueraria lobata) *was initially promoted by the U.S. Department of Agriculture for erosion control and forage, but it has overgrown other vegetation throughout the southeastern United States.*

Problems also arise when a species moves into new habitats beyond the intended area of introduction. A recent example is the cactus moth *(Cactoblastis cactorum).* Introduced to the West Indies to control prickly pear cactus *(Opuntia* spp.), the moth has since spread northward into Florida. Conservationists fear it may eventually threaten indigenous prickly pear cacti throughout the United States, 16 species of which are rare and under review for listing under the Endangered Species Act (31). The seven-spotted ladybeetle *(Coccineila septempunctata),* an aphid predator, has dispersed throughout much of the United States. It appears to be outcompeting the native nine-spotted ladybeetle (C. *novemnotata)* and has displaced that species in alfalfa fields (33).

Species that escape from human cultivation, in a sense, also move beyond their anticipated distributions. Feral populations of domesticated mammals, such as goats *(Capra hircus)* and pigs *(Sus scrofa),* cause great ecological damage and erosion in natural areas by trampling, uprooting, and consuming plants. Many weeds, such as crabgrass, originally were cultivated for agriculture (26). Some ornamental plants also cause harm when they escape and form free-living populations. English ivy *(Hedera helix)* and

Figure 2-5-How Often Do Intentional Versus Unintentional Introductions Have Harmful Effects?



[a]Includes species reported by OTA's contractors as causing any economic or environmental harm. Some species may also have beneficial effects. Analysis excludes species that have been introduced both intentionally and unintentionally or for which the mode of introduction is unknown. Numbers of harmful and total species are listed above each bar.

SOURCES: Summarized by OTA from: J. C.Britton, "Pathways and Consequences of the Introduction of Freshwater, Terrestrial, and Estuarine Mollusks in the United States," contractor report prepared for the Office of Technology Assessment, October 1991; W.R. Courtenay, Jr., "Pathways and Consequences of the Introduction of Non-Indigenous Fishes in the United States," contractor report prepared for the Office of Technology Assessment, September 1991; K.C. Kim and A.G. Wheeler, "Pathways and Consequences of the Introduction of Non-Indigenous Insects and Arachnids in the United states," contractor report prepared for the Office of Technology Assessment, December 1991; C.L. Schoulties, "Pathways and Consequences of the Introduction of Non-Indigenous Plant Pathogens in the United States," contractor report prepared for the Office of Technology Assessment, December 1991; S.A. Temple and D.M. Carroll, "Pathways and Consequences of the Introduction of Non-Indigenous Vertebrates in the United States," contractor report prepared for the Office of Technology Assessment, October 1991.

Japanese honeysuckle *(Lonicera japonica)* overgrow and eventually kill trees and understory plants and have fundamentally altered the character and structure of some eastern forests (82). Among the 300 non-indigenous weeds of the western United States, at least 8 were formerly cultivated as crops and 28 escaped from horticulture (100).

THE SURPRISE OF UNINTENTIONAL INTRODUCTIONS

Many NIS currently in the United States arrived and spread as unintended stowaways on human transport. For example, in the past, many weeds moved as contaminants of agricultural seed, and many plant pathogens arrived in the soil of potted plants (43,72) (see also ch. 3).

In contrast to most intentional introductions, unintentionally introduced species have not been chosen for any beneficial characteristics. Thus, a logical expectation might be that unintentionally introduced species are more likely to cause harmful effects than intentionally introduced species. Evaluation of the 1,483 NIS examined by OTA's contractors would seem to support this, since only 12 percent of the intentionally introduced species had harmful effects compared to 44 percent of the unintentionally introduced species (10,33,72,79). However, when specific groups of organisms are examined separately, clear differences appear (figure 2-5). Far more unintentional introductions of insects and plant pathogens have had harmful effects than have intentional introductions of these organisms. For terrestrial vertebrates, fish, and mollusks, however, intentional introductions have caused harm approximately as often as have unintentional introductions, suggesting a history of poor choices of species for introduction and complacency regarding their potential harm.

MANY SPECIES HAVE BOTH BENEFITS AND HARMFUL EFFECTS

Finding:

Certain NIS have both positive and negative consequences, especially species occurring across several regions or States. In addition, perceived effects of NIS can vary in relation to the observer's perspective. Different constituencies can hold widely divergent and deep-seated views of the potential effects and desirability of even a single species.

Many NIS simultaneously have benefits as well as harmful effects (figure 2-4). Even some NIS known for their harmful effects can also have some benefits. For example, imported fire ants, which sting people and damage crops, also suppress populations of agricultural pests and enhance available soil nutrients (73). Some non-indigenous (''exotic' game animals grown on ranches have potential economic benefits. Ranching may also help preserve animals endangered in their native ranges. Ranched non-indigenous game, however, sometimes hybridize with and dilute the gene pools of related indigenous species, or carry and spread new animal diseases (77).

The effects of some species also change as they enter new environments—a factor making prediction of harm difficult. Predators, competitors, parasites, and pathogens that keep a species' population small in one locale may be absent in another. Also, new environments may affect rates of reproduction, susceptibility to disease, and other features that affect a species' success, Consequently, a NIS that causes little damage to agriculture or natural ecosystems in one area may cause significant problems in another. Melaleuca, the paper bark tree, is a harmless ornamental in California, but causes great ecological harm in the Florida Everglades. Non-indigenous cheatgrass *(Bromus tectorum) occurs in all* 50 States, but is only a serious weed in the Midwest and West (44). Even garden flowers like baby's breath *(Gypsophila paniculata) can* be difficult-to-control weeds in some areas (100).

The perceived effects of a species can also vary with the eye of the beholder (85). While many State fish and wildlife managers firmly support continued stocking with certain non-indigenous fish, some experts consider the practice to be detrimental (box 2-B). Similarly, managers of natural areas view purple loosestrife ***(Lythrum** salicaria),* originally from Eurasia, as a highly damaging plant because it grows prolifically in wetlands, displacing indigenous plants and providing lower quality habitat and food for wild animals. In contrast, some horticulturists in the nursery trade see purple loosestrife as a desirable plant. It also is a source of nectar for honey production.

The perceived desirability of certain NIS has changed over time, as human values and popular views have changed. The intentional introduction of songbirds, like the English sparrow *(Passer domestics) in the* mid-1800s probably would not be allowed today, because a higher value is placed on indigenous birds. Kudzu *(Pueraria lobata)* was widely promoted for erosion control in the 1940s (89); yet the very characteristics considered beneficial then-rapid growth, ease of propagation, and wide adaptability--cause it to be considered a pernicious weed today.

ECONOMIC COSTS

Finding:

Harmful NIS annually cost the Nation hundreds of millions to perhaps billions of dollars. Economically significant species occur in all groups of organisms examined by OTA and affect numerous economic sectors. Available accountings tend to underestimate losses attributable to NIS, since they omit many harmful species and inadequately account for intangible, nonmarket impacts.

A conservative estimate is harmful NIS cause annual losses of hundreds of millions of

Box 2-B–The Case of the Brown Trout: Opposing Views of Fish Introductions

In Favor . . .

by *Bruce Schmidt, Chief of Fisheries*
Utah Department of Natural Resources
Salt Lake ***City, Utah***

The introduction of non-indigenous fishes is neither ail good nor all bad; **judgments must be made individually. Introductions can affect pristine ecosystems, but sport fish management** frequently must deal with far-from-pristine environments. Given the human species' penchant for modifying the environment it is unrealistic to set a standard that demands no alteration of indigenous fauna. in Utah, most fish habitats are artificial reservoirs or tail waters, or are altered by water diversion, siltation, agriculture run-off, unstable banks or pollution, conditions outside the control of fisheries managers. Only four sport fish are indigenous to Utah, and none are adapted to most of these altered systems, so providing sport fishing requires introductions.

The benefits are widespread. Many spades have produced excellent sport fishing when introduced into new waters in nearly all States. Sport fishing is a multibillion dollar industry, directly through input to local economies ($2.8 billion **expended nationwide in 1985; $154 million by resident anglers in Utah alone in 1991) and indirectly through mental and physical benefits to people. Introductions play a significant role in this success.**

Brown trout (Salmo trutta) are one example. They grow **large, are aggressive, and are among the most prized** sport fish in North America, supporting a massive recreational fishery. Brown trout have significant advantages over indigenous trout species in some situations. They **can tolerate somewhat degraded environments with warmer temperatures and decreased water quality** and are more resistant to intense angling pressure. Thus, they are better suited to many of the actual conditions existing today. Although brown trout would be inappropriate where they affect rare indigenous fishes, they play a major role in satisfying public demand for quality fishing opportunities.

and Against . . .

by ***Walter Courtenay, Professor of Biology***
Florida Atlantic University
Boca Raton, Florida

The brown trout is widely regarded as a successful introduction **of a non-indigenous fish, first made in 1888. Since then, the introduction of numerous other fishes, both of foreign and U.S. origin, has become a standard management tool. Negative impacts have rarely been considered before the introductions. Overall, very few introductions can be considered successful from both human and biological standpoints. As a management toot, introductions have shown minor to major negative biological impacts, including extinctions of indigenous species.**

Management agencies are mostly constituent -oriented and thus are political pawns. Although agency names often contained the words "conservation" **and, more** recently, "natural **resources" agendas are largely blind to** conserving natural resources. Agency biologists often are not practicing biology, but are forced into managing, and the two are not synonymous.

Fortunately, the brown trout mostly occupies waters not preferred by indigenous trouts. in many **waters, however, it is rarely as popular as transplanted rainbow trout** *(Oncorhynchus mykiss) or indigenous* **trouts. The** positives can be counterbalanced, in part, by negatives. California, in concert **with the U.S. Forest and National Park Services, has spent almost $1 million since 1985 to eradicate brown trout from the Little Kern River to save the golden trout** *(Oncorhynchus aquabonita),* **California's "state fish;" from almost certain extermination there. Despite at least a century of fishery experience with introductions, managers** seem intent on improving on nature without understanding it.

dollars to U.S. agriculture, forests, rangelands, and fisheries. Losses could reach as high as several billion dollars, especially in high-impact years. Massive expenditures on pesticides and other control and prevention technologies prevent potential additional losses of millions to billions more. Rough estimates are that the United States annually expends about $7.4 billion for pesticide applications (box 2-C), a significant proportion of which goes to control non-indigenous pests. Weeds and insects are the most costly groups, corresponding to their high numbers when compared with other MS groups (see ch. 3).

Types of Economic Impacts

Harmful NIS affect numerous economic sectors. These include agriculture, forestry, fisheries and water use, utilities, buildings, and natural areas.

AGRICULTURE

Non-indigenous weeds, insects, mollusks, birds, and pathogens reduce crop and livestock production, increase production costs, and cause post-harvest crop losses. Managing the array of agricultural pests requires costly research, development, and application of control technologies.

Weeds can outcompete or contaminate crops. They have other effects as well. Johnson grass *(Sorghum halepense)* hybridizes with cultivated sorghum *(Sorghum bicolor)*, producing worthless ''shattercane' (43). Some weeds are either poisonous or rejected as forage by livestock (100). They reduce the value of rangelands (100); much public land has been lost for grazing because of weed infestations (43). For example, unpalatable leafy spurge *(Euphorbia esula)* has spread to 1.5 million acres of rangeland in the northern Great Plains. Direct livestock production losses together with indirect economic effects due to this species alone approached $110 million in 1990 (2). Annual U.S. losses because of weeds amount to billions of dollars (box 2-C).


USDA

The cotton boll weevil (Anthonomis grandis) *caused estimated cumulative losses of at least $50 billion for 1909-1949.*

Some weeds do not directly harm agriculture, but instead are hosts for agricultural pests. Barberry *(Berberis vulgaris)* harbors the wheat rust fungus *(Puccinia recondite)*, and large losses of wheat production can occur where the plant is present (43). Wheat rust has caused approximately $100 million worth of crop losses annually over the last 20 years (37), and it caused even more significant losses before barberry was largely eradicated earlier in this century. Tumbleweed *(Salsola* spp.) similarly is a host for the curly top virus, a pathogen of crops such as sugar beets and tomatoes (102). Crested wheatgrass *(Agropyron desertorum)*, widely planted for soil conservation, harbors the Russian wheat aphid *(Diuraphis noxia)*, itself a significant wheat pest.

Scores of non-indigenous insect species pose serious threats to agriculture. The boll weevil *(Anthonomus grandis)*, a pest of cotton, historically has the highest documented impacts-at least $50 billion (in 1991 dollars) of cumulative losses estimated for the years 1909-1949 (8). Repeated outbreaks of the medfly in California necessitate costly control programs to avert projected annual losses of up to $897 million in damaged produce, control, and reduced export revenues (34). Some other estimates of annual

Box 2-C-Economic Losses Caused by Non-Indigenous Weeds

The Weed Science Society of America (WSSA) recently published the report Crop Losses *Due to* Weeds-1992, covering all States but Alaska. The report relies on crop loss estimates for 46 major crops (including field crops, fruits, nuts, and vegetables) obtained through survey responses by cooperating weed seientists. The scientists estimated the cumulative value of average losses to be $4.1 billion annually, undercurrent appropriate herbicide control strategies. They also estimated that if no herbicides were available the crop losses would total $19.6 billion.

The WSSA figures have several limitations for OTA's purposes: they only characterize a 3-year period (1969-1991); they do not cover weeds of forestry, grazing lands, horticulture, and other agricultural sectors; and they include indigenous weeds. However, indigenous weeds are less important economically than NIS, which are known to comprise the majority of weeds for most crops. For example, 23 of 37 major soybean weeds, or 62 percent, are NIS. Experts estimate that 50 percent to 75 percent of major crop weeds overall are NIS. Based on these percentages, the portion of the$4.1 billion of annual crop losses attributable to non-indigenous weeds would be approximately $2 billion to $3 billion. According to the Environmental Protection Agency, U.S. farm expenditures on pesticides amount to about $5.1 billion annually, 60 percent of which is for herbicides. Thus, roughly $1.5 billion to $2.3 billion spent annually for herbicides would be attributable to NIS.

A ballpark range for total direct non-indigenous weed costs is $3.6 billion to $5.4 billion annually. The environmental, human health, regulatory, and other indirect costs of using herbicides on non-indigenous weeds have not been adequately calculated, but rough estimates exceed an additional $1 billion annually.

SOURCES: D.C. Bridges (cd.), *Crop Losses Due to Weeds in the United States —1992* (Champaign, IL: Weed Science Society of America, 1992); D.T. Patterson, "Research on Exotic Weeds," in *Exotic P/ant Pests and North American Agriculture,* C.L. Wilson and C.L. Graham (eds.) (New York, NY: Academic Press, 1983), pp. SS1-93; D. Pimentel et al., 'Environmental and Economic Effects of Reducing Pesticide Use," *Bioscience, vol.* 41, No. 6, June 1991, pp. 402-9; U.S. Environmental Protection Agency, "EFM's Pesticide Programs," Publication No. 21 T-1OO5, Washington, DC, May 1991; T.D. Whitson et al., *Weeds* of the *West* (Jackson, WY: Pioneer of Jackson Hole, 1991).

losses from insect pests compiled for OTA by the Animal and Plant Health Inspection Service of USDA include: $500 million (in 1990) for the alfalfa weevil *(Hypera postica); $172.8* million (in 1988) for the Russian wheat aphid; and $16.6 million (annual average for 1960-1988) for the pink bollworm *(Pectinophora gossypiella) in* California (17).

The honey bee industry currently faces two new pests, the tracheal mite *(Acarapis woodi)* and the varroa mite *(Varroa jacobsoni),* which parasitize and kill honey bees. The National Association of State Departments of Agriculture estimates potential annual losses of $160 million—due to lost honey production, lost pollination fees, and costs of replacing bees—should each pest have nationwide effects similar to those reported in Michigan (1990) and Washington (1989) (59).

FORESTRY

In the early 1900s, the chestnut blight, brought in on diseased horticultural stock from China, all but eliminated the American chestnut *(Castanea dentata), killing* as many as a billion trees. American chestnut had been the most economically important hardwood species in eastern forests (91). It was widely used in urban plantings and had been a significant food source for wild animals (72). Dutch elm disease *(Ceratocystis ulmi) also* devastated vast numbers of shade trees following its U.S. discovery in 1930-an aesthetic loss for many U.S. cities as well as an expense to replace the 40 million elms estimated to have died (91).

Several other NIS currently threaten U.S. forests, including insects like the balsam wooly adelgid *(Adelges piceae)* and pathogens such as white pine blister rust *(Cronartium ribicola).* Pear thrips (Taeniothrips inconsequens) damaged 189,0(X) hectares of Vermont sugar maple in 1988 and is expected to spread throughout the Appalachians (35). The European gypsy moth exacts the greatest measurable losses and expenditures for research, control, and eradication. The USDA estimated losses of $764 million from the European gypsy moth in 1981 alone, although that figure so far has been the all-time high (17). The Asian strain of the moth recently necessitated a $14 to $20 million eradication program in the Pacific Northwest (see ch. 4, box 4-B).

FISHERIES AND WATERWAY USE

Both wild fisheries and aquiculture have been damaged by harmful NIS. Some fisheries have been decimated. In the mid-1900s, the eel-like, parasitic sea lamprey *(Petromyzon marinus)* migrated via the newly constructed Welland Canal from Lake Ontario to other Great Lakes. It caused tremendous economic losses to commercial and recreational Great Lakes fisheries. Today, about $10 million is spent annually on control and research to reduce its predation, plus roughly an equal amount annually on fish stocking (86). If control were terminated and populations of the lamprey expanded again, the total value of the lost fishing opportunities plus indirect economic impacts could exceed $500 million annually (75).

The European ruffe *(Gymnocephalus cernuus),* a fish that entered the Great Lakes via expelled ballast water in the early 1980s, poses a new threat. Based on experience in Scotland and Russia, and preliminary assessment of North American impacts, experts predict the ruffe will cause populations of commercially valuable fish to decline, The Great Lakes Fishery Commission estimates that annual losses of more than $90 million could occur if it is not controlled (24).

Several non-indigenous aquatic weed species clog waterways. An estimated $100 million is spent nationally each year to control aquatic weeds, a majority of which are non-indigenous (20). Hydrilla *(Hydrilla verticillata) in the* Southeast blocks irrigation and drainage canals, enhances sedimentation in flood control reservoirs, interferes with public water supplies, impedes navigation, and generally restricts public water uses (32). At high densities, it also reduces productivity of recreational fisheries (32).

UTILITIES

Fouling of water pipes by zebra mussels has imposed large expenses on the electric power industry and its customers. Costs have been incurred for the development and implementation of antifouling technologies, application of control techniques to remove zebra mussels already present, and plant shut-downs. Another mollusk, the Asian clam, has had similar effects (box 2-D). Zebra mussels and the Asian clam also clog water pipes for municipal and irrigation water supplies.

BUILDING STRUCTURES

Non-indigenous pests damage commercial and residential structures, threaten the health of occupants, and reduce property values. The full effects of structural pests-cockroaches, rats, and others that are non-indigenous-are beyond the scope of this report. However, they contribute significantly to the national market for pest control inside buildings, which totals roughly $6 billion dollars in annual sales of extermination services, retail products, and associated items (63).

NATURAL AREAS

Millions of dollars are spent annually to address the harmful effects of NIS on natural ecosystems, mostly by public agencies (see ch. 6). Expenditures are required for the development and application of control and eradication measures, as well as for ecological restoration. Indirect economic effects result from reduced recreational opportunities in areas invaded by harmful MS, and the loss of indigenous species. Because of the absence of clear financial incentives, such *as* exist in agriculture, many NIS problems in natural areas remain unaddressed. The cost of backlogged control or eradication projects is difficult to estimate, but is very likely higher than for any

Box 2-D-Case Study of an Affected Industry: The "One-Two Punch" of Asian Clams and Zebra Mussels on the Power Industry

Two harmful non-indigenous species-the Asian clam, *Corbicula fluminea,* **and the zebra mussel, Dreissena polymorpha-have and** will continue to have significant and lasting effects on the U.S. power industry and electricity consumers.

The Asian clam entered North America some time before 1924. This small dam grows and reproduces rapidly, producing massive numbers of shells shortly after entering new waterways. Its harmful effects received little attention until the 1950s, when it was found dogging California irrigation systems as well as condensers of the Shawnee Steam Electric Power Station at Paducah, Kentucky. Populations of Corbicula grew explosively during the 1960s and 1970s. During that period it disrupted the operations of numerous steam and at least three nuclear electric generating stations, with down-time, corrective actions, and maintenance costing millions of dollars. In 1980, the Arkansas Nuclear One power plant was forced to shut down because of waterline clogging by Asian dams, prompting the Nuclear Regulatory Commission to issue a directive requiring the nuclear electric industry to determine whether Corbicula fouling was a hazard at each nuclear facility in the nation. The estimated cost of compliance with this directive was $4.5 million. One estimate put total losses at $1 billion annually in the early 1980s. More recently, populations of the Asian clam have begun to decline for unknown reasons. Nevertheless, it remains a serious fouling pest.

The industry was dealt a second blow by entry of another mollusk. The zebra mussel entered the Great Lakes by way of discharged ballast water during the mid-1980s and has since spread as far as the Hudson, Susquehann, Mississippi, and Illinois river basins. Like Asian dams, zebra mussels are highly fertile, enabling populations to quickly reach large sizes. Zebra mussels adhere to water pipes by tough threads, dogging water flow and increasing sedimentation and corrosion. One expert from the New York Sea Grant Extension Service estimated costs for the power industry of up to $800 **million for plant redesign and $60 million for annual** maintenance. Fouling by zebra mussels of cooling or other critical water systems in power plants can require shut-down, costing as much as $5,000 per hour for a 200-megawatt system. Some experts expect total costs to the power industry from zebra mussels to match those for the Asian dam, perhaps reaching $3.1 billion (1991 dollars) over a 10-year period.

SOURCES: J.C. Britton, "Pathways and Consequences of the Introduction of Freshwater, Terrestrial, and Estuarine Mollusks in the United States," contractor report prepared for the Office of Technology Assessment, October 1991; M. Cochran, "Non-Indigenous Species in the Unites States-Economic Consequences," contractor report prepared for the Office of Technology Assessment, March 1992; B.G. Isom, "Historical Review of Asiatic Clam (*Corbicula*) Invasions and Biofouling of Waters and Industries in the Americas," *American Malacological Bulletin,* special edition No. 2, pp. 1-5,1986.

other sector. For example, removal of all of the damaging salt cedar *(Tamarix* spp.) infestations bordering the lower Colorado River, and restoration of the indigenous vegetation, would cost an estimated $45 million to $450 million (94).

Cumulative Losses

OTA summarized some of the estimated economic losses to the United States from introductions of 79 harmful NIS between 1906 and 1991 (table 2-2). The species range from the brown tree snake *(Boiga irregulars) (the* costs of keeping it out) to hog cholera virus. The estimated total of $97 billion (1991 dollars) provides a minimum benchmark for true losses during the 85 years. This total is likely a fraction of the total costs during the period. Only about 14 percent of NIS known to be harmful are included, because comparable estimates of economic effects for the remaining 86 percent were unavailable; one of the most costly groups-non-indigenous agricultural weeds (see box 2-C)--is omitted.

Under-Counted Effects

The economic data on NIS are heavily weighted toward direct market effects and government

Table 2-2—Estimated Cumulative Losses to the United States From Selected Harmful Non-Indigenous Species, 1906-1991

Category	Species analyzed (number)	Cumulative loss estimates (millions of dollars, 1991)	Species not analyzed[a] (number)
Plants[b]	15	603	—
Terrestrial vertebrates	6	225	>39
Insects	43	92,658	>330
Fish	3	467	>30
Aquatic invertebrates	3	1,207	>35
Plant pathogens	5	867	>44
Other	4	917	—
Total	79	96,944	>478

[a]Based on estimated numbers of known harmful species per category (figure 2-4).
[b]Excludes most agricultural weeds; these are covered in box 2-D.

NOTES: The estimates omit many harmful NIS for which data were unavailable. Figures for the species represented here generally cover only one year or a few years. Numerous accounting judgments were necessary to allow consistent comparison of the 96 different reports relied on; information was incomplete, inconsistent, or had other shortcomings for most of the 79 species.

SOURCE: M. Cochran, "Non-Indigenous Species in the United States: Economic Consequences," contractor report prepared for the Office of Technology Assessment, March 1992.

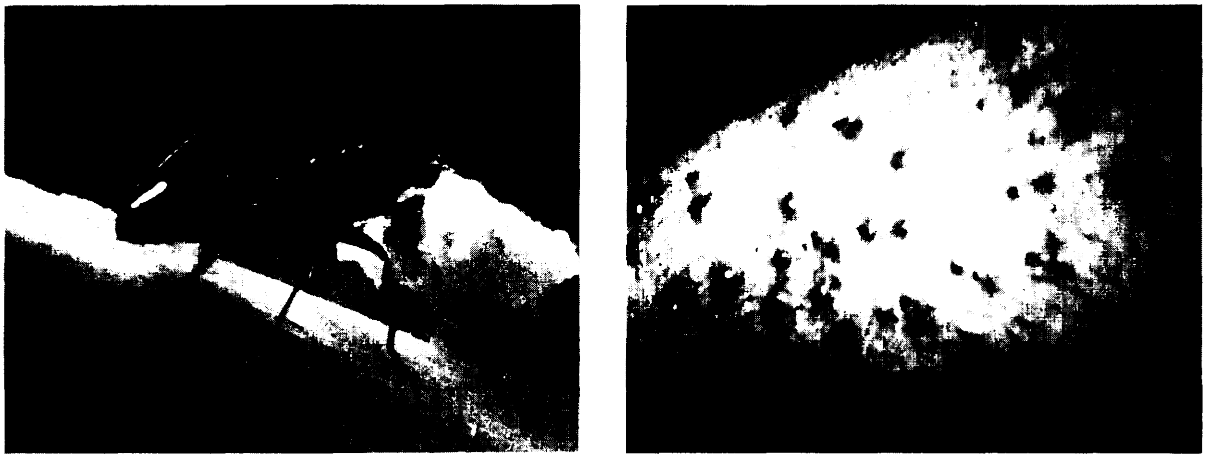
control costs. Past accountings generally incorporated little information on several other important effects, such as research and private control costs (8). The latter are especially significant in agriculture, where farmers bear much of the cost of control, Even outside of farming, control costs can be substantial; North Carolina homeowners spent an estimated $11 million annually to protect residential trees from the European gypsy moth (12). Accounting for nonmarket effects may be the only way to capture the fill economic impacts of NIS affecting natural areas. Chapter 4 discusses such accounting difficulties and the disputed role of economics in NIS decisionmaking. Harmful NIS have numerous other health and environmental costs that are difficult to count in dollars.

HEALTH COSTS

Non-indigenous diseases of humans are beyond the scope of this assessment (figure 2-l). A number of other NIS directly affect human health, however. African honey bees and imported fire ants sting, and can also cause severe allergic reactions in sensitive people (78,90). African honey bees have in addition a propensity to sting with little provocation and repeatedly, The Brazilian pepper tree *(Schinus terebinthifolius), currently* spreading throughout Florida, produces allergens that cause respiratory difficulty in many people and contact dermatitis in many more (43). Approximately half of the poisonous plants found in non-agricultural areas of eastern North America are non-indigenous (98), including foxglove *(Digitalis purpurea)* and tansy *(Tanacetum vulgare)* (101). Hybrids *(Canis lupus x C. familiars)* between dogs *(Canis familiars)* (non-indigenous) and wolves *(Canis lupus)* (indigenous), although popular as pets, are dangerous to humans (5).

Human health may also be indirectly influenced by some NIS. For example, non-indigenous aquatic weeds growing en masse provide a sheltered habitat for mosquito larvae, which spread human diseases when they mature (21). Several NIS currently in the United States are vectors for human diseases, although some of the diseases are not yet present in this country. For example, the snail *Biomphalaria*, presently in Florida and Texas, can carry the blood fluke *(Schistosoma* spp.) that causes schistosomiasis, although the populations in the United States do not yet harbor the flukes (7). The Asian tiger mosquito *(Aedes albopictus)* entered the United

USDA



Imported fire ants (Solenopsis spp.) probably reached the United States in dry ship ballast; they have negative health as-well as economic eflects.

States in 1985 and is now established in 21 States (see ch. 3; box 3-A) (55). This insect can transmit several human diseases not yet present in the United States, including dengue and yellow fever, as well as a virulent form of encephalitis already present (55).

ENVIRONMENTAL COSTS

Finding:

Harmful NIS threaten indigenous species and exact a significant toll on U.S. ecosystems. Numerous declines in populations of indigenous species have been attributed to NIS, a signal of their diverse and growing impacts across the country. The worst NIS have caused species extinctions and wholesale transformations of ecosystems.

Populations of many NIS expand rapidly upon reaching new habitats where the competitors, predators, pathogens, and parasites that formerly kept them in check are no longer present. Some of these NIS become harmful by competing with, preying upon, parasitizing, killing, or transmitting diseases to indigenous species. They may also alter the physical environment, modifying or destroying habitats of indigenous species. In places, NIS that outcompete indigenous species have, to some extent, replaced them. Abundant evidence shows declines in indigenous species resulting from NIS introductions, in some cases causing or contributing to a species' endangerment or extinction. At the worst, such processes have caused fundamental-and perhaps irreversible-changes in the functioning of U.S. ecosystems (1 1).

The popular press and environmentalists frequently stress the role of NIS in species extinctions (1,16,40,46). However, much of the supporting evidence is anecdotal or equivocal, in part because demonstrating the cause of an extinction after the fact is difficult. Also, NIS introductions in many cases may be just one of several factors contributing to a species' demise, and the exact role of NIS is therefore hard to evaluate (42).

Overemphasizing the significance of extinction as a consequence of MS tends to divert attention from their other very significant and unambiguous environmental effects. Species extinctions do not have to occur for biological communities to be radically and permanently altered. Nor are extinctions necessary for the United States to experience a significant decline in the abundance, diversity, and aesthetic value of its biological resources as populations of indigenous species shrink and numbers of NIS increase.

Decline of Indigenous Species

Many examples exist of declines in populations of indigenous species resulting from NIS introductions. Such declines occur across abroad array of ecosystems and as a result of diverse MS.

Some NIS displace indigenous species by out-competing them. Throughout the American West, several non-indigenous grasses, including the widely planted crested wheatgrass, have been shown to suppress the of seedlings of oaks, pines, and other indigenous plants by reducing light, water, and nutrients (1 1). At least 10 indigenous plant species are less common in parts of Arizona where African lovegrass *(Eragrostis lehmanniana) occurs* (1 1).

Competition from the introduced house sparrow and European starling *(Sturnus vulgaris)* caused dramatic declines in the numbers of eastern bluebirds *(Sialia sialis)* and other indigenous birds (79). Presence of the mosquitofish *(Gambusia affinis)* has been associated with localized declines in populations of at least 15 indigenous fishes found in desert rivers and springs (71), The non-indigenous crayfish *Orconectes rusticus* competes with the indigenous O. *virilis* and caused its local disappearance from several Wisconsin lakes during the 1980s (38). Introduction of a periwinkle (the snail *Littorina littorea)* to U.S. shores in the late 1800s pushed the mud snail *(Ilyanassa obsoleta)* out of many near shore habitats (6).

Non-indigenous diseases, parasites, and predators have driven down populations of some indigenous species. The brown-headed cowbird *(Molo/hrus ater),* a bird indigenous to the eastern United States, parasitizes other birds by placing its eggs in their nests, where young cowbirds compete aggressively for food. Its range expansion following the growth of U.S. agriculture contributed to a drop in populations of migratory songbirds such as Kirtland's warbler *(Dendroica kirtlandia) (80).* Predation by non-indigenous fishes on young razorback suckers *(Xyrauchen texanus)* has contributed to its decline in the Colorado River basin (45). Introduced predatory rosy snails *(Euglandina rosea)* have been observed decimating populations of indigenous tree snails in Hawaii (25). The balsam woolly adelgid has killed almost all of the adult fir trees in Great Smoky Mountains National Park, formerly the repository of about 74 percent of all spruce-fro forest in the southern United States (35).

Some introduced NIS are not harmful themselves, but carry diseases or other organisms that harm indigenous species. Widespread concerns exist among State wildlife biologists that non-indigenous game raised on ranches can be a source of diseases affecting indigenous wild animals (36). Sika deer, for example, can harbor meningeal worms *(Pare laphostrongylos tenuis)* and numerous other parasites and pathogens that can infect wild animals and livestock. The Asian tapeworm *(Bothriocephalus opsarichthydis)* was inadvertently released in the United States via infected grass carp *(Ctenopharyngodon idella)* from China and now infects indigenous fishes in North America (22).

Some NIS are closely enough related to indigenous species to hybridize with them. Hybridization results in a loss of successful reproduction when the offspring are less viable. It can also genetically "swamp" and eliminate an indigenous species when successive generations of offspring become increasingly genetically similar to the NIS, as has occurred with certain indigenous trout in western locales (13). Hybridization with NIS can impair recovery of endangered species. An international group of experts has called for governments to prohibit or tightly restrict ownership and breeding of wolf/dog hybrids because they can interbreed with endangered wolves (52).

Species Extinction

The introduction of NIS has been closely correlated with the disappearance of indigenous species in Hawaii and other islands ***(29,79).*** Some observers consider competition by non-indige-

Table 2-3-Contribution of Non-Indigenous Species to Threatened and Endangered Species Listings by t he U.S. Fish and Wildlife Service[a]

		Category of impact on threatened and endangered species		
	Total threatened and endangered species (number)	Species where NIS contributed to listing (number, percent)	Species where NIS are a major cause of listing (number, percent)	Species where NIS are *the* major cause of listing (number, percent)
Plants	250	39(1 6%)	—	14 *(6°/0)*
Terrestrial vertebrates.	182	47(26%)	3(2%)	19(10%)
Insects[b]., ...	25	7(28%)	—	2 (8%)
Fish	86	44(51 %)	8(9%)	5 (6%)
Invertebrates[c], ... , ...	70	23(33%)	1 (l%)	1 (l%)
Total	613	160	12	41

c Includes species listed through June 1991.
[b] Includes arachnids.
c Includes mollusks and crustaceans.

SOURCE: M. Bean, 'The Role of the U.S. Department of the Interior in Non-Indigenous Species Issues," contractor report prepared for the Office of Technology Assessment, November 1991.

nous weeds and predation by non-indigenous animal pests to be the single greatest threat to Hawaii's indigenous species (60). There, introduced biological control agents have been implicated in the extinction of 15 indigenous moth species (29). Similarly, scientists believe predation by the introduced brown tree snake in Guam has caused the extinction of 5 species or subspecies of birds and the decline of numerous others (15,68).

The U.S. Fish and Wildlife Service considers NIS to have been a contributing factor in the listing of 160 species as threatened or endangered under the Endangered Species Act! (3). Of these, approximately one-third are from island ecosystems in Hawaii or Puerto Rico. Non-indigenous species are considered to have been the *major* cause of listing for 41 species, of which 23 are from Hawaii or Puerto Rico (table 2-3).

Direct evidence that a NIS has caused the extinction of an indigenous species in the continental United States is lacking. However, even in the continental United States, patchy environments like forest remnants, lakes, hot springs, and artesian springs form habitat "islands." Species whose distributions are limited to such islands tend to have small localized populations and narrow ecological requirements. Consequently, they are more vulnerable to extinction than are widespread species. Effects of introductions under such conditions can mirror those on true islands. For example, the snail *Elimia comalensis* lives only in several springs and spring-fed rivers in Texas. Introduction of two non-indigenous snail species in the late 1960s has caused populations of E. *comalensis* to reach precariously low levels several times (7).

NIS clearly have caused population declines of indigenous species in mainland habitats. When other stresses such as pollution and habitat destruction adversely affect a population in concert with NIS, populations may be pushed to dangerously low levels (57). The combination of water projects and introductions of species better adapted to altered habitats is considered to be the major cause of declines in California's indigenous fishes, 76 percent of which are now declining, threatened, endangered, or extinct (58).

6 Endangered Species Act of 1973, as amended (7 U. S.C.A. 136, 16 U. S.C.A. 4601-9 *et. seq.*).

RON PEPLOWSKI

Zebra mussels (Dreissena polymorpha), one *of the most costly recent accidental imports, clog intake pipes, coat equipment, and are expected to significantly after aquatic ecosystems.*

Transformation of Ecological Communities and Ecosystems

Some NIS transform ecosystems by modifying basic physical and chemical features of the environment. These NIS "don't merely compete with or consume native species, they change the rules of the game by altering environmental conditions or resource availability' (1 1). Zebra mussels, for example, rapidly filter water, decreasing the food available for other aquatic animals and increasing light penetration. This, coupled with the zebra mussel's dense, bottom-dwelling populations, is expected to cause major changes in the biological communities found within U.S. lakes, rivers, and streams-including the possible extinction of part of the rich indigenous mussel fauna in the United States (7).

The Australian melaleuca tree is rapidly modifying large areas of the Florida Everglades by changing soil characteristics and topography, Dense, pure stands of melaleuca displace indigenous vegetation and provide poorer habitat and forage for wildlife (70). Salt cedar, now abundant along the lower Colorado River, was originally introduced as an ornamental and for erosion control (61). It forms thickets along waterways, crowding out indigenous plants, banking up sediments, and altering water flow (39). Certain non-indigenous plants, like cheatgrass in northwestern States and bunchgrass *(Schizachyrium condensatum)* and molasses grass *(Melinis minu - tiflora) in* Hawaii, burn easily and recover rapidly from fires, unlike indigenous plants of these areas. Where abundant, they increase the frequency of brush fires, seriously offsetting the normal ecological processes by which indigenous plant communities become established. Bunchgrass and molasses grass now comprise 80 percent of the plant cover in parts of Hawaii Volcanoes National Park (11),

Wild hogs, descended from animals that escaped from hunting enclosures in 1912, in Great Smoky Mountains National Park now eat, uproot, or trample at least 50 species of herbaceous plants and can reduce the cover of understory plants in forests by 95 percent (64). Their rooting displaces animals like voles and shrews, which depend on undisturbed leaf litter for habitat. It also increases soil erosion and the resulting turbidity of small streams. Hogs consume small animals, including potentially threatened salamanders and snails, and compete with several indigenous species for food. Aquatic equivalents of hogs are the grass *(Ctenopharyngodon idella)* and common carps *(Cyprinus carpio),* widely introduced to control aquatic weeds. These fishes indiscriminately consume aquatic vegetation, destroying habitats for young fish and increasing water turbidity (57).

Some NIS have major effects on ecosystems because they affect indigenous species that play a pivotal ecological role, Initial effects of the NIS on one species then cascade throughout the system, like a line of falling dominoes. Recent introduction of the opossum shrimp *(Mysis relicta)* into the Flathead River-Lake ecosystem of Glacier National Park caused populations of many other animals to drop. Because of feeding by the shrimp, zooplankton became less numerous. This decline, in turn, contributed to a drop in forage fish, ultimately driving away the area's fish predators—including eagles, otters, coyotes and bears (76).

Declines in indigenous plants can have important repercussions because they change the physical structure of the environment and reduce available habitat for the insects, birds, or other organisms that normally dwell in the vegetation. Chestnut blight virtually eliminated stands of the American chestnut in about 91 million hectares of eastern U.S. forests, where, in places, it previously constituted up to 25 percent of the trees (96). Loss of the American chestnut is thought to have caused at least five indigenous insect species to disappear and also to have contributed to an increase in oak wilt disease *(Ceratocystis fagacearum)* because of subsequent changes in the density and distribution of red oak *(Quercus rubra) (41).* Several vines, including kudzu and Oriental bittersweet *(Celastrus orbiculatus), overgrow* and eventually pull down trees, and have changed parts of some eastern forests from open canopies to dense thickets (51, 82). The spread of purple loosestrife to wetlands in 41 States has been called an "ecological disaster" (83). In some areas, it has displaced half of the previous biomass of indigenous plants—many of which are important sources of food for other species—and has further contributed to the decline of bird and turtle species by destroying their habitats (83). European leafy spurge, now widespread on U.S. rangelands, attracts few insect grazers, diminishing food supplies for insect-eating birds (4).

Special Consideration of NIS in the National Parks

Finding:

Increasing numbers of NIS are causing ecological disruption in the U.S. National Parks. Removal or control of NIS is not keeping pace with species' invasions and spread. Concerns are increasing that the ecological changes overtaking the parks may be so severe that they will eliminate the very characteristics for which the parks were originally established.

The conservation mandate of the U.S. National Park Service has resulted in the development of restrictive policies related to introductions of NIS. Consequently, NIS seen as beneficial in some locales are considered harmful in the National Parks. For example, rainbow trout *(Oncorhynchus mykiss)* and brown trout widely stocked for sport fisheries are being eradicated in the Great Smoky Mountains National Park because of their harmful effects on indigenous brook trout *(Salvelinus fontinalis* (10).

National Parks in all areas of the United States are experiencing problems with NIS in spite of the restrictive policies and eradication efforts (table 2-4) (27,41). A backlog of unfunded NIS control programs continues to expand (30). Increasing concern exists among scientists, environmentalists, and others that the threats from NIS in some National Parks are so severe that park ecosystems will be permanently altered if large-scale control and eradication efforts are not undertaken (43). In the Everglades Conservation Areas near Everglades National Park, the spread of melaleuca is rapidly changing the wetlands—known as a "river of grass'—into a stand of non-indigenous trees. Unchecked, such changes eventually will eliminate the National Parks' role as a caretaker of U.S. ecosystems and indigenous species.

These concerns are not confined to National Parks. NIS threaten many State parks as well. In Missouri's Cuivre River State Park, one of the State's largest and most rustic parks, European buckthorn *(Rhamnus cathartic)* has spread widely, forming impenetrable thickets throughout the forest understory (54). A 1991 Missouri study concluded NIS are among the State's parks' 10 most serious and widespread threats (54).

RELATIONSHIP TO BIOLOGICAL DIVERSITY

The preservation of biological diversity is of growing concern among the public, Con-

Table 2-4—Examples of Non-Indigeneous Species Problems in the National Parks

Park	Impacts
Channel Islands National Park, California	Feral mammals, like the European rabbit *(Oryctolagus cuniculus),* are thought to have caused irreversible loss of topsoil by destroying vegetation and causing erosion. Introduced ice plant *(Mesembranthemum crystallinum)* accumulates salt, changes soil salt content, and excludes indigenous vegetation.
Everglades National Park, Florida	Australian pine (Casuarina equisetifolia) causes development of steeper shorelines thereby impairing nesting by loggerhead sea turtles *(Caretta caretta).*
Canyonlands National Park, Utah	Salt cedar *(Tamarix* spp.) replaces indigenous vegetation, banks up sediments, reduces channel width, and increases overbank flooding. Non-indigenous grasses largely replace indigenous grasses and are thought to have increased the frequency of fire on grasslands.
Big Bend National Park, Texas	Salt cedar lowers the water table and dries up springs, contributing to the decline of desert bighorn sheep (Ovis canadensis).
Theodore Roosevelt Island, Washington, DC	Japanese honeysuckle (Lonicera japonica) and English ivy (Hedera helix) inhibit growth of new trees and understory plants. They also overgrow and kill adult trees.
Hawaii Volcanoes National Park, Hawaii	Non-indigenous plants (fire tree Myrica faya and leucaena Leucaena ieucocephala) elevate nutrient levels on young lava flows, potentially enhancing invasion by other NIS. Non-indigenous grasses, like crested wheatgrass (Agropyron desertorum), increase the frequency and intensity of wildfires.

SOURCE: I.A.W. MacDonald et al., "Wildlife Conservation and the invasion of Nature Reserves by introduced Species: Global Perspective," *Biological Invasions: A Global Perspective,* JA. Drake et al. (eds.) (New York, NY: John Wiley and Sons, Ltd., 1989), pp. 215-255.

gress,[7] scientists, and conservationists. Biological diversity[8] encompasses the biological variation occurring within and among species as well as among ecological communities and ecosystems. Processes that reduce this variation at any level negatively affect biological diversity. Many harmful MS clearly impair biological diversity by causing population declines, species extinctions, *or* simplification of ecosystems. Moreover, the very establishment of a NIS diminishes global biological diversity: as NIS like starlings, grass carp, and crabgrass spread to more places, these places become more alike biologically.

The relationship between NIS and biological diversity is not always straightforward, however. Under certain circumstances, such as those listed below, NIS *may* actually enhance biological diversity although negative counter-examples exist for each category. The same NIS, under other circumstances, may diminish biological diversity. Thus, each situation requires careful case-by-case analysis (see ch. 4).

- Where Indigenous Species Utilize or Depend on NIS--Certain indigenous birds appear to reside almost exclusively in eucalyptus *(Eucalyptus* spp.>introduced to California over 135 years ago (99). Monarch butterflies *(Danaus plexippus) also* prefer eucalyptus to the native woodlands. In Florida, heavy human use of beaches disturbs nesting by the American oystercatcher *(Haematopus palliatus).* Some achieve greater nesting success within stands of introduced Australian pine (84).
- Where Altered Environments Are Inhospitable to Indigenous Species—Non-indigenous fishes may be the only ones able

[7] For example, U.S. Congress, 102nd Congress, 1st Session, H.R. 585, proposed the National Biological Diversity Conservation and Environmental Research Act (1991).

[8] A previous OTA study defiied biological diversity as "the variety and variability among living organisms and the ecological complexes in which they occur" (87).

to live in the new reservoir habitats created when rivers are dammed (69). Some introduced plants, like red bromegrass *(Bromus rubens) in* southern California, may prove to be more suited to heavily polluted areas than indigenous ones (99). In such cases, ‘ ‘artificial diversity” may be the only feasible option unless the underlying human disturbance is eliminated or modified.

- Where NIS Hybridize with Certain Endangered Indigenous Species-Only 30 to 50 individuals remain of the Florida panther *(Felis concolor coryi),* a critically endangered subspecies. Some carry genes from a Central or South American subspecies, probably from captive animals released into the Everglades decades ago (18). Commentators have argued that this should not detract from the panther’s protected status under the Endangered Species Act (62). Similarly, some endangered indigenous trout species in the Southwest have heavily hybridized with introduced cutthroat *(Oncorhynchus clarki)* and rainbow trouts (13). Eradicating these hybrids could destroy the only remaining vestiges of the indigenous fish.
- Where the NIS Itself Represents Valuable Genetic Diversity—Feral hogs on Ossabaw Island, Georgia (Sus *scrofa domesticus) are* descendants of animals introduced by Spanish explorers in the 16th and 17th centuries. They appear to have evolved certain unique biochemical features (47). Eradication of the hogs would mean a loss of this genetic diversity.
- Where a Species Must be Introduced at New Locales to Ensure Its Survival—The brown tree snake, now well established in Guam, has driven the Guam rail *(Rallus owstoni)* near extinction. Introduction of the bird outside its natural range (e.g., in Hawaii) may be better than allowing it to become extinct or to survive only in captivity (9).
- Where a NIS Removes Harvesting Pressure From Indigenous Species —The Washington State Department of Fisheries actively promotes the shad *(Alosa sapidissima),* which was introduced decades ago, to reduce fishing pressure on the low numbers of indigenous salmon (49).

Management decisions, under circumstances like those listed above, may be controversial, even among experts seeking to maximize biological diversity. They raise legitimate concerns about whether short-term solutions (e.g., introducing pollution-tolerant plants) are acceptable or counterproductive over the long term. Although contentious cases are relatively uncommon, they sometimes command the lion’s share of resources and attention. For example, “hundreds of other exotics and naturalized aliens go unattended in California parks’ while much of the budget for NIS control is devoted to the controversial fight against eucalyptus (99).

CHAPTER REVIEW

This chapter is the first of two that, taken together, paint a picture of harmful NIS in the United States today, This chapter defined NIS and described the impacts that distinguish beneficial from harmful species, e.g., those that cut agricultural or other productivity, those with high control and eradication costs, and those associated with the decline of indigenous species or ecosystems. Not all NIS cause damage; nor does each have the same positive or negative impacts every place it occurs. Yet harmful NIS generate substantial economic, health, and environmental costs for the Nation-costs often uncounted in the past. With highly damaging species in virtually every State, the sketch that emerges from this chapter is worrisome.

Chapter 3 completes the picture. It traces the various pathways by which NIS enter the United States and spread from state to state and estimates the numbers of species involved.