The Changing Numbers, Causes, and Rates of Introductions

3

Non-indigenous species (NIS) arrive by way of two general types of pathways (figure 3-l). First, species having origins outside of the United States enter the country and become established either as free-living populations or under human cultivation—for example, as pets or in agriculture, horticulture, or aquiculture. Some cultivated species subsequently escape or are released and also become established as free-living populations. Second, species already within the United States, of U.S. or foreign origin, can spread to new locales. Pathways of both types include intentional as well as unintentional species transfers.

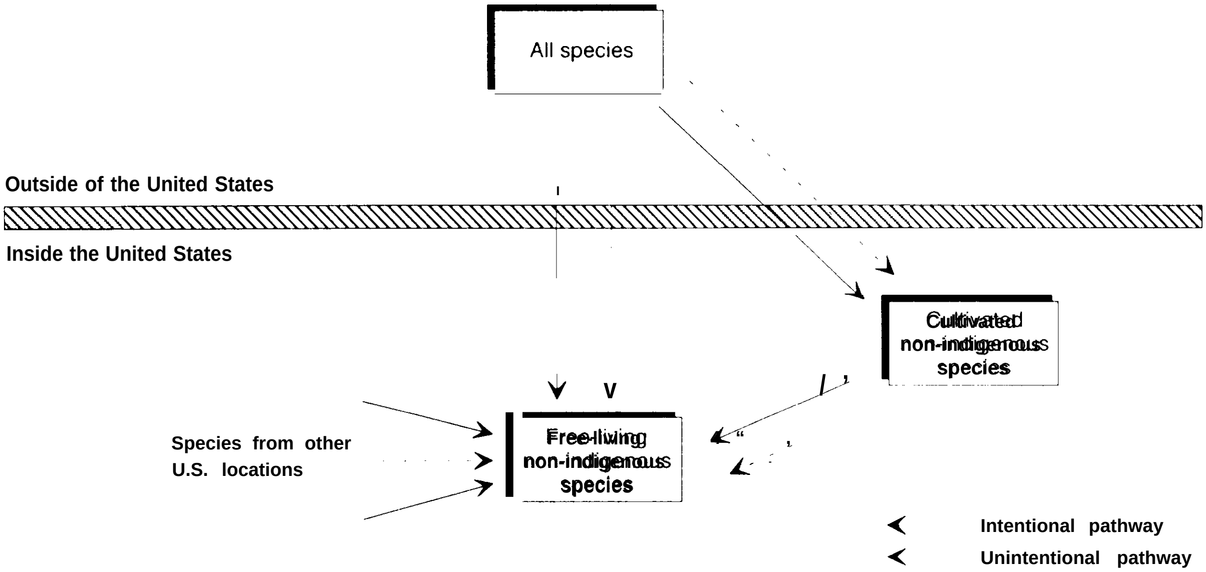
This chapter first identifies current pathways that either are known or can be reasonably inferred to have been routes of introduction for NIS since 1980. Included are routes for both harmful and beneficial introductions; effects of NIS can change over time or as they enter new environments, and some introductions that appear benign today may eventually cause harm (ch. 2). The chapter goes on to assess the growing numbers of NIS in the United States, their geographical distribution, and the various factors affecting rates and pathways of species transfers.

PATHWAYS: HUMANS INCREASE THE MOVEMENT OF SPECIES

Finding:

Naturally occurring movements of species into the United States are uncommon. Most arrive in association with human activities or transport. Species can be brought into the country and released intentionally, or their movement and

Figure 3-l-Generic Pathways of Species Entry and Spread



SOURCE: Office of Technology Assessment, 1993.

release can be an unintentional byproduct of cultivation, commerce, tourism, or travel. In addition, human modification of natural habitats continues to provide new opportunities for species establishment.

Geographic distributions of species naturally expand or contract. However, over historical time intervals (tens to hundreds of years), species' ranges rarely expand thousands of miles or across physical barriers like mountains or oceans (12,26,53,63,82). Such large-scale movements have become commonplace today, driven by human transformations of natural environments as well as the continual transport of people and cargo around the globe. Resulting rates of species movement dwarf natural rates in comparison.

The Role of Habitat Change

Habitat modification can create conditions favorable to the establishment of NIS. Soil disturbed in construction and agriculture is open for colonization by non-indigenous weeds. Non-indigenous plants, in turn, may provide habitats for the non-indigenous insects that evolved with them. For example, European viper's bugloss *(Echium vulgare),* a weed common along roads and railroad tracks, provides a habitat for the Eurasian lace bug *(Dictyla echii).* Non-indigenous plants that would not tolerate dry conditions flourish in newly irrigated parts of arid regions, such as the American Southwest (63). Other human-generated changes in fire frequency, grazing intensity, soil stability, and nutrient levels similarly facilitate the spread and establishment of non-indigenous plants (47).

Thermal effluents from power generating stations and industrial installations create suitable environments for tropical non-indigenous fish and snails (12). Gardens as well are common habitats for non-indigenous snails and slugs (12). Pollution and habitat degradation have made some environments inhospitable to certain indigenous species. Such changes encourage fisheries managers and others to introduce NIS more tolerant of the degraded conditions (26).

When human changes to natural environments span large geographical areas, they effectively create conduits for species movement between previously isolated locales. Such modifications have an important role in facilitating the spread of NIS within the country. The rapid spread of the Russian wheat aphid *(Diuraphis noxia)* to 15 States in just 2 years following its 1986 arrival has been attributed, in part, to the prevalence of alternative host plants that are available when wheat *(Triticum* spp.) is not, Many of these are non-indigenous grasses recommended for planting on the 40 million or more acres enrolled in the U.S. Department of Agriculture's Conservation Reserve Program (54) (see also ch. 6), Many newly introduced weeds followed railway construction across the continent to the American West because they can grow in disturbed land beside the tracks (63). Roads and backcountry trails have helped to spread non-indigenous grasses within Glacier National Park, Montana (98). The 1829 construction of the Welland Canal in the Great Lakes provided a route for the sea lamprey *(Petromyson marinus), alewife (Alosa pseudoharengus),* and rainbow smelt *(Osmerus mordax)* to migrate upstream from Lake Ontario (26). The Asian clam *(Corbicula fluminea)* expanded its range following irrigation and drinking water canals in California and Arizona (12). The growth of agriculture, urbanization, pollution, and a host of other human habitat modifications have enhanced the movement of many species across the country.

Present Pathways Into the United States

More than 205 NIS were introduced or frost detected in the United States since 1980. (See table 3-1 at the end of this chapter.) Fifty-nine of these are expected to cause economic or environmental harm. These NIS followed many different pathways into the country.

A number of factors confound quantitative evaluation of the relative importance of various entry pathways. Time lags often occur between NIS establishment and detection, and tracing the pathway for a long-established species is difficult (65). One expert estimates that non-indigenous weeds usually have been in the country for 30 years or have spread to 10,000 acres before they are detected (65). In addition, Federal port inspection is a major source of information on NIS pathways, especially for agricultural pests. However, it provides data only on whether NIS enter via scrutinized routes, not on whether and how many NIS enter via as-yet-undetected pathways. Finally, some comparisons between pathways defy quantitative analysis-for example, which is more 'important': the entry pathway of one very harmful NIS or one by which many less harmful NIS enter the country? For these reasons, OTA has chosen not to rank the pathways according to relative significance.

UNINTENTIONAL PATHWAYS

Many species enter the United States each year as unintentional contaminants of commodities. Agricultural produce, nursery stock, cut flowers, and timber sometimes harbor insects, plant pathogens, slugs, and snails (12,53). Of 23 non-indigenous insect species that became established in California since 1980, 20 arrived on imported plants, 2 on fruit, and 1 on infested wood (35). At least 45 percent of the snails and slugs intercepted by agricultural inspectors between 1984 and 1991 were found on plants or plant products (12). Bulk commodities like gravel, iron ore, sand, wool, and cotton *(Gossypium hirsutum)* can contain hidden weed seeds (63,106). Commodities were the single greatest source (81 percent) of noxious weed Federal interceptions from October 1987 through mid-July 1990 (106).

Weeds continue to enter the United States as seed contaminants even though the content of imported seed is regulated under the Federal Seed Act (63,106).[1] These weed seeds ultimately can be widely distributed and then planted in favorable environments along with the desired agricul-

I Federal Seed Act (1939), as amended (7 U. S.C.A. 1551 et *seq.*).

tural or other seed. For example, serrated tussock *(Nassella trichotoma)—a* noxious weed that degrades rangelands and pastures-was repeatedly found in 1988 in seed from Argentina of tall fescue *(Festuca arundinacea)* a lawn and pasture grass. Contaminated seed ultimately was distributed to at least five States and sold through such popular retailers as K-Mart, Walmart, and Ace Hardware. Over 58,000 pounds were sold before the seed was recalled in 1989 (103).

Despite Federal requirements for inspection and quarantine, plant pathogens sometimes arrive as unintended contaminants of plant materials. Importation of seeds and other plant germ plasm for propagation and breeding was a pathway for at least three plant pathogens entering the country between 1982 and 1991 (82) (table 3-l).

A number of fish and shrimp pathogens and parasites have similarly entered the country in infected stock for aquiculture or fishery enhancement (42,60). The introduction of the Pacific oyster *(Crassostrea gigas)* to the West Coast in the 1920s brought with it a Japanese snail *(Ocenebra japonica)* that preys on oysters, a flatworm *(Pseudostylochus ostreophagus),* and possibly also a copepod parasite *(Mytilicola orientalism) (104). The* Asian tapeworm *(Bothriocephalus opsarichthydis)* was found infecting several indigenous fishes in North America during the 1970s; it entered the country earlier, probably in infected grass carp *(Ctenopharyngodon idella) (42,48).*

Today, most imported freight is packed into standardized, boxcar-sized containers for ease of shipping and handling (70). Containerized freight is difficult to inspect, requiring costly unloading and reloading of the contents (61). Consequently, inspections tend to occur only when there is good cause to suspect illegal imports or contamination by pests. Decreased inspection increases the possibility that NIS will go undetected (82).

Freight containers can sit idle at ports for weeks or longer before loading, during which time organisms can board and become hidden (12,63). Also, containers generally are not cleaned between shipments (70). Containerized freight is thus thought to be a significant pathway for the entry of insects, weed seed, slugs, and snails into the country (12,53,63). Containerized shipments of used tires were the source for introductions of the Asian tiger mosquito *(Aedes albopictus)* from 1985 to 1988, until new U.S. Public Health Service regulations required tires to be mosquito free (30) (box 3-A). At least 15 percent of the snails and slugs intercepted by Federal agriculture inspectors between 1984 and 1991 were in freight containers (12). Since containers frequently are not unloaded until they reach their inland destinations, any species they contain are released within the country rather than at a port of entry. This reverses the historical pattern wherein species generally first appeared at ports of entry (53).

Crates were the source of at least 11 percent of the mollusks intercepted by Federal inspectors from 1984 to mid-1991 (12). The crating and packing material itself poses additional risks. A threatening new bark beetle *(Tomicus piniperda),* discovered near Cleveland, Ohio in 1992, is believed to have entered the country in ship's dunnage (wood packing material) (78). Packing material used to ship dishes from Greece is suspected to have been the pathway for the new weed early millet *(Milium vernale) (65).* Unprocessed wood and wood products have been a source of forest pests and pathogens in the past (1 1); current concerns center on their potential to convey pests from Asia to forests in the Pacific Northwest (101) (see also box 4-B). Wooden crates carrying oysters have been suggested, although not proven, as a possible source of wood-boring aquatic animals as well (19).

Some NIS stow away on cars and other conveyances. This is thought to be a pathway by which weed seeds spread, including across national borders from Mexico and Canada into the United States (63). Noxious weed seeds have been intercepted in aircraft, automobiles, railway cars, ships, tractor trailers, and other vehicles entering the country (106). The Asian gypsy moth *(Lymantria dispar),* a new strain of this destruc-

Box 3-A–The Unwelcome Arrival of the Asian Tiger Mosquito

On August 2, 1985, the Asian tiger mosquito *(Aedes* albopictus) was discovered in Houston, apparently imported in containerized shipments of used tires. An aggressive biter and prolific breeder, this species is a vector of several serious viral diseases such as dengue fever, LaCrosse encephalitis, and eastern equine encephalitis. The last has a 30 percent mortality rate in humans. As of 1991 the mosquito had been found in 22 States. Experts predict that rapid evolution of cold-tolerant and heat-tolerant strains may eventually allow the mosquito to occupy an even broader range. The mosquito thrives in used tires-it breeds in the small, protected pools of water often found inside. Unfortunately, more than 2 billion scrap tires are now piled up in the country, usually close to large population centers, with 250 million more tires added each year.

Official response was slow and inadequate to stop the mosquito. Not until 1988 did the Centers for Disease Control and Prevention (CDC) of the Public Health Service impose regulations requiring that used tire imports be dry and free of mosquito eggs or larvae. According to one expert, inspection to ensure compliance with the regulations is minimal. Further, in early 1987, CDC rejected the recommendation of its own expert panel to develop a $20 million research and control plan, citing fiscal constraints. The American Mosquito Control Association officially censured CDC's rejection of the control plan.

Although CDC has done significant research, formulating responses has been largely left to State and local governments. Their uncoordinated, uneven control efforts have been no match for the problem. Meanwhile, at a major Florida tire dump nine miles from Disney World, scientists recently isolated eastern equine encephalitis from the Asian tiger mosquito for the first time since the mosquito was discovered in the country.

SOURCES: G. Craig, Professor of Biology, University of Notre Dame, letter to P.T. Jenkins, Office of Technology Assessment, March 14, 1992; R.B. Craven et al., "Importation of *Aedes albopictus* and Other Exotic Mosquito Species Into the United States In Used Tires from Asia," *Journal of the American Mosquito Control Association*, vol. 4, No. 2, 1966, pp. 136-142; C.J. Mitchell et al., "Isolation of Eastern Equine Encephalitis Virus From *Aedes albopictus* In Florida," Science, vol. 257, July 24, 1992, pp. 526-527,

tive forest pest, is thought to have recently found its way to the Pacific northwest on grain ships (31). Cargo in planes and trucks are important pathways for insects entering the country (53).

Military freight enters the United States continuously, periodically in high volume. The geographic origin depends on the location of recent military action. Equipment and supplies sometimes are covered with dirt or mud from the field (5). These can bean unintended source of insects and plant pathogens if not properly washed. Military cargo and equipment historically has resulted in several introductions of harmful species, like the golden nematode *(Globodera rostochiensis).* This process was vividly demonstrated in the spread of the brown tree snake *(Boiga irregulars)* across islands of the Pacific by military cargo planes after World War II (41) (see also box 8-B). In 1992, concerns again surfaced that military transport of equipment might provide a pathway for non-indigenous pests—this time from Operation Desert Storm in the Middle East (5).

Establishment of the harmful zebra mussel *(Dreissena polymorpha) in the* Great Lakes during the 1980s focused attention on ballast water as an unintentional pathway by which aquatic species enter the country. Ballast water is taken on by large cargo ships when they are empty to provide stability at sea. It is then dumped when the ship is loaded at a different port. If environments at the two ports are similar, species taken up in the water at one may become established at the other, Since 1980, at least eight new NIS entered U.S. waters by way of dumped ballast water (71) (table 3-l). These include the potentially damaging European ruffe *(Gymnocephalus cernuus)* and two non-indigenous clams newly established in California bays *(Theora lubrica* and *Potamocorbula amurensis) (12,21). The* po -

tential for species transfers by ballast water is great; at least 367 distinctly identifiable taxonomic groups of plants and animals have been found in the ballast water of ships arriving in Oregon from Japan (22).

INTENTIONAL PATHWAYS

Large amounts of plant germ plasm arrive annually for use in the breeding and development of plants for agriculture, horticulture, and soil conservation. Plants for pasture and range improvement and wildlife forage may be directly planted in uncultivated areas. Some notable pests have been introduced in the past for soil conservation including kudzu *(Pueraria lobata)* and multiflora rose *(Rosa multiflora).* Scotch broom *(Cytisus scoparius)* was introduced to California as an ornamental plant, and also used by the U.S. Soil Conservation Service for preventing erosion. It now has spread to at least 500,000 acres in the State, where it displaces indigenous flora and fauna and is a serious weed of tree plantations (10). Concerns continue today regarding the pest potential of new species deliberately released for preventing erosion (84).

Although most plant introductions are legal, some do occur illegally. Often these involve species for ornamental horticulture smuggled into Hawaii (63). Some seeds are sent to plant breeders in the United States through international first-class mail to avoid inspection or quarantine at the port of entry (8). Baggage accompanying individuals visiting or returning to the United States is a common pathway for the illegal transport of NIS. At least 82 percent of the plants or seeds of noxious weeds intercepted at U.S. ports of entry between October 1987 and mid-July 1990 occurred in baggage (106). The ultimate fate of organisms entering in baggage is unknown, but it is likely some have been grown or otherwise released by their owners. For example, Asian water spinach *(Ipomoea aquatica)* is a Federal noxious weed and a prohibited aquatic weed under Florida State regulations. Yet, from 1979 through 1990, Florida State officials recorded 20 cases of illegal possession of seeds or deliberate plantings (83).

Intentional importation and release for biological control of pests has been a source of non-indigenous insects, snails, fish, plant pathogens, and nematodes (12,26,53,82). Estimates are that a total of 722 non-indigenous insect species have been purposely introduced in the United States for biological control of pests. Of these, 237 have become established (44). Since 1980, at least 6 insect species have been newly introduced in the country for biological control (table 3-l). Insects also have been purposely released for plant pollination; researchers from the U.S. Agricultural Research Service working in California released several thousand mason bees *(Osrnia cornuta)* from Spain in experimental tests from 1976 to 1984 (96).

During the late 1980s, two plant pathogens were introduced for biological control: a nematode *(Subanguina picridis)* from Russia to control Russian knapweed *(Centaurea repens)* and a rust fungus *(Puccinia carduorum)* from Turkey to control musk thistle *(Carduus nutans) (82).* Two illegal introductions of plant pathogens in 1990 were a smut fungus *(Ustilago esculenta),* which is grown on Manchuria rice *(Zizania latifolia)* to produce edible galls, and the chrysanthemum white rust *(Puccinia horiana),* which is used by hobbyists to produce unusual flowers (82). In both cases of illegal introduction the infected plants were located by authorities and subsequently destroyed (82).

Although generally less common today than in the past, State wildlife managers continue to import and release non-indigenous birds for game hunting. Between 1985 and 1988 the State of Michigan imported 3,600 eggs of the Sichuan pheasant from China-a subspecies of the already established ring-necked pheasant *(Phasianus colchicus) (97).* Like its predecessor, the bird is expected to cause few problems; nevertheless, the Sichuan's broad habitat range and ''unbelievable adaptability" (97) suggest its introduction should be carefully evaluated.

USDA

The advent of containerized freight allows direct introduction of harmful non-indigenous species throughout the country-instead of just at U.S. ports of entry.

Intentional introductions of fishes from abroad also are less common today, but continue still. The State of Texas tried unsuccessfully to introduce the Nile perch (Lates *niloticus)* and bigeye lates (Lates *mariae)* in 1979 and 1983, respectively (26). North Dakota recently proposed to introduce the European zander *(Stizostedion lucioperca),* which critics feared might transmit diseases to or hybridize with indigenous fish like the walleye (S. *vitreum) (28).*

Some non-indigenous clams and oysters have been intentionally imported and released for commercial exploitation (12). Among these is the Pacific oyster, imported from Japan, which now is successfully grown and harvested in West Coast bays from Washington to California (46). Recent proposals to transfer the Pacific oyster to the East Coast have been controversial, and the introduction has not occurred thus far (see ch. 7).

ESCAPE OR RELEASE FROM CONFINEMENT

Species imported to be held in captivity sometimes subsequently escape or are released. Often, determining which of the two has occurred is difficult (i.e., whether the introduction is intentional or accidental). For example, the source of bighead carp *(Hypophthalmichthys nobi!is)* recently established in Mississippi is unclear. Some contend it escaped from aquiculture facilities, while others believe it was illegally released in order to establish free-living populations (27).

Many plants and seeds of foreign origin are directly marketed in the United States, especially for ornamental horticulture. Quarantine of imported species primarily guards against unintentional importation of insects, pathogens, and other pests, rather than the noxious qualities of the plant itself. Thus, specialized nurseries can offer ‘‘ivies of the world’ (7), even though English ivy *(Hedera helix)* is known to cause ecological damage in deciduous forests of the eastern United States.

Significant numbers of non-indigenous plants have escaped from human cultivation. Among the 300 weed species of the western United States, at least 28 escaped from horticulture and 8 from agriculture (107). Baby’s breath *(Gysophila elegans),* foxglove *(Digitalis purpurea),* and creeping bellflower *(Campanula rapunculoides) all are* horticultural species that become weeds outside of gardens (107). Some 300 established non-indigenous plant species in California are escapees from ornamental horticulture (68). These include a number of invasive weeds of native vegetation, such as European gorse *(Ulex europaeus),* Andean pampas grass *(Cortaderia jubata),* and Scotch broom (68). A new addition is oleander *(Nerium oleander),* now well established along the Sacramento River and in the northern Central Valley (14). The edible fig *(Ficus carica),* has recently escaped from agriculture and become established in some riparian woodlands (14).

Several NIS imported for medical diagnostic or research purposes have escaped in the past. The recent spread of African honey bees *(Apis mellifera scutellata)* to the United States was set in motion by escape of bees from a research facility in Brazil in 1957 (52). The giant tiger shrimp *(Penaeus monodon),* originally from the Indo-Pacific, escaped into South Carolina’s coastal waters from the Waddell Research Facility in

1988 (19). The African clawed frog *(Xenopus laevis)* was originally imported in the **1930s** for use in diagnostic pregnancy tests, but had established free-living populations in California by 1969 (69). The Asian Amur maple *(Acer ginnala)*-**a** potential weed of Midwestern natural areas-has now become common in woods and fields surrounding the Lincoln, Missouri, plant testing center of the U.S. Soil Conservation Service, from where it apparently escaped (36).

A different kind of research introduction involved peanut *(Arachis hypogaea) germ* plasm imported from China in 1978 that was unknowingly contaminated with the peanut stripe virus (82). In 1983, the virus was found in peanut breeding lines at university experimental farms from Texas to Virginia to Florida-it had inadvertently been introduced by distribution of the diseased germ plasm to numerous researchers.

Throughout a number of States, ranchers have introduced non-indigenous, big-game animals onto private lands for ranching, to enhance hunting opportunities, or for other purposes. The more than 450 members of the Exotic Wildlife Association combined own an estimated 200,000 head of some 125 NIS (92). Many of the game animals are held in fenced enclosures, but some eventually escape. Indeed, a committee from the State of Wyoming considers such escapes 'inevitable" (57). Texas has the highest numbers of non-indigenous big-game animals; in 1989 the State was home to l64,257 free-ranging animals of 123 species (94). The State government, however, treats these animals as livestock and not as wildlife (94).

About 23 percent of the vertebrate species of foreign origin that currently live in the wild were originally imported as cage birds or other wildlife pets (95). Given the high U.S. rates of pet imports-estimated to be hundreds of thousands to millions of wild birds, aquarium fish, and reptiles annually (33,59)-the potential for pet escapes and releases is great. Illegal imports further expand the total numbers and types of organisms brought into the country. In one recent example, perhaps as many as hundreds of fist-sized African giant snails *(Achatina fulica)* were smuggled into the country from Nigeria and sold in Florida and Virginia pet stores (3,4).

USDA

Snails commonly enter the United States unintentionally on plants or agricultural produce but the African giant snail (Achatina fulica) *was smuggled into the country and sold in Florida and Virginia pet stores.*

The Massachusetts Division of Fisheries and Wildlife recently summarized the frequent reports of pet escapes in that State (16), Escaped or recovered pets in that State from 1988 through 1992 included: a 20-pound crocodile *(Caiman crocodiles); three* Boa constrictors *(Boa constrictor);* a Nile monitor lizard *(Varanus niloticus);* several hundred birds (various species of cockatoos, cockatiels, parrots, parakeets, and macaws); three wallabies; a bobcat from Texas (Felis *rufus);* and nine European fallow deer *(Dama dama).* Escaped monk and black-hooded parakeets *(Myiopsitta monachus* and *Nandayus nenday) are* known to have established free-living populations in the northeast (16). More anecdotal accounts of escaped pets generally are common in the popular press (2).

Fish and aquatic invertebrates such as shrimp frequently escape from confinement. The peacock cichlid *(Cichla ocellaris)* was intentionally stocked in Florida's warm water canals during the mid-1980s. It subsequently escaped (1 10), despite detailed analysis by the State before stocking that concluded the fish would remain limited to the canals (81),

The aquarium trade remains a significant pathway by which snails enter the United States. During the past few decades at least three snail species entered U.S. waters when they were discarded by aquarium dealers or their customers (12). Some plants also are distributed for use in aquaria. Hydrilla *(Hydrilla verticillata),* an aquatic weed that causes a significant navigation hazard and ecological harm, first entered U.S. waters sometime after 1956, it is thought, when it was released by aquarium dealers to create a domestic source (11 1). Release from aquaria was the source of at least 7 non-indigenous fish species that have become established since 1980 (27). Some were found in remote natural areas, like the green swordtail *(Xiphophorus helleri)* and zebra danio *(Brachydanio rerio),* which were discovered in the 1980s living in warm springs of Grand Teton National Forest (26). The aquarium fish trade is thought to be the source of at least 27 non-indigenous fish species now established in the continental United States (29).

Pessimism about the ability to keep aquiculture species confined is so great that, according to some, including the Federal interagency Aquatic Nuisance Species Task Force, species maintained for this purpose are virtually guaranteed of eventually escaping to the wild (26,89,99). Potentially free-living non-indigenous shrimp are grown in at least four coastal States (79), and the commonly cultured Pacific white shrimp *(Penaeus vannamei)* was captured in 1991 off the coast of South Carolina (1). Escape from aquiculture facilities is thought to have been a major source of the many tropical aquarium species now found in Florida's waters (29).

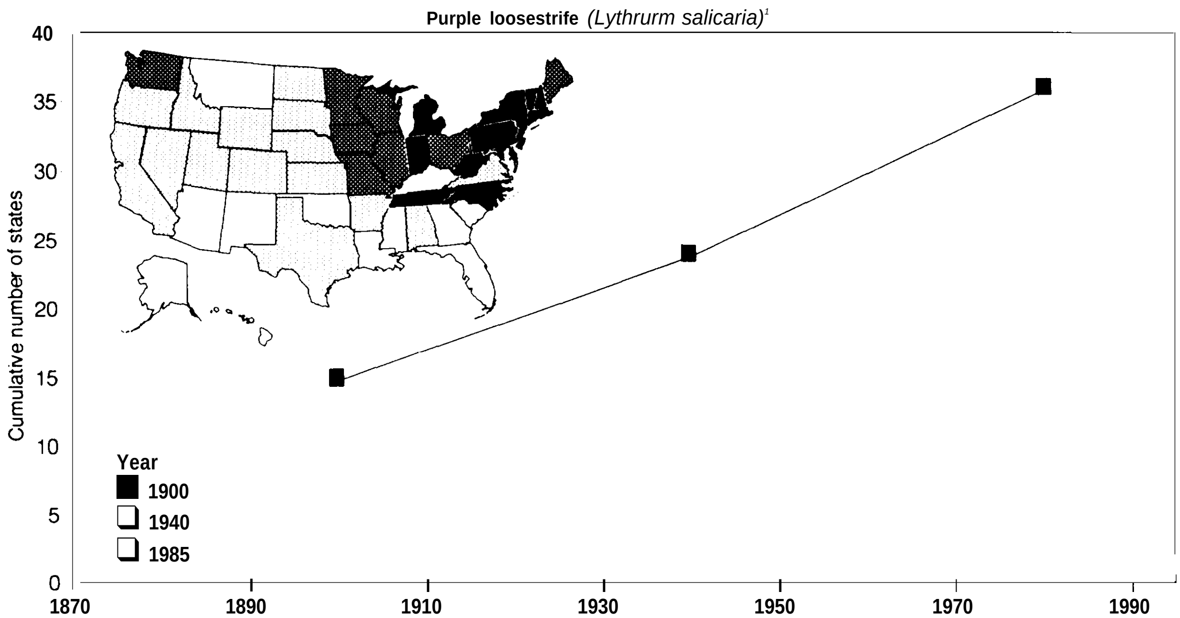
If an NIS imported into confinement harbors any other species, these also may eventually escape. Escape from a fish aquiculture facility is thought to have been the source of the freshwater snail *(Potamopyrgus antipodarum)* found in the Snake River in 1987 and now threatening indigenous mollusks in the region (12). Numerous fish pathogens and parasites have accompanied introductions for aquiculture and fishery enhancement (42). Five non-indigenous shrimp viruses entered the United States in contaminated shrimp stock and have become widely distributed in the aquiculture industry (60). Fish imported into the aquarium trade commonly harbor parasites. One 1984 study of hundreds of fish shipped from southeast Asia and South America found infestation rates of from 61 to 98 percent (90). Whether and how many pathogens and parasites have escaped from aquiculture facilities or aquaria is unknown.

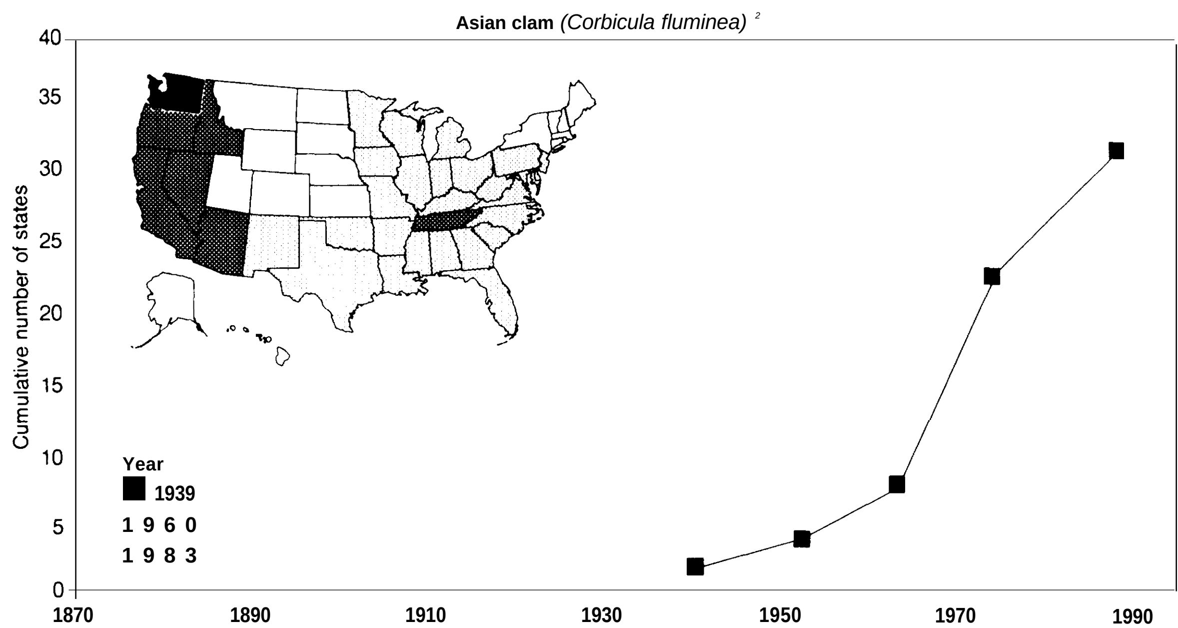
Present Pathways of Spread Within the United States

Many NIS have continued to spread within the United States long after they entered and became established, sometimes even after the pathway by which they entered the country was closed. This is true for European gypsy moth *(Lymantria dispar)* and purple loosestrife *(Lythrum salicaria),* which continue to spread and cause harm at new locations (figure 3-2). For such species, the means of transport *within* the country is more important from a management or regulatory perspective than how they originally entered. Pathways of species movement within the country also are significant for U.S. species that have been transported beyond their natural ranges.

However, there is relatively little quantitative information about the pathways and rates of species movement within the country. Systematic reporting of regional species transfers is virtually non-existent, In part this results from a definitional inconsistency. Many resource managers do not consider U.S. species moved outside of their natural ranges to be non-indigenous. In some cases, particularly in fisheries management, a distinction is made between "exotic' species (i.e., non-indigenous to the United States) and ''transplanted' ones (i.e., species indigenous to the United States but moved beyond their natural

Figure 3-2-State by State Spread of Four Harmful Non-Indigenous Species

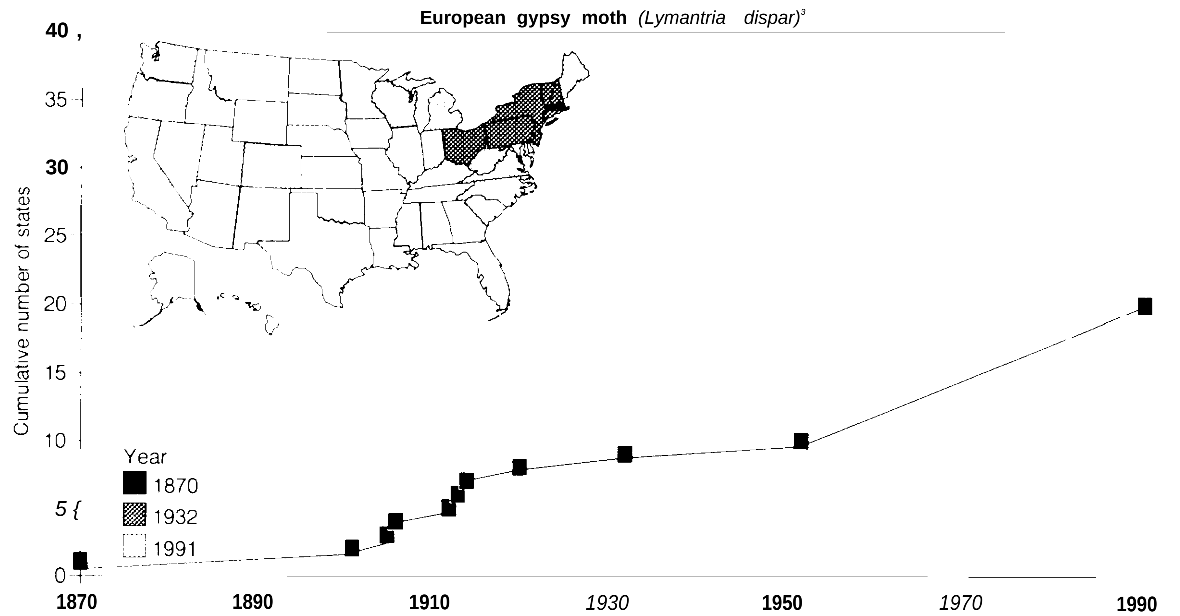


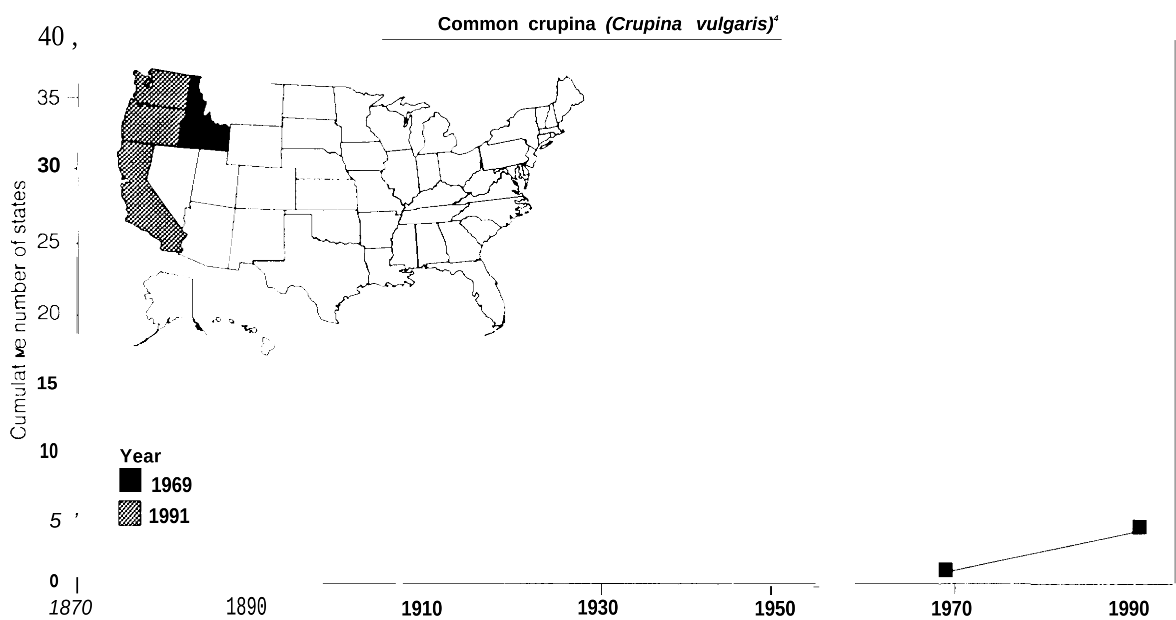


SOURCES:

1. D.Q. Thompson, R.L. Stuckey, and 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. C.L. Counts, III, "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.

Figure 3-2—State by State Spread of Four Harmful Non-Indigenous Species-Continued





SOURCES:

3. P.W. Schaefer and R.W. Fuester, "Gypsy Moths: Thwarting Their Wandering Ways," *Agricultural Research,* May 1991, pp. 4-11; M.L. McManus and T. McIntyre, "Introduction, " *The Gypsy Moth: Research Toward Integrated Pest Management,* C.C. Deane and M.L. McManus (eds.) (Washington, DC: U.S. Forest Service, Technical Bulletin no. 1584, 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. T.S. Prather et al., "Common Crupina: Biology, Management, and Eradication," University of Idaho, Agricultural Experiment Station, Current Information Series No. 680, 1991.

ranges) (66). Introduction dates are largely unrecorded for most transplanted fish (26). Systematic reporting also is lacking for continued restocking of NIS already established in an area or of new introductions of NIS in common use elsewhere in the United States. Several generalizations can be made despite these limitations.

UNASSISTED SPREAD

Once established, some NIS of foreign origin disperse even in the absence of human activities. Few geographic barriers block the transcontinental expansion of some NIS, like the African honey bee and Asian tiger mosquito. The American elm bark beetle *(Hylurgopinus rufipes)* can be a vector of Dutch elm disease *(Ceratocystis ulmi) (56).* Plants like the Brazilian pepper tree *(Schinus terebinthifolius) in* Florida have been spread by wildlife that consume the tree's seeds (1 11). The range of certain fish parasites has expanded as infected fish have migrated within and between watersheds (42).

Natural disasters provide new opportunities for the establishment of certain NIS. The 1992 passage of Hurricane Andrew through Florida knocked down indigenous trees, spurring the growth of non-indigenous vines in some natural areas; State officials fear this ''window of opportunity' may result in permanent domination of certain indigenous plant communities by NIS (45). A similar situation exists in Hawaii, where Hurricane Iniki in 1992 cleared the way for expansion of several harmful plants like banana poka *(Passiflora mollissima) (37).* A recent aquatic example is the explosive population growth by an Asian clam *(Potamocorbula amurensis) in* San Francisco Bay following a major flood that eliminated other species more vulnerable to reduced salinity (75).

UNINTENTIONAL AND INTENTIONAL PATHWAYS

In contrast to these unassisted types of spread, a significant number of NIS expand throughout the United States via pathways associated with human activities. Some of these are the same pathways that bring new species into the country, like ballast water (71). Others are unique to the domestic movement of species, such as the releases of non-indigenous bait animals like the sheepshead minnow *(Cyprinodon variegates)* and the Asian clam (12,26).

A number of these domestic pathways are linked to national distribution systems that enable a NIS to become widely disseminated and introduced many times throughout the country. Such multiple introductions speed NIS dispersal and have significant consequences for the choice of appropriate management strategies (see ch. 5).

Species that are sold commercially, for example, have great potential to be transported throughout a broad geographic area. Commercial distribution in the 19th century seed trade aided the spread of at least 28 non-indigenous weeds, including several of the nation's worst weeds, like Johnson grass *(Sorghum halepense),* salt cedar *(Tamarix africana* and T. *gallica),* water hyacinth *(Eichhornia* spp.), and kudzu (62,64). Sales of harmful non-indigenous plants continue today. At least six non-indigenous plant species on the Federal noxious weed list-hydrilla, for example-were sold in interstate commerce in 1990 (105). Of Illinois's 35 weeds of natural areas, 21 are legally sold in the nursery trade throughout the State (85). Seed of both federally and State-listed noxious weeds+. g., animated oats *(Avena sterilis)* and dyer's woad *(Isatis tinctoria-currently* can be bought at retail stores in Washington State (65).

Species recommended for specific applications can become widely distributed. Various agencies and organizations currently recommend a number of invasive plants. At least seven cultivars released by the U.S. Soil Conservation Service since 1980 are potentially invasive, according to one weed expert (65). Other examples of recommended species include: autumn olive *(Elaeagnus umbellata),* a plant that displaces indigenous vegetation in natural areas of the Midwest, by the Army Corps of Engineers; sawtooth oak *(Quercus serrata),* an Asian tree currently invading southeastern forests, by the South Carolina Department of Fish and Game; and leuceana *(Leucaena leucocephala)*, a rapidly growing tree from Central America that invades disturbed lowlands in Hawaii, by the Arbor Day Foundation (77).

Current popular interest in "wildflowers" for ornamental uses and ''native grasses" for livestock and wildlife forage (86) may inadvertently be fueling widespread planting of NIS in natural and semi-natural areas. In one 1992 "wildflower' seed catalog, only about 60 percent of the listed species were indigenous, and at least 80 percent of the NIS listed have escaped cultivation in the United States—plants like cornflower *(Centaurea cyanus)*, crimson clover *(Trifolium incarnatum)*, and dame's rocket *(Hesperis matronalis)*, all originally from Europe (109). Plants marketed as ''native grasses' in seed catalogs sometimes are non-indigenous and may even be known to be potentially invasive, like Bermuda grass *(Cynodon dactylon)*, Russian wild rye *(Psathyrostachys junceus)*, and Japanese millet *(Echinochloa crus-galli var.frumentacea) (65,87,108).*

Non-indigenous plants, including both those sold in the horticultural trade and known weeds, find their way into natural areas through various pathways. Rock Creek National Park in the District of Columbia now has 33 invasive NIS, some of which spread from adjacent gardens or landscape plantings; rooted from discarded yard refuse; entered as seed in topsoil, root balls, riprap, and lawn-legume mixtures; or were carried in by animals (39). Garlic mustard *(Alliaria petiolata)*, a weed of natural areas, was frost recorded in Illinois in 1918. It has since spread throughout 42 counties in the State, carried by flood waters; automobiles; trains; mowers; and the boots, clothes, and hair of hikers (76).

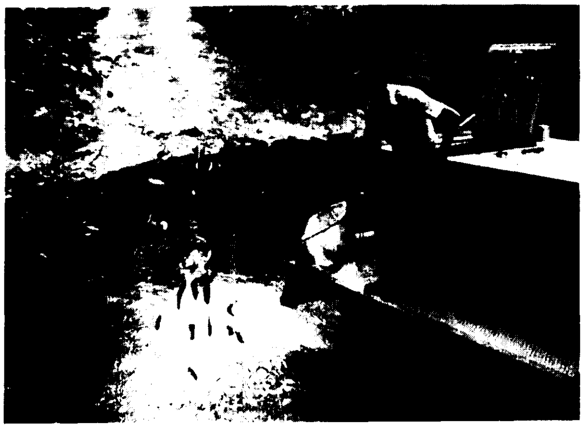
Numerous highly damaging weeds, such as cheatgrass *(Bromus tectorum)* and spotted knapweed *(Centauraea maculosa)*, were spread as contaminants of agricultural seed before the enactment of seed purity laws early in this century (9). The extent to which contamination of seed currently not covered by these laws, such as flower seed, is a pathway for harmful NIS is unknown,

Shipments of live plants can also inadvertently harbor NIS. A 1989 survey found that cabbage *(Brassica oleracea) seedlings* transported to New York from Georgia, Maryland, and Florida were infested with an average of up to eight larvae of the diamondback moth *(Plutella xylostella)* per hundred plants (88). A tree frog *(Hyla cinerea), an* anole *(Anolis* spp.), and a scarlet kingsnake *(Lampropeltis triangulum elapsoides)* were some of the finds in recent plant shipments to Massachusetts (16). The high volume of traffic in nursery stock and landscaping plants is thought to play an important role in moving non-indigenous insects throughout the United States (53). Between 1989 and 1992, three of the six non-indigenous insect species from elsewhere in the United States that became established in California arrived on plants (35).

Inadvertent transfers of animals can occur when plants are transplanted for restoration or wildlife enhancement. In 1957, shoal grass *(Diplanthera wightii)* was shipped from Texas to the California Salton Sea to provide waterfowl forage. The plants carried a number of aquatic invertebrates (like the crustaceans *Gammarus mucronatus* and *Corophium louisianum)*, which subsequently became established there (19).

Agricultural produce shipped interstate sometimes harbors non-indigenous pests. This is the basis for many of the U.S. Department of Agriculture's domestic quarantines.[2] Some of the costly infestations of Mediterranean fiuit flies *(Ceratitis capitata) in* California might have originated in tropical produce sent via frost-class mail from Hawaii (91). A recent cooperative warrant system for inspection of first-class mail between Hawaii and the mainland has reduced such pest transfers, although not in other areas of the country.

[2] 7 CFR 301.



States frequently stock non-indigenous fish to enhance sport fisheries, and this has been an important pathway for the entry and spread of non-indigenous species historically.

Various animals are available through the mail for wildlife enhancement nationwide, including water fleas *(Daphnia* spp.), freshwater shrimp, crayfish, fresh water clams, turtles, and bull frogs (108); whether these species are non-indigenous in some regions where they are marketed is impossible to determine, since species names are not always listed. The 1989 "Buyer's Guide" in *Aquiculture Magazine* lists 82 species of freshwater and marine fish, invertebrates, and algae available for sale in the United States (20). Sales of the European fish the rudd *(Scardinius erythrophthalmus)* for use as bait eventually resulted in its capture in eight States (13).

Interstate shipments of fish and wildlife sometimes harbor NIS other than the intended species. Reported incidents include inadvertent introductions to California of the Texas big-scale logperch *(Percina macrolepida)* and rainwater killifish *(Lucania parva)* from New Mexico with shipments of largemouth bass *(Micropterus salmoides) (73). The* distribution of the sticklebacks *(Gasteosteus aculeatus) in* regions of Southern California where it is non-indigenous maybe due to its unintended presence in trout stocks used to enhance sport fisheries (73). Fish shipped interstate sometimes carry larvae of freshwater mussels *(Anodonta* spp.) (93). Containers of the Pacific oyster from California to the East Coast in 1979 contained numerous stowaway mussels, worms, and crustaceans (19). A fish parasite, the Asian copepod *Argulus japonicus, is* thought to have spread throughout the country via the aquarium trade (71).

Indigenous and non-indigenous insects, snails, and fish have been transferred within the United States for biological control (12,53). Since the 1970s, the non-indigenous snail *Rumina decollata has* been raised, sold, and distributed throughout an estimated 50,000 acres of citrus groves in California as a biological control for non-indigenous snail pests (38). The grass carp, originally from Asia, has been widely propagated and sold for biological control of aquatic weeds (26).

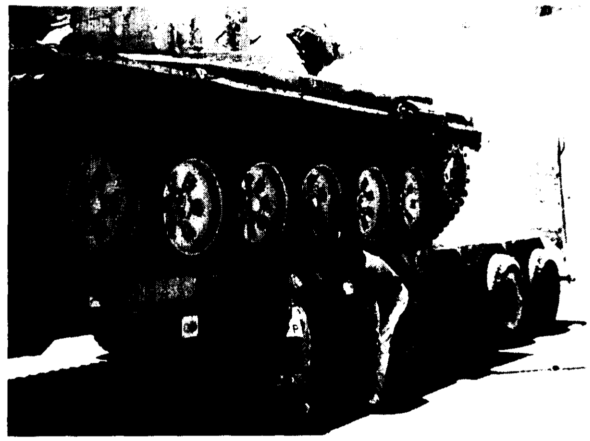
Although largely unmonitored today, interstate shipments of biological control agents are a potential source of insect pathogens and parasites; according to an expert on the species, the wasp *Perilitus coccinellae,* **a** parasite of the indigenous convergent lady beetle *(Hippodamia convergent) already* is spread in this reamer (5 1). In international transit, by contrast, such pests would probably be intercepted through inspection and quarantine.

Interstate transfers of honey bee *(Apis mellifera)* colonies inadvertently facilitated the rapid spread of honey bee parasites (varroa mites—*Varroa jacobsoni—and* tracheal mites—*Acarapis woodi) (74).* According to a 1982 survey, about a quarter of all commercially operated colonies (500,000) are moved south each winter to prevent losses from the cold, and about 2 million colonies are rented each year for pollination. The result is large-scale movements of colonies throughout the country that helped spread the damaging varroa mite to 30 States in just 4 years following its 1987 detection in Florida and Wisconsin (74). The honey bee industry has concerns that such interstate transfers may similarly enable rapid spread of the African honey bee which recently arrived in Texas (74).

Researchers working on NIS have been the source of several introductions throughout the country. The rapid spread of the Asian clam, a serious fouler of pipes in power plants, is thought to have been assisted by inadvertent research releases (25). The California sea squirt *(Botrlloides diegense,* a marine animal) was released by a scientist at Woods Hole, Massachusetts, in 1972 and is now an abundant fouler of rocks, piers, and boat hulls throughout southern New England (19). Plant breeders regularly trade germ plasm for breeding purposes-some from potentially invasive species. One reported having acquired the salt- and drought-tolerant ruby salt bush *(Enchylaeua tomentosa),* originally from Australia) "from a nursery in Tucson who got it from Soil Conservation Service, who decided not to officially release it since it was such a potential pest, which it is" (8).

Even shipments of inanimate objects and vehicles can harbor NIS. The European gypsy moth can travel long distances clinging to household articles, lawn furniture, firewood, lawn mowers, and recreational vehicles such as motor homes, campers, and boats (32). Since 1984, California border inspectors have intercepted imported fire ants *(Solenopsis invicta* and *S. ritcheri)* along State lines, in decreasing order of frequency, in nonagricultural shipments (e.g., pallets, roofing materials, carpets); empty trucks; agricultural shipments; automobiles; U-Hauls; and nursery stock (58). At least 3,000 Japanese beetles *(Popillia japonica)* were found in cargo planes landing at Ontario, California, from the eastern United States in 1986 (34). The Asian cockroach *(Blattella asahinai)* has spread in Florida mainly by hitching rides on cars leaving infested areas (72). The tiny Argentine ant *(Iridomyrmex humilis)*--an inadvertent 1906 introduction to New Orleans-has dispersed widely by way of the dirt on truck mud flaps, among other means (23).

Dumped ballast water, known to be a significant pathway for harmful introductions from abroad, has also provided a means for species spread within the country. Since 1980, at least three NIS entered the Great Lakes from other U.S. locales in ballast water: the four-spine sticklebacks fish *(Apeltes quadracus),* an aquatic worm *(Ripistes parasitic),* and a green alga *(Nitellopsis obtusa) (71).* In the absence of effective control or containment, the ruffe-a harmful Eurasian fish (see ch. 2)--is expected to spread via ships' ballast and other means perhaps are far as the Ohio, Mississippi, and Missouri River drainage basins (43).



USDA

Several harmful non-indigenous species have hitchhiked into the country with returning military equipment, e.g., the brown tree snake (Boiga irregulars), *witchweed* (Striga asiatica), *and the golden nematode* (Globodera rostochiensis). *Similarly, motor homes, automobiles, and boats help spread harmful NIS within the United States.*

HOW MANY NON-INDIGENOUS SPECIES ARE THERE?

Finding:

Estimated numbers of NIS in the United States increased over the past **100** years for all groups of organisms OTA examined. At least several thousand non-indigenous insect and plant species occur in this country, as do several hundred non-indigenous vertebrate, mollusk, fish, and plant pathogen species.

Table 3-2-Estimated Numbers of Non-indigenous Species in the United States[a]

Category	Number	Percentage of total species in the United States in category
Species with origins outside of the United States		
Plants	>2,000	b
Terrestrial vertebrates	142	=6%
Insects and arachnids	>2,000	=2%
Fish	70	=8%
Mollusks (non-marine)	91	=40/0
Plant pathogens	239	- P
Total	4,542	
Species of U.S. origin introduced beyond their natural ranges		
Plants	b	b
Terrestrial vertebrates	51	=2%
Insects and arachnids	—b	b
Fish	57	=17%[c]
Mollusks (non-marine)	b	b
Plant pathogens	b	b

[a] Numbers should be considered minimum estimates, Experts believe many more NIS are established in the country, but have not yet been detected.

[b] Number or proportion unknown.

[c] percentage for fish is the calculated average percentage for several regions. Percentages for all other categories are calculated as the percent of the total U.S. flora or fauna in that category.

SOURCES: Summarized by the Office of Technology Assessment from: J.C. Britton, "Pathways and Consequences of the Introduction of Non-Indigenous 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; R.N. Mack, "Pathways and Consequences of the Introduction of Non-indigenous Plants in the United States," contractor report prepared for the Office of Technology Assessment, September 1991; C.L. Schoulties, '(Pathways and Consequences of the Introduction of Non-Indigenous Plant Pathogens in the United States, "contractor report prepared forthe 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.

Current Numbers

An estimated total of at least *4,500 NIS* of foreign origin presently are established in the United States (table 3-2). This estimate is based on analysis of six categories of organisms, omitting several others such as animal pathogens and crustaceans (see ch. 2, table 2-l). It also does not capture most marine species, like the majority of the 96 species of sponges, worms, crustaceans, and other non-indigenous marine invertebrates now found in San Francisco Bay (17). Also, numbers shown in table 3-2 are minimum estimates for each category. For example, about half of the U.S. insect fauna is unknown, suggesting information on a similar proportion of non-indigenous insects may be lacking (53). Studies of plant pathogens focus on species of economic importance; species affecting only natural areas are chronically under-reported (82). Newly established species that have not yet been detected also do not figure in table 3-2.

Numbers of NIS vary among the categories. Plants and insects total in the thousands, while NIS in other categories range from tens to hundreds (table 3-2). This is at least in part because there simply are more plants and insects than fish or terrestrial vertebrates. Despite these differences in absolute numbers, the proportion of NIS is relatively constant among most categories, ranging from 2 to 8 percent.

Origins of most plant pathogens are unknown, making evaluation of the contribution of NIS to the current U.S. total difficult (82). A survey of six potential host plants (potato, rhododendron, citrus, wheat, Douglas fir, kudzu) found that an average of at least 13 percent of their pathogens are non-indigenous (82). Non-indigenous pathogens are least common on indigenous or newly introduced plant hosts (82).

Very little information exists on how many species of U.S. origin have been transplanted within the country beyond their natural ranges. Estimates are approximately 2 percent of the U.S. fauna for terrestrial vertebrates and 17 percent for fish (table 3-2).

Past Numbers

The number of NIS of foreign origin has grown in the United States over the past 200 years. Figure 3-3 shows how the totals have expanded for the six categories of organisms. The major increase occurred during the past 100 years for all categories.

GEOGRAPHIC DISTRIBUTION

Finding:

Non-indigenous species are unevenly distributed across the country. Higher concentrations occur around international ports of entry, in areas of active commerce, and in altered habitats. Nevertheless, NIS having significant negative impacts can be found in most regions of the country.

Non-indigenous species are more common in some places than others. Differences occur both among States (table 3-3), and also among regions within individual States. Ports of entry often harbor high numbers of NIS. This is especially true for plants, insects, snails, and slugs that arrive undetected in incoming ships and planes (12,53,63). The type of material arriving at a port influences the specific NIS that become established nearby. For example, numerous European insects were frost detected in Rochester, New York, when the city supported an extensive nursery industry and large numbers of plants were routinely unloaded there (53).

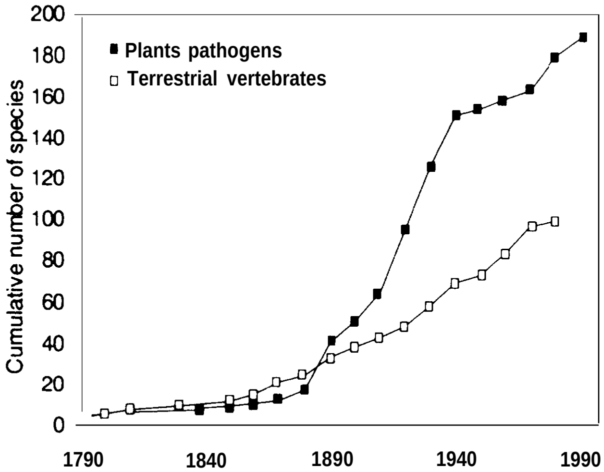
Existing patterns of higher densities of NIS surrounding port areas developed over the past 200 years during colonization of the United States. The emergence of containerized freight since the 1950s may change this pattern, since freight containers often are not unloaded until reaching their destination well away from a port.

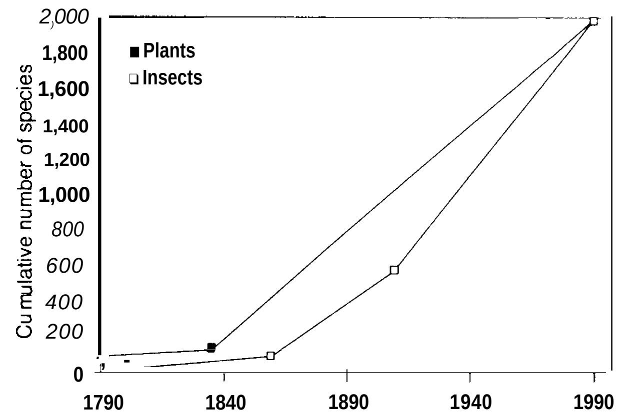
Areas of frequent commerce away from ports also tend to have higher numbers of NIS, For example, extensive agriculture and related trade and shipping in the Intermountain West (northern Utah and the Columbia Plateau) over the past 100 years have provided abundant opportunities for NIS associated with agriculture to enter and spread within the region (63).

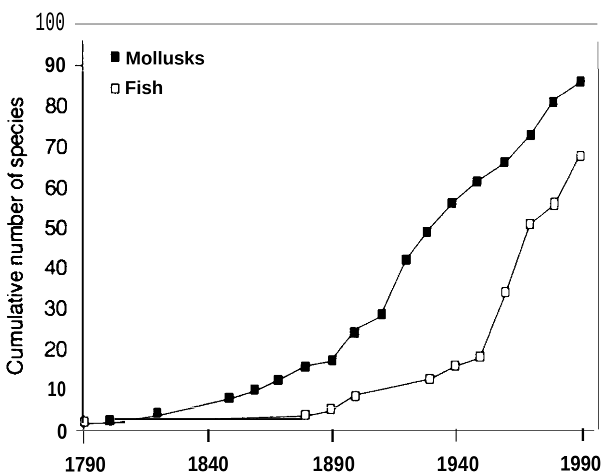
Certain NIS tend to cluster around human population centers. High concentrations of escaped non-indigenous pets occur around Los Angeles and Miami (95). Disproportionately high numbers of non-indigenous snails and slugs similarly occur in populous areas, reflecting their association with greenhouses, gardens, and agricultural commerce (12). Areas, such as Hawaii, supporting human populations with international origins tend to have larger numbers of NIS, because the species imported and released mirror the human population's diversity of tastes and experience (63).

Urban centers often are an important site for the discovery of non-indigenous insect pests. For example, in California 85 percent of non-indigenous scale insects and whiteflies were first reported in cities (40). However, in this case proximity to ports of entry and the enhanced detection potential may also have been factors. Detection of NIS sometimes may be greater in

Figure 3-3-Estimates of the Cumulative Numbers of Non-indigenous Species of Foreign Origin in the United States[a]







SOURCES: Summarized by the Office of Technology Assessment from: J.C. Britton, "Pathways and Consequences of the Introduction of Non-Indigenous Freshwater, Terrestrial, and Estuarine Mollusks in the United States," contractor report prepared forthe Office of Technology Assessment, October 1891; 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; R.N. Mack, "Pathways and Consequences of the Introduction of Non-Indigenous Plants in the United States," contractor report prepared for the Office of Technology Assessment, September 1991; Sailer, R. I., "History of Insect Introductions," *Exotic Plant Pests and North American Agriculture*, C.L. Wilson and C.L. Graham (eds.) (New York, NY: Academic Press, 1983), pp. 15-38; 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.

[a]Figure only includes data on species with known introduction dates for plant pathogens (n = 188), terrestrial vertebrates (n = 100), mollusks (n = 85), and fish (n= 68). Graphs for plants and insects are based on rough estimates.

more densely populated areas simply because collection and observation intensity is higher (12,63).

Regions naturally depauperate in fish and game have been the sites of numerous intentional introductions. A lack of indigenous game animals in the arid State of Nevada prompted State managers to introduce numerous species including the chukar partridge *(Alectoris chukur)*, ring-necked pheasant, Himalayan snow cock ***(Tetraogallus** himalayensis)*, and Rocky Mountain goat *(Oreamnos americanus) (102).* **State agencies** have released many non-indigenous fish in the American West for similar reasons, where 28 percent of the current fish species are non-indigenous to the region (26).

Intrinsic vulnerability to the establishment of NIS varies among regions in complex ways. The

Table 3-3—Estimated Numbers of Non-Indigenous Species in Selected States[ab]

State	Plants	Terrestrial vertebrates	Mollusks
Alaska	170 (12%)	c (1%)	0 (c)
California	975 (16%	c (2%)	31 (c)
Florida	=925 (27%)	53 (6%)	46 (19%)
Illinois	814 (28%)	c (2%)	12 (c)
Maine	c	c (1%)	15 (c)
Massachusetts	c	c (2%)	27 (c)
Minnesota	c	c (2%)	2 (c)
New Mexico	231 (6%)	c (2%)	5 (c)
Oregon	c	c (2%)	7 (c)
Texas	443 (9%)	c	28 (c)
Utah	580 (23%)	c (2%)	2 (c)
Virginia	427 (17%)	c	17 (c)
West Virginia	400 (19%)	c (2%)	2 (c)
Great Plains	354 (13%)	c	c
New England	821 (29%)	c	c

[a]Numbers should be considered minimum estimates. Experts believe many more NIS are established in the country, but have not yet been detected.
[b]Data reported as the number with percent of species in the State in parentheses. Includes only species non-indigenous to the United States.
c Number not reported in source material.

SOURCES: Summarized by the Office of Technology Assessment from: J.C. Britton, "Pathways and Consequences of the Introduction of Non-Indigenous Freshwater, Terrestrial, and Estuarine Mollusks in the United States, " contractor report prepared for OTA, October 1991; R.N. Mack, "Pathways and Consequences of the Introduction of Non-Indigenous Plants in the United States," contractor report prepared for OTA, September 1991; M. Rejmanek, C.D. Thomsen, and I.D. Peters, "Invasive Vascular Plants of California," R.H. Graves and F. DiCastri (eds.), *Biogeography of Mediterranean Invasions* (Cambridge University Press); pp. 81-1 01; 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 OTA, October 1991. See also sources for tables 8-1, 8-5.

tropical and semi-tropical environments of Hawaii and Florida are favorable to greater numbers of non-indigenous plants than climatically harsher regions experiencing winter frost and freezing (63). Escaped fish from aquiculture are more likely to establish in the benign environment of "sun-belt" States, where warm temperatures allow outdoor aquiculture year-round (26).

Disturbed areas are particularly likely to have large numbers of NIS, as are human modified habitats. For example, livestock increase disturbance by trampling and grazing. In some rangelands, livestock create conditions unfavorable to indigenous grasses, allowing colonization by non-indigenous plants (63).

Combined effects of several of the above factors especially favor NIS. In New England, proximity to ports, extensive agriculture, and removal of indigenous forests have created a region where 29 percent of the plant species are non-indigenous (63).

Are Rates of Movement and Establishment Increasing?

Finding:

OTA found no clear evidence that the rates at which NIS are added from abroad to the Nation's flora and fauna have consistently increased over the past 50 years. Instead, rates have fluctuated widely over time in response to an array of social, political, and technological factors.

A common assertion is that rates of species movement into the United States are increasing dramatically. OTA tested this by examining the numbers of NIS added each decade over the past 50 years for terrestrial vertebrates, fish, mollusks,

Table 3-4-Number of New Species of Foreign Origin Established Per Decade[a]

	1940-1950	1950-1960	1960-1970	1970-1980	1980-1990
Terrestrial vertebrates. .	3	11	13	3	b
Fish	2	15	18	5	12
Mollusks	5	5	6	10	4
Plant pathogens	3	5	4	16	7

[a]Numbers should be considered minimum estimates. Experts believe many more NIS are established in the country, but have not yet been detected.
[b]Data unavailable.

SOURCES: J.C. Britton, "Pathways and Consequences of the Introduction of Non-Indigenous 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; 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.

and plant pathogens. No consistent increase occurred for any of the categories (table 3-4). Instead, the rate of NIS addition fluctuated. The greatest numbers of terrestrial vertebrates and fish were added during the 1950s and 1960s. The 1970s saw the most mollusks and plant pathogens arrive. A limitation of this analysis is that recently established species may not yet be detected. Thus numbers for the period 1980 to 1990 are likely underestimates.

Suitable data for comparable analyses of plants and insects are unavailable. However, a previous study of agricultural pests (insects and other invertebrates) in California showed the numbers of species established each year similarly varied greatly between 1955 and 1988 from zero to a high of 17 (figure 3-4) (34).

Even though rates of species addition tend to change over time, it is important to note that they rarely reach zero. NIS are continually being added to the nation's flora and fauna, and the cumulative numbers are climbing (figure 3-3). Also, rates throughout the 20th century have been consistently higher than those during the preceding century.

FACTORS AFFECTING PATHWAYS AND RATES

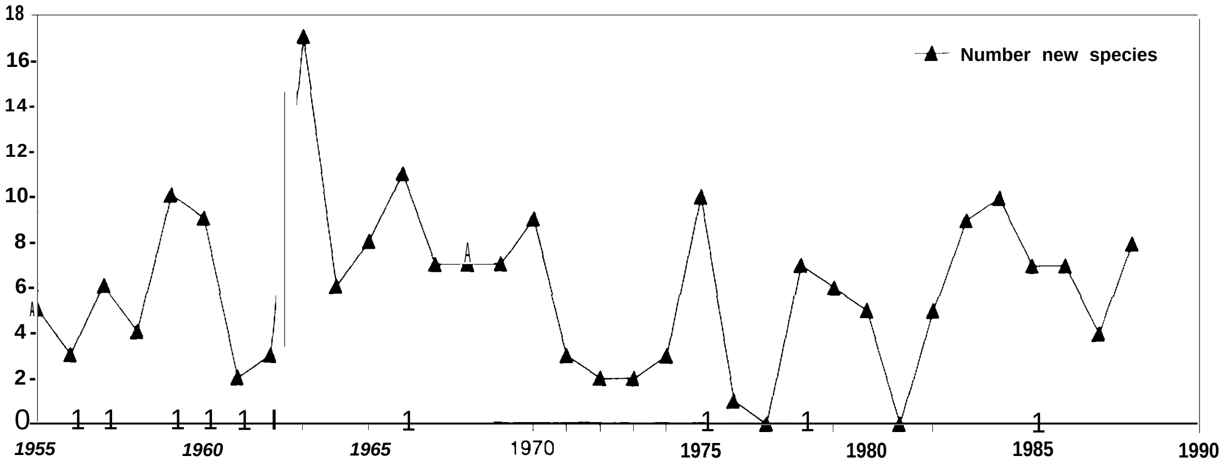
Pathways and rates of species entry to the United States vary because they are influenced by many factors (table 3-5). Many pathways that were significant sources of NIS in the past have either declined in importance or ceased to operate. Such pathways, nevertheless, frequently are mentioned in discussions of NIS and can confuse attempts to identify present-day problems (boxes 3-B and 3-C).

Some technological innovations enhance introduction rates. For example, the advent of commercial air traffic in the 1930s greatly facilitated the transport of small birds and fish that previously had been difficult to keep alive and healthy on longer voyages (67,95). It had a similar effect on the successful number of insect introductions for biological control (44).

Other new technologies have slowed rates. Many important weeds, such as tumbleweed *(Salsola iberica),* entered and spread throughout the United States as contaminants of agricultural seed in the 1700s and 1800s (63). Improvements in threshing and harvesting machinery beginning in the 1800s decreased seed contamination (63).

Changing fashions in species preferences can drive importation, especially of organisms valued for their aesthetic qualities. Preferences for potted plants in Hawaii support an active illicit commerce in NIS from other tropical and subtropical areas (112). Rates of introduction of aquatic snails accelerated during the 1970s, apparently because of expansion of the aquarium trade and renewed interest in freshwater aquiculture (12). Some preferences relate to patterns of human

Figure 3-4-Numbers of New Insect and Other Invertebrate Species Established in California 1955-1988



SOURCE: R.V. Dowell and R. Gill, "Exotic Invertebrates and Their Effects on California," *Pan-Pacific Entomologist*, vol. 65, No. 2,1989, pp. 132-145.

immigration; increased immigration to California from Asia since the 1970s has led to growing importation of Asian foods and associated pests (34).

Political and economic factors are also significant. The location and size of military actions determine their potential for species transfer. Several agricultural pests returned from Europe with military cargo and supplies following World War II. Several aquatic invertebrates from southeast Asia are thought to have entered lagoons and bays of California during the Vietnam War (18).

State and Federal plant quarantine laws slowed rates of introduction of insect pests and plant pathogens after 1912 (80,82). A reversal of this trend for plant pathogens after 1970 (figure 3-3; table 3-4) may relate to globalization of agriculture and increased plant imports (82). The Federal Seed Act, diminished the flow of weed species into the United States that previously had entered as seed contaminants.

Actions of interested constituencies can have an effect insofar as they influence laws and regulations restricting species flow. Conferences, position statements, and other activities of the American Fisheries Society since 1969 helped motivate States to regulate releases of non-indigenous fish (26,55). Conversely, effective lobbying by the Pet Industry Joint Advisory Council helped halt Federal efforts to tighten regulation of fish and wildlife imports during the 1970s (26) (see also box 4-A).

Finally, the "bias of opportunity" (63)-the arbitrary aspect of where pathways happen to appear-always plays a role. For the past 30 years or more, the primary pathway for aquatic species into the Great Lakes has been through shipping—corresponding to the opening of the St. Lawrence Seaway in 1959(71). As the shipping industry has grown in this region, so too has the number of NIS introductions; shipping was the pathway for 29 NIS introduced between 1960 and 1990 (71). Construction of roads into new areas similarly increased the opportunity for species movement. Urbanization around Tucson, Arizona, contributed to an increase in the non-indigenous plants established in the area between 1909 and 1983, from 3 to 52 species (63).

HOW MANY IS TOO MANY?

Finding:

In the United States, the total number of harmful NIS and their cumulative impacts will continue to grow. An important question is

Table 3-5-Factors Affecting Species Movements

Illustrative Technological Innovations	
Innovation	**Effect**
Switch from dry to wet ballast in 1800s	Changed from transport of insects, seeds, and plant pathogens to transport of fish and invertebrates
Increased rate of transit via steam ships and airplanes	Increased survival of insects, mammals, birds, and fish during transfer; increased success of introductions
Improvements in threshing and harvesting machinery	Decreased contamination of seed lots and entry and spread of weeds
Styrofoam coolers	increased number of fish species amenable to transfer and their survival
Containerized shipping of freight	Created new mechanism for unintentional transfer of plant, insect, snail, and slug species; direct route to country interior (i.e., away from shipping port)
Importation of used tires for retreading	Created new pathway for entry of mosquitoes
Illustrative Social and Political Factors	
Social or political factor	**Effect**
New patterns of immigration and tourism	Change pathways for spread of species
Wars and military movements	Create new pathways for species spread
Globalization of trade	Create new pathways for species spread
Free trade agreements	Increase opportunity for species entry
Increased interest in exotic pets	Affect kind and number of species imported in the pet trade
Continued interest in new ornamental plants	Provide incentive for continued plant exploration and importation

SOURCE: Office of Technology Assessment, 1993.

whether there are limits to the acceptable total burden of harmful species in the country. Such long-term considerations need to be incorporated into shorter term regulatory decisions, for example, in determining the annual level of species entry that will be tolerated.

Even at current rates of species introduction, the total number of NIS in the United States will continue to grow. More than 205 NIS of foreign origin have been introduced or first detected in the United States since 1980, 59 of which are expected to cause economic or environmental harm (table 3-l). Past and projected losses attributable to just two of these are great. The Russian wheat aphid caused losses of over $600 million (1991 dollars) during 1987 through 1989 (24). Projected losses from the zebra mussel by the end of the century are expected to be from $1.8 billion to $3.4 billion (1991 dollars) (24). Both the zebra mussel and the newly arrived snail *Potamopyrgus antipodarum* from Europe are expected to seriously threaten the country's unique indigenous fauna of freshwater mussels (12).

Numbers of species new to the United States give only a partial account of how many new NIS a given State or area may need to deal with. For example, between 1984 and 1986, an early detection program identified 26 plant species new to Idaho; 12 of these were new to the Pacific Northwest, but only one was new to North America (1 13). Of 208 invertebrate pests that became established in California between 1955 and 1988,47 percent originated somewhere in the mainland United States (34).

Even some harmful NIS long-established in the country continue to spread (figure 3-2), taking several decades or more to reach their full geographic range and impact. Dutch elm disease only reached Sacramento County, California, in

Box 3-B-importations for Fish and Wildlife Management Have Decreased

Spencer Fullerton Baird, the First Commissioner of the U.S. Fish Commission (a predecessor of the U.S. Fish and Wildlife Service and National Marine Fisheries Service) strongly supported introductions of non-indigenous species to enhance U.S. fishery resources. Numerous species were imported or transferred across the country and released under his administration. However, introductions of new non-indigenous fish from abroad have lost favor among fisheries managers over the past two decades.

Proposals today are more likely to raise controversy than in the past. A recent proposal by the State of North Dakota to introduce the European zander (Stizostedion lucioperca) engendered considerable controversy among other States and the U.S. Fish and Wildlife Service over the potential for disease transmission and hybridization with the indigenous walleye. As introductions of foreign origin decline, transfers of indigenous or established non-indigenous fish to new locales within the United States have increased and probably will continue to do so.

A similar pattern holds for introductions of terrestrial vertebrates. Wide support existed for introductions of species from abroad in the past. Numerous private organizations purposely imported and released wildlife species. For example, the Brooklyn Institute successfully introduced the house sparrow (Passer domesticus) in the 1850s, and the Cincinnati Acclimatization Society did the same for **20 additional bird species in the 1870s. The** U.S. Fish and Wildlife Service's program in foreign game investigations introduced **at least** 32 new game species from abroad between 1948 and 1970.

The importation and release of new game species by State managers has declined over the past few decades. This has resulted from a decrease in perceived need and greater awareness of potential risks, rather than from Federal legislation or regulation and could revert should prevailing attitudes change. At the same time, rates of importation by private individuals and game ranchers have increased. Also, NIS already established in the United States continue to be propagated and introduced at new locations, and interstate transfers of indigenous species are on the rise.

SOURCES: 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; 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.

1990, although it was first detected in the United States in 1930 (15). Imported fire ants became established in Alabama between 1918 and 1945, but only began being intercepted along California borders in 1984-39 to 66 years later (58).

Moreover, the harmful impacts of a NIS in a given State or region can also grow as its distribution and abundance increase. The paper bark tree *(Melaleuca quinquenervia), originally* introduced into Florida in 1906, has spread explosively across the State since the 1960s (49). The predicted range expansion of lea.& spurge *(Euphorbia esula) in* Montana, Wyoming, and the Dakotas between 1990 and 1995 is expected to cost an additional $32 million due to diminished grazing capacity (6).

Summed effects of a single harmful species can be staggering over periods of decades. The European gypsy moth has been defoliating trees in a growing area of the eastern United States for at least 120 years (50). In 1990, despite a suppression program costing approximately $20 million, it defoliated an estimated 7.4 million acres (100).

Affected sectors face not just newly introduced species, but all those which arrived before and proved impossible to eradicate. American agriculture alone must deal with at least 235 economically significant insect pests that are non-indigenous to the United States (80). Planning for the future will require assessing not just how many new introductions will be tolerated each

Box 3-C-Dry Ballast Has Ceased to be a Pathway

Ships arriving in the United States used to carry dry ballast in the form of rocks, soil, and debris. The ballast was loaded abroad then off-loaded around wharves in the United States to provide cargo space. By one estimate, 1,180 tons of ballast were loaded onto ships bound for America at just one English port in 1815.

Ballast shipped between England and the United States was one of the most significant sources of unintentional insect introductions until the 1880s. it also was the pathway for many plants, including purple Ioosestrife (Lythfum salicaria) which now occurs throughout many northern and Midwestern States and causes significant harm to natural areas. increasing commerce with South America after the Civil War, and consequent ballast shipments, led to the introduction of several pests including fire ants (Solenopsis invicta and S. richteri), southern mole crickets (Scapteriscus acletus), and tawny mole crickets (S. vicinus).

Large modern ships use water for ballast instead of dry materials like soil and rock Thus, the dry ballast pathway has closed. Fire ants discovered in Mobile, Ala-in 1941 are thought to be the last important pest conveyed by this route. The switch from dry to wet ballast accounts, in part for the current prominence of the latter as an unintentional pathway for aquatic species entry.

SOURCES: RJ. Sailer, "History of Insect Introductions," *Exotic Plant Pests and North American Agriculture*, C.L. Wilson and C.L. Graham (eds.) (New York, NY: Academic Press, 1SS3), pp. 15-SS; K.C. Kim and A.G. Wheeler, "Pathways and Consequence of the Introduction of Non-Indigenous Insects and Arachnids *in* the United States," contractor report prepared for the Office of Technology Assessment, December 1991.

year, but whether there are limits to the cumulative burden of harmful NIS as well.

CHAPTER REVIEW

This chapter traced the pathways-foreign and domestic, intentional and unintentional-by which non-indigenous species arrive in U.S. locales. Some pathways remain open at all times. The nature and relative importance of other pathways change with time and technology. Combined, they allow sizable numbers of new ham-did NIS to flourish here. More than 205 NIS of foreign origin were introduced or frost detected in the United States since 1980, and 59 are expected to cause economic or environmental harm. These will join the more than 4,500 foreign NIS already here, a number that is certainly an underestimate. Given that the United States faces increasing numbers and costs of harmful MS, OTA next turns to the technical questions surrounding their management and control.

Table 3-l-Some Species of Foreign Origin Introduced or First Detected In the United States From 1980 to 1993

Common name	Scientific name	Pathway[a]	Harmful[b]
Plants (9)			
Corn brome	*Bromus squarrous*	Seed contaminant	Yes
Early millet	*Milium vernale*	Stowaway in packing	—
Feather-head knapweed	*Centaurea* trichocephala	Escaped ornamental *or* stowaway in packing material	Yes
Forked fern	*Dicranopteris flexuosa*	Unassisted spread	—
Japanese dodder	*Cuscata japonica*	Seed contaminant	Yes
Lepyrodiclis	*Lepyrodiclis holosteoides*	Seed contaminant	—
Little lovegrass	*Eragrostis minor*	Seed contaminant material	—
Poverty grass	*Sporobolus vaginiglorus*	Stowaway of commerce	—
Serrated tussock	*Nassella trichotoma*	Seed contaminant	Yes
Insects and arachnlds[c] (158)			
African honey bee	*Apis mellifera* scutellata[d]	Escape from research facility then spread to U.S.	Yes
Ambrosia beetle	*Xyleborus pelliculosus*		—
Ambrosia beetle	*Xyle/borus atratus*		—
Ambrosia beetle	*Ambrosbdmus lewisi*		—
Anobiid beetle	*Lasioderma haemorrhoidale*	—	—
Anobiid beetle	*Priobium carpini*	—	—
Ant	*Pheidole tenetiffana*	—	—
Ant	*Technomyrmex albipes*	—	—
Ant	*Gnamptogenys aculeaticoxqe*	—	—
Aphid	*Greenidia formosana*	—	—
Apple ermine moth	*Ypnomeuta malinellus*	—	Yes
Apple pith moth	*Blastodacna atra*	Stowaway on plants	Yes
Apple sucker	*Psylla mali*		Yes
Ash whitefly	*Siphoninus phyllyreae*	Stowaway on plants	Yes
Asian cockroach	*Blattella asahinai*	Stowaway on ship or plane	Yes
Asian gypsy moth	*Lymantra dispar* [d e]	Stowaway on ship	Yes
Asian tiger mosquito (forest day mosquito)	*Aedes albopictus*	Stowaway in used tires	Yes
Avocado mite	*Oligonychus persae*	Stowaway on plants	Yes
Bahamian mosquito	*Aedes bahamensis*	—	—
Baileyana psyllid	*Acizzia acaciae-baileyanae*	Stowaway on plants	Yes
Banana moth	*Opogona sacchari*	Stowaway on plants	Yes
Bark beetle	*Pityogenes bidentatus*	Nursery stock	—
Bark beetle	*Chramesus varius*		—
Bark beetle	*Pseudothysanoes securigerus*		—
Bark beetle	*Coccotrypes robustus*		—
Bark beetle	*Coccotrypes vulgaris*		—
Bark beetle	*Theoborus solitariceps*	—	—
Bark beetle	*Araptus dentifrons*		—
Beach fly	*Procanace dianneae*	—	—
Black parlatoria scale	*Parlatona ziziphi*	Stowaway on plants	Yes
Blow fly	*Chrysomya megacephala*	Introduced outside of U.S. then spread into country	Yes
Blue gum psyllid	*Ctenarytaina eucalypti*	Stowaway on plants	Yes
Bostrichid beetle	*Heterobosfrychus hamatipennis*	—	—
Burrower bug	*Aethus nigritus*	—	—
Cactus moth	*Cactobiastis cactorum*		Yes
Cactus moth	*Ozamia lucidalis*		—
Carabid beetle	*Trechus discus*	—	—

(continued on next page)

Table 3-I-Continued

Common name	Scientific name	Pathway[a]	Harmful[b]
Case-bearer moth	*Coleophora deauratella*	Stowaway on plants	Yes
Case-bearer moth	*Coleophora culutella*	Stowaway on plants	—
Click beetle	*Anchastus augusti*	—	—
Cockroach	*Ischnoptera bilunata*	—	—
Cockroach	*Ischnoptera nox*	—	—
Cockroach	*Epilampra maya*	—	—
Cockroach	*Neoblattella detersa*	—	—
Cockroach	*Symplooe morsei*	—	—
Collembolan	*Xenylla affiniformis*	—	—
Delphacid planthopper	*Delphacodes fulvidorsum*	Stowaway on plants	—
Delphacid planthopper	*Sogatella kolophon*	Stowaway on plants	—
Dermestid beetle	*Anthrenus pimpinellae*	—	—
Dusky cockroach	*Ectobius lapponicus*	—	—
European barberry fruit maggot	*Rhagoletis meigenii*	—	—
European violet gall midge	*Dasineura affinis*	Stowaway on plants	Yes
European yellow underwing moth	Noctua pronuba	Stowaway on plants into Nova Scotia then spread to U.S.	—
Eucalyptus longhorn borer	*Phoracantha semipunctata*	Stowaway in wood	Yes
Eucalyptus psyllid	*Ctenarytaina* sp.	Stowaway on plants	Yes
Eugenia psyllid	*Trioza eugensae*	Stowaway on plants	Yes
Eulophid wasp	*Tetrastichus haitiensis*	—	—
Flea beetle	*Longitarsus luridus*	Stowaway on plants	—
flea beetle	*Chaetocnema concinna*	Stowaway on plants	—
flower fly	*Syritta flaviventris*	—	—
Flower fly	*Eristalinus taeniops*	—	—
Forest cockroach	*Ectobius sylvestris*	—	—
Fuchsia mite	*Aculops fuchsiae*	Stowaway on plants	Yes
Green wattle psyllid	*Acizzia* nr. *jucunda*	Stowaway on plants	Yes
Ground beetle	*Harpalus rubripes*	—	—
Ground beetle	*Trechus quadristriata*	—	—
Ground beetle	*Notiophilus biguttatus*	—	—
Ground beetle	*Bembidion properans*	—	—
Ground beetle	*Bembidion bruxellense*	—	—
Guava fruit fly	*Bactrocera (=Dacus) correcta*	Stowaway in fruit	Yes
Hairy maggot blow fly	*Chrysomya rufifacles*	Introduced outside of U.S. then spread into country	Yes
Honey bee mite	*Acarapis woodi*	—	Yes
Honey bee varroa mite	*Varroa jaoobsoni*	—	Yes
Lady beetle	*Decadiomus bahamicus*	—	—
Lady beetle	*Harmonia quadripunctata*	—	—
Lady beetle	*Harmonia axyridis*	—	—
Lady beetle	*Stethorus nigripes*	—	—
Lady beetle	*Scymnus suturalis*	—	—
Lauxaniid fly	*Lyciella rodda*	—	—
leaf beetle	*Chrysolina fastuosa*	—	—
Leafhopper	*Eupteryx atropunctata*	Stowaway on plants	—
Leafhopper	*Grypotes puncticollis*	—	—
Lichen moth	*Lycomorphodes sordida*	—	—
Longhorn beetle	*Tetrops praeusta*	—	—
Mealybug	*Allococcus* SP.	Stowaway on plants	—
Mediterranean mint aphid	*Eucarazzia elegans*	Stowaway on plants	Yes

Common name	Scientific name	Pathway[a]	Harmful[b]
Megachilid bee	*Chelostoma campanularum*	Stowaway in transported twigs and wood	—
Megachilid bee	*Chelostoma fuliginosum*	Stowaway in transported twigs and wood	—
Mite	*Melittiphis alveartus*	Stowaway on plants	—
Moth	*Agonopterix alstroemenana*	Stowaway on plants	—
Moth	*Grapholita delineana*	—	—
Moth	*Athrips mouffetella*	—	—
Moth	*Athrips rancidella*	—	—
Nesting whitefly	*Paraleurodes minei*	Stowaway on plants	—
Noctuid moth	*Noctua comes*	Stowaway on plants into Canada then spread to U.S.	—
Noctuid moth	*Rhizedra lutosa*	Stowaway on plants	—
Paper wasp	*Polistes domirrulus*	—	—
Peach fruit fly	*Bactrocera (= Dacus) zonata*	Stowaway in fruit	Yes
Pepper tree psyllid	*Caiophya schini*	Stowaway on plants	Yes
Pine shoot beetle	*Tomicus piniperda*	Stowaway on dunnage	Yes
Plant bug	*Ceratocapsus nigropiceus*	—	—
Plant bug	*Prepops cruciferus*	—	—
Plant bug	*Jobertus chrysolectrus*	—	—
Plant bug	*Psallus lepidus*	Nursery stock	—
Plant bug	*Orthocephalus saltator*	—	—
Plant bug	*Hyalopsallus diaphanus*	Stowaway in tropical fruit	—
Plant bug	*Stheneridea vulgaris*	Stowaway in tropical fruit	—
Plant bug	*Psallus variabilis*	Stowaway on plants	—
Plant bug	*Psallus albipennis*	Stowaway on plants	—
Plant bug	*Paracarnus cubanus*	Stowaway in tropical fruit	—
Plant bug	*Proba hyalina*	Stowaway in tropical fruit	—
Plant bug	*Rhinocloa pallidipes*	—	—
Pirate bug	*Brachysteles parvicornis*	—	—
Poinsettia whitefly (sweetpotato whitefly)	*Bemisia tabaci* [d,f]	—	Yes
Potter wasp	*Delta campaniforme rendalli*	—	—
Potter wasp	*Zeta argillaceum*	—	—
Privet sawfly	*Macrophya punctumalbum*	—	Yes
Pyralid moth	*Hiieithia decostalis*	—	—
Red clover seed weevil	*Tychius stephensi*	—	—
Rhizophagid beetle	*Rhizophagus parallelocollis*	—	—
Rove beetle	*Gabrius astutoides*	—	—
Rove beetle	*Sunius melanocephalus*	—	—
Rove beetle	*Oxypoda opaca*	—	—
Rove beetle	*Heterota plumbea*	—	—
Rove beetle	*Coenonica puncticollis*	—	—
Rove beetle	*Staphylinus brunnipes*	—	—
Rove beetle	*Staphylinus similis*	—	—
Rove beetle	*Tachinus rufipes*	—	—
Russian wheat aphid	*Diuraphis noxia*	Introduced outside of U.S. then spread into country	Yes
Sawfly	*Liliacina diversipes*	—	—
Sawfly	*Pristiphora aquilegiae*	—	Yes
Scale predator	*Anthribus nebulosus*	—	—
Seed bug	*Plinthisus brevipennis*	—	—
Seed bug	*Chilacis typhae*	—	—

(continued on next page)

Table 3-I-Continued

Common name	Scientific name	Pathway[a]	Harmful[b]
Shore fly	*Placopsidella grandis*	Stowaway on ship	—
Shore fly	*Brachydeutera longipes*	Stowaway on aquatic plants	—
Siberian elm aphid	*Tlnocallis zelkowae*	Stowaway on plants	—
Spider	*Trochosa ruricola*	—	—
Spider	*Lepthyphantes tenuis*	—	—
Spider wasp	*Auplopus carbonarius*	—	—
Spindletree ermine moth	*Yponomeuta cagnagella*	Stowaway on plants	Yes
Spruce bark beetle	*Ips typography*	Dunnage	Yes
Stink bug	*Pellaea stictica*	—	—
Tatarica honeysuckle aphid	*Hyadaphis tataticae*	Nursery stock	Yes
Thrips	*Thrips palmi*	Stowaway on plants	Yes
Tortoise beetle	Aspidomorpha transparipennis	Stowaway on plants	—
Tortoise beetle	*Metriona tuberculata*	Stowaway on plants	—
Tristania psyllid	Ctenarytaina longicauda	Stowaway on plants	Yes
Weevil	*Amaurorhinus bewickianus*	—	—
Weevil	*Brachyderes incanus*	Nursery stock	—
Weevil	*Rhinoncus bruchoides*	—	—
Wood-boring wasp	*Xiphydria prolongata*	—	—
Wood-boring wasp	*Urocerus* sah	Stowaway on wood products	—
Wheat bulb maggot	*Delia coarctata*	—	Yes
Waxflower wasp	*Aprostocetus* sp.	Stowaway on plants	—
Whitefly	*Tetraleurodes* new sp.	Stowaway on plants	Yes
—	*Rhagio strigosus*	—	—
—	*Rhagio tringarius*	—	—
(Numerous additional insects and arachnids have been intentionally introduced since 1980 for biological control of pests. None have yet been shown to have harmful effects.)			
Fishes (13)			
Bighead carp	*Hypophthalmichthys nobilis*	Illegal biological cmtrol introduction	—
Blue-eyed cichlid	*Cichlasoma spilurum*	Aquarium release	—
European ruffe	*Gyrnnocephalus cernuus*	Ballast water	Yes
Jaguar guapote	Cichlasoma *managuense*	Aquarium release	—
Long tom	Strongylura kreffti	—	—
Mayan cichlid	*Cichlasoma urophthalmus*	Aquarium release	—
Rainbow krib	*Pelviachromis pulcher*	Aquarium release	—
Redstriped eartheater	*Geophagus surinamensis*	Escape from aquaculture	—
Round goby	*Neogobhis melanostomus*	Ballast water	—
Tubenose goby	*Proterorhinus marmoratus*	Ballast water	—
Zebra danio	*Danio redo*	Aquarium release	—
Yellowbelly cichlid	Cichlasoma salvini	Aquarium release	—
—	*Ancistrus* sp.	Aquarium release	—
Mollusks (7)			
Clam	*Potamocorbula amurensis*	Ballast water	Yes
Clam	Theora fragilis	Ballast water	—
Snail	*Alcadia striata*	—	—
Snail	*Potamopyrgus antipodanum*	Contaminant of aquaculture stock that subsequently escaped	Yes
Snail	*Cernuella virgata*	—	Yes
Zebra mussel	*Dreissena polymorpha*	Ballast water	Yes
Zebra mussel	*Dreissena* sp.[g]	Ballast water	Yes
Plant pathogens (9)			
Blight (on chickpea)	*Aschochyta rabiei*	Stowaway in infected seed	Yes
Citrus canker	*Xanthomonas campestris* pv. citri	—	Yes

Common name	Scientific name	Pathway[a]	Harmful[b]
Corn cyst nematode	*Heterodtera zeae*	—	Yes
Needle caste	*Mycospaerella Iaricina*	Stowaway on infested larch (live or wood?)	Yes
Nematode	*Subanguina picridis*	Biocontrol introduction	—
Potato virus y-necrotic strain (n)	Potyviridae (Potyvirus)	Infected potatoes	Yes
Rust fungus	*Puccinia carduorum*	Biocontrol introduction	—
Rust fungus (on chrysanthemum)	*Puccinia horiana*	Smuggled on infected chrysanthemum	Yes
Smut (on rice)	*Ustilago esculenta*	Smuggled on infected rice	Yes
Other (9)			
Aquatic worm	*Phallodrilus aquaedulcis*	Ballast water	—
Aquatic worm	*Tenendrilus* mastix	Ballast water	—
Aslan copepod	*Pseudodiaptomus inopinus*	Ballast water	—
Chinese copepod	*Pseudodiaptomus forbesi*	Ballast water	—
Giant tiger shrimp	*Penaeus monodon*	Escape from research facility	—
Japanese crab	*Hemigrapsus sanguineous*	Ballast water	—
Japanese copepod	*Pseudodiaptomus marinus*	Ballast water	—
Pacific white shrimp	*Penaeus vannamei*	Escape from aquiculture	—
Spiny water flea	*Bythotrephes cederstroemi*	Ballast water	Yes

[a] Listed pathways are according to expert opinions. Often, it is impossible to determine with 100 percent certainty the pathway an NIS followed after the species has become established. A dash in this column indicates that the pathway by which the species entered the United States is unknown.

[b] Know to cause economic environmental, or other type of ham] (see ch, 2). A dash in this column indicates either there are no known harmful effects or they have not yet been well documented.

[c] Where available, common names are those used officially by the Entomological Society of America,

[d] Thought t. be a new strain or subspecies of NIS already established in the United States.

[e] The exact origin of the Asian Gypsy moth is not yet known; some scientists believe it may be a different species than the established European gypsy moth. The Asian gypsy moth has also been referred to as the "Siberian" gypsy moth in the popular press.

[f] The pointsettia whitefly that recently caused great crop losses in southern California is considered by many to be a new strain of the sweet potato whitefly which became established in the region several decades ago. Some, however, believe it is a new species.

9 Recent genetic surveys of Great Lakes zebra mussels suggest a second species of Dreissena is also established there; however, its taxonomy remains unclear.

SOURCES: Compiled by the Office of Technology Assessment, 1993 from: J.C. Britton, "Pathways and Consequences of the Introduction of Non-Indigenous Freshwater, Terrestrial, and Estuarine Mollusks in the United States," contractor report prepared for the Office of Technology Assessment, October 1991; J.T. Carlton, "Dispersal of Living Organisms into Aquatic Ecosystems as Mediated by Aquiculture and Fisheries Activities," *Dispersal of Living Organisms into Aqua tic Ecosystems,* A. Rosenfield and R. Mann (eds.) (College Park, MD: Maryland Sea Grant, 1992), pp. 13-46; J.T. Carlton, "Marine Species Introductions by Ship's Ballast Water: An Overview," *Introductions* and *Transfers of Marine Species,* M.R. DeVoe (cd.) (Charleston, SC: South Carolina Sea Grant, 1992), pp. 23-29; J.T. Carlton and J.B. Geller, "Ecological Roulette: The Global Transport of Nonindigenous Marine Organisms," Science, vol. 261, July 2, 1993, pp. 78-82; 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; W.R. Courtenay, Jr., Professor of Zoology, Florida Atlantic University, FAX to E.A. Chornesky, Office of Technology Assessment, Apr. 13, 1993; R.V. Dowell, Entomologist, California Department of Food and Agriculture, FAX to E.A. Chornesky, Office of Technology Assessment, Apr. 12, 1993; R.V. Dowell, Entomologist, California Department of Food and Agriculture, personal communication to E.A. Chornesky, Office of Technology Assessment, May 28, 1993; Entomological Society of America, "Common Names of Insects and Related Organisms, 1989;" D.H. Habeck and F.D. Bennett, "*Cactoblastis cactorum* Berg (Lepidoptera: Pyralidae), a Phycitine New to Florida," florida Dept. of Agriculture and Consumer Services, Entomology Circular No. 333, August 1990; E.R. Hoebeke and A.G. Wheeler, "Exotic Insects Reported New to Northeastern United States and Eastern Canada Since 1970," *New York Entomological Society,* vol. 91, No. 3,1983, pp. 193-222; E.R. Hoebeke, "Referenced List of Recently Detected Insects and Arachnids," contractor report prepared for the Office of Technology Assessment, June 22, 1993; E.R. Hoebeke, "*Pityogenes bidentatus* (Herbst), a European Bark Beetle New to North America (Coleoptera: Scolytidae)," *J. New York Entomological Society, vol. 97, No. 3,* 1989, pp. 305-308; E.R. Hoebeke and W.T. Johnson, "A European Privet Sawfly, *Macrophya punctumalbum* (L.): North American Distribution, Host Plants, Seasonal History and Descriptions of Immature Stages (Hymenopteran: Tenthredinidae)," *Proc. Entomol. Soc. Wash., vol. 87, No.* 1, 1985, pp. 25-33; K.C. Kim and

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Table 3-I-Continued

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; K.C. Kim, Professor of Entomology, Penn State University, personal communication to E.A. Chornesky, Office of Technology Assessment, May 17, 1993; R.N. Mack, "Additional Information on Non-Indigenous Plants in the United States," contractor report prepared for the Office of Technology Assessment, 1992; R.N. Mack, Professor, Oregon State University, FAX to E.A. Chornesky, Office of Technology Assessment, May 26, 1993; D.R. Miller, Research Leader, Systematic Entomology Laboratory, U.S. Department of Agriculture, Agricultural Research Service, letter to E.A. Chornesky, Office of Technology Assessment, July 1, 1993; J. Morrison, "Cockroaches on the Move, "Agricultural *Research,* vol. 35, No. 2, February 1987, pp. 6-9; 6A. Parfume et al., "Discovery of Aedes *(howardina) baharnensis* in the United States," *Journal of the American Mosquito Control Association, vol. 4, No. 3,* September 1988, p. 380; M.P. Parrella et al., "Sweet Potato Whitefly: Prospects for Biological Control," *California Agriculture,* vol. 46, No. 1, January-February 1992, pp. 25-26; 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; U.S. Congress, House Committee on Appropriations, Subcommittee on Agriculture, Rural Development, and Related Agencies, *Hearings on Agriculture, Rural Development, Food and Drug Administration, and Related Agencies Appropriations for 7993, Part 3,* Serial No. *54-8880,* Mar. 18-30, 1992a; A.J. Wheeler, Adjunct Professor, Pennsylvania State University, personal communication to E.A. Chornesky, Office of Technology Assessment, May 6, 1993.