Two Case Studies: Non-Indigeneous Species in Hawaii and Florida

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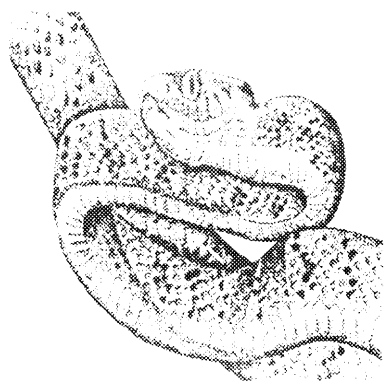
In this chapter, OTA focuses on the status, problems, and policies regarding nonmarine, non-indigenous organisms in two particular States: Hawaii and Florida. These two States have large numbers of non-indigenous species (NIS) because of their particular geography, climate, and history. Each has experienced considerable problems as a result. And each area has developed interesting policy responses in the attempt to solve these problems. Their efforts are worth attention in their own right and also because they may provide lessons for other parts of the United States.

Several common themes appear in both States. Invasive NIS threaten the uniqueness of certain areas. In Hawaii, this threat is to the remaining indigenous species, most of which occur nowhere else in the United States or the world. In both States, the greatest threat of NIS is to unusual natural areas as a whole, Both States are transportation hubs and tourist destinations. Therefore, entry and establishment of non-indigenous pests in either State provide a route for further spread into other parts of the United States.

Of course, Hawaii and Florida are very different from each other. Hawaii is the only State subject to a Federal agricultural quarantine that includes comprehensive Federal inspection activities. Many policies affecting Hawaii would be different if California, with its massive agricultural sector, were not nearby. No other State receives as much U.S. military traffic and, thus, needs to pay as much attention to this pathway. Florida is the center for U.S. production of tropical aquarium fish, and few other States have engaged in environmental manipulation on the large scale Florida has.



These two States have learned certain lessons in dealing with harmful NIS:

- Federal and State approaches need to be coordinated;
- seldom do those who are the source of NIS problems also bear their cost;
- agriculture and natural areas bear a high cost for introductions, whatever their source; and
- public education is vital to preventing new species entry and spread.

These lessons are worth the attention of other States, perhaps with less severe problems right now. Also, these lessons are worth the attention of Federal policymakers. The Federal Government has both helped and hindered these States in their efforts to deal with harmful NIS. Better integration of Federal and State policies and programs in the future would benefit both the Nation and the States.

NON-INDIGENOUS SPECIES IN HAWAII

Finding:

Hawaii has a unique indigenous biota, the result of its remote location, topography, and climate. Many of its species, however, are already lost, and at least one-half of the wild species in Hawaii today are non-indigenous. New species have played a significant role in the extinction of indigenous species in the past and continue to do so. Hawaii, the Nation, and the world lose something valuable as the indigenous flora and fauna decline.

The Nature of the Problem

By many measures, the Hawaiian Islands represent the worst-case example of the Nation's NIS problem. No other area in the United States receives as many new species annually, nor has as great a proportion of NIS established in the wild. At the same time, Hawaii, the Nation's so-called extinction capital, has the greatest concentration of threatened and endangered species in the United States and the greatest number of extinct species as well. While habitat destruction has been and continues to be a main factor in the demise of the indigenous biota, NIS[1] have been identified as an important, if not the most important, current threat (27,85,86,128).

In addition, Hawaii may be the State most visibly transformed by NIS. Most of the coastal areas and lowlands of the mountainous islands appear to be the proverbial paradise-green, often lush, replete with birds and flowers. But except in a few pockets, most of the trees, foliage, flowers, and birds are non-indigenous. Only at higher elevations can one find any appreciable expanse of the globally unique flora and fauna.

Non-indigenous species have had a distinctive impact in Hawaii for several reasons.

- The island ecology. The Hawaiian Islands are the most remote land mass in the world, separated from the continents by a 2,500-mile-wide ocean moat. As a result, only a relatively few kinds of plants, insects, birds, and other organisms managed to colonize the islands before human settlement (see ''original immigrants' in table 8-l). The original several hundred species that arrived by ocean or air currents evolved into many thousands of species, more than 90 percent of which are endemic (unique) to Hawaii.

  Missing from this assemblage were many of the predators, grazers, pathogens, and other organisms that have shaped the ecology of the continents. Birds, plants, brightly colored snails, and insects dominated the original Hawaiian landscape. Yet there were no ants, mosquitoes, or cockroaches, nor any snakes or other reptiles. The only mammals were a small insect-eating bat and a marine mammal, the Hawaiian monk seal *(Monarchus schauinslandi).*

[1] In Hawaii, alien species is the preferred term.

Table 8-I—Past and Present Status of Nonmarine Species in Hawaii

Group	Original immigrants (number)	Indigenous species (number)	Endemic species (no./%)	Extinct species (no./%)	Threatened/ endangered *(no./%)*	Established NIS[b] (no./%)
Plants[c]	407	=1 ,400	=1 ,200/867.	/=1 O%	/=30%	=900/450/0
Birds[c]	21	=100	92/=920/.	60/=60	30%700/0	38/480/0
Mammal	1	1	0	0	1/100%	1 9/950/0
Reptiles	0	NA	NA	NA	NA	1 3/1 00%
Amphibians	0	NA	NA	NA	NA	4/1 00%
Freshwater fish		5	5/100%	0	0	29/84%
Mollusks[c]	22-24	=1 ,060	/=99%	/=50%	/100%	=30/6%
Insects[c]	350-400	=8,000	/=98%		/=30%	=2,500/=25%

a percentage of remaining species, for most cases representing unofficial estimates. As of December 1992, 104 plant species (all but one as endangered) and 30 bird (marine and nonmarine) species and subspecies (all but one as endangered) were on the U.S. Endangered Species List. Another 61 plant species were proposed for listing (all but one as endangered). A total of 189 plant species were slated to be listed by 1993 under a Federal court settlement (Civil No. 89-953 ACK).

b Refers t. species non-indigenous to Hawaii. This includes many species originating in the continental United States.

C Numbers for plants, birds, mollusk (mostly land snails), and insects in most categories are rounded estimates based on species lists, other published reports, and expert opinion.

NA = not applicable.

SOURCES: Adapted by the Office of Technology Assessment from W.L. Wagner, D.R. HerbSt, and S.H. Sohmer, *Manual of the Flowering Plants of Hawaii* (Honolulu, Hi: University of Hawaii Press, Bishop Museum Press, 1990); L.L. Loope, O. Hamann, and C.P. Stone, "Comparative Conservation Biology of Oceanic Archipelagoes," *BioScience, vol. 38, No. 4,* April 1988, pp. 272-282; G.M. Nishida (cd.) *Hawaiian* Terrestrial *Arthropod Checklist* (Honolulu, HI: Bishop Museum Press, 1992); and personal communications from H.F. James, ornithologist, National Museum of Natural History, Smithsonian Institution, Jan. 23, 1992; W. Devick, aquatic resources specialist, Hawaii Department of Land and Natural Resources, Jan. 7, 1992; M. Hadfield, zoologist, University of Hawaii, Honolulu, Jan. 6, 1992; and F.G. Howarth, entomologist, Bishop Museum, January 1992.

Because they evolved in the absence of any large herbivorous animals like deer, many of the plants lost their physical and chemical defenses against such animals (17). Hawaii's indigenous raspberries (Rubus *hawaiensis)* do not have the sharp thorns of related species. The 50 species of indigenous mints lack the herbivore-deterring aromatic scent of sage *(Salvia officinalis),* basil *(Ocimum basilicum),* and other continental mints. Similarly, more than a dozen species of flightless, ground-dwelling birds (88) evolved on the islands, as did several unusual flightless moths, flies, and other insects (55).

This isolated evolution is seen as the prime reason why Hawaii, and oceanic islands in general, are especially vulnerable to ecological invasions (70). In addition, most indigenous species in Hawaii are not adapted to free, which has increased considerably with human settlement. This now common physical disturbance not only eliminates indigenous species, particularly rare and threatened or endangered plants, it provides an inroad to invasions by better adapted NIS (109). Trampling by large non-indigenous animals also facilitates invasions.

. The tropical climate. Hawaii's average temperatures vary little between winter and summer, at sea level ranging from about 72 to 78 degrees F. In contrast, rainfall, delivered to the islands by trade winds from the northeast, " varies tremendously. Windward mountain slopes can receive 300 to 400 inches per year, while leeward coasts receive as few as 10 to 20 inches.

The variation in rainfall, along with the diverse, volcano-created terrain, accounts for Hawaii's large variety of habitats, which in turn accounts at least in part for the diversity of recently arrived organisms that have successfully colonized the islands (69). And the lack of a killing frost except at high elevations means

that Hawaii is subject to invasion by many species that would not be a threat to the largely temperate continental United States.

. The transportation hub. Lying close to the middle of the Pacific Ocean, Hawaii is a portal between Asia and North America. Traffic through the islands has been increasing dramatically, given the rising economic importance of the Pacific Rim nations and the increasing popularity of Hawaii as a vacation spot. With a 50-percent increase in traffic during the 1980s, Honolulu's airport was 15th busiest in the United States in 1990, according to the Federal Aviation Administration. Equally important is the military traffic through Hawaii, the Pacific center for U.S. defense (see below).

The large volume and variety of traffic is responsible for the great number of NIS that arrive in the State. In addition to stowaways on transport equipment or cargo, plants and animals are brought in, intentionally or unintentionally, by the increasing number of travelers, both residents and tourists.

RATES OF INTRODUCTIONS

The rate of NIS introductions in Hawaii increased dramatically with the start of regular air service to the islands in the 1930s. But Hawaii's transformation by NIS began 1,500 or more years ago, with the arrival of sea-faring Polynesians.

Polynesians intentionally introduced about 30 kinds of plants for cultivation—including sugar cane *(Saccharum officinarum)* and coconut (Cocos *nucifera),* two images closely allied with Hawaiian culture today—and accidentally brought along several weeds. They also brought a few domesticated animals (pigs, dogs, chickens) and stowaways like rats, lizards, and probably several insects. The rate of species becoming established in the islands thus changed from the natural rate of one new species every 50,000 years to three or four new species every 100 years (70).

Hawaii began to absorb a new wave of species with the arrival of Europeans in 1778, when the rate of successful introductions jumped to hundreds of thousands of times the natural rate. Among the most significant and persistent introductions were the goats *(Capra hircus),* sheep *(Ovis aries),* European pigs (Sus *scrofa),* and cattle *(Bos taurus)* released by explorer James Cook and other early ship captains as gifts or to create herds to feed their crews. Feral European pigs and goats in particular remain serious pests of natural areas (and to some extent agriculture) today.

In the subsequent two centuries of European and Asian settlement, horses, deer, and more rodents have also been introduced. More non-indigenous bird species (including 15 game species) have become established in Hawaii than anywhere else (64). More than 4,600 non-indigenous plant species have been introduced, primarily for cultivation. Of these, almost 900 have become established, so that Hawaii's wild non-indigenous plant species today are approaching the number of indigenous species (129). Non-indigenous freshwater fish, most of which were intentionally introduced for sport, food, or other reasons (71), far outnumber the relatively few indigenous freshwater species. In the case of insects, NIS make up perhaps 25 percent (table 8-l). Many of Hawaii's NIS are indigenous to the continental United States; according to the Hawaii Department of Agriculture, about one-quarter of Hawaii's non-indigenous pests are mainland species (47).

Like goats and pigs, many other present-day pest species were deliberate, well-intentioned introductions in the past (table 8-2). Several plants originally brought in for agricultural or ornamental purposes have become extremely invasive, as in the case of strawberry guava *(Psidium cattleianum)* or bananapoka *(Passiflora mollissima).* Some animals brought in to control other pests became problems themselves. The Indian mongoose *(Herpestes auropunctatus),* introduced via Jamaica in the 1880s, was supposed to control rats in sugar cane fields, but has come to prey on birds, including the Hawaiian goose (nene, the State bird) *(Branta sandvicensis),* and

Table 8-2—Significant Non-Indigenous **Pest Species in Hawaii**

Species	Origin	Date introduced	Reason	Impacts
Pig (Sus *scrofa)*	**Europe**	**1778**	**Gift, food**	**Damages crops; degrades natural habitats by foraging, trampling; spreads alien plants; causes erosion, harming watersheds**
Goat *(Capra hircus)*	**Europe**	**1778**	**Gift, food**	**Degrades natural habitat by foraging, trampling; spreads alien plants; causes erosion, harming watersheds**
Myna bird *(Acridotheres tristis)*	**India**	**1865**	**Control armyworm in pastures**	**Spreads alien plants; damages crops; spreads avifaunal diseases**
Cattle egret *(Bubulcus ibis)*	**Southern Eurasia Africa**	**1959**	**Control insect pests on cattle**	**Damages crops, aquiculture; airport hazard; preys on indigenous waterbird chicks**
"Trifly"	**Widespread**		**Accidental**	**$300 million in lost produce markets; $3.5 million in damaged produce; $1 million in postharvest treatment in 1989**
Melon fly *(Dacus cucurbitae)*		*1895*		
Mediterranean fruit fly ***(Ceratitis*** *capitata)*		***1907***		
Oriental fruit fly *(D. dorsalis)*		**1945**		
Strawberry guava *(Psidiurn Cattleianum)*	**Brazil**	**1825**	**Cultivated for fruit**	**Forms a thicket shading out indigenous plants; fruit attracts pigs; crowds out cattle forage; serves as primary host to oriental fruit fly**
Koster's curse *(Clidemia hirta)*	**Tropical America**	**pre-1 941**	**Possibly for erosion control**	**Highly invasive, forming a thicket in forest understory; 80,000 acres affected**
Banana poka *(Passiflora mollissima)*	**Andes**	**pre-1921**	**Ornamental**	**Heavy vines damage indigenous trees; alters forest understory; 100,000 acres affected**
Fountain grass *(Pennisetum setaceum)*	**Africa**	**early 1900s**	**Ornamental**	**Invades bare lava flows, natural areas, rangelands; provides** *fuel* **for damaging wildfires and is spread by fire**
Fire tree (Myrica ***fava)***	**Azores, Canary Islands**	**pre-1900**	**Ornamental, or for fruit (wine) or firewood**	**Invades natural areas to forma dense stand, obliterating indigenous ground cover; upsets nitrogen balance in soils, encouraging other weeds; attracts pigs**

SOURCE: Office of Technology Assessment, 1993.

at least seven other endangered species. The rosy snail *(Euglandina rosea)* from Florida was introduced in 1955 to prey on a non-indigenous pest, the African giant snail *(Achatina fulica),* but is widely believed to have also hunted many of the endemic snails to extinction (55).

Today organisms brought in for biological control are more rigorously screened to avoid nontarget effects; ‘‘no purposely introduced species, approved for release in the past 21 years, has been recorded to attack any native or other desirable species” in Hawaii (40). Other scientists, however, question whether monitoring adequately assesses other important impacts, such as competition with indigenous species (55). Still, most new problem species today are believed to be the result of accidental or smuggled introductions.

The rate of MS establishment nevertheless remains high, About five new plant species per year have become established during the 20th century (133), For the 50-year period from 1937 to 1987, Hawaii received an average of 18 new insect and other arthropod species annually (6, 48)----more than a million times the natural rate and almost twice the number absorbed each year by North America (77). Since the mid- 1940s, the annual rate for this fairly well-documented group has been highly variable (see also ch. 3)--ranging from at least 35 new species in 1945 and 1977 to 10 or fewer in 1957 and the beginning of the 1990s (86). It has been suggested that some of the upsurges may be related to wartime activities at the ends of World War II and the Vietnam War (6). Annually about three of Hawaii’s new arthropod species turn out to be economic pests (7).

STATE OF INDIGENOUS SPECIES

The impact of the high rate of biological invasions in Hawaii is partly reflected in the extreme numbers of its extinct and threatened or endangered indigenous species (table 8-1). Some of the best evidence of extinction by MS comes from Hawaii, as in the case of the rosy snail (ch. 2). Although habitat destruction was probably the greater force behind extinctions in the past, today MS, through predation and competition, are often considered to be the main threat because they can invade parks and other natural areas protected from development (128).

Hawaii has been described as the 50th State but first in terms of biological imperilment. It occupies only 0.2 percent of U.S. land area-the fourth smallest State—but takes up disproportionate space on the Federal Endangered Species List: about a third of the plants and birds listed or being considered for listing belong to Hawaii,

Much of the unique plant and animal life is already gone. Of all the plants and birds known to have gone extinct in the United States, two-thirds are from Hawaii (128).

Hawaii’s spectacular bird life has been the most visibly diminished. Half of the original bird species, including all of the flightless birds, are known only from skeletal remains. Polynesians and their animals probably hunted the birds to extinction, or ensured their demise by clearing their habitat. About a dozen additional species are thought to have gone extinct since Cook’s arrival. Most of the remaining birds are either threatened or endangered (table 8-l), accounting for the greatest known concentration of endangered birds in the world,

At least a tenth of Hawaii’s plant species are already extinct, and about 30 percent of the remaining species are considered threatened or endangered (129); some botanists say as many as half may be at risk. The indigenous insects and other life forms are too poorly known to allow an assessment of their status, but experts believe they have been similarly affected (table 8-l). At least half of Hawaii’s distinctive land snails, for example, are thought to be extinct, while the remaining species are probably all threatened or endangered, in large part because of the imported rosy snail (43,54).

Because islands are especially vulnerable to biological invasions, many of their indigenous species—Hawaii’s in particular-were once thought to be doomed to extinction. But recent

work in ecological restoration in Hawaii has been promising, and some biologists and conservationists now express optimism that some habitats can recover when browsing animals, for example, are removed (55,70).

Causes and Consequences

Findings:

As a set of islands, Hawaii is unique among the 50 States in its vulnerability to the sometimes devastating ecological impacts of NIS. On the other hand its geographic isolation limits the pathways for introductions and presents unique opportunities for the design of prevention strategies.

Hawaii's natural areas and agriculture bear the brunt of new species' harmful impacts. However, agriculture, including horticulture and forestry, also has been a source of problem introductions.

Few economic or noneconomic activities in Hawaii are unaffected by or uninvolved in the influx of NIS to the State. Specific costs incurred because of harmful NIS, however, are available in only some cases, (The State does not maintain records of crop damages from pests.) Many of the consequences of invasions, especially in natural areas, are unquantified.

NATURAL AREAS

In Hawaii, harmful NIS have taken their greatest toll on natural areas. Although they produce no commodities like timber in substantial amounts, they are of value for their unique biological diversity, for maintainingg the islands' freshwater supply, for providing scenery and some recreation in a tourist-dependent economy, and as a scientific laboratory.

Hawaii is considered an unparalled site for the study of evolution (see special issues of *Bioscience,* April 1988; *Trends in Ecology and Evolution,* July 1987; *Natural History,* December 1982). The diverse indigenous species all evolved from a small number of colonizers (table 8-1) and

NATIONAL PARK SERVICE

Harmful non-indigenous species have taken their greatest toll on Hawaii's natural areas, including Haleakala National Park.

as such have been important for understanding how new species arise. One of the world's most dramatic examples of this process is Hawaii's 600 or more species of fruit flies, a quarter of the world's species, all the evolutionary descendants of one colonizing species. Similarly, a single colonizing finch species gave rise to 40 remarkably varied species of honeycreepers.

This evolutionary proliferation of species has endowed Hawaii with the most biological diversity per unit area in the United States (68); as such it is a potential source of useful new biological materials for research and development (123). Hawaii's endemic cotton plant *(Gossypium tomentosum),* for example, lacks the nectar-producing glands of other cotton species and has been used by plant breeders to create a commercial strain that is less attractive to insect pests. A marine coral produces a promising antitumor compound. Only a fraction of Hawaii's unique species, however, have been screened for such properties.

Many indigenous species—perhaps one-third or more of the insects, for example-have not even been described, prompting calls for a thorough inventory of the remaining species and important baseline population studies. The re-

cently signed Hawaii Tropical Forest Recovery Act[2] specifies development of "actions to encourage and accelerate the identification and classification of unidentified plant and animal species" (sec. 605) and baseline studies (sec. 607) in Hawaii forests. The legislation also authorizes grants for NIS control (sec. 610). The 1992 Hawaii legislature also took action[3] to establish a biological survey of the islands' indigenous and NIS.

Natural areas that still support indigenous species in relatively intact habitat makeup about 25 percent of Hawaii (114). These areas are protected by the Federal Government (56 percent), the State (41 percent), and others, primarily the Nature Conservancy of Hawaii (3 percent).

The State forest reserves were established at the beginning of this century in recognition of the forests' importance as watersheds (27). Early management involved large-scale plantings of non-indigenous trees, as well as fencing and removal of feral goats, pigs, and other ungulates. By rooting, browsing, and trampling, these animals destroy the vegetation that holds soil in place, especially on steep terrains, resulting in run-off into rivers and streams. Communities have spent millions of dollars for water filtration systems to deal with the contamination, siltation, and discoloration (41).

Damage by feral ungulates is still one of two main non-indigenous threats to forests and other natural areas. Control of feral ungulates has been best achieved in parts of two national parks, but at considerable cost. Areas must be fenced off then cleared of animals by shooting. At Haleakala National Park (HALE), for example, 45 miles of fencing were installed around two important areas-including a rainforest of exceptional biological diversity-at a cost of $2.4 million, provided by the National Park Service's Natural Resource Preservation Program. Maintenance of fences—because of damage from storms, humidity, tree falls, and the like-costs an estimated $130,000 per year (67). Fencing is also underway at Hawaii Volcanoes National Park at a comparable cost.

Weeds constitute the second main non-indigenous threat to natural areas. About 90 of the estimated 900 established non-indigenous plant species in Hawaii are serious pests (109), capable of invading undisturbed natural areas. Hawaii's national parks have a much greater proportion of non-indigenous plant species than do other U.S. national parks (65). At Hawaii Volcanoes National Park, the non-indigenous plant problem is especially severe: 30 of the worst plant pest species are present, 24 of which are widespread (26). Out of 900 total plant species in the park, two-thirds are non-indigenous. Control by hand clearing, chemicals, or in some cases biological agents is concentrated on portions of the park that are especially sensitive; parkwide control is considered impossible.

Non-indigenous insects also threaten natural areas, by competing with or preying on indigenous species and altering pollination patterns, although the extent of their impact is less understood and has received less attention. Perhaps the worst of the insect pests are the predatory Argentine ant *(Iridomyrmex humilis)* and western yellow jacket *(Vespula pensylvanica),* which are the subject of monitoring and control research in the national parks.

For all natural areas, the control and management of harmful NIS consume the vast bulk of their resource management budgets. In the case of the two national parks, which have the most aggressive management programs, the 1987 resource management budget was $1.8 million (114); the 1991 budget was $1.2 million (86) prompting concerns among managers regarding shrinking and inconsistent funding. (Resource management represents 40 percent of the total park budget at HALE (66). By contrast, in the

[2] Hawaii Tropical Forest Recovery Act (1992), Public Law 102-574

[3] H.B. 3660

Table 8-3-Non-Indigenous Species in Hawaii: Roles of Federal and State Agencies

Federal Agencies

Treasury Department
- **Customs Service-inspects cargo and passengers from foreign points of origin; directs cases to USDA or FWS**

Interior Department
- **Fish and Wildlife Service-manages 14 wildlife refuges, includes NIS control**
  - **. Law Enforcement Division-inspects wildlife imported into United States to enforce CITES, ESA, and Lacey Act**
- **National Park Service—manages 2 nature parks, includes NIS control and research**

Agriculture Department
- **Agricultural Research Service-research on pest control and eradication**
- **Animal and Plant and Health inspection Service**
  - **Animal Damage Control—works to reduce feral animal problems**
  - **Plant Protection and Quarantine-inspects foreign arrivals and domestic departures for U.S. mainland to prevent movement of agricultural pests**
  - **Veterinary Service-quarantines animals for rabies and other diseases**

Forest Service-NIS control research

Defense Department
- **Military Customs inspection--inspects military transport arriving from foreign areas under Customs and APHIS authority**

***State** Agencies*

Governor's Office
- **Agricultural Coordinating Committee**

Department of Agriculture
- **Board of Agriculture**
  - **Technical Advisory Committe-advises on plant and animal imports, based on input from five technical subcommittees**
- **Plant Industry Division**
  - **Plant Quarantine Branch-inspects arriving passengers and cargo to prevent entry of pests; reviews requests to import plants and animals; regulates movement of biological material among islands; provides clearance for export of plant material to meet quarantine standards**
  - **Plant Pest Control Branch-carries out eradication and control of plant pests through two sections: Biological Control and Chemical/Mechanical Control**
- **Animal Industry Division**
  - **inspection and Quarantine Branch-inspects animals entering Hawaii, manages animal quarantines**

Department of Land and Natural Resources
- **Division of Forestry and Wildlife-manages State forests, natural area reserves, wildlife sanctuaries; involves watershed protection, natural resources protection, control/eradication of pest species.**

SOURCE: Office of Technology Assessment, 1993.

National Park system as a whole, less than 10 percent of the budget is directed to natural resource management, a figure OTA finds to be low (ch. 6).) The budget for the State's Division of Forestry and Wildlife, which oversees State-owned forests, natural areas, public hunting areas, and wildlife sanctuaries (table 8-3), has been substantially increased in recent years. In 1991, it spent $2.8 million for pest control activities (86).

AGRICULTURE

Agriculture is Hawaii's third largest source of revenue-$551 million in 1991 (farmgate value)--behind tourism and military-related spending. Although declining in importance, sugar and pineapple remain Hawaii's two main agricultural products, respectively generating about $200 million and $100 million in recent years. "Diversified' agriculture-macadamia nuts, papayas, flowers, beef, dairy, coffee, and other products—

provides the rest and represents a growth industry for Hawaii.

All these products are derived from imported species, and virtually all the agricultural pests (primarily insects) are non-indigenous as well (8). (By contrast, estimates of non-indigenous agricultural pests on the U.S. mainland range from 40 to 90 percent of all pests.) Many pests arrived in Hawaii on agricultural material that was imported to improve genetic stocks or to introduce new crops. All of today's pineapple pests, for example, were brought in on vegetative material for propagation. The pests not only destroy crops but also limit markets in mainland and foreign areas that have imposed quarantines on produce from Hawaii because of the threat of new pests. This loss of export markets is often cited as the main barrier to the expansion of Hawaii's diversified crops, such as avocados (46).

The Governor's Agriculture Coordinating Committee spent $3.8 million from 1987 to 1990 on research to control or eliminate pest impacts on agricultural commodities (86). The Federal Animal Damage Control (ADC) unit (table 8-3) in Hawaii spent $181,000 (36 percent Federal funds) in 1989 to minimize feral animal damage to agriculture, as well as to natural resources, human health, and property (about half of ADC's work involves controlling bird strike hazards at airports). Agricultural and nonagricultural damage by non-indigenous animal pests confirmed by or reported to ADC in 1989 amounted to $6.9 million (126).

Specific pest-control or -damage costs borne by various types of agriculture follow. Instances where agriculture has contributed to Hawaii's NIS problem are also noted. In general, about half of Hawaiis non-indigenous established plants are thought to have been introduced as crops or ornamental (133).

Crops-Costs of pest control and damage are best documented for sugar cane, Hawaii's main crop. Throughout its 150-year history, the sugar cane industry has been confronted with a series of damaging insect pests, most of which were eventually controlled biologically. In 1904, the sugar cane leafhopper *(Perkinsiella saccharicida)* from Australia was responsible for the loss of 70,000 tons of sugar, at a cost of $25 million in 1990 prices ($350 per ton), according to the Hawaiian Sugar Planters' Association (91). By 1907, the leafhopper was subdued by several predators imported from Australia.

The sugar cane beetle borer *(Rhabdoscelus obscurus)* from New Guinea was first found in 1865 and remains an important pest of sugar cane, Damage from the insect is exacerbated in areas where rats are a problem, since damaged stalks are favorable for egg laying. A study of losses at two plantations in the 1960s estimated that borers destroyed 2.2 percent of the crop. Industry-wide losses from this pest amount to about 3,000 tons of sugar per year, or about $1 million annually (1990 prices).

Since 1985, at least four new insect pests of sugar cane have become established in the State (90). The lesser cornstalk borer *(Ehsmopalpus lignosellus)* has exacted an estimated $9 million in lost yields and other costs since it appeared in 1986 (124). A parasitoid from Bolivia was established in 1991 and is now suppressing the borer in sugar cane fields.

Chemical controls are used on weeds, which are even more costly to the sugar cane industry than are insect pests (91). (Chemical pesticide manufacturers have generally not addressed the needs of Hawaii's agriculture, however, because of its small size and the expense involved in obtaining clearance for new pesticides by the Environmental Protection Agency.) Research costs for all types of pest control in the sugar cane industry in recent years have approached $1 million annually (table 8-4). Development of sugar cane resistance to recently introduced diseases, primarily sugarcane smut and rusts, accounts for another large portion of the industry's research (an estimated $400,000 in 1991 and 1992).

Table 8-4—Research Costs for Sugar Cane Pest Control in Hawaii, 1986-1992

Pest	1986-87	1988-89	1991-92
Weeds	$60,000	$214,000	$280,000
Rats	$104,400	$281,000[a]	$232,500[a]
Insects	$101,000	$224,600	$179,000
Diseases	$152,700	$208,000	$172,000
Total	$418,100	$927,600	$863,500

[a]includes $220,000 from USDA

SOURCE: Sugar industry Analyses, 1986,1988,1991.

Quarantines imposed on Hawaii's fresh produce because of established pest species have been a substantial cost to growers by limiting markets. The most serious market-limiting pests are the Mediterranean fruit fly *(Ceratitis capitata), the* melon fly *(Dacus cucurbitae),* and the Oriental fruit fly *(Dacus dorsalis),* known as the trifly complex (box 8-A). The financial impact of such quarantines are difficult to gauge; it has been conservatively estimated that Hawaii's export market could increase by 30 percent if quarantines on tropical fruits were lifted (46).

Ranching—Hawaii's pastures and rangelands are vulnerable to invasions by non-indigenous plants, such as the ornamental fountain grass (Pennisetum setaceum), which are unpalatable and lower livestock (primarily cattle) productivity. Grasses planted on rangelands themselves are imported and have been plagued by such pests as the army worm *(Pseudaletia unipuncta)* and grass webworm *(Herpetogramm lifsarsisalis). Since* its discovery in Kona in 1988, the highly invasive yellow sugarcane aphid *(Sipha flava)* has spread to all the islands and exacted several million dollars in losses annually from State ranchers and $200,000 in biological control research (124).

Seeds, grasses, and animal feed imported by ranchers are believed to have been the avenue for the introduction of some weeds, as in the case of broomsedge *(Andropogon virginicus) (27),* an invasive North American grass that is adapted to fire. Many sugar cane weeds are believed to have arrived in imported rangeland materials (91). Kikuyu grass *(Pennisetum clandestinum),* a rangeland cover imported from Africa, has itself become a weed in natural areas (109). Finally, browsing cattle have been a destructive force in natural forests and other habitats (27).

Ornamentals—The ornamental plant and floral industry in Hawaii has grown in recent years, although it too has been limited by quarantines on specific fresh products. Based predominantly on NIS, the industry has also been affected by new diseases and pests. A bacterial blight was responsible for a drop in revenues from anthuriums *(Anthurium* spp.), a shiny, brilliantly colored flower from Central America, and a lucrative commodity for the State ($8 million in 1988, the sixth largest crop). A sample of some 50 farms lost $5.5 million in 1987 revenue and $1.6 million in 1989 revenue because of the disease (124).

Two non-indigenous birds, the red-vented bulbul *(Pycnonotus jocosus)* and the red-whiskered bulbul *(P. cafer), are* responsible for significant damage to orchids, a leading product in the cut flower industry, as well as to fruits and other horticultural products. In 1989 the total cost of damaged orchids on Oahu, the only island to be invaded thus far, was $300,000 (46). Indigenous to India and prohibited from entry by State law, bulbuls probably were smuggled into Hawaii as pets, which then escaped or were released in the mid- 1960s.

In turn, horticultural activities have been responsible for much of Hawaii's non-indigenous plant problem. Several hundred non-indigenous plants introduced for landscaping or cultivation have escaped and become established (138).

One of Hawaii's worst weeds, the banana poka, a pink-flowered vine, was introduced as an ornamental early in this century and today infests about 100,000 acres of forest. It is notolious for engulfing indigenous trees, killing them or breaking branches and altering the understory. About $1 million in State and Federal funds was spent between 1981 and 1991 on research for the biocontrol of banana poka and Koster's curse

Box 8-A-Costs of Hawaii's Major Fruit Fly Pests and Their Eradication

Three of Hawaii's insect pests-the Mediterranean fruit fly (medfly) (Cetatitis capitata), the Oriental fruit fly (Dacus dorsalis), and the melon fly (Dacus cucurbitae)- were responsible for $300 million in lost markets in 1989, according to the Hawaii Agricultural Alliance. In addition, the so-called trifly complex cost $3.5 million in damaged produce and $1 miilion in fumigation of other postharvest treatments. The triflycomplex has "imposed strong constraints on the development and diversification of agriculture in Hawaii and has provided a large reservoir for the unwanted and increasingly frequent introduction of fruit flies into the mainland United States and other areas of the world viacontrabandfruit," accordingtothe Agricultural Research Service. Consequently, ARS is conducting a series oftechnology demonstration tests to help determine the feasibility of statewide eradication of the fruit fly pests.

The three flies became established in Hawaii beginning with the melon fly in 1895, the medfly in 1907, and the oriental fruit fly in 1945. Their establishment was aided by the spread in Hawaii of non-indigenous plants that serve as host plants for the pests. The medfly alone—considered one of the world's worst agricultural pests-infests 250 fruit and vegetable crops. A 1980-1982 effort to eliminate the medfly from seven California counties cost $100 million, acoording to the U.S. Department of Agriculture (USDA).

Cailfornia agricuitural interests have been strong proponents, if not the strongest, of the proposed eradication project in Hawaii, as well as of the inspection of first-class mail from Hawaii, since the islands are assumed to be a major source of medfly arrivals in California But preliminary DNAanalysis of medflies trapped in California during its 1989 and 1991 infestations indicates the flies very likely did notcome from Hawaii; genetically they resemble medflies from Argentina and Guatemala While the finding does not rule out the possibility that Hawaii may be a source of medfly introductions in the future, it also raises the possibility that Hawaii's role in medfly introductions to the mainland maybe overemphasized. Additional genetic studies should help clarify where new infestations are coming from and hence where resources should be targeted.

In the meantime, Hawaii'sfirst demonstration project, slated to end in 1993 at a3-year cost of $5 million, is attemptingto eradicate a large established medfly population on the island of Kauai through the release of sterile insects, although noeradication has been achieved with this technique alone; traps with lures and the insecticide malathion are expected to have to be used against the more abundant oriental fruit fly and melon fly. Demonstration projects for eradication of these fruit fly species are scheduled to run into the next century, at which point the decision is expected to be made on whether to proceed with statewide eradication.

Statewide eradication plans have been controversial becauseof concernsforpublic health, as well as for the diverse endemic fruit flypopulations in Hawaii, given the likely use ofinsecticide. Objections have also been raised over the enormous cost of such an undertaking-perhaps $200 million or more for medfly eradication alone-and, if it succeeds, the strong possibility that the pests could become reestablished unless Hawaii's and USDA's inspection and quarantine efforts are substantially improved. The Malaysian fruit fly *(Bactrocera latifrons),* which is also targeted in the eradication plans, was introduced as recently as 1983.

SOURCES: J.R. Carey, "The Mediterranean Fruit Fly In California: Taking Stock," *California Agriculture*, Jan.-Feb. 1992, pp. 12-17; W.S. Sheppard, G.J. Steck, and 6A. McPheron, "Geographic Populations of the Medfly May Be Differentiated by Mitochondrial DNA Variation; *Experientia*, vol. 4S, No. 10, October 1982, pp. 1010-1013; U.S. Department of Agriculture, Agricultural Research service, Tropical Fruit and Vegetable Research Laboratory, "I. ARS Perspective for Fruit Fly Eradication in Hawaii and Pilot Test Requirements for Demonstration of Technology," and "II. Pilot Test to Eliminate Mediterranean Fruit Fly from the Islands of Kaual and Nihau: Detailed Work Plan," drafts (Honolulu, Hi: December 19S9); R.I. Vargas, research scientist, ARS, personal communications, Dec. 18,1991, Feb. 10,1992.

(Clidemia hirta), another forest weed (46) (table 8-2); additional sums are spent by public and private groups in pulling weeds or applying herbicide. A 2-year poka eradication effort on Maui **was** allotted $244,000 by the State (56).

Other ornamental that have escaped to become problems in natural areas are the fire tree *(Myrica fava),* fountain grass (table 8-2), and other grasses. In some cases, botanic gardens have been the source of the escapees (109). For

example, the velvet tree *(Miconia calvescens), an* incipient invader described as the botanical equivalent of rabbits, probably escaped from a private botanic garden.

TOURISM

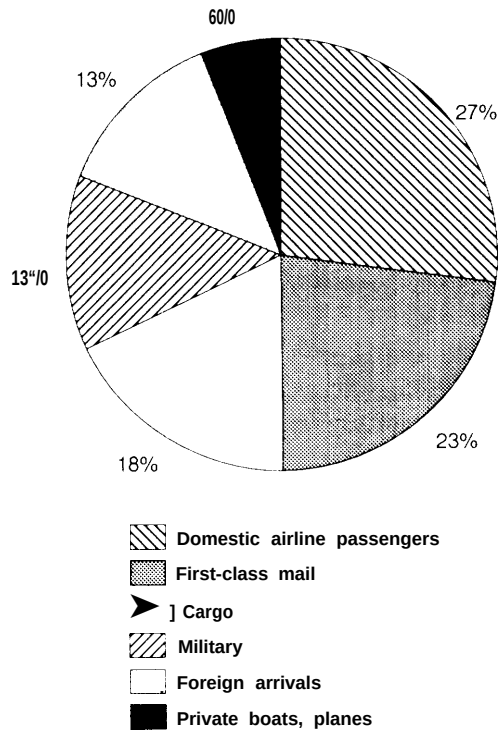
The large volume of traffic associated with tourism is often cited as a factor behind the influx of harmful NIS to the islands. At the same time, the $9.9 billion visitor industry (in 1991) is the State's biggest source of revenue and largest employer. Consequently, some observers believe there has been resistance in Hawaii to implementing controls that may be perceived as deterring visitors.

The number of visitors in 1990 was 6.9 million, according to the Hawaii Visitors Bureau, an increase of about 50 percent from 1980. Most of the visitors are from the U.S. mainland and Canada, especially the West Coast, with an increasing number from Japan. The remainder come from other countries in Asia and western Europe (78).

According to an opinion survey of State agriculture inspectors, airline passengers are thought to be the most common pathway for insect pests and illegal animals to be introduced, on undeclared plants hidden in carry-on or checked baggage (49) (figure 8-l). For domestic arrivals, this pathway may become less important if a 1992 State law is well enforced. Previously, the State's agricultural declaration process was easily bypassed; the law now requires all passengers to fill out a declaration form, with increased penalties for bringing in prohibited organisms.

Development catering to the large number of visitors may also contribute to the NIS problem by disturbing natural habitats, providing inroads for invasive species. Unauthorized importations of grass materials for golf courses are thought to be the inadvertent avenue for the recent increase in the number of introductions of sugar cane (also a grass) and rangeland pests (91,124). The yellow sugarcane aphid, for example, was first found in 1988 near a new golf course development.

Figure 8-l—Perceived Importance of Pathways in the Introduction of Insect Pests and Illegal Animals in Hawaii



SOURCE: Based on an opinion survey of State agriculture inspectors in the Department of Agriculture, State of Hawaii, Honolulu, "Report to the 15th Legislature, 1989 Regular Session."

Many observers point out that Hawaii's tourism depends on the unique natural beauty of the islands and that it would be harmed if the indigenous natural resources are further diminished by harmful NIS (12,78). But there is also said to be little emphasis within the visitor industry on ecotourism or the distinctiveness of Hawaii's indigenous plant and animal life (109,113). Resorts and residences are typically landscaped with tropical plants from around the world: bougainvillea *(Bougainvillea buttiana)* (from Central America); bird-of-paradise flower *(Strelitzia reginae)* (from Africa); palms from other tropical areas. Even the traditional Hawaiian lei is usually made with non-indigenous plants.

MILITARY

Defense spending accounts for about $2 billion, or 10 percent, of State revenues, the second largest share. The military is also believed to be a significant contributor of new introductions to the State and among the islands (figure 8-1) because of the large volume of traffic associated with it. Military personnel traveling from Fiji may have been responsible for the introduction of bulbuls, for example (135).

Military transport in recent years is thought to have been responsible for bringing in from Guam one of the most serious non-indigenous pest threats to Hawaii, the brown tree snake *(Boiga irregulars).* Although the snakes were dead or seized, the possibility of their introduction remains a serious concern (box 8-B), especially with the relocation of military personnel from closed bases in the Philippines to Singapore and Guam. Traffic between Guam and Hawaii is projected to increase accordingly (1 1).

OTHER SECTORS

Two additional groups are often highlighted for their impact on the NIS problem in Hawaii: sport hunters and pet keepers.

Sport hunting—All of the legally hunted game birds and mammals in Hawaii are introduced, and the maintenance of these populations—including feral ungulates-has often conflicted with conservation of natural areas. Negative impacts on natural areas have been documented for many of the game species (27). The kalij pheasant *(Lophura leucomelana),* for example, feeds on and disperses the seeds of the invasive banana poka, enhancing its spread. Game and other non-indigenous birds are also the source of introduced diseases afflicting indigenous birds (131). On the other hand, sport hunting provides the State with one means of reducing feral ungulates and generates almost $100,000 annually from the sale of licenses (51).

The conflict may have peaked in 1988, when a Federal court found that the State Department of Land and Natural Resources had "demonstrated susceptibility" to hunters by not protecting the habitat of one of Hawaii's endangered birds, the palila *(Loxioides bailleui),* from destruction by feral goats and sheep (120). Under the ruling, the State was required to remove the animals from the palila's habitat (see ch. 7). More recently, the State has begun to address the issue of feral ungulate removal from other especially sensitive natural areas (86).

Pet trade-Animals escaped from their cages or dumped by their owners are a common source of vertebrate introductions today, particularly of birds and reptiles (80). Several species of aquarium fish have also found their way into Hawaii's streams (71). According to the Hawaii Department of Agriculture, about 22,000 birds from U.S. and foreign sources were imported in 1989, primarily for pet stores. They also sell thousands of rabbits *(Oryctolagus cuniculus)* each year.

In October 1989, a resident released six unwanted rabbits at Haleakala National Park. Feral rabbits can severely damage indigenous plants and birds (by attracting predators), and the rabbits' eradication became the park's top priority once the population was discovered. By May 1991, 100 rabbits had been snared, shot, or trapped. The emergency eradication cost $15,000 (National Park money) (66). Although the rabbits were considered eradicated in 1992, future releases of escaped pets are expected to be a recurring problem, with no Federal, State, or island agency mandated to prevent rabbits from establishing (67).

Searching for Solutions

Finding:

Hawaii's geographic isolation makes it the state most in need of a comprehensive policy to address NIS—virtually a separate "national" policy with its own programs and resources. The greatest challenge is to coordinate this need with Federal priorities, which can differ. For example, Federal port inspections and

Box 8-B—The Potential Invasion and Impact of the Brown Tree Snake in Hawaii

The brown tree snake has been singled **out as one of the more serious-and perhaps imminent-new biological invasions facing Hawaii. It also illustrates how approaches** to such threats are often cobbled together, with unclear lines of authority or responsibility among agencies.

Indigenous to the Solomon Islands, Papua New Guinea, and northern Australia, the snake *(Boiga irregulatis)* has been accidentally dispersed-usually as a stowaway on planes and ships-to several Pacific Islands, including Hawaii. So far, however, the snake is only known to be established on Guam, where the social cost has been great and the ecological impact disastrous.

As on most Pacific Islands, the indigenous birds of Guam evolved in a snake-free habitat (the island has only one small, blind, wormlike snake species) and consequently lack the protective behaviors of other birds. They were easy prey for the bird- and egg-eating brown tree snake when it arrived sometime around 1950. Of 11 species of indigenous forest birds present in 194&some of which were unique to the island-9 have gone extinct on Guam. The remaining species have been drastically reduced. Experts attribute the extinctions and declines to the brown tree snake.

Along with birds, the snake also feeds on introduced rats and shrews, whose numbers have also declined. Today the snake is sustained primarily by introduced lizards. The large number of introduced species and other ecological disturbances on Guam have facilitated the snake's invasion of the island. With a diverse and vulnerable prey base and no natural predators, the snake population has soared, reaching densities of 10,000 to 30,000 per square mile.

An able climber, the brown tree snake damages power lines, frequently interrupting service and costing Guam millions of dollars a year. Although it is not considered dangerous to human adults, it is mildly venomous and can poison small children. During a 14-month period in Guam, 27 people were treated for snake bites at one hospital emergency room. The 8-foot-long adult snake commonly enters homes through sewer lines, air conditioning vents, and other openings.

Several characteristics of the brown tree snake make it a likely candidate for invading other islands from Guam. "It is tolerant of disturbed habitats and can maintain dense populations near shipping ports. it is nocturnal [hiding during the day] and readily escapes detection in or around cargo. It is able to live for long periods of time without food, and is thus able to survive for long periods in ships' holds or cargo bays of aircraft. Finally, the broad range of feeding habits ensures that snakes arriving in new environments will adapt to available lizard, bird, and mammal prey species and will therefore be likely to successfully colonize [a new] island" (32). Several reports in 1992 of snake sightings on Saipan in the Marianas, a U.S. Trust Territory, have raised suspicions that the brown tree snake may be colonizing that island.

The increased threat to Hawaii-where the climate is hospitable, habitats have been extensively disturbed, and many indigenous and introduced species exist as a potential prey base-is seen to be the result of t he high snake densities on Guam and t he frequent number of military and civilian flights from the island. The brown tree snake has turned up in Hawaii at least six times between 1981 and 1991, at Honolulu International Airport, Barbers Point Naval Air Station, and Hickam Air Force Base. Two snakes were found on the same day in September 1991: one crushed on an airport runway, the other live, coiled underneath a military transport that had arrived 12 hours earlier.

Pest problems are best contained by interceptions at the points of departure, and inspection of military flights departing Guam for Hawaii (typically five per week) is said to have been tightened as awareness of the threat has increased. Jurisdictional questions remain, however, about inspection of the 10 to 15 civilian flights per week-whether it is a Federal, Territorial, or State (Hawaii) responsibility. Such questions have resulted in a generally uncoordinated response to the problem.

(continued on next page)

Box 8-B-The Potential Invasion and Impact of the Brown Tree Snake in Hawaii-Continued

The main vehicle for the Federal Government's response has been a line item in the budget for the Office of Territorial and International Affairs in the Department of the Interior. Beginning in 1990, the office has received $500,000 to $600,000 **annually for brown tree snake** research and control, with $100,000 to$200,000 earmarked for the Hawaii Department of Agriculture, to explore the use of dogs in detecting snakes. The remainder has been disbursed to Guam; a Fish and Wildlife Service research program; and, beginning in fiscal year 1992, the Animal Damage Control unit of the U.S. Department of Agriculture's Animal and Plant Health Inspection Service. Also beginning in 1992, the Department of Defense (DOD) was appropriated $1 million in new money for brown tree snake research and control, in addition to funds available for the brown tree snake through its Legacy program (which provides for natural resources management on DOD lands).

In addition to these appropriations, Congress has addressed the brown tree snake in several pieces of legislation. The Nonindigenous Aquatic Nuisance Prevention and Control **Act (NANPACA) of** 1990,[1] which focuses on the zebra mussel, directs that a program be developed to control the snake in Guam and other areas. Two other bills direct that the Secretary of Defense[2] and the Secretary of Agriculture[3] take steps to prevent the introduction of the brown tree snake into Hawaii. In Hawaii, in addition to the federally funded airport dog teams for snake detection, State-run SWAT teams have been established on each of the islands to respond in the event of snake sightings.

Despite these actions-as well as a memorandum of agreement intended to coordinate the various State, Territorial, and Federal departments involved-the overall Federal response to the brown tree snake is perceived in Hawaii to have been uneven and sometimes slow. **A** committee to carry out the NANPACA-directed activities was not in place until 1993, and no agency has taken on the crucial task of inspecting civilian aircraft in Guam before departure.

Ultimately, safeguarding Hawaii and the Pacific basin will depend on establishment of long-term control on Guam. Research by the Fish and Wildlife Service is aimed at an ecological control, along with more immediate controls such as the use of methyl bromide for fumigating cargo and the use of toxicants, baits, and traps. Costs for the various controls that would need development have been estimated to be about $2.5 million annually over several years.

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1 P.L. 101-646, sec. 1209.

2 Department of *Defense* authorization, P.L. 102.190, sec. 348.

3 Farm Bill Technical Corrections, P.L. 102.237, see, 1012.

SOURCES: T.H. Fritts, U.S. Fish and Wildlife Service, *The Brown Tree Snake: A Harmful Pest Species* (Washington, DC: U.S. Government Printing Office, 1988); J. Engbring and T.H. Fritts, "Demise of an Insular Avifauna: The Brown Tree Snake on Guam," *Transactions of the Western* Section *of the Wildlife Society,* vol. 24, 196S, pp. 31-37; T.H. Fritts, personal communications to the Office of Technology Assessment, Jan. 10, Jan. 30, and December 1992; G.R. bong and P. McGarey, legislative assistants to Sen. D.K. Akaka, personal communications to Office of Technology Assessment, Jan. 6, 19S2, and Dec. 3,1992, respectively; P. Delongchamps, Office of Territorial and International Affairs, personal communications to Office of Technology Assessment, May 22 and December 1992; L Nakahara, Plant Quarantine Manager, Hawaii Department of Agriculture, personal communication to Office of Technology Assessment, Apr. 16,1992 and June 23, 1993.

quarantines are directed at protecting mainland agriculture and enforcing international trade agreements, sometimes at the expense of Hawaii's natural resources and agriculture.

FEDERAL INVOLVEMENT

Hawaii's experience with NIS is also distinctive in terms of Federal involvement. Hawaii is the only State where all passengers and cargo enroute to other States (to the U.S. mainland) are subject to "preclearance activity" by Federal agricultural inspectors, a function of Hawaii's geographic isolation and a Federal quarantine imposed before Hawaiian statehood. Agricultural inspection of traffic from the mainland to Hawaii, however, is for the most part left to the State; the

nature of mainland pest problems do not meet the existing criteria to warrant Federal inspection of Hawaii-bound passengers and goods.

The domestic quarantine on Hawaii has in turn led to Federal inspection of first-class mail leaving Hawaii and a recent proposal (which failed) to collect inspection fees from passengers departing the State for the mainland, The Federal intent of all these actions, along with the proposed fruit fly eradication program (box 8-A), has been protection of mainland agriculture. An unintended effect, however, has been creation of a double standard, since reciprocal protective measures have not been applied to Hawaii. In 1992, Congress took action to begin to redress this imbalance; any changes in the system have yet to be evaluated.

Details about the Hawaii quarantine, inspection fee, and first-class mail issues follow.

Hawaii quarantine—Passage of the Plant Quarantine Act? led to the quarantine of Hawaii to prevent importation of the Mediterranean fruit fly and other agricultural pests.[5] The U.S. Department of Agriculture (USDA) began inspecting goods bound for the U.S. mainland in 1910 and goods arriving in the islands from foreign ports in 1949. Hawaii's own plant and animal quarantines were begun before the turn of the century.

The Federal quarantine regulations stipulate that cargo and passengers from Hawaii to the U.S. mainland are to be inspected by USDA's Animal and Plant Health Inspection Service (APHIS) for prohibited materials (fresh produce, cut flowers, and other plant materials). Certain products are allowed provided they are treated or handled according to prescribed methods to kill any pests.

This preclearance activity, aimed at preventing pests *from* reaching the mainland, accounts for about 85 percent of APHIS Plant Pest Quarantine activity in Hawaii (106). Inspection of ships and planes arriving from foreign countries accounts for 15 percent. The division of resources is said to be roughly proportional to the number of domestic and foreign passengers.

APHIS inspection of foreign arrivals focuses on federally prohibited agricultural pest species, which in turn reflects the temperate climate that predominates in the United States (1 10). This policy may allow new pests into Hawaii that could otherwise be avoided, For example, State officials tried unsuccessfully to have a mealybug pest *(Pseudococcus elisae)* of bananas declared a federally prohibited species after it repeatedly turned up in the mid- 1980s on bananas from Central America that were shipped from the U.S. mainland, where they are inspected by APHIS. The mealybug eventually slipped into Hawaii, became established, and has resulted in lost markets: California rejected shipments of cut flowers from Hawaii because of mealybug infestation (124).

Since the State has no authority over foreign traffic, State agricultural inspectors rely on Federal inspectors (table 8-3) for referrals in order to intercept State-prohibited species. Cooperation among the agencies in this regard is generally said to be good, although neither State nor Federal inspection staffing has kept pace with the growth in traffic through Hawaii in recent years. Between 1971 and 1988, for example, State inspection activities on Oahu increased by a total of 138 to 1000 percent, while staffing increased by 15 percent (49). In the last 5 years, APHIS has received less than its requested budget, and staffing has remained constant, although the 1992 budget allowed for an increase (52).

Over the past decade, Customs has undergone a change in policy, from one of inspection of all foreign arrivals to "profiling'' —inspection of only a fraction of arrivals-in order to facilitate the movement of passengers. In Honolulu, which is said to be one of the stricter ports of entry into the United States, APHIS and Customs each

[4] Plant Quarantine Act of 1912, as amended (7 U. S.C.A. 161)

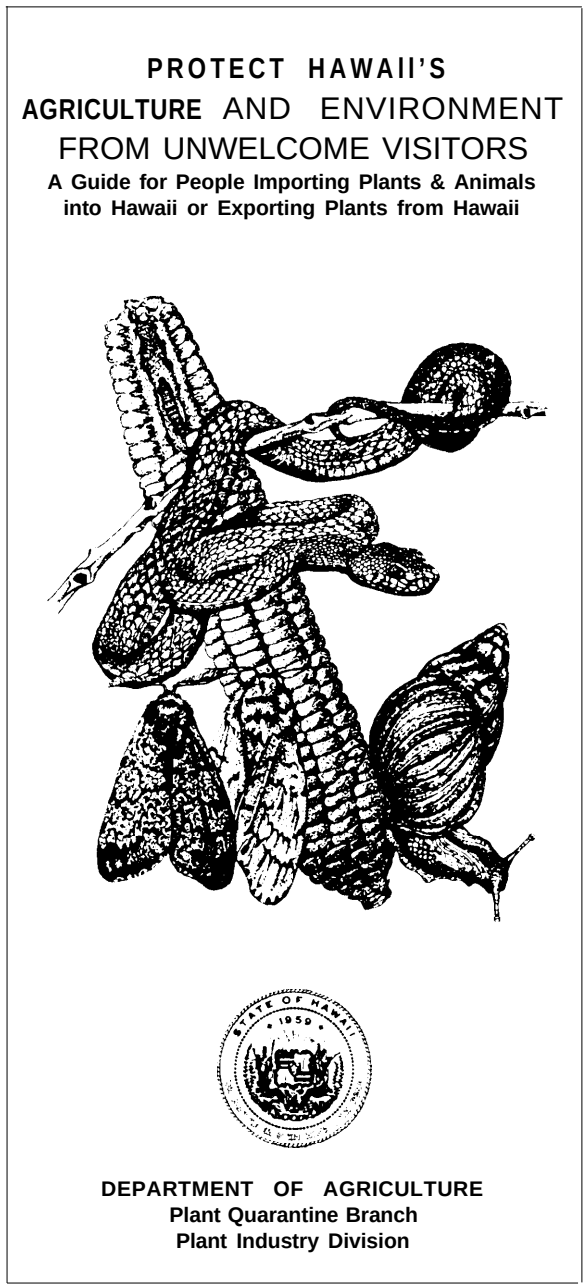
[5] 7 CFR Ch. III part 318 (Jan. 1, 1991).

manage to check about 15 percent of the international baggage passing through the airport. (A goal is to check all of the baggage originating from high-risk areas such as the Philippines.) In contrast, APHIS inspects all of the baggage bound for the mainland by x ray. Many observers maintain that goods and people coming into Hawaii should be as thoroughly inspected as is mainland-bound baggage to minimize the flow of unwanted new species into the State and, in turn, the rest of the country.

Pests found on the U.S. mainland may be as threatening to Hawaii as those brought in from foreign points of origin: seven of the eight new insect pests of grasses that have appeared in Hawaii in the last decade occur in the continental United States, including the economically important yellow sugarcane aphid and the lesser cornstalk borer (124). The transit of goods and people from Florida and the Caribbean through the mainland to Hawaii is thought to be an increasingly common pathway of harmful new pests (7).

Domestic quarantine user fees-In 1991, APHIS proposed to collect user fees from inspected passengers and vessels departing Hawaii for the mainland. The user fee, of $2 per passenger, was intended to cover the cost of agricultural inspections,[6] in order to meet deficit reduction goals. The fee would have been similar to the fees collected by U.S. Customs and Immigration and Naturalization services.

But the fee was interpreted as a "tourist tax" that discriminated against Hawaii, being the only State subject to domestic agricultural quarantine and inspection activities. After the rule had been made final,[7] the Hawaii congressional delegation took the unusual step of inserting a provision in the 1992 Federal budget that prohibits such domestic inspection user fees (45). Again, the proposed action was seen as benefiting the



Inspections of foreign arrivals are intended to intercept harmful non-indigenous *species, while educational materials are often aimed at decreasing the number that reach inspection stations.*

[6] **56** *Federal Register 8148* (Feb. **27, 1991).**

[7] **58** *Federal Register 18496* (Apr. 23, 1991).

mainland at the expense of Hawaii's tourists and residents.

First-class mail—First-class mail and express mail delivery services have been identified as an important pathway for the introduction of new pests to Hawaii (figure 8-l). Plant material mailed into the State is possibly responsible for the introduction of the large number of whiteflies established in the last 25 years, since these pests can only be transported long distances on living plants (7). Similarly, prohibited seeds, plants, fruits, other insects, and small animals have all made their way into Hawaii through the mail,

Prohibited materials have been intercepted only when suspicious packages were noticed and the State informed, since domestic first-class mail is federally protected from inspection. (Foreign mail may be inspected.) Congress, however, following passage of the Agricultural Quarantine Enforcement Act,[8] which prohibits mailing of quarantined agricultural material, authorized a trial frost-class mail inspection program in Hawaii, but only of pieces departing for the mainland. The intent was to determine if fruit flies were arriving *on the* mainland through domestic first-class mail.

The trial program, originally proposed to run for 60 days at a cost of $30,000 in USDA funds, involved use of an APHIS dog at the main Honolulu post office to sniff parcels for any biological material. Reportable fruit flies, the target of the program, and other insect pests were found on produce seized from 130 parcels (94), most of which were bound for California, Oregon, or Washington. According to another report on the program, fruit flies were found in 29 of the 2 million packages processed between June and October 1990; five contained the Mediterranean fruit fly. The report concluded that frost-class domestic mail from Hawaii is a means of transport for the medfly larvae, ''but that the rates are low" (16).

The trial program has been indefinitely extended, entailing three additional staff positions (107), at an estimated cost of $100,000 annually. The use of Federal funds to conduct the one-way inspection was again perceived as discriminatory in Hawaii, given the importance of frost-class mail as a pathway for introduction to the islands (93). Consequently, legislation readdressing the issue for Hawaii was introduced and signed in 1992. The Alien Species Prevention and Enforcement Act[9] is intended to prevent the introduction of *new pests* to Hawaii through first-class mail by allowing inspection of incoming parcels as well.

With each of these issues, the historical lack of reciprocal protection for Hawaii's agriculture and especially for the large number of federally listed endangered species has created the perception of a Federal bias, with the $17 billion California agriculture industry seen as the primary beneficiary. It is frequently observed as well that the growing national interest in conserving tropical forests in the developing world should be extended to U.S. tropical forests—namely, those in Hawaii (2,85).

A greater Federal role in protecting Hawaii from new damaging introductions may also be warranted because of the large military presence in the State. All military arrivals from foreign ports, as well as military departures for the mainland, are inspected in Hawaii under the authority of Customs and APHIS. Military customs inspectors collaborate with APHIS on foreign arrivals and routinely spray plane cabins with insecticide. Military arrivals from the mainland, however, are a State responsibility, and inspections are said to be limited (49).

On the other hand, the Federal Government—namely the National Park Service-has been considered the most effective manager in terms of

[8] Agricultural Quarantine Enforcement Act of 1988, Public Law 100574.

[9] Alien Species Prevention and Enforcement Act of 1992, Public Law 102-393, Part 3015.

preserving Hawaii's habitats through the control of harmful NIS (1 12,1 14).

Finding:

The National Park Service devotes considerable resources to eradicating or controlling harmful NIS in Hawaii within and outside park boundaries. The impact of these efforts are limited, however, because State management on its own lands has been less aggressive. Influx of a significant number of new species annually, despite Hawaii's relatively strict system of regulating introductions, compounds the problem.

STATE ROLE

State laws governing the entry of new plant and animal species specify protection of agriculture, the natural environment, and public health. Natural resources, however, are said to rank behind agriculture and other economic issues, especially tourism, as a priority for the State (61,108). Comparison with other States' spending levels bears out this observation.

Hawaii's Division of Forestry and Wildlife in the Department of Land and Natural Resource, which oversees the State-owned natural areas (table 8-3), ranks 8th out of 50 States in terms of the area it is responsible for (900,000 acres), but 38th in permanent staff and 45th in funding (13). Similarly, Hawaii ranks 44th in terms of its annual expenditures on natural resources and the environment (0.85 percent of the State budget), although this ranking may reflect the State's small size and relative lack of 'brown' environmental problems associated with heavily industrialized States. In per capita spending, it ranks 29th ($25.35) (10).

Hawaii spends almost $1.9 million annually on its agricultural quarantine program, 90 percent of which involves inspection of incoming passengers and goods and other preventive measures (50,124). But coverage of incoming traffic to the islands is still incomplete. A 1989 assessment by the Hawaii Department of Agriculture estimated that the additional cost of extra staffing and 16 x-ray units (for 16 baggage claims) to ensure complete inspection of incoming domestic baggage alone would be about $2.25 million (49). In contrast to Federal inspection of mainland-bound baggage, which is all x rayed, State inspectors have relied on agriculture declaration forms to bring to light any incoming produce, plants, or animals.

Opinion differs on the efficacy of the State's importation and quarantine system. In one high-profile example, the importation of Christmas trees each year, the likelihood of harmful new insect introductions has taken a backseat to a traditional societal demand. Because there is no effective fumigant that does not damage the trees, they are only visually inspected. Christmas trees were very likely the vehicle on which yellow jackets arrived in Hawaii, as might gypsy moths *(Lymantria dispar),* according to some observers.

Other prevention efforts are improving. In 1990, State inspectors began to use beagles to sniff baggage and cargo arriving from the mainland. Use of one portable x-ray unit for random inspection of domestic baggage was also instituted. Penalties for smuggling in prohibited species have been substantially increased, and the State list of prohibited plant species is being updated for the first time in 10 years. To emphasize protection of natural areas, the Department of Land and Natural Resources, with the support of environmental groups, is exploring the possibility of creating a separate list of State-prohibited plant species that threaten natural areas.

Many observers point out that the most cost-effective approach to dealing with new pests anywhere is to prevent their introduction (86). Hawaii clearly needs tightened inspection and quarantines to minimize the number of harmful new introductions. Neither State nor Federal efforts have been up to the task.

Harmful new introductions are expected to be reduced once the recently authorized program for inspection of first-class mail from the mainland to Hawaii is in place. New pests could be further reduced by inspection of:

In 1990, *State inspectors began using beagles to sniff baggage and cargo for prohibited soil, agricultural products, and other biological materials.*

- all arriving domestic airline passengers and baggage. Complete inspection by x ray or beagles would require reconfiguration of Honolulu's airport, or that agricultural monitoring be made along with security checks at the main U.S. points of departure for Hawaii. Federal involvement in domestic arrival inspections would require a change in APHIS's mandate; complete inspection by the State would require a redoubling of current efforts and a clarified legal mandate.
- military transport arriving from the mainland, requiring increased State effort and/or military effort or a change in APHIS's mandate.
- all arriving international airline passengers and baggage. Complete inspection by x ray or beagles would require increased APHIS staffing and airport reconfiguration.

A more controversial option, because of objections by the public to pesticides, would involve treating planes arriving from the Pacific region with insecticide, since visual inspection of a plane is not fail-safe. Such treatment was once routine for mosquito (malaria) control.

Shortcomings exist in the State's efforts to control and eradicate NIS. Responsibility is divided, depending on the type of species (insect, plant, or other animal); whether it has an economic impact; and where the infestation is occurring. Response to emergencies is said to be slow for this reason. The jurisdictional difficulties of controlling pest species on private land is a particular problem (86).

Monitoring to detect pests before they become too widespread to eradicate is also incomplete. The Hawaii Department of Agriculture maintains a program using traps, sweepings, and surveys to detect new insect pests, but there is no clear authority for monitoring in cases like feral rabbits.

EDUCATION

Finding:

Public education is considered central to solving problems involving NIS in Hawaii. These efforts are better developed in Hawaii than elsewhere in the United States.

Education is repeatedly cited as the primary tool for enlisting the public's cooperation in containing the problem of harmful NIS. The state of public understanding about the issue in Hawaii is probably no different than anywhere else, but the ecological repercussions of a lack of public understanding are more severe, as in the case of the released rabbits in Haleakala National Park.

The rabbit case also indicates how effective public education can be. Park-generated publicity and media attention resulted in calls from the public about rabbit sightings. The pet owner

responsible for the release was unaware of the rabbits' impact and was said to be apologetic. The incident led to a proposal to create a National Park Service public outreach position devoted to such issues. The idea was praised, although it did not receive funding.

Other public and private groups in Hawaii have begun educational campaigns related to NIS, including the Alien Species Alert Program (ASAP) of the Hawaii State office of the National Audubon Society; publicity about prohibitions of mailing fruits and vegetables to the mainland by the USDA and the U.S. Postal Service; informational outreach about indigenous species by the Division of Forestry and Wildlife; and the Bishop Museum's Ohia project (named for a common indigenous tree), a grade school curriculum designed to increase understanding of Hawaii's ecology.

In February 1992, the Hawaii Department of Agriculture publicized a l-week amnesty program encouraging residents to turn in illegal animals. The campaign netted 53 animals, including snakes, other reptiles and amphibians, harvester ants, hamsters, and birds (82).

The traveling public is singled out as an important target for educators. As one botanist puts it: "Tourists come for the scenery, but unless they've been educated, they won't care if the plants are native or not, just as long as the hills are green. There has been little effort to inform visitors of Hawaii's NIS problem by posters, amnesty buckets, or other means upon arrival, although a State-funded educational video began to be shown on flights of a few domestic carriers in 1992.

The brief video ("It Came From Beyond") takes a decidedly friendly approach to informing visitors about NIS and is expected to reduce the number of ''innocent' introductions; some observers believe a stern approach emphasizing the law with its steep fines and penalties is necessary to reduce the potentially more harmful flow of smuggled species, which are probably more commonly brought in by residents with commercial or hobby interests.

Educational efforts in Hawaii also need to be developed and targeted to the State's diverse cultural and ethnic groups. An edible gourd-producing vine *(Coccinia grandis)* that has recently become a weed in Hawaii might have been intentionally brought in as a delicacy from Southeast Asia, for example.

COOPERATIVE EFFORTS

Finding:

In recent years, various groups in Hawaii—from State and Federal agencies, nongovernmental organizations, agriculture, and universities—have taken a strong interest in NIS. Increasingly, they view harmful NIS as a unifying threat.

Awareness of the widespread impact of damaging NIS in Hawaii has prompted a high degree of cooperation across diverse groups. One such effort involves an interagency agreement to research the biological control of forest weeds, an area that no agency was adequately addressing despite the spread of weeds like banana poka. The agreement involves the National Park Service; U.S. Forest Service; Hawaii's Division of Forestry and Wildlife and Department of Agriculture; and the University of Hawaii.

There is growing interest in Hawaii in expanding interagency cooperation to address the larger jurisdictional and informational gaps in the present system. Most of the agencies involved are supporting a plan by the Nature Conservancy of Hawaii and the Natural Resources Defense Council on improving interagency cooperation (86) (box 8-C). A single interagency system may prove more effective for Hawaii's particular needs than applying stop-gap measures to the existing approach.

NON-INDIGENOUS SPECIES IN FLORIDA

Finding:

The problems caused by non-indigenous species (NIS) in Florida are among the most severe in the United States. Certain features of

Box 8-C-A View From Hawaii: Recommendations of the Nature Conservancy and Natural Resources Defense Council

In 1992, the Nature Conservancy of Hawaii and the Natural Resources Defense Council released a detailed analysis of the "alien pest species invasion in Hawaii" and offered a plan to create a coordinated multiagency response to the problems, to be led by the Hawaii Department of Agriculture. It does not, however, advocate centralizing all inspection or other activities under one agency. The report stresses public education and involvement in curbing Hawaii's pest problems and identifies the following areas that need initial attention:

. Pre-entry prevention, Visa applications, importation permits, travel and tourist materials, mail order and shipping instructions, and similar materials should be reviewed with an eye to stopping pests at their origin. Similarly, international inspections and trade agreements should be reviewed and improved.
. Port-of-entry sampling and inspection. Methods for sampling and inspection should be developed to meet a standard of pest interceptions.
- Statutes, policy, and rules. Conflicts and gaps in authority should be identified and resolved. A clear system for allowing and prohibiting species should be created.
. Rapid response. Specific plans for dealing with new infestations should be created, including central reporting mechanisms, staffing and equipment concerns, contingency funding, and identification of priority pests.
- Statewide control. Federal, State, and private groups should collaborate in developing strategies to isolate or eradicate selected major pests.

The report further identifies several long-range needs, namely, joint training among agencies for inspection and response activities, coordinated information systems, coordinated research for prevention and control methods, and expanded public awareness campaigns. The pest prevention and control systems of New Zealand and Australia are highlighted as instructive models for Hawaii (see box I-D).

SOURCE: The Nature Conservancy of Hawaii and Natural Resources Defense Council, "The Alien Pest Species Invasion in Hawaii: Background Study and Recommendations for Interagency Planning," July 1992.

the State have contributed to the problems: the subtropical climate; major ports of entry; burgeoning pet, aquarium, and ornamental plant industries; high rates of human immigration; increasing urbanization; and extensive environmental manipulation.

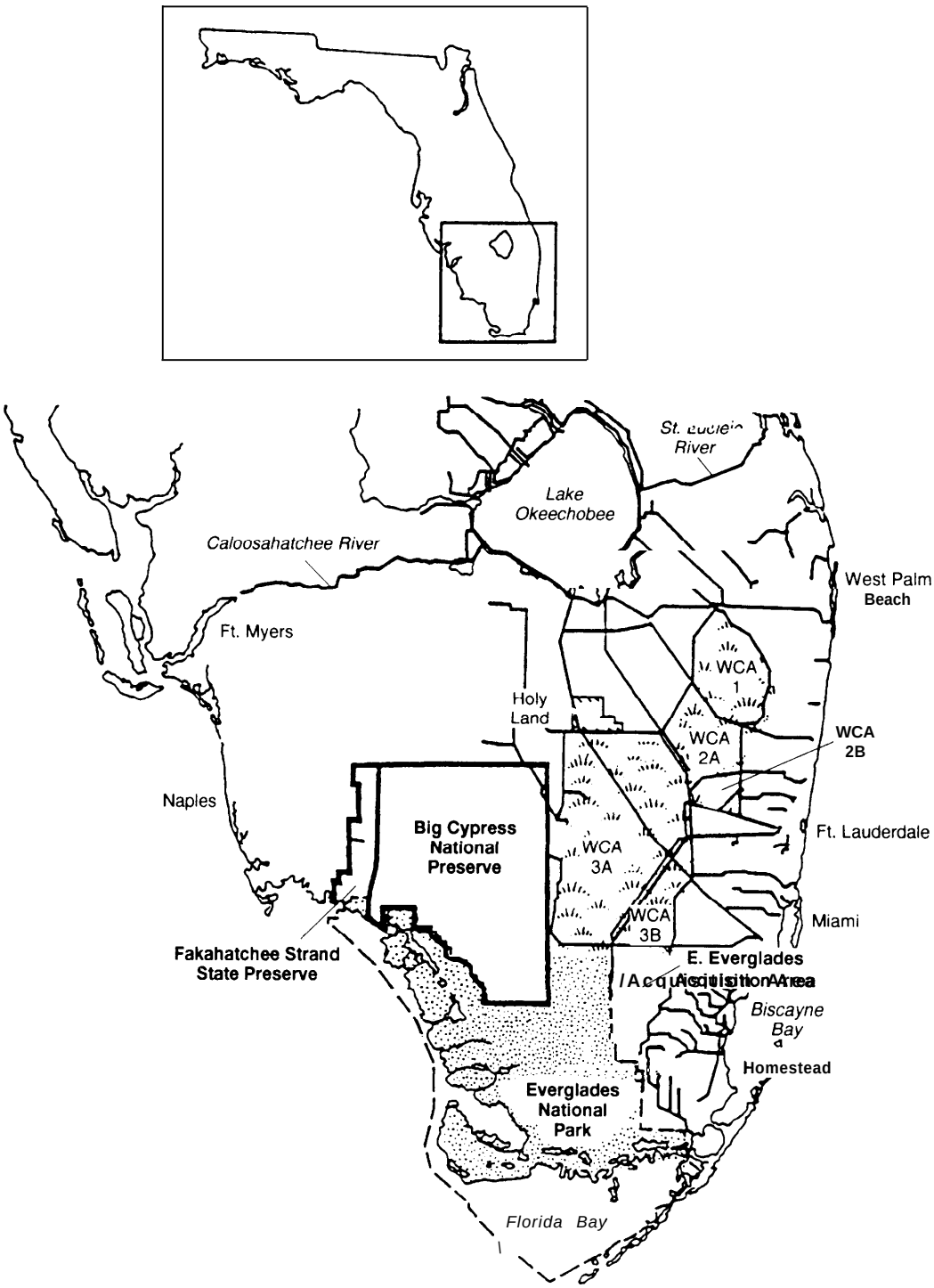
The Nature of the Problem

Florida is renowned for its mild climate, abundant waterways, beaches, and other natural attractions. Its freshwater lakes and streams afford recreation, navigation, commercial fishing, and wildlife habitat (57). Its major forest types, various mixtures of oak and pine (22), are crucial for wildlife as well as timber. South Florida contains one of the largest complexes of preserved ecosystems in the eastern United States, totaling about 3,500 square miles: Everglades National Park, Big Cypress National Preserve, Loxahatchee National Wildlife Refuge, and Fakahatchee Strand Preserve (figure 8-2).

South Florida also contains troublesome infestations of several aggressive non-indigenous plants, most of which were deliberately introduced (30). The State has approximately 925 established non-indigenous plant species (130). Non-indigenous plants and land mammals constitute about 25 percent of all species in the State (table 8-5). Sixty-three percent of the introduced non-indigenous bird species in the continental United States are found in Florida (l), which also has the largest number of established non-indigenous amphibian and reptile species in the United States (136).

Non-indigenous species cause severe ecological, economic, and resource management prob-

Figure 8-2—Protected Areas in Southern Florida



SOURCE: Adapted by OTA from M. Bodle, South Florida Water Management District, West Paim Beach, FL.

Table 8-5-Estimated Numbers of Non-Indigenous Species in Florida

Group	Established NIS	Total species
Plants.	≈9	3,450
Insects	271	
Freshwater snails .	6	98
Land snails	40	140
Freshwater fish . . .	19[a]	80
Amphibians , ...	3	55
Reptiles	22	100
Birds	11[b]	607[c]
Land mammals . . .	17	70

a Described as "established" and including one transplant; 4 other species are "possibly established," 9are "formerly reproducing," and 41 are "collected without evidence of reproduction."
b Although only 11 are considered established, at least 140 have been classified as "free-flying exotics."
c Many birds found in Florida are migratory and do not breed there.

SOURCES: Compiled by the Office of Technology Assessment from: R. Ashton and P. Ashton, *Handbook of Reptiles and Amphibians of Florida,* Parts 1,2,3 (Miami, FL: Windward Publishers Inc., 1981, 1985, 1888); J.H. Frank and E.D. McCoy, "The Immigration of Insects to Florida, With A Tabulation of Records Published Since 1970," *Florida Entomologist*, vol. 75, No. 1, 1992, pp. 1-28; J.N. Layne, Checklist of Recent Florida Mammals, MS, 1987, 10 pp.; W.B. Robertson, Jr. and G.E. Woolfenden, *Florida Bird Species: An Annotated List*, Special Publication No. 6 of the Florida Ornithological Society, Gainesville, Florida, 1992, 260 pp.; P.L. Shafland, "Management of Introduced Freshwater Fishes In Florida," Proceedings of the 1990 Invitational Symposium/Workshop: New Directions in Research, Management and Conservation of Hawaiian Stream Ecosystems, Hawaii Dept. of Natural Resources, Div. of Aquatic Resources, Honolulu, Hi, 1991; L.A. Stange, "Snails and Slugs of Florida," *Florida Garden Guide*, January/ February 1980, pp. 1-2; D.R. Thompson, APHIS/USDA, personal communication, May 27, 1992; D.B. Ward, "How Many Plant Species Are Native to Florida?" *Palmetto*, winter 89/90, 1989-90; and L D. Wilson, Professor of Biology, Miami Dade Community College, Miami, FL, personal communication to D.W. Johnston.

lems in the State, They have had negative impacts on fishing and water sports and have degraded wildlife habitat, decreased biological diversity, and altered natural ecosystems. Future harmful effects on agriculture and human health can be anticipated from continued immigrations of insects and plant pathogens (39), as well as continued range expansion of established NIS (81).

Disturbed areas-construction sites, abandoned farm land, drained or stressed wetlands, roadsides, and canals and ditches—are often the sites where NIS gain footholds and eventually become established. In such areas NIS often displace indigenous forms, thus altering ecosystem dynamics. Debate persists as to whether NIS become established by actively out-competing and displacing indigenous species even in undisturbed areas or whether they primarily colonize disturbed habitats that are no longer optimum sites for indigenous species. In many south Florida urban and suburban sites, a lizard, the invasive Cuban brown anole *(Anolis sagrei)* has out-competed, and thereby replaced, the indigenous green anole *(Anolis carolinensis) (136).* Undisturbed areas are difficult for many NIS to colonize, but most of Florida's natural areas and waterways have experienced disturbance in some varying degrees, thus making them prone to NIS invasions (35,8 1).

Other conditions in Florida favor the introduction and establishment of NIS. The State has a subtropical climate and prolonged growing season; abundant freshwater resources; large and growing industries of aquiculture, ornamental and nursery plants, and the pet trade; a thriving tourist industry; and cargo flights originating in Central and South America (102).

- Subtropical Climate. Florida's subtropical climate is attractive to people and to certain industries, such as those dealing with ornamental and aquarium plants. The climate is moderated by large bodies of water on three sides. Furthermore, Florida is as close to the equator as is any conterminous State, so that most of it is in the humid subtropical climatic zone; the southern tip, from approximately Lake Okeechobee southward, is tropical savanna, the only such zone in the United States (22). Areas in this last zone are always hot, with alternate dry and wet seasons.

  The State has an average annual maximum temperature of 82 degrees F and an average annual minimum temperature of 63 degrees F (137). Winter temperatures (40 degrees F and lower), especially in south-central Florida, probably limit the northward dispersal of many NIS (100,103,136). Florida is one of the wettest States, with an average annual rainfall of 53

inches (60 or more inches in southeastern and panhandle parts). This climate is conducive to the establishment of many NIS of tropical origin. Florida is also subject to tropical weather systems, such as 1992's Hurricane Andrew, which can facilitate the spread of NIS through disturbance (box 8-D).

- Routes of Entry. Florida has numerous pathways of entry for NIS. Large numbers of plants (333 million in 1990) and animals pass through Miami International Airport each year, the shipments originating chiefly in Latin America; 85 percent of all plant shipments into the United States pass through the Miami Inspection Station (118). The shipments are destined for a great variety of ornamental, nursery, and landscaping businesses; the aquarium industry; and commercial pet trade. This influx of NIS sets the stage for potential escapes and unintentional and intentional releases.

  Unintentional releases and escapes from animal dealers, aquiculture, subsequent purchasers, public and private collections, and tourist attractions have been documented (92,95). Specific examples of harmful or potentially harmful species are the African giant snail *(Achatina fulica)* (1 11), cane toad *(Bufo marinus) (136),* and monk parakeet *(Myiopsitta monachus) (95).*

  Deliberate introductions for sport, biological control, food, pharmaceutical material or dyestuffs, ornamental uses, and aesthetics are also well known in Florida (98). In the 1800s and early 1900s, botanist David Fairchild imported large volumes of non-indigenous plants into Florida (96). Since 1900, the most disastrous deliberate introduction has been that of melaleuca *(Melaleuca quinquenervia),* a fast-growing tree brought in to dry out the swamplands of south Florida. Another tree, Brazilian pepper *(Schinus terebinthifolius),* introduced for its showy foliage, is also spreading rapidly in south Florida. At least two introduced aquatic plants continue to cause extensive ecological and economic damage: hydrilla *(Hydrilla verticillata)* and the showy water hyacinth *(Eichhornia crassipes) (97).* Plant pathogens and other stowaways have concomitantly gained entry through importation of foodstuffs and plants on ships or aircraft (28).

  In the 19th century and as late as 1941, several insects, such as mole crickets *(Scapteriscus vicinus* and S. *acletus)* and a variety of beetles, probably arrived in ship ballast (96). For most non-indigenous plants and some animals, however, the exact path of entry into the State is unknown.
- Industries Dealing With NIS. Several industries have played large direct or indirect roles in the introduction of harmful NIS into Florida. A $1 billion woody ornamental industry continues to import large numbers of plants for landscaping and shade. A few woody ornamental, such as Australian pine *(Casuarina equisetifolia)* and Brazilian pepper, have become major pest plants in Florida (79). Florida's aquiculture industry is the largest of any state; tropical fish and aquarium plants shipped from Florida are valued at $170 million annually, according to the Florida Tropical Fish Farms Association. Most of Florida's 19 non-indigenous fish species escaped from aquarium fish culture facilities (25). The aquarium plant trade introduced hydrilla into canals near Tampa about 1950, and later into Miami canals and the Crystal River (58). Pet merchants and pet owners have been implicated in the escape of tropical birds, reptiles, and mammals (92,122).
- Human Population Growth. Florida continues to be one of the fastest g-rowing States: its 1990 population totaled 12.9 million, an increase of 32.8 percent since 1980 (127). Population growth over the years has increased pressure to develop more land and to make adequate water supplies available. Most of the natural ecosystems of south Florida have been severely altered. The disturbed areas-urban, suburban, and rural-have become prime sites for colonization by non-indigenous plants and animals.

Box 8-D—Non-indigenous Species and the Effects of Hurricane Andrew

On the morning of August 24,1992, the small but intense Hurricane Andrew cut a25-mile swath across south Florida fromt he Dade County coast westward to Monroe Count y's west coast. Alt hough total rainfall was relatively light (5 inches or less), maximum sustained winds were 135 to 140 miles per hour and gusts exceeded 164 miles per hour. Estimates of property damage to urban and suburban sites reached $20 billion, thus ranking Hurricane Andrew as among the costliest natural disasters in U.S. history. Natural areas were also affected. The hurricane caused an estimated $51 million in damage at Everglades and Biscayne National Parks and Big Cypress National Preserve.

A large number of non-indigenous animals escaped from captivity when zoos, pet stores, and tropical fish farms were destroyed, Escapees included fish, lizards, nonvenomous snakes, birds, and primates (e.g., some 500 macaque monkeys and 20 baboons).

Based on knowledge of the ecology of non-indigenous trees in south Florida and their invasions enhanced by two previous hurricanes (Donna in 1960 and Betsy in 1965), a significant increase in the spread of some non-indigenous plants can be predicted fort he next few years. The hurricane spread melaleuca seeds *(Melaleuca quhquenervia)* and other non-indigenous plants in its path, thus setting back years of efforts to control melaleuca in t he East Everglades. Newly disturbed natural communities in south Florida will be more susceptible to invasions. Other potential problems might come from escaped non-indigenous invertebrates and plants that are not already established in south Florida.

As a direct result of the hurricane, Florida's Department of Natural Resources estimates that mechanical and chemical control of non-indigenous plants over the next 5 years will cost $14 million, approximately tripling costs. Because those control measures might not completely eliminate harmful NIS, the Department recommends that biological control agents be introduced as quickly as possible. For species of primary concern in the aftermath of the hurricane-melaleuca, Australian pine *(Casaurina equisetjfolia),* Brazilian pepper *(Schinus terebinthifolius),* lather leaf *(Colubrina asiatica),* and air potato *(Dioscorea* bulbifera)-funding for research, quarantine and grow-out facilities are estimated to be $53 million over the next 10 years.

SOURCES: A. DePalma, "Storm Offers Chance to Rethink Everglades," *The New York Times,* Sept. 29, 1992, p. A14; G.E. Davis et al. (eds.), "Assessment of Hurricane Andrew Impacts on Natural and Archaeological Resources of Big Cypress National Preserve," Biscayne National Park, and Everglades National Park, Draft Report, U.S. National Park Service, Atlanta, GA, Sept. 15-24, 1992; *Exotic* Pest *Plant Council* Newsletter, vol. 2, No. 3, fall 1992; Florida Game and Fresh Water Fish Commission, "Effects of Hurricane Andrew on Fish and Wildlife of South Florida: A Preliminary Assessment," Tallahassee, FL, Sept. 25, 1992; D. Schmitz, personal communication to Office of Technology Assessment, Jan. 21, 1993.

Causes and Consequences

Findings:

Natural habitats, especially in south Florida, have been altered or lost by drainage and water storage projects, urban and suburban land development, and land reclamation for agriculture. Harmful NIS often invade and become established in altered ecosystems from which they can invade surrounding areas.

Invasive NIS in the State have disrupted navigation and recreational activities, displaced indigenous wildlife and their habitats, and reduced biological diversity. Severe ecological and economic impacts from several aquatic plants, such as hydrilla and water hyacinth, and trees, such as melaleuca and Brazilian pepper, have been documented.

The most conspicuous non-indigenous plants in Florida are aquatic weeds (e.g., water hyacinth and hydrilla) and trees (melaleuca, Australian pine, and Brazilian pepper). Their success is due to their ecological characteristics as well as the condition of the ecosystem being invaded. In disturbed ecosystems, NIS are sometimes better adapted than indigenous species. Aquatic plants have clogged waterways, hindered navigation, disrupted fishing and water sports, and smothered natural vegetation. In drier habitats, invasive trees

have often created monoculture, displacing indigenous species, decreasing biological diversity, and destroying wildlife habitats. Insects, pathogens, and nematodes have caused damage to agricultural crops. Several invading plants and insects have created public health problems.

Invasion and establishment of many non-indigenous plants and animals is closely related to the degree of ecosystem disruption. Alterations to accommodate water management projects, human population growth, and agriculture have been especially important (81 ,98).


DON SCHMITZ

Altered hydrology in south Florida has been linked to the spread of non-indigenous fish, aquatic plants, and trees-such as melaleuca (Melaleuca quinquenervia).

WATER MANAGEMENT IN SOUTH FLORIDA

Water management programs in the southeastern part of the State have greatly contributed to the spread of non-indigenous plants and fishes (83). Waterways and marshes were among the frost natural systems in Florida to be affected by increasing numbers of people because of demands for irrigation, urban water supplies, and recreation.

As early as 1907, drainage of south Florida's Everglades was promoted for land reclamation, to reduce flooding, and to supply water to developing southeastern coastal cities (42). Drainage was accelerated in the 1930s, and by 1947, the U.S. Army Corps of Engineers had created the Everglades Agricultural Area and a plan for management of Everglades' waters, thus laying the base for the vast urban areas now found on Florida's southeast coast. Areas along the eastern margin of the Everglades, critical to movement of its waters underground, are now drained and paved.

Today, a complex network of canals, dams, pumping stations, and levees stretches from Lake Okeechobee to southern Dade County, just east of Everglades National Park (119). This network—80 percent of it federally funded and built by the Corps of Engineers-now controls flooding and diverts large volumes of water for agriculture and coastal urban areas. Half the Everglades-once occupying about 3,600 square miles, perhaps the largest wetland in North America-is now farms, groves, pastures, and cities. The remaining fragments of natural communities now function so poorly that plant and animal life suffers as water and food supplies are diminished, distorted, and polluted (132).

Altered hydrology in the East Everglades has been linked to the spread of non-indigenous trees such as melaleuca (104). This alteration of the natural water flow has decreased populations of nesting wading birds (92) and accelerated the proliferation and spread of non-indigenous fishes and aquatic plants (24,59,60,102).

Some 700,000 acres of agricultural land just south of Lake Okeechobee-nearly two-thirds of it in sugar cane-not only use much of south Florida's water, but also release run-off contaminated with nitrogen and phosphorus (105). Excessive growth of hydrilla and other plants has been linked to this increased pollution (15).

URBANIZATION

Florida's population in 1990 was concentrated in three principal areas: Miami-Fort Lauderdale (3.19 million), Tampa-St. Petersburg (2.1 million), and Orlando (1.1 million) (127). Natural areas, such as the Atlantic Coastal Ridge and scrub communities, have been developed to supply urban demands for house sites, municipal

services, and landscaping. Many urban sites in south Florida have become dominated by NIS, especially ornamental plants, birds, and fishes (23,59,122,136).

Many non-indigenous animal species are today found chiefly or entirely in urban and suburban areas of south Florida. Collectors, hobbyists, and pet owners have deliberately or accidentally released tropical fish, mammals, birds, reptiles, and invertebrates into urban and suburban settings where they find plentiful food, breeding sites, shelter, and a subtropical climate conducive to growth and reproduction (25,31,72,95,136). In cities, non-indigenous birds such as parrots have few predators, diseases, or parasites (122). At ports of entry, such as Miami, stowaway insects and other invertebrates have escaped from their imported hosts (28). The Asian tiger mosquito *(Aedes albopictus)* commonly breeds in water that collects in waste tire dumps and flower pots in cemeteries (89).

THE SPREAD OF MELALEUCA

The last three decades have been marked by an explosive invasion of melaleuca across south Florida (53), where some 450,000 acres are infested (73). In 1983, its estimated rate of spread was 8 acres per day, but less than a decade later the rate is estimated to be 50 acres per day. Thus, melaleuca has the potential to invade all of south Florida's wetlands within the next 50 years (37).

Indigenous to Australia, melaleuca's release from natural competitors, predators, and disease and its characteristics of prolific seed production and adaptation to fire have facilitated its spread. Its monoculture have replaced sawgrass marshes, sloughs, forests, and other natural habitats to the extent that melaleuca is now regarded as the most serious threat to the integrity of all south Florida's natural systems (74).

Because of its proximity to the numerous melaleuca plantings in the urban areas of the Palm Beaches, Loxahatchee National Wildlife Refuge has one of the most severe infestations of melaleuca anywhere in the Everglades. The trees were rare in the 1960s, but by 1990, 14 percent of the refuge was moderately to heavily infested (36). Moderate to heavy infestations also occur in Big Cypress National Preserve, the eastern half of the East Everglades Acquisition area, in marshes of Okeechobee, in large areas of Broward and Dade counties east of the Everglades, and in an area designated Water Conservation Area 2-B. Equally severe problems exist on the west coast of Florida from Charlotte Harbor to U.S. Highway 41 (74).

ECONOMIC COSTS

The various control programs for melaleuca have been expensive. Since 1986, 2 million melaleuca and Australian pine stems have been treated in the East Everglades at a cost of $287,000 for helicopter services and herbicides (104). Mehdeuca management costs in the Big Cypress National Preserve were $60,000 in 1989. Costs for mechanical removal of trees range from $500 to $2,000 per acre. Estimated melaleuca management costs in recent years for Water Conservation Areas 2-A, 2-B, 3 in south Florida, and Lake Okeechobee have been nearly $1 million annually (74).

One estimate in 1991 placed the cost of melaleuca removal in Florida at $1.3 million. For fiscal year 1992 the estimated expenditures for herbicide and mechanical control of melaleuca were $720,000 in the South Florida Water Management District, $150,000 in Loxahatchee National Wildlife Refuge, and $180,000 in Everglades National Park (1 17). Based on the current rate of expansion, in one water conservation area alone, complete eradication of melaleuca with herbicides and mechanical removal would cost $12.9 million over 5 years (1 17).

The benefits and costs for removal of melaleuca have been estimated (29). The total annual benefits, especially to tourism, of preventing a complete infestation of melaleuca would be $168.6 million, whereas the resulting losses in honey production and pollination services (the tree provides honey bees with nectar) would cost

only $15 million. Thus, eradication of melaleuca would greatly benefit the State's economy, according to this analysis, although some of its assumptions may inflate the benefits (21).

Florida has experienced severe economic impacts from other NIS as well. The economic impact of hydrilla on tourism and recreational fishing can be staggering. For example, a study of Orange Lake in north central Florida indicated that the economic activity on the lake was almost $11 million annually, but in years when hydrilla covers the lake, these benefits are all but lost (63). During the 1980s, statewide costs for controlling hydrilla totaled approximately $50 million (98). Today hydrilla is the most costly aquatic plant to manage, with an annual expenditure of $7 million. Since 1980, management of all non-indigenous aquatic plants by State and Federal agencies has cost $120 million (98).

Consequences to the State's agriculture also have been documented. The value of citrus crops in Florida from 1955 to 1985 totaled $13.5 billion. An estimated 15 percent of the citrus was lost because of the burrowing and citrus nematodes *(Radopholus similis, Tylenchulus semipen - etrans), with* an average annual estimated cost of $77 million (33). While the nematodes' origins are not certain, experts speculate that one or both are non-indigenous. Fire ants *(Solenopsis invicta)* from South America have extensively damaged eggplants, soybeans, and potatoes. Brazilian pepper growing in proximity to agricultural areas is believed to support large populations of vegetable-damaging insects, especially when vegetable crops are nearing harvest (19). In 1984, the cost of damage and control of mole crickets in Florida, Georgia, Louisiana, and Alabama was about $45 million, with most of the cost to Florida. By 1986, the losses had risen to $77 million for turf grasses alone (38).

From 1957 to 1991, NIS eradication and control programs cost $31 million for citrus canker *(Xanthomas camestris* pv. *citri), $11* million for fire ants, and $10 million for citrus blackfly *(Aleurocanthus woglumi). In 1990* and 1991, Meditemanean fruit fly (medfly) eradication programs totaled $0.5 million, according to the Florida Department of Agriculture and Consumer Services.

POTENTIAL OR ACTUAL HEALTH CONSEQUENCES

Many NIS have been linked to human health problems, and an increasing number of incidents are reported annually in the growing urban areas. Very common trees, such as melaleuca and Brazilian pepper, can cause contact dermatitis, allergies, and respiratory problems. A large number of other cultivated and established plants in Florida contain some poisonous compounds (3).

The Asian tiger mosquito, now in virtually all Florida counties, can carry dengue fever and a form of equine encephalitis virus (39) (ch. 10). In addition to their agricultural impacts, non-indigenous fire ants can cause stings, allergic reactions, and secondary infections in people.

EFFECTS ON ENDANGERED SPECIES

Non-indigenous aquatic plants are threatening the integrity of habitats occupied by certain endangered and threatened species in Florida. Both water hyacinth and water lettuce *(Pistia stratiotes)* can cover surface waters, thus hampering efforts of the endangered snail kite *(Rostrhamus sociabilis)* to find its prey (116). Non-indigenous trees are invading habitats of the endangered Cape Sable seaside sparrow *(Ammodramus maritimus mirabilis).* Australian pines have interfered with nesting of endangered and threatened sea turtles (84); on the other hand, they have improved nesting conditions for the American oyster catcher *(Haematopus palliatus) (121). The* endangered beach mouse *(Peromyscus polionotus phasma)* and key deer *(Odocoileus virginianus clavium) are* subject to predation by feral cats or dogs (4). Populations of the endangered Okaloosa darter *(Etheostoma okatoosae)* have been reduced because of competition from the introduced brown darter *(E. edwini) (14).*

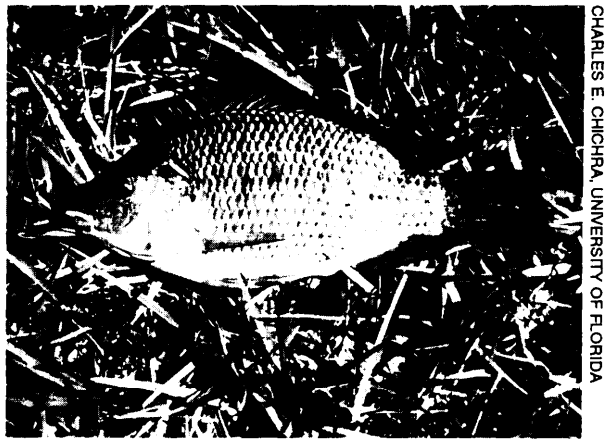
CONFLICTING INTERESTS ON NON-INDIGENOUS SPECIES

The introduction of cetiain NIS into Florida has resulted in conflicts between agencies and user groups. Grass carp *(Ctenopharyngodon idella)* were introduced to control aquatic weeds (1 15), but the carp shows a preference for important waterfowl food plants, thus apparently causing declines in waterfowl populations (134). Peacock bass *(Cichla* spp.) were introduced to control other non-indigenous fish and as a game fish in southeast Florida canals (101), but the bass is slowly reducing populations of indigenous bass and bream (73). Perhaps the most troublesome of the 19 non-indigenous fish species is the blue tilapia *(Tilapia aurea),* introduced by the Florida Game and Fresh Water Fish Commission as a possible weed-control and sport fish. Blue tilapia competes directly with indigenous fishes and is now established in 18 Florida counties (73).

Hunters value wild hogs *(Sus scrofa)* as game, and management and relocation programs are common in Florida. Yet wild hogs have detrimental effects on terrestrial habitats and are probable public health threats (parasites and diseases) (9).

Certain aquatic plants frequently categorized as pest species may be beneficial for wildlife. Despite extensive, costly efforts to control or eradicate hydrilla, some hunters like the plant because it is an important duck food and its mats provide habitats for wintering waterfowl (44,57). At least in small amounts, it is also believed to improve sport fishing (76).

Aside from those species introduced for biological control or sport, some NIS in Florida benefit people and wildlife. The aesthetic values of colorful tropical birds are intangible, but are important to urban dwellers in an otherwise less colorful environment (92). Avid birdwatchers travel to the Miami area to observe its non-indigenous avifauna (122). The importance of NIS as food for indigenous wildlife is only partly understood, but the endangered Florida panther *(Felis concolor coryi)* feeds on non-indigenous wild hogs and nine-banded armadillos *(Dasypus novemcinctus),* whose negative environmental impacts have been documented (18,72).


CHARLES E. CHICHRA, UNIVERSITY OF FLORIDA

Blue tilapia (Tilapia aurea) *is among the most troublesome of Florida's 19 non-indigenous fish species.*

Non-indigenous ornamental shrubs and trees are in great demand for landscaping (because of their showy leaves or flowers), fruit, and shade from the intense sunlight of south Florida (79). Many species of introduced fig trees *(Ficus* spp.) line southeastern Florida's roadsides, and Australian pines offer shade along beach fronts.

POTENTIAL FUTURE IMPACTS OF NON-INDIGENOUS SPECIES

Biologists and ecologists caution that many poorly studied NIS have the potential of becoming agricultural pests, transmitting diseases, or displacing indigenous species. Potentially serious pests include Cogon grass *(Imperata cylindrical),* which is invading pine forests (81); about 20 recent insect immigrants (39); the Asiatic clam *(Corbicula manilensis) (87);* catclaw mimosa *(Mimosa pigra var. pigra),* a highly invasive plant of disturbed areas; the disease-carrying Asian tiger mosquito; and African honey bees *(Apis mellifera scutellata),* predicted to be in Florida by 1994.

I Searching for Solutions

Findings:

Florida's Exotic Pest Plant Council has provided an effective forum for the exchange of ideas and conflict resolution concerning NIS. It has identified the most invasive NIS and involved policy makers in its discussions.

Florida's extensive problems with NIS and its high human immigration rate suggest that public education is vital to the management or eradication of NIS in the State.

SPECIFIC MANAGEMENT PROGRAMS

The Exotic Pest Plant Council (EPPC) was the first multiorganizational effort in Florida to control non-indigenous water weeds because of the growing environmental threats posed by pest plants that were crossing political and jurisdictional boundaries. EPPC is an organization of 40 member agencies, and local and private groups. Through frequent meetings, a newsletter, and other publications, EPPC promotes coordinated efforts in developing management programs. It also assists in writing appropriate legislation; pushes for State and Federal funds to manage invasive plants in wetlands and upland forests; and organizes symposia to bring together scientists, policymakers, and the public to exchange information and formulate plans (30).

EPPC assisted in coordinating efforts by the National Park Service, Dade County Department of Environmental Resource Management, South Florida Water Management District, and the Florida Department of Corrections to establish and maintain a melaleuca-free buffer zone along the eastern boundary of Everglades National Park (the East Everglades).

Because of melaleuca's highly invasive nature, its control and eradication have received top priority in the East Everglades, South Florida Water Management District, Loxahatchee National Wildlife Refuge, and other sites in south Florida. At least three techniques are currently in use: manual removal of seedlings and young trees, mechanical removal of older trees, and herbicides (62).

The future use of biological control agents has been identified as one of the keys to effective, long-lasting management of melaleuca (5). Major efforts are under way to identify natural controls for melaleuca, both in the United States and Australia. Even after biological control agents are identified, several years must pass before their effectiveness can be determined. Meanwhile, herbicidal and mechanical control will be needed to arrest further spread of the tree (74).

Control of Australian pine and Brazilian pepper demands a combination of mechanical removal and herbicides. Hydrilla is currently managed at considerable cost with herbicides and mechanical removal and in some cases with sterile triploid grass carp. At one time, water hyacinth infested more than 120,000 acres of Florida waterways. Herbicidal and mechanical controls have limited the plant to less than 3,000 acres in public waters (98). Three natural enemies, the bagoine weevil *(Bagous affinis)* and two leaf-mining flies *(Hydrellia* spp.), also show some promise in controlling hydrilla (62). Management of these and other species would benefit from increased coordination.

Several other control and eradication projects have been successful in Florida. In the mid- 1980s at least 18 million young citrus trees were destroyed to eradicate citrus canker (99). Other species successfully eradicated include the medfly; the giant African snail; and 13 species of insects, viruses, and rusts, according to the Division of Plant Industry in Florida.

LONG-TERM NEEDS

Resource managers in Florida stress that successful management and eradication programs for existing and future problem NIS in Florida will require an educated public along with coordination among agencies, long-range planning, and consistent funding.

Inventories of existing harmful NIS, their distribution, and impacts in the State are needed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The critically endangered Florida panther (Felis concolor coryi) *and other indigenous species rely on remnants of undisturbed habitat that are susceptible to damage by non-indigenous species.*

to develop priorities for management. Early detection of damages enhances the probability of success in controlling any pest (20). Because the establishment and spread of any NIS may be due to a lack of natural enemies, the search for biological control agents is an important consideration.

Relatively undisturbed ecosystems in Florida are fast disappearing and are usually represented by small fragments of their original extent. These areas warrant special attention to protect them from injurious NIS. The State needs to enhance strategies for controlling or eradicating injurious non-indigenous animals such as wild hogs (75).

Ample evidence indicates that the existing management of water flow through the Everglades has altered hydroperiods and contributed to the invasion of non-indigenous trees. A new design and management of water flow would be needed to restore a natural water regime, one that would protect the quality and quantity of water feeding the Everglades (34).

Some aspects of water quality management in the Everglades, especially those related to phosphorus, are being addressed now, In 1988, the U.S. Department of Justice sued the Florida Department of Environmental Regulation and the South Florida Water Management District for not enforcing water quality standards for water entering Everglades National Park. In July 1993, these parties, along with agricultural interests, environmental groups, and Indian tribes, agreed to a mediated framework for a 20-year, $465 million restoration and clean up plan. The impact of these efforts on harmful NIS will not be clear for some time.

COORDINATED EFFORTS FOR MANAGING NIS

Centers or councils to coordinate the work of various agencies and industries could be of help in developing and implementing effective management of harmful NIS. They might also encourage statewide resource protection, public awareness, and consistency in policies, goals, administration, and control methods, The structure and operations of the Exotic Pest Plant Council could be used as a model for coordinating work on pestiferous fish and insects, for example. A planned "Center for Excellence, " combining expertise from the University of Florida, Division of Plant Industry, and the U.S. Department of Agriculture, also shows promise in coordinating biological control research and implementation in the State, especially for agricultural crops.

FUNDING FOR RESEARCH, MANAGEMENT AND BIOLOGICAL CONTROL

Except for a few highly invasive aquatic plants and trees, little biological and ecological information is available for most of Florida's MS. Equally lacking are data on natural enemies of the species and ecological data for the ecosystem likely to be invaded. Without the necessary research to reveal this information, effective programs of control, management, and eradication cannot be fully developed nor expected to be successful.

For the most part, funding for management and research of NIS in Florida has been piecemeal and often inadequate for programs to achieve maximum *success.* For example, management pro-

grams for noxious weeds and biological control research are said to have been underfunded and short-term. Current quarantine facilities for biological control research are inadequate, thus hampering efforts to control melaleuca and other species. Development and implementation of strategies to arrest further spread of NIS and to decrease their environmental impacts would require consistent, adequate funding.

PUBLIC EDUCATION

Florida's continuing population growth and tourist influx plus the magnitude of the impacts from harmful NIS suggest that public education and awareness programs could be intensified to prevent new introductions. Such programs could be targeted toward unintentional and intentional introductions, including ornamental plants, aquarium fishes, other pets, and insects. Attempts could be made to discourage the planting of invasive ornamental species and to warn of the need to control their spread. The major biological and economic impacts of melaleuca, water hyacinth, and hydrilla could be widely publicized to encourage support for management issues. The importance of protecting remaining natural communities warrants emphasis, especially since undisturbed ecosystems can serve as barriers against the spread of NIS.

CHAPTER REVIEW

Virtually all parts of the country face problems related to harmful NIS, but Hawaii and Florida have been particularly hard hit. Both States have large numbers of established NIS, constituting significant proportions of their flora and fauna, and including numerous high-impact species. Many harm natural areas that are unique or otherwise special reservoirs of the Nation's biological heritage. Both Hawaii and Florida have turned to cooperative, interagency mechanisms and public education to address their particular problems with NIS. Federal action and inaction have sometimes hindered the States' efforts. Lessons learned in these States are likely to serve well elsewhere. The situation in Hawaii and Florida, while unusual in some ways, nevertheless heralds what other States face as numbers of harmful NIS climb and people become more aware of their damage.