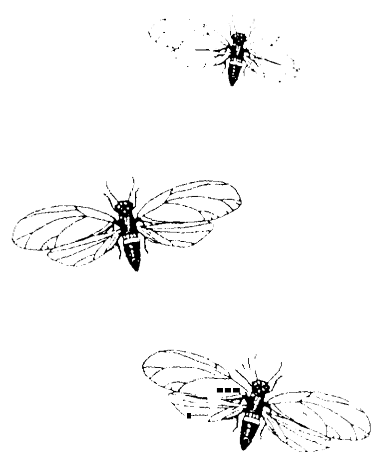
Technologies for Preventing and Managing Problems 5

This chapter describes technologies and related issues for preventing and managing harmful non-indigenous species (NIS) in the United States. Programs are discussed in the order of their occurrence for dealing with NIS: prevention, followed by eradication, containment, and suppression. Education is a key component within all of these programs.

The adage “an ounce of prevention is worth a pound of cure’ holds true for many harmful NIS. However, prevention is not always sufficient. Harmful NIS do enter the country, although it is not possible to predict when or where the next harmful MS will enter, or what its specific impact will be. Alternative programs are required to prevent establishment of these MS or to manage them.

Eradication is the first step in such reactive approaches. Destroying a population when it is relatively small or before it spreads can eliminate the need for long-term management programs. Eradication is not always possible, however, or may not be implemented. The next step is containment or development of a strategy to limit or slow the population’s spread. Long-term management using specific control technologies is the final phase. At this point the goal is to suppress the population below acceptable thresholds.



TECHNOLOGIES FOR PREVENTING UNINTENTIONAL AND ILLEGAL INTRODUCTIONS

Finding:

Shortcomings exist in Federal prevention programs. The high volume of people and goods in transit can overwhelm inspectors, limiting thorough surveillance. Confusing regulatory authority can lead to delays in applying known technologies. Lag times often exist between the identification of a harmful NIS and the implementation of an effective prevention technology.

Inspection and Exclusion Activities at U.S. Ports of Entry

Experts often consider prevention the most economical, desirable, and effective management strategy for harmful NIS. The manifestation of this policy is government inspection and exclusion programs for NIS. The main factors involved in successfully preventing the entry of NIS are: the availability and efficacy of technologies for known problems (e.g., fumigation for imported fruits and nuts); the development of applicable technologies and programs for new NIS (e.g., ballast water treatment for zebra mussels, *Dreissena polymorpha);* and applying these technologies effectively (e.g., matching availability of inspectors to volume of passengers from international flights).

Preventing the introduction of harmful NIS involves various Federal and, to a lesser degree, State agencies, often working together. This cooperation may include assuming inspection duties or sharing of resources and information. Chapters 6, 7, and 8 discuss the roles of the different Federal agencies in NIS prevention activities.

TRAVELERS AND BAGGAGE

A recognized pathway for NIS at U.S. ports of entry is the traveling public and their baggage (14). Under normal circumstances, insufficient time and staffing and the numbers of international travelers prevent 100 percent inspection of passengers and baggage. A profile system based on country of origin and passenger descriptions identifies high-risk flights and passengers.

Preferably, selective and efficient inspection technologies are used to reduce NIS introduction.

USDA

Inspections-before imports are shipped, at U.S. ports of entry, and after shipments are treated-are important means of excluding agricultural pests from the country.

The categorization of flights from areas of known NIS of quarantine significance can allow inspectors to most effectively use their limited resources. Human ‘‘rovers’ also play an important role in identifying passengers who might intentionally introduce damaging NIS.

X-ray machines and beagles are important tools in detecting prohibited NIS in baggage. Presently, dogs are used at nine major airports in the United States. X-ray equipment is used at 42 major airports and land-border stations (43). Dogs and xrays have various limitations. For example, they cannot distinguish between permissible and forbidden items of similar type. Their effectiveness also depends on the quantity of goods in a sample and the packaging of the items.

Some innovative approaches to detecting NIS in baggage are being developed; these include carbon dioxide ‘‘sniffers’ and other electronic or mechanical probes (1 1).

INTERNATIONAL TRADE: AGRICULTURE AND COMMERCIAL PRODUCTS

International commerce provides another avenue for the introduction of potentially harmful NIS into the United States. Preventing their introduction requires the establishment of regulatory quarantines. Such quarantines can require that a commodity be treated with a specific technology or that live organisms (e.g., large game animals, plant germ plasm, or potential biological control agents) be held in a quarantine facility to test for the presence of restricted pathogens, predators, or parasites.

Commodities (Fruits and Vegetables)— Techniques for preventing unintended introductions of NIS with commodities include treatment schedules and sampling programs. For example, mangoes from Brazil are tested for the presence of Mediterranean fruit fly *(Ceratitis capitata).* Ideally, treatments should provide complete effectiveness (100 percent kill); cause little or no damage to the commodity; cause only minor delays in commercial transit; and have no human health risks (69).

Procedures such as picking fruit and vegetables early to minimize the chance of infestation or using cultivars resistant to specific pests can be implemented before a commodity leaves the originating country. In addition, changing the planting date to avoid pest outbreaks, rotating crops, or using chemical pesticides to establish pest-free zones can reduce the chances of infestation (69).

The goal of a pest-free zone is to remove the pest problem in a specific part of a country. Protocols for establishing such zones include: surveys; required action if the survey detects the target pest within the area; procedures for sampling, marketing, certifying, and safeguarding exported products; and a documented history of pest-free status. The U.S. Department of Agriculture (USDA) has pest-free zone agreements with Mexico, Chile, and other countries (105).

While a commodity is in transit, or after it has arrived at a U.S. port of entry, specific treatments such as the application of chemicals or holding items at specific temperatures for designated time periods are available (table 5-l). Several factors limit the use of temperature or chemicals, including the biology of the NIS, the frailty of the commodity, and the feasibility of application.

Some chemical treatments cause damage or reduce the product’s shelf life (29). Temperature treatments are nonchemical alternatives but require strict adherence to protocols for efficacy. For example, a hot water dip for papayas was discontinued because of difficulties in monitoring the process (94).

By combining cultural and physical treatments in the country of origin, some commodities can receive pre-clearance before entering the United States. Pre-cleared commodities are permitted entry without further inspection. For example, inspectors trained by USDA’s Animal and Plant Health Inspection Service (APHIS) working in cooperation with local inspectors in Japan, can monitor field production, storage, packaging, and shipment of Satsuma oranges, which are inspected for the presence of citrus canker *(Xanthomonas campestris* pv. *citri) (72).* Pre-clearance programs exist between the United States and 24 other countries, yet, with the exception of Canada, they remain relatively small (43,103).

Subset sampling is part of the pre-clearance inspection for highly perishable commodities or when known NIS potentially infest specific commodities. APHIS has established protocols for subset sampling (93), which involves sampling small portions of an imported commodity to assess whether NIS are present. Limited resources, loading techniques, or large lots can

Table 5-l—Examples of Treatment Technologies for Importing Commodities

Chemical treatment:

Commodities are treated with chemical fumigants at specific atmospheric pressures for specific time periods.

Example: **Under normal atmospheric pressure and at 90-96 oF, imported chestnuts are fumigated for 3 hours with methyl bromide for infestations of the chestnut weevil** ***(Curculio elephas),***

Temperature treatment:

Freezing:

Fruits and vegetables are frozen at subzero temperatures with subsequent storage and transportation handling at temperatures no higher than 20 oF.

Cold ***treatment:***

Commodities are cooled and refrigerated for specific temperatures and days.

Example: **Fruit infested with the false coding moth** *(Crytophlebia leucotreta)* **requires refrigeration for not less than 22 days at or below 31 'F.**

Vapor heat:

Commodities are heated in water-saturated air at 110 'F. Condensing moisture gives off latent heat, tilling eggs and larvae.

Examp/e:The **temperature of grapefruit from Mexico is raised to 110 'F at the center of the fruit in 8 hours and is held at that temperature for 6 hours.**

Hot water dip:

Commodities are treated with heated water for specific periods of time.

Example: **Mangoes weighing up to 375 grams from Costa Rica are dipped in 115'F water for 65 minutes.**

Combination treatment:

Combination of fumigation and cold treatment.

Example: **Fruit infested with Mediterranean fruit fly** *(Ceratitis capitata) is* **exposed to methyl bromide for 2 hours then refrigerated for 4 days at 33-37 oF.**

Irradiation treatments:

Commodities are exposed to irradiation at specific rates and times.

Example: **Papayas shipped from Hawaii would be treated with a minimum absorbed ionizing radiation dose of 15 kilorads. (This treatment schedule has USDA approval but is not commercially used at this time.)**

SOURCES: 7 CFR Ch. 111 (1-1-91 Ed.) Animal and Plant Health Inspection Service, USDA, Part 319- Foreign Quarantine Notices, Subpart- Fruits and Vegetables, 319.56; 7 CFR Ch. 111 (1-1-92 Ed.) Animal and Plant Health Inspection Service, USDA, Part 318- Hawaiian and Territorial Quarantine Notices, Subpart - Hawaiian Fruits and Vegetables, 318.13.

reduce the randomness of samples, compromising accuracy (91).

One technology with potential for treating many commodities such as flowers, grain, and fruits is irradiation (e.g., gamma radiation). Irradiation kills organisms directly or indirectly (e.g., causes sterility or other mutations in immature life stages) so that new populations cannot be established. This technology is currently used to increase the shelf life of foods such as strawberries and for treating spices.

To become an effective tool, it is necessary to establish dosage levels for specific pest species and commodities. The doses required to directly kill some non-indigenous pests can damage commodities. For example, some flowers from Hawaii cannot tolerate certain radiation levels (29), but decreasing the doses potentially leaves live (though nonfertile) pests. These present problems for inspectors, because practical methods that distinguish nonfertile from fertile pests are limited.

Public concern over health risks also affects the use of irradiation. Although irradiated products pose no known hazards to consumers, potential occupational health risks exist (63).

Animals (Livestock, Zoos and the Pet Trade)---NIS such as "exotic" game animals are recognized as sources of disease for domesticated and wild indigenous animals (47). Therefore, various non-indigenous animals being imported are temporarily held at quarantine stations, where they are examined for general clinical signs of disease, ectoparasites, and specific diseases based on the species and country of origin. Categories of vertebrate animals quarantined include domestic livestock and swine, poultry, pet birds, and various ''exotic' game animals. Other categories of vertebrates have no or few restrictions. For example, no Federal quarantine requirements exist for non-indigenous fish, and few exist for non-indigenous reptiles.

Animals are held either in USDA Veterinary Services quarantine stations or in various private facilities approved by the USDA at or near ports of entry. Veterinary Services maintains quarantine stations in Newburg, New York; Miami, Florida; and Honolulu, Hawaii. In addition, the Harry S. Truman Animal Import Center at Fleming Key, Florida, quarantines imported animals when highly contagious diseases (e.g., foot-and-mouth disease) are a risk or where high security is required.

Animal quarantine does not completely prevent the introduction of animal disease or disease vectors, however. Some non-indigenous animals circumvent quarantine when they are shipped to approved zoos. While these animals are technically held in a permanent quarantine (i.e., the zoo), the potential exists for diseases to escape via other vectors such as insects. Importation of animals such as red deer *(Cervus elaphus)* for game and ostriches *(Struthio camelus)* for commercial purposes also provides a potential pathway for NIS. A gap in prevention occurs because it is difficult to recognize diseases or their vectors carried on these novel imports and to develop appropriate tests quickly.

Plant Germ Plasm—High-risk plant germ plasm is quarantined to check for the presence of pests or pathogens such as viruses, bacteria, insects and mites, or fungi. The National Plant Germplasm Center in Beltsville, Maryland, conducts tests for detection methods. Present facilities and staffing are inadequate to process expected future volumes of incoming material (65), and the Center is in the process of expansion. Ongoing construction activities may extend into 1997 (92).

Some standard techniques for detecting pathogens in germ plasm include visually looking for signs and symptoms of disease, and checking for transmission to healthy plants (79). More specific techniques involving electron microscopy, immunosorbent assays (ELISA, EIA), molecular probes, and other tools have been developed or improved for particular pathogens (38). These tools, used alone or in combination, allow faster and more precise pathogen detection, although they also have limitations to their use. Research is needed to detect other pathogens of quarantine signtificance and to make these technologies more practical at inspection stations (38).

Biological Control Agents-Certain groups of non-indigenous biological control agents (e.g., insects and pathogens) are also quarantined upon importation. The quarantine may screen for non-target effects of control agents, for hyperparasites, or for purity to guard against the inadvertent introduction of additional NIS (43).

Biological control quarantine facilities exist in Federal, State, and university laboratories. The USDA provides guidelines for their development and sets standards for features such as air intake systems, drains, escape-proof containers, and greenhouses. These standards vary depending on the type of organisms being held. Quarantine facilities in Frederick, Maryland, for example, are designed to prevent plant pathogens from escaping (58).

Education at Ports of Entry

A portion of travelers carrying prohibited NIS are unaware of Federal restrictions or have made honest mistakes about possessing prohibited items. These travelers would more likely comply with restrictions if they were aware of the reasons for

USDA

Attempts to educate travelers regarding the dangers of importing non-indigenous species have relied on posters and other written materials, with mixed success.

regulatory actions, and the environmental and economic risks involved (38). A well-organized, active public education campaign could disseminate such information.

One example of a public education campaign for travelers was a USDA program begun in the early 1960s. It used the media to build general awareness in order to deter entry of prohibited products (54). The program included printed information, radio and television advertisements, films, foreign language fliers, and the development of the symbol "Pestina" (akin to the U.S. Forest Service's Smoky the Bear).

The program had mixed results. No formal evaluation attempted to determine the program's effectiveness (52). The program did illustrate a lack of cooperation and coordination between Federal agencies and the private sector, as airlines, travel agencies, and port authorities were indifferent about giving full support to the USDA programs (54,91).

Although public education is considered an essential element of prevention programs, OTA could not identify a formal national education program directed against NIS importation. Limited public education at ports of entry depends primarily on printed materials (e.g., posters and pamphlets). Showing videos on airplanes is an interesting approach. Hawaiian, Northwest, and Continental Airlines are sporadically involved in such a program on flights to Hawaii.

Where, when, and how to educate the public about NIS policy are important questions. Education before travelers depart (allowing them to leave prohibited items behind) offers perhaps the best way to prevent introductions. Educating after departure but before arrival also is beneficial, acting not so much as a safeguard for the existing trip, but as a method for building awareness for future trips (54).

Evaluation of Prevention Programs and Methods

Assessing the effectiveness of inspection and quarantine programs is difficult. For example, the number of reported interceptions at a port of entry only provides the quantity and types of regulated NIS discovered, This information provides little data on the effectiveness of the prevention system because it does not estimate the total pest entries. OTA was only able to identify ad hoc programs that evaluate the effectiveness of prevention programs.

THE "BLITZ"

One approach to understanding how many prohibited items enter the country is through ''blitzes,' or brief 100 percent inspection. During one week in May 1990, USDA/APHIS, the California Department of Food and Agriculture, and some southern California counties conducted a blitz at Los Angeles International Airport. Out of a total of 490 flights, 100 percent of the baggage of 153 targeted flights (from high-risk countries of origin) and several non-targeted flights was inspected. The remainder underwent standard USDA inspection.

The blitz showed that passenger baggage on foreign flights is an important pathway for plant and animal pests (7). Inspection involving 16,997 passengers (i.e., passengers *and their* baggage) from the targeted flights intercepted 667 lots of prohibited fruits and vegetables and 140 animal products (equaling 2,828 pounds). Another 690 lots of prohibited fruits and vegetables and 185 of animal products (2,969 pounds) were intercepted from non-targeted flights. The results also demonstrated that at this airport considerable illegal importation occurs. A study of the blitz concluded that more resources are needed to close this pathway and to more strongly deter common illegal activity (8).

"Shutting the Door"—Blitzes can evaluate the effectiveness of prevention programs already underway, Assessing when and how new programs are established is another important issue. Lag times often occur between the identification of new pathways (and new NIS) and the implementation of new prevention programs (table 5-2). Eliminating such lags could help prevent the establishment of new harmful NIS.

Both political and technical limitations cause delays. For example, effective methods such as xrays and dogs exist for identifying domestic frost-class mail containing prohibited agricultural products. But postal laws and lack of departmental interest have limited the control of this pathway (7). And while many techniques are available to treat ballast water, few are practical for large-scale use (97).

Even when programs are established, gaps in their implementation may continue to allow the entry of NIS. The protocols to prevent introductions via ballast water apply only for the Great Lakes (97). Ships entering other U.S. ports can still introduce non-indigenous aquatic organisms. The development of a domestic first-class mail inspection program between Hawaii and California does not address the potential movement of harmful MS between Puerto Rico and California (77).

TECHNOLOGIES FOR MANAGING ESTABLISHED HARMFUL NON-INDIGENOUS SPECIES

Prevention programs are less than perfect at keeping potentially damaging NIS out of the United States. Programs to manage already introduced species are essential and use additional technologies.

Finding:

Accurate and timely species-level identification is essential at all levels of a NIS management program. Applications of computer technologies provide new approaches to NIS monitoring and information acquisition. However, these technologies are only tools. Their information output is only as good as what is put in.

Species Identification and Detection

As illustrated in chapter 3, information concerning the identity and number of NIS in the United States is incomplete. Correct identification is vital for distinguishing NIS from indigenous ones and for establishing management programs. For example, some scientists now believe that the 1991 infestations of the sweet potato whitefly *(Bemisia tabaci) in* California were in fact a different species (2). If true, the search for control methods would require a different focus because many technologies are species specific (e.g., pheromone traps, classical biological control). Improper species identification can lead to the failure of these species-specific management programs.

COLLECTIONS AND STAFFING

National, State, and university taxonomic collections provide reference material for comparing and identifying species. They maintain records of known species and their historical and present-day distribution. Plant and animal collections of USDA and the Fish and Wildlife Service are held

Table 5-2—Lag Times Between Identification of Species' Pathway and Implementation of Prevention Program.

Species	Pathway	Date pathway identified	Date prevention program implemented	Remaining gaps
Mediterranean fruit fly *(Ceratitis capitata)*	Fruit shipped through first-class domestic mail from Hawaii	mid 1930s	1990, mail traveling from Hawaii to California inspected	First-class mail from elsewhere or other potential pathways (e.g., Puerto Rico to California)
Aquatic vertebrates, invertebrates, and algae	Ship ballast water	1981	1992, Coast Guard proposes guidelines for treating ballast water into the Great Lakes	International shipping into other U.S. ports; ship ballast water from domestic ports
Asian tiger mosquito *(Aedes albopictus)*	Imported used tires	1986	1988, protocols established for imported used tires	Interstate used tire transport
Forest pests	Unprocessed wood (including dunnage, logs, wood chips, etc.)	1985	1991, first restrictions imposed on log imports from Siberia	Wood imports other than from Siberia

SOURCES: Bio-environmental Services Ltd., The *Presence and Implication of Foreign Organisms in Ship Ballast Waters Discharged into the Great Lakes*, vol 1, March 1981; C.G. Moore, D.B. Francy, D.A. Eliason, and T.P. Monath, "*Aedes albopictus* in the United States: Rapid Spread of a Potential Disease Vector," *Journal of the American Mosquito Control Association*, vol. 4, No. 3, September 1988, pp. 356-361; LA. Siddiqui, Assistant Director, California Department of Food and Agriculture, Sacramento, CA, testimony at hearings before the Senate Committee on Governmental Affairs, Subcommittee on Federal Services, Post Offices, and Civil Services, Postal *Implementation of the Agricultural* Quarantine EnforcementAct, June 5, 1991; United States Department of Agriculture, Animal and Plant Health Inspection Service, "Wood and Wood Product Risk Assessment," draft, 1985.

at the Smithsonian Institution's National Museum of Natural History, the National Arboretum, and taxonomic laboratories of the USDA Agricultural Research Service. In addition, the American Type Culture Collection, a non-profit, privately held organization, maintains reference and research material on microorganisms.

Some groups of organisms are better known and easier to identify than others. Indigenous birds and mammnals are thoroughly inventoried, but experts believe more than half of the indigenous insects and arachnids in the United States are unidentified (40). The lack of information on indigenous species hampers the identification of some NIS in the United States. The Clinton Administration's proposed national biological survey, slated by the Department of Interior to begin in October 1993, is an attempt to bolster information on U.S. biological diversity (81).

Taxonomists (people who describe, identify, and classify species) work at field locations, museums, and universities across the country. A shortage of trained taxonomists at all levels in the United States (40,102) impedes rapid and accurate identification of intercepted species and the collection of scientific information on NIS (40).

MOLECULAR BIOLOGY TECHNIQUES

Traditionally, taxonomists study variations in anatomy, physiology, and morphology to distinguish between different species. For many NIS, identification is hampered by the species' small size or because of taxonomic complexity or ambiguity. Alternatively, methods of molecular biology can provide effective options. Tools such as gel electrophoresis can reveal enough genetic variation to separate species (60). Molecular biology methods can identify genetic strains, or distinguish between hybrids and natural populations (27,36).

Molecular techniques may also provide faster identifications, which is important for NIS like the African honey bee. European *(Apis mellifera)* and African *(A.m. scutellata)* honeybees can exist at the same location, and quick identification of the African type is important for management programs. The morphological approach to identification measures variation of specific body parts, while mitochondrial DNA testing works faster and is more accurate (15).

Aside from species identification, molecular testing is useful for determining geographic origin of a NIS (56). For example, molecular markers may in the future help identify the origin of Californian populations of the Mediterranean fruit fly (ch. 8, box 8-A). Understanding a species' origin can help identify routes of invasion or spread and aid in developing appropriate prevention or management programs (39,74).

Fast and accurate species identification is essential for designing detection methods and management plans but distinguishing some species, e.g., European and African honey bees, requires expertise that is in short supply.

Species Surveys and Population Monitoring

Planned detection systems are useful for identifying early infestations of NIS, monitoring populations after they are established, and documenting effects. For example, monitoring water systems for young zebra mussels can provide early warnings of an invasion (55).

DETECTION TECHNOLOGIES

Visual surveys, traps, and physical inspection can locate infestations of NIS. Visual surveys are used for such species as weeds, birds, and mammals. Trapping locates organisms that are more difficult to see, such as insects or aquatic invertebrates. Physical inspection is *especially* useful for diseases associated with livestock.

Surveys for known harmful NIS occur at the local level, as part of pest management programs; at the State level, as part of domestic quarantine programs; and at regional or national levels. Surveys to detect new introductions are generally conducted by the Federal Government (California is an exception), in part because surveys generally have little or no immediate economic value and can have significant long-term costs.

Traps can provide information on the presence and geographical distribution of NIS. Further information, such as the host, geographic origin, age, and sex of a NIS are potentially obtainable (9). The basic components of a monitoring system are the attractant, the trap itself, and information about the species' biology (100). Desirable attributes of trapping systems are low cost, ready availability, easy servicing and inspection, and provision of specimens in good condition for taxonomic identification (13).

Commercially available traps incorporating behavior-modifying compounds (biorationals) such as sex pheromones or other attractants are relatively inexpensive and effective tools for surveying NIS in certain situations. Most research involving pheromones and other attractants in traps is aimed at non-indigenous insects that are agricultural pests. Such traps are potentially useful with other NIS (e.g., terrestrial vertebrates) (25). (For more on the use of pheromones see "Tools of the Control Trade" below.)

Limitations to the broader use of pheromone monitoring programs include the high cost of the active ingredients, inadequacies in synthetic pheromone formulation technologies, the lack of commercial development, and shortcomings in technology transfer to the marketplace (78).

REMOTE SENSING

Remote sensing shows promise in NIS detection programs. Remote sensing of habitats with video and still-camera equipment can provide information on the distribution and spread of certain NIS, especially plants. Helicopters, planes, and even satellites gather information using infrared or near-infrared photography. Image-processing software creates a digital mosaic in which dominant species can sometimes be distinguished on a regional basis.

Federal and State agencies are conducting research into and applying remote sensing technology. The data collected are important for identifying new infestations of damaging NIS and developing management plans. For example, the Agricultural Research Service used Landsat imagery in a bollworm *(Helicoverpa zea)* control program for cotton in Texas (32). Remote sensing data are also often suitable for use in geographical information systems.

GIS TECHNOLOGY

Geographical information systems (GIS) store, manipulate, analyze, and display spatial data. The combination and display of variables such as topography, vegetation types, and climate has recently been enhanced by the merging of GIS with online satellite data. By sorting and filing vast amounts of information, GIS can rapidly correlate and map such variables. Limiting factors in GIS technology are the high cost of data acquisition and a lack of data linking NIS to geographical variables (39).

Federal and State agencies and universities use GIS technology for various natural areas' issues, e.g., to study wildlife migration patterns and rates of wetlands loss. Such tools are also applicable for monitoring NIS. The National Fisheries Research Center in Gainesville, Florida, now uses GIS to analyze non-indigenous fish and certain mollusks (84). The National Park Service determines resources vulnerable to fire or gypsy moths *(Lymantria dispar) (85).*

The applications of GIS vary with the availability of suitable MS data. Detailed knowledge of a NIS allows the prediction of high-risk areas for unplanned invasions or expansion. Conversely, monitoring planned or known introductions can generate NIS data by identifying habitat correlations. Hypotheses can rapidly be tested, for example, relating invasions to habitat disturbance or identifying particular corridors that invasions are likely to follow (39).

Information Collection and Dissemination

The development of tools to collect information about NIS quickly and easily is important, as are mechanisms to disseminate the information. Methods to distribute information about NIS presence and distribution should be timely and reliable. The range of potential mechanisms varies from printed books, journals, newsletters, and abstracts to electronic computer storage, CD-ROM (Compact Disk-Read Only Memory), and expert systems.

Few programs for disseminating information strictly about NIS are available within the United States. As one example, the New York Sea Grant Marine Advisory Service operates the Zebra Mussel Information Clearinghouse in Brockport, New York, to provide information on zebra mussel distribution, impacts, research, and other issues (84).

Potentially, computer technologies could help develop national or even global centralized NIS databases. The function of such databases would be not only to provide information on available management technologies, but also to warn of possible harmful NIS. No single organization is likely to develop such programs, as the creation and maintenance of the databases is expensive (33).

Technologies such as computerized databases could aid information management related to NIS. For example, the BIOCAT database records the results of nearly 5,000 introductions of biological control agents in about 200 countries since 1880 (28).

An interest at the Federal level (especially within the USDA) exists for increased use of computerized databases (17,88). Within the USDA, however, OTA has found sharp contrasts between the start-up and long-term support of databases involving NIS. NAPIS (the National Agricultural Pest Information System) and DATAPEST (the National Historical Pest Database) under CAPS (the Cooperative Agricultural Pest Survey), WHAID (Western Hemisphere Immigrant Pest Database), NAIAD (North American Immigrant Arthropod Database), ROBO (Releases of Beneficial Organisms), and PINET (Pest Information Network) are among some of the USDA databases that have been recently developed. However, few of these databases are properly functioning (17, 40). For example, critics find that NAPIS suffers from poor data (43); ROBO only was published in 1988, with information collected in 1981 (17).

Advances in computer technologies provide relatively inexpensive approaches for quick dissemination of information on NIS. Various Federal agencies have begun to apply these technologies to NIS problems.

CD-ROM first appeared in 1985 and has developed into an easy-to-use, well-standardized technology (48). By applying indexing techniques, CD-ROM is commercially suitable for building both general and specialized databases (e.g., the National Agricultural Library's AGRICOLA database, which indexes agricultural papers). Information specific to NIS could be gathered in this format.

Electronic mail or computer-based message systems are used by various agencies to transfer NIS information. For example, information on plant pests is collected and electronically sent to the NAPIS. The rapid transmittance and minimal costs of information via electronic mail can allow for better and more timely decisionmaking (48).

Expert systems may also have use for NIS concerns. An outgrowth of artificial intelligence research, expert systems are computer programs that make inferences and draw conclusions from statements supplied by a user. These systems have begun to find commercial application in the last few years (48). For example, a prototype system was recently developed to assist in European gypsy moth management.

Eradication

Finding:

Feasible eradication technologies do exist for many NIS, but public opinion and cost often prohibit implementation of a fully effective program. Three issues that complicate a successful eradication program include: the difficulty in identifying the zero-population level, diminishing returns as the population approaches zero, and the potential for reinfestation from surrounding areas. Although eradication of a NIS can have high short-term costs, the alternative is often a long-term management program with far greater cumulative costs.

It is important to distinguish between eradication and control, Both strategies use the same technologies (e.g., chemical pesticides or biologically based methods), but they have different goals. The goal of eradication is to remove the entire population of a species from a specific area. The alternative is to keep the population below a defined threshold through containment or suppression. Eradication programs for NIS (especially terrestrial vertebrates) are often long, costly, frustrating, and controversial (73), yet the failure to fully eradicate a harmful NIS can lead to long-term management programs, with continual yearly investments of time and money.

APPLICATION OF ERADICATION

Both governmental (State and Federal) and non-governmental organizations (NGOs) conduct MS eradication programs. The reasons for eradication vary. For example, a Federal program to eradicate witchweed *(Striga asiatica)* in North and South Carolina is based on the potential economic effects that would result if the weed were to spread to the Midwest. Localized eradication programs for Asian tiger mosquito *(Aedes albopictus)* infestations occur because they are vectors for human diseases. Eradication programs for feral goats *(Capra hircus) in* Hawaii Volcanoes National Park were implemented because of the goats' impact on the natural resources of the area.

Studies assessing different eradication programs indicate that several factors influence the ease of eradicating NIS (19,42). Some of the most important include:

- adequate monitoring and early detection,
- quick implementation after detection,
- sensitive enough tools to detect low population densities,
- effective control technologies, and
- public perception and cooperation.

Eradication programs also require adequate planning and a commitment of sufficient resources (19,98). These two elements in particular affected the outcomes of eradication programs for imported fire ants *(Solenopsis invicta, S. richteri)* and boll weevil *(Anthonomis grandis) (box 5-A).*

THE ROLE OF THE PUBLIC

Public interaction can play a significant role in eradication programs for both governmental and non-governmental organizations. Favorable public opinion can lead to help and cooperation during a program while opposition can lead to legal actions aimed at ending a specific program. Perceived risk from control technologies, outrage from involuntary quarantine restrictions, or moral issues of animal rights may charge public opinion against an eradication program. The desire for humane treatment of MS can restrict or prohibit the use of specific control technologies or eradication generally. Programs to eradicate damaging NIS (like feral horses *(Equus caballus)* and donkeys *(Equus asinus)* have evoked such public opposition (23).

In some instances, negative reaction can simply stem from a lack of accurate information (73). Implementing education programs around the use of specific technologies and the reasons for removing particular NIS can help alleviate public fears.

I Domestic Quarantine and Containment

The goals of domestic quarantine and containment are to prevent or limit the spread of potentially harmful NIS. Domestic quarantine provides a regulatory means to prevent or slow down the spread of a NIS within the United States, often during control or eradication programs. Plants, animals, and diseases have all been subject to domestic quarantine. Containment more often applies to non-indigenous animals. Some containment of cultivated game and other non-indigenous animals is required, for example, to prevent their spread into natural areas.

DOMESTIC QUARANTINE

Domestic quarantine attempts to slow or limit the spread of a harmful NIS within or to a State or region of the United States. Generally, domestic quarantines exist for pests that threaten agriculture, horticulture, or forestry. All States have some type of domestic quarantines (68).

Two important factors for a successful domestic quarantine program, like that for witchweed (71), are an effective certification process for pest-free commodities and other items within the quarantine area, and the cooperation of the general public (71).

Unfortunately, not all domestic quarantines work as well. The domestic quarantine of the imported fire ant has not prevented it from spreading. Movement reportedly has occurred in association with nursery material (l).

Domestic quarantines cannot slow or prevent NIS from moving by natural means; they can only hinder NIS from spreading through human-assisted mechanisms such as interstate shipments of nursery stock or household goods. Their

Box 5-A–Failure and Success: Lessons From the Fire Ant and Boll Weevil Eradication Programs

Imported Fire Ant Eradication:

Two species of imported fire ants are assumed to have entered at Mobile, Alabama, in dry ship ballast: *Solenopsis* richteri in 1918 and, around 1940, *Solenopsis invicta*. The ants became a public health problem and had significant negative effects on commerce, recreation, and agriculture in the States where they were found. In late 1957, a cooperative Federal-State eradication program began. it exemplifies what can go wrong with an eradication program.

Funding was provided to study the fire ants, but information on the biology of the species was lacking, and the ant populations increased and spread. Various chemicals (heptachlor and mirex) were used to control and eradicate the ants over a 30-year period. Although they did kill the ants, the chemicals caused more ecological harm than good. Their widespread application, often by airplane, destroyed many non-target organisms, including fire ants' predators and competitors, leaving habitats suitable for recolonization by the ants.

The chemicals eventually lost registration by the Environmental Protection Agency, leaving few alternatives available. In the 5 years after 1957, fire ant infestations increased from 90 million to 120 million acres.

Boll Weevil Eradication:

The boll weevil, *Anthonornus grandis*, a pest of cotton, naturally spread into Texas, near Brownsville, from Mexico, in the early 1890s and crossed the Mississippi River in 1907. By 1922, it infested the remainder of the southeastern cotton area. Unlike the imported fire ant eradication program, boll weevil eradication does not rely solely on chemicals.

The eradication program centers around the weevil's life cycle and uses many different techniques. Part of the boll weevil population spends the winter in cotton fields. Insecticides are used to suppress this late season population. In spring and early summer, pheromone bait traps and chemical pesticides reduce populations before they have a chance to reproduce. Still other control technologies (e.g., sterile male release or insect growth regulators) limit the development of a new generation of boll weevils.

Boll weevil eradication trials were conducted from 1971-1973 (in southern Mississippi, Alabama, and Louisiana) and from 1978-1980 (in North Carolina and Virginia). Although results of the trials were mixed, cotton producers in the Carolinas voted in 1983 to support the boll weevil eradication program in their area and to provide 70 percent of the funding. The USDA Animal and PIant Health Inspection Service was charged with overall management of the program.

By the mid-1980s, the boll weevil was eradicated from North Carolina and Virginia. This 1978-1987 eradication program achieved a very high rate of return, mainly from increased cotton yields and lower chemical pesticide spending and use. In 1986, pesticide cost savings, additions to land value, and yield increases amounted to a benefit of $76.65 per acre. The benefit was $78.32 per acre for the expansion area in southern North Carolina and South Carolina.

SOURCES: G.A. Carlson, G. Sappie, and M. Hamming, "Economic Returns to Boll Weevil Eradication," U.S. Department of Agriculture, Economic Research Service, September 19S9, p. 31; W. Klassen, "Eradication of Introduced Arthropod Pests: Theory and Historical Practice," Entomological Society of America, Miscellaneous Publications, No. 73, November 19S9; E.P. Lloyd, "The Boll Weevil: Recent Research Developments and Progress Towards Eradication in the USA," Management *and* Control *of Invertebrate Crop Pests*, G.E. Russell (cd.) (Andover, Hampshire, England: Intercept, 1989), pp. 1-19; and C.S. Lofgran, W.A. Banks, and B.M. Glancey, "Biology and Control of Imported Fire Ants," *Annual Review of Entomology* vol. 30, 1975, pp. 1-30.

effectiveness is based on enforcement by government agencies and the education of the general public to prevent inadvertent spread.

State border station systems are one mechanism to enforce domestic quarantines. Presently they are used in California and Florida to inspect agricultural commodities for the presence of State quarantined pests (68). The effectiveness of State border inspection is illustrated by California's enforcement of the Federal domestic gypsy moth program. Stricter enforcement raised compliance with quarantine restrictions from about 20 percent in 1985 to approximately 80 percent in 1990 (7).

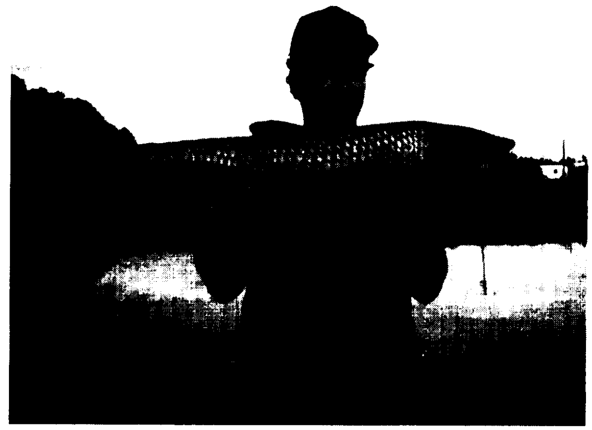
CONTAINMENT OF LARGE GAME AND FISH

Non-indigenous animals are kept as pets, for food production, sport, and as part of conservation programs. The escape of a NIS can introduce disease or parasites to wild populations, alter habitats, and lead to competition for limited resources or hybridization with wild populations. The scenarios that follow illustrate where deleterious effects might occur or have occurred.

Large-Game Ranching—Ranchers have kept large game in the United States for at least 40 years. Non-indigenous animals such as African ungulates are raised for sport, show, food, and for their aesthetic value. Interest in species preservation has also increased the numbers of large game in the United States. The first documented escape of contained non-indigenous mammals occurred approximately 45 years ago, from private ranches in Texas, California, and New Mexico (47; see ch. 7).

For most large mammals, no official national minimum containment standards exist. States such as California and Florida have established guidelines, but they are far from uniform (75). The USDA has asked the American Association of Zoological Parks and Aquariums to develop minimum standards for mammal containment, but these are still under development (75).

Big game animals are most commonly contained with standard-grade sheep or goat fencing, often electrified. The reasons and means of escape vary, but they usually include poor fence maintenance or design, weather damage, or vandalism (47). Further, when startled or upset, many mammals are capable of escaping either over or through fences.



CHARLES E. CICHRA

Triploid grass carp (Ctenopharyngodon idella) ***are*** *tested for sterility before their release as biological control agents for aquatic weeds.*

Aquiculture-In aquiculture, *NIS are* propagated for food (e.g., salmon, crayfish, and oysters), biological control (e.g., grass carp—*Ctenopharyngodon idella),* and for the pet trade (e.g., tropical fish). Improvements in production systems and new developments in genetics and biotechnology are expanding the size of the industry. Fish have escaped from commercial and experimental culture facilities (12), raising concern about the containment of NIS as aquiculture markets expand.

Scientists have created guidelines for the containment of transgenic or non-indigenous fish for research purposes (35, 96). These guidelines aim to prevent the escape of NIS from containment facilities. They have little application to commercial aquiculture, however, because they often involve small, indoor buildings. Many States, such as Florida, have minimum containment standards for commercial aquiculture. In general, no national standards exist for commercial aquaculture.

outdoor facilities for containing NIS for aquaculture include ponds, pools, raceways, canals, tanks, and floating pen nets. Escapes can be prevented by constructing levees, placing ponds above 100-year flood lines, or using fences or nets. Escapes from tanks or pools can be prevented with the use of closed circulatory systems and filtered drainage systems. Floating pen nets are generally anchored to prevent drifting and covered with nets to prevent escape or removal of animals.

The production of sterile or single-sex populations can prevent establishment of reproducing populations if escape occurs. Single-sex fish populations are created by hybridization and sex reversals. Sex reversal in fish is possible in the early developmental period by administering hormones in the diet or in slow-release implants. These methods are not 100 percent effective, however (35).

Reproductive sterilization is accomplished with radiation, chemicals, or hybridization. Reproductive sterilization is perhaps the most secure approach for the biological containment of NIS. Currently, the use of triploid sterility[1] has the greatest potential (35). Although the sterilization techniques are not 100 percent effective, some NIS can be tested for triploidy. For example, tests to guarantee grass carp and Pacific oyster *(Crassostrea gigas)* sterility are available.

Tools of the Control Trade

Finding:

No "silver bullets" exist for NIS control. Alternatives to chemical pesticides are being developed, but these new pesticides must provide advantages (cost, efficacy, environmental stability) before they can replace chemicals. Biotechnological improvements may overcome some of the limitations of biological control agents. As with chemicals, the potential for pest resistance exists.

The final stage in the management of a NIS is the development of a long-term control to suppress the population below specific thresholds. Three major groups of control technologies exist: physical controls, including manual, mechanical, and cultural methods; chemical pesticides, including synthetic and organic chemicals; and biologically based technologies, including natural or modified organisms, genes, or gene products and related techniques (table 5-3). The broad array of NIS in the United States requires an assortment of controls for use in agriculture, urban and suburban habitats, and natural areas. Whether to eradicate an NIS, contain it, or limit its economic damage to a crop, no control technology is optimal for all species, or in all settings.

PHYSICAL CONTROL

Physical controls may be mechanical (e.g., mowing), manual (e.g., hand pulling), or cultural (e.g., burning) (table 5-3). Physical controls are often applied to small populations of NIS because of the time (and therefore cost) associated with controlling larger populations. Physical controls may also be used where other control technologies are infeasible (e.g., a control program for an aquatic plant occurring close to a municipal water supply).

Use of physical controls may be limited by their low efficacy and other environmental factors. Hand pulling or cutting may leave roots, vegetative fragments, or seeds to resprout or germinate, leading to the establishment of new populations. Similarly, small populations of non-indigenous animals (e.g., goats) can repopulate an area if hunting or trapping does not remove all reproductive pairs.

Physical techniques may also lead to high levels of disturbance. The disturbance involved in the removal of non-indigenous plants, for example, may encourage invasion by other, nearby weedy non-indigenous plants and the germination of weed seeds already present.

[1] Triploid organisms have 3, instead of 2, sets of chromosomes. For the most part, these organisms cannot reproduce. This third set of chromosomes arises from altering the earliest stages of development. Techniques to induce triploidy include temperature, chemical, and pressure treatments.

Table 5-3-Examples of Control Technologies for Non-Indigenous Species

	Physical control	Chemical control	Biological control
Aquatic plants	Cutting or harvesting for temporary control of Eurasian watermilfoil *(Myrlophyllum spicatum)* in waters	Various glyphosate herbicides (Rodeo is one brand registered for use in aquatic sites) for controlling purple loosestrife (Lythrum *salicaria)*	imported Klamathweed beetle *(Agasicies hygrophila)* and a moth *(Vogtia malloi)* to control alligator weed *(Alternanthera philoxeroides)* in southeastern United States
Terrestrial plants	Fire and cutting to manage populations of garlic mustard *(Alliaria petiolata)* in natural areas	Paraquat for the control of witchweed *(Striga asiatica)* in corn fields	introduction of a seed head Weevil *(Rhinocy//us conicus)* to control musk thistle *(Carduus nutans)*
Fish	Fencing used as a barrier along with electroshock to control non-indigenous fish in streams	Application of the natural chemical rotenone to control various non-indigenous fish	Stocking predatory fish such as northern pike (Esox *lucius)* and walleye *(Stizostedion vitreum)* to control populations of the ruffe *(Gymnocephalus cernuus)*
Terrestrial vertebrates	Fencing and hunting to control feral pigs *(Sus scrofa)* in natural areas	Baiting with diphacinone to control the indian mongoose (Herpestes *auropunctatus)*	Vaccinating female feral horses *(Equus caballus)* with the contraceptive PZP (porcine zona pellucida) to limit population growth
Aquatic invertebrates	Washing boats with hot water or soap to control the spread of zebra mussels (Dreissena polymorpha) from infested waters	in industrial settings, chlorinated water treatments to kill attached zebra mussels	No known examples of successful biological control of non-indigenous aquatic invertebrates (Target specificity is a major concern)
Insects/mites	Various agricultural practices, including crop rotation, alternation of planting dates, and field sanitation practices	Mathathion bait-sprays for control of the Mediterranean fruit fly *(Ceratitis capitatis)*	A parasitic wasp *(Encarsia partenopea)* and a beetle *(Clitostethus arcuatus)* to control ash whitefly *(Siphoninus phiilyreae)*

SOURCE: Office of Technology Assessment, 1993.

CHEMICAL CONTROL

When used properly, chemical pesticides are an effective tool for controlling pests. Their greatest application has occurred within agriculture. In 1989, U.S. users spent approximately $7.6 billion for conventional pesticides, with agriculture accounting for more than two-thirds (4). The use of chemical pesticides for NIS control is limited based on availability and application to specific environments.

Quick and effective control technologies are often desirable to limit the impact of a NIS, and chemical pesticides can be applied and take effect within a short period of time. For example, in natural areas, systemic herbicides applied to a non-indigenous plant population can suppress it before it has a chance to produce seeds and thereby prevent future populations.

Although chemical pesticides are effective for many NIS, problems do exist in using many of them in control programs. For non-indigenous aquatic plants, effective chemical pesticides may be available, but are not registered for use in aquatic settings. Public concern can also limit the use of chemical pesticides by government agencies. For example, Utah's decision to use the biopesticide *Bacillus thuringiensis* instead of chemical pesticides to control the European gypsy moth was influenced by the general public and environmental groups (44).

An important issue related to the use of chemical pesticides is their future availability. Methyl bromide, a widely used chemical pesticide, may soon become unavailable because of its effect on the atmosphere (63). In addition, the 1988 amendments to the Federal Insecticide, Fungicide, and Rodenticide Act[2] may also limit the availability of many chemical pesticides for NIS (see the following section, "EPA Reregistration and Minor Use Pesticides").

BIOLOGICAL CONTROLS

Alternatives to chemical pesticides are often desirable for either economic or ecological reasons. Biological control has been in use in the United States and elsewhere for more than 100 years, although the development of synthetic chemicals in the 1940s shifted focus away from biological control (61). Attention has recently focused again on the development and use of biological control. Biological control attributable to natural enemies (i.e., classical biological control) is distinguished here from controls involving other biologically based methods (e.g., genetic control, hormones and pheromones, and contraceptives) (70). Both forms are important alternatives to chemicals for NIS control.

Biological Control With Natural Enemies—The standard definition of biological control is the use of natural enemies—parasites, predators, or pathogens—to reduce populations of target species and thereby reduce their damage to tolerable levels (16). Applying biological control involves research in many branches of biology—behavior, development, physiology, genetics, reproduction, systematic, biogeography, population biology, and ecology.

Biological control is divided into three broad categories: *importation* (or classical), involving the establishment of a NIS as a natural enemy in a new habitat; *augmentation* (often called the biopesticide approach), involving direct manipulation of established populations of natural enemies through mass production or colonization; and *conservation,* involving habitat manipulations to encourage populations of natural enemies. To date, importation is considered the most successful of these approaches (16).

Classical Biological Control-h theory, classical biological control re-establishes natural control by predators or parasites for foreign NIS that were introduced without their natural enemies. The goal of classical biological control is not to eradicate a NIS, but to lower the population level to economically or aesthetically acceptable levels.

Classical biological control has several advantages over other types of control technologies. *When* successful, reasonably permanent management of the target species results. Control agents are self perpetuating, will increase and decrease with populations of the pest, and are self disseminating. Costs are non-recurrent and benefit/cost ratios are high relative to other types of control (20,101). The average benefit/cost ratio for successful biological control projects is about 30:1, although the ratio varies widely among various projects (83).

Historically, however, most biological control projects have not been successful (59). The worldwide rate of establishment of introduced beneficial predators and parasites is about 30 percent; approximately 36 percent of these established agents successfully reduced or completely controlled their targeted pests-a proportion that is probably estimated too high (28). According to another author, the introduction of natural enemies sufficiently reduced host densities to replace

2 Federal Insecticide, Fungicide, and Rodenticide Act of 1947 (7 U.S.C.A. 135 *et seq.*); 1988 amendments, Public Law 100-532.

chemical control only in approximately 16 percent of 600 projects (59).

Constraints to implementing biological control stem from uncoordinated efforts among agencies, inadequate funding for overseas and domestic research, as well as the lack of a theoretical framework for determining what species or combinations of species will likely control a target pest in a given situation (20). Classical biological control does not work well in certain agricultural settings (e.g., annual crops where control must be rapid). It does show great promise for controlling NIS in natural areas or rangelands. For example, an Australian weevil is the first natural enemy imported for use against melaleuca *(Melaleuca quinquenervia) in the* Everglades (3).

Microbial Pesticides—Microbial pesticides (or biopesticides) include the use of fungi, viruses, bacteria, protozoa, and nematodes to control targeted species. Microbially derived herbicides and insect pathogens are commercially available in the United States (table 5-4, table 6-5). Microbial pesticides represent only a small portion of the pesticide market. The biggest obstacles in their development and commercialization involve host specificity, production technologies, lack of virulence, and the time frame needed to suppress the pest populations. The prospects for developing additional microbial pesticides, naturally or through genetic modification, are considered good (83).

The research and development costs of biopesticides are significantly less than those for chemical pesticides. The estimated cost for developing and deploying a biopesticide is between $1 million and $2 million, involving 11 to 13 scientist-years, whereas a chemical pesticide takes at least $10 million (10). Although biopesticides will not completely replace chemicals in the foreseeable future, they will complement chemicals and allow the development of improved integrated control measures (37). Market size is an important criterion in the development of these control technologies because lead times are long and the development and registration costs for new products are high.

Table 5-4-Examples[a] of Registered Microbial Biological Control Agents

Fungi
Phytohthora **palmivora controls citrus strangler vine** *(Morrenia odorata)*
Lagenidium gigantium controls various mosquito larvae
Viruses
Hellothis nuclear polyhedrosis virus (NPV) controls the cotton bollworm ***(Helicoverpa zea)***
Gypsy moth NPV controls European gypsy moth larvae *(Lymantria dispar)*
Bacteria
Bacillus **popilliae controls Japanese beetle larvae** *(Popillia japonica)*
Bacillus thuringiensis **controls various moth larvae**
Protozoa
Nosema ***locustae*** **controls various grasshoppers**

[a] See table 6-5 for a Complete list.

SOURCE: F. Betz, Acting Chief, Science Analysis and Coordination Staff, U.S. Environmental Protection Agency, letter to E.A. Chornesky, Office of Technology Assessment, Apr. 10, 1992.

Other Biologically Based Methods--Several types of other biologically based methods have become available for NIS control.

Sterile Male Release (genetic control)-The release of sterile male insects was first successfully used in the United States in 1953 to control the new world screwworm *(Cochliomyia hominivorax). Since* then, it has been attempted with a large variety of insects, such as the Mediterranean fruit fly and the boll weevil, with varying success (51).

Sterile males released in large numbers mate with females, leading to the production of unfertilized eggs. Difficulties in implementing this technology exist, especially with mass rearing. Not only are appropriate facilities necessary to breed large populations of a given species, but adequate information about dietary needs and biology are vital. Accurate sterilization techniques are also required, as is knowledge about the effects of sterilization on species behavior.

*Vertebrate Contraceptives--Contraceptives pro*vide reversible fertility control for captive and free-roaming non-indigenous animals. Their use is seen as a humane alternative to hunting or other management practices. Use of contraceptive methods requires continual monitoring and repeat applications.

New research is centering on the use of immuno-contraception (relying on an animal's immune system) instead of hormone levels to interfere with a part of the reproductive process, Other research has focused on the use of commercially available contraceptives such as Norplant and in identifying antisperm antigens for male animals (41). These controls are still in the research and development stages for most NIS.

Semiochemicals-Semiochemicals are a group of compounds (e.g., sex pheromones) that can modify behavior. The compounds, either natural forms or synthetic copies, are useful for large-scale trapping or to disrupt mating behavior (78).

Semiochemicals are presently useful only against insects (46). Their use has been inhibited by high development and registration costs and low use in specialized markets. The Environmental Protection Agency (EPA) considers pheromones pesticides, requiring toxicity and residue testing under FIFRA. Such species-specific technologies are often more expensive than more traditional techniques such as chemical pesticides. In agricultural settings, this generally makes the use of semiochemicals economical only on high-value crops (46).

Host Plant Resistance—Enhanced host plant resistance is the artificial selection and breeding of plants to produce specific physical traits (e.g., very hard or hairy leaves) or biochemical traits (e.g., production of specific chemicals) that deter pest damage (16). It is useful in agricultural and horticultural settings.

Resistance is developed against non-indigenous plant diseases and plant-eating insects. It is useful in situations where no registered chemicals exist or when alternative controls are unavailable (16). Host plant resistance is compatible with other control measures.

Development of host plant resistance requires large-scale support. A lack of specific information about plant genetics can limit the use of this technology. Long production times mean it has little application as a quick fix against new harmful NIS (16).

Biotechnology--Many new biological control technologies currently in the research stage depend on biotechnology to increase the virulence and efficacy of controls. This approach, involving recombinant DNA, so far has been applied only to microorganisms. Limited knowledge curtails the genetic manipulation of more complex organisms, such as insects used for biological control.

The long-term goals of biotechnology research include increasing the shelf life of microbial pesticides and their persistence in the field. For example, the bacterium *Bacillus thuringiensis* (Bt) releases an insecticidal toxic crystal along with its reproductive spores. Researchers have inserted the toxin gene into another bacterium that produces the toxin during the non-reproductive phase. After the bacterium is killed chemically, the dead cell wall protectively coats the crystal and increases its stability. This process also eliminates the release of viable spores, an area of environmental concern.

The importance of biotechnology for biological control will likely increase in the future, although more economic research into biotechnology methods is needed (83). One application of biotechnology that will have a significant impact, especially in agriculture, is the development of transgenic plants, an alternative approach to chemical or classical biological control that involves genetically engineering crops to express insecticidal or antifeedant proteins.

The first successful application of transgenic technology occurred within the past 5 years (57). Most of the work has focused on inserting genes from various Bt strains into plants, which then produce the insecticidal toxins. The Bt toxin is considered safe (specific to certain groups of species) and is relatively simple to work with (57). Research has so far focused on cotton, tomato, and potato. Private companies hope to have transgenic tomato and cotton plants on the market by the mid- 1990s (45).

Concerns exist that pests, especially insects, will develop resistance to transgenic plants. Recently, resistance to Bt has been documented in both laboratory and field settings (45), Efforts to prevent resistance counter-intuitively seek to maintain the susceptible population, thus delaying complete population resistance. Possible techniques for maintaining susceptible populations include rotating Bt toxins with other toxins, establishing nontoxic plant refuges, spatially alternating toxic and nontoxic plants, and expressing toxicity only in specific plant parts (53).

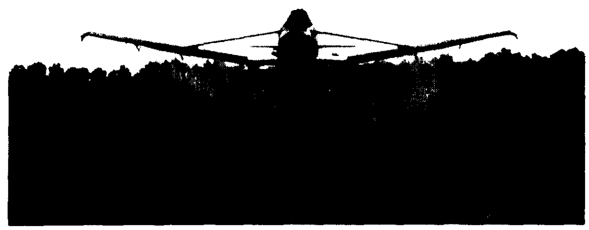
Scientists are just beginning to study the effectiveness of these techniques in preventing pest resistance. Some feel government legislation to coordinate use by farmers will be required for the proper application of this technology (50). Other issues surrounding the used of transgenic organisms are discussed in chapter 9.

Integrated Pest Management—Integrated Pest Management (lPM) is used in agricultural and natural areas for the control of NIS. IPM is defined as a management system that uses all suitable techniques in an economical and ecologically sound reamer to reduce pest populations and maintain them at levels that do not have an economic impact while minimizing danger to humans and the environment (90).

IPM may combine biological control, pest resistance, autocidal, cultural, and mechanical and physical control technologies with limited use of chemical pesticides (64). IPM uses monitoring and other decisionmaking tools to gauge the health of the ecosystem, and consequently requires an understanding of the biology and ecology of the resource, the pest, and the pest's natural enemies.

Research establishes the needed economic thresholds and natural suppression factors. An understanding of the effectiveness of the control technologies and damage caused by different stages of pests is important. Because IPM does not necessarily rely on chemical pesticides, quick, simple, inexpensive but accurate tools are needed to monitor the environment and implement programs before a pest becomes an economic problem.

USDA



The boll weevil (Anthonomis grandis) *eradication program integrates a variety of control measures: chemical pesticides, releases of sterile males, pheromone bait traps, and insect growth regulators.*

Education and Management

The need for greater public awareness regarding harmful NIS and for educating various specialized groups was cited repeatedly in recommendations by OTA's expert contractors (39,43,49,82) and its advisory panelists. Also, this theme surfaced frequently in recommendations by nongovernmental groups (39). For example, successful education campaigns have been identified by many experts as a key mechanism for gaining public support of NIS management programs (18,31,39).

To assess the breadth of current NIS education programs, OTA asked the North American Association for Environmental Education to conduct a survey of government and non-governmental organizations (NGO) involved in educational programs relating to MS. Federal and State agencies and NGOs conduct many activities related to NIS education. The survey of NIS education programs found:

- Education programs are typically small: funding averages less than 10 percent of agencies' budgets.
- Predicted funding outlays over the next 3 years varied depending on the organization.
- NGOs generally devote a larger share of their budgets to NIS issues as compared with Federal and State agencies.
- The need for increased funding for NIS education was often voiced.
- Little coordination of educational efforts among agencies and organizations exists.
- Information exchange is hampered by a lack of networks and materials to exchange.
- The success of the education programs is rarely evaluated.
- Programs that are evaluated rely on assessing subjective factors (76).

THE SCOPE AND METHODS OF EDUCATION PROGRAMS

Some environmental education programs tackle overarching environmental issues while others focus on NIS in particular-. Groups in Hawaii are among the leaders in environmental education. Generally, they have taken a broad approach, linking NIS to endangered species, land development, park protection, and agriculture. For example, the formal school-based Ohia project educates children about the biology of the Hawaiian islands (ch. 8). Part of the project deals with the effects of NIS on Hawaii's ecology.

On the other hand, numerous groups have created focused educational materials on single NIS such as zebra mussels, gypsy moths, or purple loosestrife *(Lythrum salicaria),* sometimes for specific user groups. For example, APHIS has produced pamphlets and small fliers to educate people leaving the quarantine zone for the European gypsy moth. They provide information about how to identify, inspect, and treat for moths on firewood, vehicles, and outdoor household items. Vermont's Department of Environmental Conservation began with a program focused on stopping the movement of Eurasian watermilfoil *(Myriophyllum spicatum).* It is moving now to a broader, regional watershed approach (76). Sometimes the selection of a narrow approach relates to a program's enabling legislation and funding rather than its educational merits.

Few formal national programs exist to identify and distribute information concerning harmful NIS. Minnesota's Department of Natural Resources has compiled this kind of information at the State level in its 'Exotic Species Handbook' (62). The Handbook provides basic information on organizing citizen-level awareness programs and contains reference materials on various NIS in Minnesota. Information on obtaining educational material and a directory to the many agencies and organizations involved are included. The USDA's Cooperative Extension Service has been cited as a good Federal model for relaying information about invasive NIS to the public (76). The Extension Service does some technical training now, e.g., for pesticide applicators. And the Extension Service, in combination with Land Grant and Sea Grant universities, is doing the most comprehensive and innovative public education regarding zebra mussels (76).

Media and methods used in education about MS mirror the larger field of environmental education in both scope and type. Techniques and media vary considerably and include almost any device or activity commonly used in education and informational efforts (76). For example, Federal and State organizations and NGOs have relied on a wide variety of channels to inform people about zebra mussel problems (table 5-5).

RELATED ISSUES

Ecological Restoration

Finding:

Ecological restoration is a relatively new practice that shows some promise in prevent-

Table 5-&Examples of Technologies Used in Zebra Mussel (Dreissena polymorpha) Education Programs

Technique	Organization	Description or title
Booklet, brochure, or leaflet	Ohio Department of Natural Resources	"Zebra Mussels in Ohio"
Fact sheet	Illinois-Indiana Sea Grant Program	Information on how to report a sighting
	Ohio Sea Grant Program	Information on zebra mussels in the Great Lakes
Newsletter, magazine	Minnesota Department of Natural Resources	"On the LOOSE"
	Vermont Department of Environmental Conservation	"Out of The Blue"
Poster or sign	Ohio Department of Natural Resources	Boater's advisory on zebra mussels
Report	Zebra mussel Task Force Report to the Michigan legislation	Zebra mussel control in Michigan
Workshops/lectures	Indiana Academy of Sciences	Presentation on zebra mussels, Conference on Biological Pollution: the Control and Impact of Invasive Exotic Species, October 1991
Video or slide show	Ohio Department of Natural Resources	Zebra mussel slide series
		Zebra mussel video
Classroom kits	Illinois Department of Conservation	"Lakes in My World" K-8 Workbook

SOURCE: Office of Technology Assessment, 1993.

ing NIS introductions and controlling reintroductions of NIS. The goal of ecological restoration, when applied to NIS control or eradication, is to modify those biotic and abiotic conditions that make the habitat suitable for NIS.

Ecological restoration is a branch of applied ecology that became visible as a management tool in the 1980s. It is the intentional return of an ecosystem to a close approximation of its condition before human disturbance (66). The goal is re-creation of whole, healthy, self-maintaining ecosystems in which natural ecological processes, such as nutrient cycling and succession, can operate without continual intervention by resource managers or reliance on synthetic engineered structures (5). Generalizations about ecological restoration's effectiveness are difficult, mainly because of the time it takes to see a project through to completion.

Ecological restoration is almost invariably a sequel rather than a preventive prelude to NIS invasion. Reestablishing prairie burns (i.e., fire as a restoration tool) is an exception to this statement. To date, ecological restoration has not been widely used to control harmful NIS (5) and its importance varies. At one extreme, the success of a restoration project may rest entirely on the removal of NIS. In other cases, control of a NIS may occur only after other phases of restoration have been completed (i.e., in which the restoration itself may eliminate the introduced species).

Existing data suggest ecological restoration is useful for MS control, as it has been in part of Everglades National Park, Florida, for example (box 5-B). Limitations of ecological restoration in the management of NIS do exist, however. It will not repel an invader that is genetically or behaviorally very similar to a desired indigenous species. Ecological restoration also does not seem effective in managing NIS capable of invading ecosystems in pristine condition. For example, the non-indigenous garlic mustard *(Alliaria petiolata) is* capable of invading relatively stable forests in Illinois (5).

The genetic make-up of species used in restoration projects has recently become an important issue. Locally adapted germ plasm is important for assessing ecosystem performance, avoiding restoration failure, and assuring long-term genetic conservation (5).

Box 5-B-Ecological Restoration in the Hole-in-the-Donut, Everglades National Park, Florida

Work in the "Hole-in-the-Donut," 4,000 hectares of former agricultural land in Everglades National Park, Florida, is testing ecological restoration's ability to manage a damaging non-indigenous species and prevent its reintroduction. Chemical and fire techniques were used to rid the site of Brazilian pepper (Schinus *terebinthifolius).* Neither method was successful. in 1989, attempts were made to alter the environmental factors favoring NIS over indigenous species and to restore the site to pre-agricultural conditions.

In the 1950s, approximately half of the site was rock plowed, i.e., the limestone substrate was crushed to produce soil better suited for crops. The area remained in cultivation for 25 years. The changes in the soil-from primarily low-nutrient anaerobic conditions to higher nutrient aerobic conditions-were more favorable to Brazilian pepper and other non-indigenous plants.

in 1975, Everglades National Park acquired the land. With the end of agriculture, the vegetation began to change. The nonrock-plowed land returned, for the most part, to indigenous species. The *2,000* hectares of rock-plowed land were invaded and eventually dominated by Brazilian pepper. Between 1979 and 1985, f ire was used to control Brazilian pepper, but monitoring of the burned sites indicated that repeated burning did not retard or reduce its growth. Studies on the economic feasibility of Brazilian pepper control with chemicals concluded that killing female trees was not an effective control strategy.

In 1989, a study on a 24.3-hectare site in the Hole-in-the-Donut attempted to determine the feasibility of ecological restoration on this former agricultural land. The idea was to remove the present vegetation and soil down to the limestone bedrock, establishing pre-agricultural conditions. Since 1989, recolonization by Brazilian pepper has been significantly reduced. The experimental site is still being monitored to determine the extent of the indigenous flora's return.

SOURCES: R.F. Doren and L.D. Whiteaker, "Comparison of Economic Feasibility of Chemical Control Strategies on Differing Age and Density Classes *Schinus terebinthifolius*," Natural Areas *Journal* vol. 10, No. 1,1990, pp. 2S-34; R.F. Doren and L.D. Whiteaker, "Effects of Fire on Different Size Individuals of *Schinus terebinthifolius,*" *Natural Areas Journal* vol. 10, No, 3,1990, pp. 107-1 13; F.J. Webb, Jr. (cd.), Proceedings of the Seventeenth Annual Conference on Wetlands Restoration and Creation, Hillsborough Community College, Tampa Florida, 1990, pp. 35-50.

A common recommendation is to use germ plasm adapted to the restoration site, preferably from the original gene pool. The notion that the germ plasm source might be important to restoration success is too new to have been tested rigorously. The reason locally adapted germ plasm is not used in plant restoration programs may be because of a lack of available seed **(5).**

Environmental Impacts of Control Technologies

Finding:

Adverse environmental impacts associated with chemical pesticides have been documented. Host specificity, residual effects, and human toxicity also need to be taken into consideration when biologically based methods are used. Classical biological control should also receive careful consideration before application, as it becomes very difficult to remove an agent from the environment once it is established.

CHEMICAL CONTROL

Since the 1940s, the chemical industry has produced an array of chemical pesticides to control damaging NIS. Many pesticides are effective against more than one species (i.e., broad spectrum), and their application can pose significant environmental or human health risks when used in natural or agricultural settings.

One consequence of chemical pesticide control of NIS is the occurrence of secondary pest outbreaks. Chemical pesticides may kill not only the target pest, but also the natural enemies that keep different pests under control. For example, both indigenous and non-indigenous pest outbreaks are associated with malathion used for Mediterranean fruit fly eradication in California in 1980 (21,22).

Beginning with the 1972 amendment of FIFRA, EPA has been reviewing chemical pesticides used in the United States for their toxic effects on nontarget organisms, including humans.

The issue of human toxicity, either through accidental poisoning in the field or in residues on food, is a large and complex issue. Because chemical pesticides will continue to play an important role in NIS management, support is needed for EPA to finish its assessment of chemical pesticide risk.

In addition, the development of resistance to chemical pesticides by NIS threatens management of problem species. At least 500 insect species are resistant to at least one synthetic insecticide, and many are resistant to several (45).

In agricultural settings, chemical resistance can lead to additional pest problems. For example, numerous new plant viruses are reported associated with the emergence of a more aggressive, pesticide-resistant, sweet potato whitefly (72). Similarly, the tomato spotted wilt virus may become an important disease outside its present range if its insecticide-resistant vector, the western flower thrips *(Frankliniella occidentals),* spreads (72).

BIOLOGICAL CONTROL

Biological control is often considered a safer, cleaner, and environmentally friendly alternative to chemical pesticides for the control of NIS. As with chemical pesticides, the risks associated with a biological control agent must be considered before it is released into the environment. Some scientists believe that, like chemical pesticides, biological control agents may disrupt existing or future control programs (34). This concern often focuses on introduced predators. For example, an introduced predator could attack a pest's existing natural enemies. Secondary pest outbreaks could result if previously controlled pests flourish. Also, newly introduced and previously established biological control agents could compete, lowering the efficacy of one or both. This topic is hotly debated among the many scientists who study and apply biological control.

Recognition of such potential environmental effects is important, since it is normally impossible to eliminate a biological control agent from the environment once it is established (30,34). Comprehensive study before and after release of a control agent would establish baseline data on the environmental effects of such agents and could limit future adverse effects.

Many species have been found to be harmful as biological control agents. Vertebrates, in particular, are poor choices for effective, host-specific control. The mosquito fish *(Gambusia* spp.), the Indian mongoose *(Herpestes auropunctatus),* and the cane toad (Bufo *marinus),* for example, were introduced for biological control and had extremely harmful non-target impacts (34). The selection of species that have relatively narrow host preferences, such as some predatory insects or microbial organisms, provides greater likelihood of minimizing the impacts on non-target organisms.

Environmental impacts of microbial pesticides also require evaluation. Although microbial pesticides are considered safer than chemical pesticides, risks and uncertainties exist. Indirect effects often are not recognized because of a lack of general research (99), although studies are beginning to assess the impacts of microbial pesticides. The use of Bt can seriously affect indigenous butterflies and moths (6,67). The effects of insect pathogens (e.g., nematodes) on species closely related to the target are not well known (34).

I EPA Reregistration and Minor Use Pesticides

Finding:

During the present EPA reregistration process, many old chemicals will become unavaila-

Box 5-C-The Loss of Chemical Pesticides: A Real Example

The loss of minor use chemical pesticides and the lack of alternative technologies pose a significant problem for NIS control. The loss of chemical pestiades used to control the sea lamprey *(Petromyzon marinus)* in the Great Lakes illustrates the importance of the problem. The Great Lakes Fishery Commission relies on two chemicals, TFM and Bayer 73 for the control of sea lampreys. TFM is a selective chemical that kills sea lamprey larvae. Bayer 73 is an additive to TFM. These two chemicals must be reregistered under FIFRA 88. Because of high reregistration costs and low revenue, the sole manufacturer of the two chemicals does not plan to reregister them. The scenario is complicated by the lack of effective alternatives. The two chemical lampricides are the only effective control. New, feasible technologies are not yet available. For example, a program based on sterile male release needs at least 10 more years of research before its effectiveness will be known (88).

The Great Lakes Fishery Commission is the only user of TFM in the world, and it has been unsuccessful in identifying additional suppliers. In order to maintain use of these pesticides, the Commission is faced with assuming reregistration costs, estimated to be $8 million over 4 years (88). The Commission has not begun incorporating the cost for reregistration into future budget proposals (89). However, FIFRA allows emergency use of unregistered pesticides for pests new to the country.

SOURCES: U.S. Congress, House Committee on Merchant Marine and Fisheries, "Status of Efforts to Control Sea Lamprey Populations In the Great Lakes,"' Sept 17, 1991, U.S. Congress, General Accounting Office, *Great Lakes Fishery Commission: Actlons Needed to Support an Expanded Program,* March 19S2, and *Pesticides: 30 Years Since Silent Spring,* July 23,1 S92.

ble, and fewer chemicals will receive registration. Concern exists that over the next 10 years, new or alternative technologies to replace chemicals will not be available for large-scale use.

Chemical pesticide use will continue to be essential for control of a significant number of NIS through the next decade, especially in agricultural settings (80). The 1988 amendments to FIFRA established reregistration guidelines for active ingredients in pesticides first registered before November 1, 1984. This reregistration process uses tightened standards for human health and environmental risk, and is scheduled for completion by December 1997.

The cost for developing and marketing a conventional chemical pesticide is more than $10 million (10). Although less expensive, reregistration also costs millions of dollars. FIFRA 88 will have its biggest impact on minor use chemical pesticides. Minor use is defined as low volume use that is not sufficient to justify the cost to a pesticide manufacturer to obtain federal registration (95).

In agricultural areas this includes chemical pesticides used on most vegetables, fruits and nuts, herbs, commercially grown ornamentals, trees, and turf. In non-agricultural areas, minor use chemical pesticides are used on aquatic plants, terrestrial vertebrates, fish, and aquatic invertebrates.

Many minor use chemicals are expected to become unavailable under FIFRA 88 (24). For example, the loss of herbicide registrations for aquatic weeds will leave a void in control programs because effective, economical substitutes are not now available (26). Chemical registration for vertebrate control has similar problems (box 5-C). It is estimated that about 1,000 minor use pesticides' registrations, having priority uses, will lose sponsorship during the reregistration process (104).

A potential model for the reregistration of minor use chemical pesticides for NIS is the Interregional Research Project No. 4 (IR-4), a USDA Cooperative State Research Service program organized in 1963 to obtain residue tolerances for minor use pesticides on food and feed crops. Since 1963, IR-4 has expanded to include registration information for pesticides used on nursery and floral crops, forestry seedlings, and turfgrass; animal health drugs, antibiotics, and antihehminthics; and for the further development and registration of microbial and specific biochemical materials used in pest management systems (95).

The IR-4 program is heavily burdened. It is estimated that 3,600 new uses and chemical reregistrations will try to pass through the IR-4 program by 1997 (95). Under the present funding schedule and timetable it is unlikely that the IR-4 program will complete the research and analysis necessary by the 1997 deadline (87,95). At best, the IR-4 program provides a model for the reregistration of minor use chemical pesticides for NIS.

CHAPTER REVIEW

This chapter examined the technologies to prevent the entry of harmful NIS and to control or eradicate those that slip through. These include a wide array of useful chemical, biological, physical, educational, and regulatory methods. Several related circumstances raise concern whether as many effective controls will be available in the future. Some important chemical pesticides probably will not be reregistered under FIFRA and so will go out of use. The environmental impacts of microbial, biological, or bioengineered substitutes are not yet clear. And efforts to make habitats less suitable for NIS in the long-term, via ecological restoration, are not now possible on a wide scale. For all of these reasons, continued research and development remain essential.

Effective management of harmful NIS involves institutional, as well as technical, issues. In the next 3 chapters, OTA examines the efforts of Federal and State institutions.