Integrated Pest Management

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Written by
Dale G. Bottrell

Preface

For many centuries human settlements, both agricultural and urban, have had to contend with a variety of unwanted and sometimes harmful insects, weeds, microorganisms, rodents, and other organisms—collectively, "pests." During the last four decades, use of chemical pesticides has become the predominant method of controlling these unwanted organisms in much of the world, including the United States. Production of synthetic organic pesticides in this country alone has increased from less than 500,000 pounds in 1951 to an estimated 1.4 billion pounds in 1977.

A decade ago, there was rising public concern over the accumulation of pesticides in the environment, with resulting adverse effects on some fish and wildlife populations and hazards to human health. In response to the problems, the Council on Environmental Quality undertook a study of alternative methods of pest control. *Integrated Pest Management,* published in 1972, stimulated increased national and international interest in integrated pest management—IPM—as an economically efficient, environmentally preferable approach to pest control, particularly in agriculture.

Since then much has been learned about the effects of pesticides, and programs have been developed which put the concept of IPM into practice. In 1976 the Council began a more comprehensive review of integrated pest management in the United States, giving attention to the potential for IPM programs in forestry, public health, and urban systems as well as in agriculture. This report presents the results of that review. It was written by Dale G. Bottrell, who obtained the cooperation and assistance of pest management experts in federal and state government, in university research and extension programs, and in the actual practice of IPM.

As this report indicates, chemical pesticides are—and will continue to be—of considerable importance in food and fiber production, forest management, and public health and urban pest control programs. However, in addition to continuing concern about their environmental and health effects, other disadvantages of heavy dependence on chemical pesticides have become increasingly apparent. First, the price of synthetic organic pesticides and the cost of their application have risen significantly in recent years, placing a financial burden on those farmers and others who use large quantities of these materials to control serious pests. Potentially of even more concern, significant groups of pests have developed strains that are genetically resistant to the pesticides. Worldwide, over 300 species of insects, mites, and ticks are known to possess strains resistant to one or more chemical pesticides, and an additional 50 species are suspected of possessing resistant strains. The resistant groups include some of the world's most serious insect pests affecting agriculture and public health.

Recent IPM research and demonstration programs are very encouraging. Among the numerous applications of IPM cited in this report are the large-scale programs administered by the Cooperative Extension Service showing the feasibility of IPM on major agricultural crops such as cotton, corn, tobacco, apples, grain sorghum, soybeans, peanuts, and citrus—with little or no reduction in yields and higher net profits than with conventional programs. IPM programs are also successful in forestry, public health, and the urban sectors.

This Administration has taken several steps to advance the development and acceptance of sound IPM programs. In his 1977 Environmental Message, President Carter instructed the Council "to recommend actions which the federal government can take to encourage the development and application" of techniques used in IPM. Our recommendations are presented in Chapter XII of this report. The recommendations include policy initiatives as well as additional research and education efforts needed to provide a sound basis for the advancement of IPM.

The recent accomplishments of integrated pest management and continued public interest in alternatives to conventional pesticide programs have resulted in some uncritical endorsement of IPM programs without regard to their feasibility and in some confusion about the concept. IPM is not a panacea; nor is it a term which embraces all programs that employ more than one control technique. We recommend that readers of this report look carefully at Chapter III, which sets forth the definition, features, and scope of IPM and the guidelines for IPM programs. Perhaps the most concise definition of IPM, however, is contained in the President's 1979 Environmental Message:

> IPM uses a systems approach to reduce pest damage to tolerable levels through a variety of techniques, including natural predators and parasites, genetically resistant hosts, environmental modifications and, when necessary and appropriate, chemical pesticides. IPM strategies generally rely first upon biological defenses against pests before chemically altering the environment.

The President's Message also directs federal agencies to take additional steps to encourage the development and use of integrated pest management. The agencies are directed specifically to review and "modify as soon as possible their existing pest management research, control, education, and assistance programs and to support and adopt IPM strategies wherever practicable." The Message and an accompanying memorandum from the President establish an interagency IPM Coordinating Committee to report "by June 30, 1980 on progress made by federal agencies in the advancement of IPM and on any institutional barriers thereto." The Committee is chaired by CEQ.

In addition, the Council will continue to work with and seek advice from federal and state agencies and other organizations and individuals interested in advancing the concept and application of integrated pest management. We believe that IPM strategies provide important opportunities for achieving national economic benefits in concert with environmental quality.

Gus Speth

GUS SPETH, Chairman

Executive Summary

What is Integrated Pest Management?

Integrated pest management (IPM) is the selection, integration, and implementation of pest control based on predicted economic, ecological, and sociological consequences. IPM seeks maximum use of naturally occurring pest controls, including weather, disease agents, predators, and parasites. In addition, IPM utilizes various biological, physical, and chemical control and habitat modification techniques. Artificial controls are imposed only as required to keep a pest from surpassing intolerable population levels predetermined from accurate assessments of the pest damage potential and the ecological, sociological, and economic costs of the control measures.

The presence of a pest species does not necessarily justify action for its control, and in fact tolerable infestations may be desirable, providing food for important beneficial insects, for example.

Why This Report?

In his May 23, 1977, Environmental Message to Congress, President Carter acknowledged that chemical pesticides have been the foundation of agricultural, public health, and residential pest control for several decades. He expressed concern that of the approximately 1,400 chemicals used in pesticide products, some pose an unacceptable risk to human health and the environment.

The President instructed the Council on Environmental Quality to review integrated pest management and recommend actions that the federal government could take to encourage the development and application of pest mangement techniques that emphasize biological controls and rely on chemical agents only as needed.

This report is the Council's response to the President's directive. The report reviews the evolution of modern pest control technology and the use and limitations of chemical pesticides (Chapters I and II); sets forth the concepts, components, and control techniques of integrated pest management (Chapters III and IV); reviews the status and prospects of integrated pest management in specific settings: agriculture (Chapter V), forests, rangelands, and rights-of-way (Chapter VI), urban areas (Chapter VII), public health (Chapter VIII), and wildlife (Chapter IX); discusses the obstacles to widespread use of integrated pest management (Chapter X); and examines the current federal role (Chapter XI). In the concluding chapter (Chapter XII), the Council recommends a series of program and research and development initiatives to advance the adoption and effective use of integrated pest management concepts and techniques.

Pest Control with Pesticides

The introduction of synthetic organic pesticides such as the insecticide DDT and the herbicide 2,4-D after World War II began a new era in pest control. These products were followed by hundreds of synthetic organic fungicides, nematacides, rodenticides, and other chemical controls.

These new materials were initially so effective and cheap that they appeared to be the ultimate control tool. They had a major impact upon the control of agricultural pests, in particular, insects and weeds. With significant success at a relatively low cost, postwar insecticides and herbicides rapidly became a primary means of pest control in productive agricultural regions. They provided season-long crop protection against insects and weeds and complemented the benefits of fertilizers and other inputs. The postwar pesticides produced equally spectacular results against public health pests.

The success of modern pesticides led to widespread acceptance and reliance upon them. Of all the chemical pesticides applied worldwide in agriculture, forests, industry, and households, one-third to one-half is used in the United States. Production of synthetic organic pesticides in this country increased from an estimated 464,000 pounds in 1951 to an estimated 1.4 billion pounds in 1977.

Herbicides have been used increasingly to replace hand labor and machine cultivation for the control of weeds in agricultural crops, in forests, on the rights-of-way of highways, utility lines, and railroads, and in cities. Agriculture now depends on herbicides to do the job previously performed by hand labor and mechanical cultivators. Herbicides are generally more effective and cheaper than either of these methods, and they require less fossil fuel energy than mechanical cultivators. Further, their use eliminates some of the problems commonly associated with mechanical cultivation—soil compaction, soil erosion, and soil moisture loss.

Agriculture consumes perhaps 65 percent of the total quantity of synthetic organic pesticides used in the United States each year. Homeowners, businesses, and governments in urban areas consume substantial amounts of the materials. According to one study, suburban lawns and gardens receive, per acre, the heaviest application of pesticides of any land area in the nation.

Chemical pesticides are—and will continue to be—significant in food and fiber production, forestry, and public health. But the inherent drawbacks of heavy dependence on them have become increasingly apparent. Apart from rising concern about the environmental and health hazards, their continued use is being challenged by other factors:

- Significant groups of pests have evolved with genetic resistance to pesticides. The increase in resistance among insect pests has been almost exponential following extensive use of synthetic organic insecticides in the last 30 years.

  The most serious problems of genetic resistance to chemical pesticides have been encountered in the control of insects, spider mites, and ticks. The rate of discovery of new insecticides to combat the problem of resistance is not keeping pace with the emergence of new strains of resistant insect pests.

  Worldwide, in 1975, 305 species of insects, mites, and ticks were known to possess strains resistant to one or more chemical pesticides, and an additional 59 species were suspected of having developed resistant strains. The resistant group includes some of the world's most serious insect pests affecting agriculture and public health. In California, the major agricultural state, 75 percent of the most serious crop insect and mite pests have developed genetic resistance to at least one pesticide, and some are resistant to two or more pesticides.
- Despite the advances in modern chemical control and the dramatic increase (about 10-fold) in chemical pesticides used on U.S. cropland during the past 30 years, annual crop losses from all pests appear to have remained constant. Losses caused by weeds may have declined slightly, but those caused by insects may have nearly doubled.
- The price of synthetic organic pesticides has increased significantly in recent years, placing a heavy financial burden on those farmers and others who use large quantities of the materials to control serious pests that have not been controlled effectively by less expensive means.

How IPM Works

Principles

The following principles are important in developing a cohesive system for managing pests:

1. Potentially harmful species will continue to exist at tolerable levels of abundance. The philosophy is to manage rather than to eradicate the pests.

2. The ecosystem is the management unit. Knowledge of the actions, reactions, and interactions of the components of the ecosystem—forest ecosystem, urban ecosystem, agricultural ecosystem (agroecosystem), or other managed ecosystem—is requisite to effective IPM programs. With this knowledge the ecosystem is manipulated in order to hold pests at tolerable levels while avoiding disruptions of the system.

3. Use of natural controls is maximized. IPM emphasizes the fullest practical utilization of the existing regulating and limiting factors (e.g., parasites, predators, weather) in the ecosystem which check the pests' population growth.

4. Any control procedure may produce unexpected and undesirable consequences.

5. An interdisciplinary systems approach is essential. Effective integrated pest managment is an integral part of the overall management of a farm, a business, or a forest.

Guidelines

Because development of the specific integrated pest management program depends on the pest complex, resources to be protected, economic values, and availability of personnel, it is difficult to establish absolute guidelines. However, the following general guidelines apply to the management of any pest group.

1. Analyze the "pest" status of each of the reputedly injurious organisms and establish economic thresholds for the "real" pests. For each of the pest organisms, information is obtained on the population level that determines its "real" pest status. This population level, often referred to as the "economic threshold," defined as the density of a pest population below which the cost of applying control measures exceeds the losses caused by the pest. Economic threshold values are based on assessments of the pest damage potential and the ecological, sociological, and economic costs created by control measures.

A given crop, forest area, backyard, building, recreational area, or other resource may be infested with dozens of potentially harmful species at any one time. For each situation, however, there are rarely more than a few pest species which recur at regular (and often fairly predictable) intervals. Pests which recur regularly at population densities exceeding economic threshold levels are known as "key" pests and are the focal point for IPM programs. Key pests are not to be confused with pests of secondary importance, which attain injurious levels at less frequent intervals, sometimes only when provoked by human activity.

2. Devise schemes for lowering equilibrium positions of key pests. A key pest will vary in severity from year to year, but its average density, known as the "equilibrium position," usually exceeds its economic threshold. Integrated pest management efforts manipulate the environment in order to reduce a pest's equilibrium position permanently to a level below the economic threshold. T[illegible]eduction may be accomplished using three prim[illegible]anagement approaches, singly or in combina[illegible]

- Deliberate introduction and establishment of natural enemies (parasites, predators, diseases) in areas where they did not previously occur.
- Utilization of pest-resistant or pest-free varieties of seed, crop plants, ornamental plants, orchard trees, forest trees, or livestock.
- Modification of the pest environment to increase the effectiveness of the pest's biological control agents, to destroy its breeding, feeding, or shelter habitat, or otherwise to render it harmless. Examples include crop rotation, destruction of crop harvest residues, and soil tillage, effective against numerous agricultural pests; selective burning or mechanical removal of undesirable plant species, pruning, and other silvicultural practices, for many forest pests; avoiding construction of homes in poorly drained sites known to favor pest survival and increase, selection of high quality building materials and construction to avoid pest attack and entry, and sanitation practices, for pests affecting households and other structures; in public health IPM programs, draining or drenching of water impoundments that serve as breeding sites for mosquitoes; and use of predator-proof fences and animal pens, for such predators as coyotes.

Pest management practices can also inadvertently increase the density of a pest, with deleterious side effects. For example, repeated applications of insecticides to crops may destroy natural enemies, creating a higher equilibrium position for a pest than when the pest was regulated by its enemies.

The equilibrium position may also be raised by inadvertent creation of new breeding sites (e.g., uncovered garbage for flies, stagnant pools of water for mosquitoes). A basic feature of IPM programs is finding ways to lower the equilibrium positions of major pests while avoiding practices that create environments favorable to pests of secondary importance.

3. During emergency situations, seek remedial measures that cause minimum ecological disruption. Utilization of the best combination of the three basic IPM components—natural enemies, resistant varieties, and environmental modification—may eliminate the need for further action against key pests except under unusual circumstances. Nearly permanent control of key insect and plant disease pests of some agricultural crops, for example, has been achieved by integrating such cultural practices as plowing and timing of irrigation with pest-resistant crop varieties and conservation of the pests' natural enemies.

When the key pests have flared up or the secondary pests are out of control, pesticides may be the only recourse. In integrated pest management programs, selection of the pesticide, dosage, and treatment time are carefully coordinated to minimize the hazards to nontarget organisms, the environment within the target area, and the surrounding ecosystems.

4. Devise monitoring techniques. Monitoring is essential to integrated pest management. Pest populations are dynamic, sometimes more than doubling in one day or less or decreasing at a comparable rate.

Because weather, crop growth, natural enemies, and other factors that affect population growth and decline are also changing constantly, pest populations and the parts of the environment influencing their abundance must be inspected frequently in order to determine when to apply or relax various control measures. Only through monitoring can the real need for control be known and the natural controls maximized.

How monitoring is conducted depends upon the ecosystem to be managed, the type of pests involved, environmental conditions, and economic resources. Light traps and traps baited with natural or synthetic lures have been used to check some insects. More sophisticated IPM monitoring schemes entail use of computer terminals into which are fed data on pest densities, natural enemies, weather, and other relevant factors. The computerized system processes the information and then alerts the farmer to what steps, if any, should be taken to correct the pest problem. Monitoring is also important for weeds, but it is primarily a matter of mapping specific weed infestations in a given field and then planning for future control procedures, most frequently in succeeding years. Some monitoring procedures involve no special equipment and very little expense, having been designed for the farmer, forester, and home gardener.

The Control Techniques

Many of the control techniques suitable for integrated pest management have been known for many years. Some of the most effective nonchemical techniques (e.g., biological control, pest-resistant crop varieties, tillage, crop rotation) were used widely before World War II but were deemphasized, particularly by insect and weed control scientists, as effective postwar chemicals became available. Recent problems such as insect pest resistance and the increasing costs of pesticides have renewed interest in the prewar control techniques. Promising new alternatives to chemical pesticides, including insect attractant chemicals, weed and insect disease agents, and insect growth regulators (hormones), are being developed; some are already being used on a small scale.

Biological control—The use or encouragement of parasites, predators, and pathogens for the reduction of pest organism populations is one of the most effective components of IPM programs for insects and mites and has been successful against some weeds and plant disease organisms. The technique cannot be expected to work against all pests, but there is substantial evidence that long-term suppression of a complex of pests is unlikely without the benefit of biological control agents.

Host resistance—The use of plant varieties tolerant of or resistant to pest attack is a proven, effective, economical, and safe method of pest control ideally suited to integrated pest management. Its development and use involve only renewable natural resources, and it is compatible with such desirable pest suppression techniques as biological control. There are now over 150 varieties of approximately 25 crops resistant to nematodes, over 100 plant varieties resistant to 25 types of insect pests, and more than 150 varieties resistant to a great diversity of plant diseases. An estimated 75 percent of the U.S. cropland is currently planted to crop varieties that resist one or more plant disease organisms. However, many varieties of important crops lack broad pest-resistant bases and are vulnerable to serious disease organisms now present at low intensities or to potentially adaptable foreign pests. Unexpected disease problems can explode at any time, with disastrous effects on these crops. Breeding for pest resistance must increasingly emphasize genetically diverse varieties that resist a much wider complex of pest species.

Although efforts to develop pest-resistant varieties of forest trees and orchard crops have been relatively slow because of their long generation times, this method has much potential for forest and orchard IPM systems. Similarly, the development of pest-resistant animal breeds has much potential for livestock IPM systems.

Cultural control—One of the oldest and most effective methods of pest suppression, cultural control is widely applicable in integrated pest management. Many procedures, such as strategic scheduling of plantings, tillage, irrigation, harvesting, and fertilizer applications, crop rotation, destruction of wild plants harboring pests that migrate to crops, and use of pest-free seed and planting stock, can be employed to achieve cultural control.

Physical and mechanical controls—Physical control procedures suitable for IPM schemes include temperature manipulations, such as heat and steam sterilization of soil in greenhouses to kill plant disease organisms; window screens to exclude flies and mosquitoes from buildings; screens placed in irrigation pipes and ditches to prevent the movement of weed seed into irrigated croplands; and specially designed containers that resist organisms that attack human food, animal feed, and other perishable products in storage. Mechanical controls such as insect traps and frightening devices (acetylene explosive devices, flashing lights, and other scintillating objects) to repel some bird and mammal pests have limited value in IPM.

Chemical pesticides—In many situations chemical pesticides are effective and without serious ecological consequence. There is a great potential for developing ways to reduce or eliminate the most serious hazards of presently available pesticide compounds; new compounds free of such hazards are urgently needed.

Miscellaneous techniques—Autocidal control, which involves the rearing and release of insects that are sterile or are altered genetically in order to suppress members of their own species, has considerable promise against a limited number of important insect pests. Insect pheromones also have considerable promise in controlling a limited number of important insect pests. Insect pheromones and other attractants are very valuable when used in traps and other devices to monitor insect populations. Chemical growth regulators, used extensively against weeds, are now being developed for insect control and, like autocidal control techniques and attractants, have considerable potential with a limited number of pests.

The unilateral use of any control measure—even the introduction of a pest-resistant plant variety—can have unexpected and undesirable consequences. For example, genetic strains of insect pests may evolve that resist chemical insecticides, resistant plant varieties, insect growth regulators, or other control techniques that were once effective. A basic assumption in developing integrated pest management programs is that no single control will be successful because of the remarkable adaptive powers of pest organisms. Integrated pest management therefore requires continual research and evaluation.

Major Achievements

Major progress has been made recently, particularly in the agricultural sectors where public research and extension agencies have taken steps to develop and demonstrate IPM concepts and techniques. To date, the largest national research effort to develop integrated management of crop pests relates to insects and mites. Major emphasis has been placed on cotton, citrus, deciduous fruits, soybean, and alfalfa, which account for approximately 70 percent of the insecticides applied annually to cropland. It is estimated that prototype IPM systems now available or being developed for these pests could reduce the quantity of insecticides currently used for their control 40-50 percent in the next 5 years and perhaps 70-80 percent in the next 10 years, with no reduction in present crop yield levels. Farmers in some regions have already begun to adopt these systems.

It has been demonstrated that in some areas of Texas cotton may be produced with 50-75 percent less insecticide. Moreover, the IPM system incorporates early maturing cotton varieties that require 80 percent less fertilizer and 50 percent less irrigation water than the later maturing varieties. The system has increased participating farmers' profits more than $100 per acre (from $62 to $170). The Texas Pest Management Association, a nonprofit farmer-administered organization, was recently formed to promote increased use of IPM systems on cotton and other crops.

Since 1971 the Cooperative Extension Service has been demonstrating the advantages of integrated pest management on a wide variety of field crops and livestock operations. The objective of the demonstrations, conducted on some 25 crops and in cattle feedlots, is to introduce farmers and livestock managers to IPM concepts and techniques. For nearly every crop included in the demonstrations in over 30 states, pesticide use has dropped significantly without a sacrifice in yield or quality and with increased profit to the farmer. The demonstrations in cattle feedlots have shown a reduction in the use of chemical pesticides and an increase in the daily weight gain and feed efficiency of the animals.

Equally encouraging results have been achieved in IPM programs directed against pests affecting urban areas, public health, and forests. In Berkeley, San Jose, Palo Alto, Modesto, and Davis, an IPM program significantly reduced insecticide use on city-owned shade trees. Before the program was initiated, approximately 16 percent of the five-city tree population (462,000) was treated for pests. Under the IPM program, only 0.08 percent of the trees were treated with chemical pesticides, and approximately 1 percent were treated with the insect disease agent *Bacillus thuringiensis*. With the number of chemical treatments reduced to 7 percent of the preprogram days, the pests were effectively managed. These results illustrate the potential for reducing pesticide use in urban areas, a significant source of contamination in rivers and other aquatic systems in metropolitan regions.

Results from mosquito control districts in California show IPM potential in public health programs. Incorporating physical, biological, cultural, and chemical methods, the system has provided effective mosquito control while significantly reducing pesticide use. In 1962—the peak year of pesticide application in the districts—615,000 pounds of insecticides were used; with integrated pest management, only 63,000 pounds were applied in 1976, a 10-fold decrease. Labor and material costs have been cut and environmental pollution is negligible.

Intensified efforts are underway to develop integrated management schemes for forest pests, particularly insects. The approach has been to develop, evaluate, and implement management systems that are environmentally safe and to provide the knowledge necessary to prevent or suppress pest outbreaks. In 1976, a disease-causing virus was registered for use against the Douglas-fir tussock moth, and in 1978 registration of another virus was granted for control of the gypsy moth—the moths are two of the nation's most serious forest insect pests. Another biological control, the disease agent *Bacillus thuringiensis*, was recently registered for use against the Douglas-fir tussock moth. Registration of these biological agents is significant, because the Douglas-fir tussock moth and the gypsy moth have accounted for a substantial portion of the insecticides used in forests in the past 2 decades.

Major Barriers to Progress

Although IPM has progressed significantly, it is not being used extensively in agriculture, urban areas, public health, forestry, or any other sector. Of all the sectors, agriculture has benefited the most.

Few operational pest management programs are truly integrated. Because of technical, economic, attitudinal, and possibly other barriers, ecologically sound pest control has not been used for a wide variety of pests and resources.

Knowledge Voids

Although research in integrated pest management has been vastly expanded in recent years, much greater effort is needed to collect the information and perfect the monitoring techniques required for IPM implementation. It is particularly important that this research embrace the coordinated efforts of scientists from all relevant disciplines. Interdisciplinary cooperation is critical to integration of the research results. The use of systems analysis and computer models should play an increasing role in integrated pest management research. A number of barriers impede the progress and must be crossed before ecologically sound pest control can be effectively mobilized and before practical IPM schemes become available for a wide variety of pests and resources.

User Uncertainty

Even when an IPM scheme exists, it is often extremely difficult to sell to farmers and others who are accustomed to the simpler chemical control strategy. These individuals must first be shown that the IPM option will adequately control the pests at lower costs than those for chemical control. Then they must be taught how to acquire and apply information necessary to IPM implementation. Many IPM systems can be implemented by farmers, livestock owners, and homeowners although they may initially feel awkward. For this reason individuals may continue to use chemical controls until they have been instructed on an IPM alternative even though the latter may be less costly and more effective.

User Information Sources

Pesticide use is further encouraged by those who customarily provide the information to farmers and other users. In California, the nation's richest agricultural state, farmers receive most of their pest control advice from pesticide salespeople. For cotton farmers there, only 1 percent of the information that they use in the control of insect pests originates with farm advisors from the Cooperative Extension Service—the agency officially responsible for educating the public on pest control.

That farmers and homeowners use information provided by chemical industry salespeople and advertisements far more often than that provided by the Cooperative Extension Service or independent pest management advisors is to be expected; there are few CES pest control specialists and independent pest management advisors compared to the number of chemical industry representatives. In Iowa, an estimated 4,000 or more persons were involved in retail sales of agricultural pesticides in 1973, compared to 119 Extension personnel working full time or part time on educational programs in agricultural pest control.

Shortage of Qualified Personnel

Nationwide, an estimated 200,000 commercial pesticide applicators are certified, including aerial applicators, pest control operators, and other commercial applicators. By comparison, specialists with the Cooperative Extension Service assigned to crop and animal health, including IPM, totaled only about 1,120 in 1977. In addition, some 500 private consultants work independently or for farm service firms and farmers' cooperatives.

Institutional Constraints

Government regulations and programs also favor continuing use of chemical pesticides and impede progress with IPM in other ways. Since the 1930's, the Food and Drug Administration has generally reduced the allowable quantities of insects and insect parts found in food, although there is no apparent health hazard from ingesting small plant-feeding insects. In addition, food processors, wholesalers, and retailers have given increasing emphasis to the cosmetic appearance (e.g., insect blemish-free) of fruits and vegetables. The results are increased losses caused by a larger portion of the crop now classified unsuitable for commercial use and the use of 10-20 percent more insecticides on fruit and vegetable crops simply to meet the FDA regulations and the cosmetic appearance standards. Consumers have a right to protection from adulterated foods that are hazardous to health, but the regulations may be more stringent than necessary.

The 1972 amendment to the Federal Insecticide, Fungicide, and Rodenticide Act discourages commercial development of some alternative control methods needed in IPM programs. The amendment requires that commercially prepared insect and weed disease agents (viruses, bacteria, fungi), insect sex attractants, and insect hormones be subject to the same general testing procedures as conventional pesticides prior to registration by EPA. Unlike broad-spectrum chemical pesticides, these alternatives are usually narrowly selective, sometimes effective against only one or a few pest species. Because the potential for economic return is therefore limited, industry is reluctant to invest in the required research, development, and commercialization.

Recommended Actions

No single government program or public or private institution can make integrated pest management work. There are roles appropriate to the U.S. Department of Agriculture; the Environmental Protection Agency; the National Science Foundation; the Departments of Health, Education, and Welfare, Defense, Interior, and State; the Executive Office; other federal agencies; state agencies; universities; and private organizations.

There are many opportunities for cooperation with foreign scientists and agencies on development of policies in pest control and pesticide regulation as well as on specific problems.

Chapter XII recommends a series of federal government initiatives leading to a national pest control policy which in turn will lead to further development and use of integrated pest management domestically and internationally. The recommendations are intended to facilitate the coherence and effectiveness of federal programs, to stimulate research and monitoring, to increase public awareness of the ecological principles related to integrated pest management, and to make available more certified integrated pest management advisors to all sector users:

Federal-State Coordination and Implementation

- Issuance of an Executive order or other Presidential directive requiring the adoption of IPM technology on all lands, facilities, and structures owned, managed, or leased by the federal government
- Establishment of an Executive Interagency Group on Integrated Pest Management to coordinate national and international policies and programs in pest control
- Initiation of a national monitoring program to detect herbicide resistance in weed species and determination of the feasibility of an "early warning system" to identify problems in controlling significant pests with chemical pesticides
- Development of computer and other information systems for use in IPM programs

- Development of procedures for accelerating the registration process for pest disease agents, insect pheromones, and other alternative methods of pest control

Encouraging Utilization, Removing Obstacles

- Establishment of criteria for approval, funding, review, and evaluation of Extension demonstrations of IPM
- Evaluation of government regulations, government tolerance standards, and the standards set by the food marketing and processing industries on both pest parts in food and the cosmetic appearance of fruits and vegetables
- Evaluation of existing and planned federal pest eradication programs and establishment of criteria for approval, funding, review, and evaluation of such programs
- Development of model certification requirements for independent pest management advisors and assistance to certified individuals in establishing IPM consulting firms
- Investigation of bank procedures for agriculturally related loans to determine whether excessive pesticide treatments are encouraged by conditions specified in the loans
- Determination of the feasibility of pest-specific risk insurance schemes for farmers participating in IPM programs
- Expanded foreign exploration for natural enemies and basic studies of serious pests of foreign origin in the pests' native ecosystems
- Establishment and maintenance of natural ecosystem and plant germ plasm preserves for scientific study and conservation in foreign regions where U.S. crops and their serious pests originated and continue to coevolve or where potentially serious pests occur

Education

- Development of public educational materials on the ecological principles related to integrated pest management
- Sponsorship of research, demonstration, and public information programs to accelerate integrated pest management in urban areas

Basic Research and Evaluation

- Improvement in the methodologies and the frequency of national pesticide use surveys
- Increased financial support of interdisciplinary research on the environmental effects of pesticides, pesticide resistance, pest monitoring and detection, and improved pesticide application methods
- Evaluation of pest control on livestock, stored products, rangelands, and rights-of-way
- Initiation of a program to develop equipment techniques, and monitoring procedures that minimize environmental and human health hazards of chemical pesticides used in integrated pest management programs
- Initiation of an interdisciplinary research program to develop ecologically sound integrated mosquito management.

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Part One

Promise and Problem

Evolution of Modern Pesticide Technology

Chapter One

Pests are organisms that diminish the value of resources in which we are interested. They do this by interfering with the production and utilization of crops, livestock, and other resources needed for food and fiber; by transmitting diseases; and by reducing the perceived quality of the environment in which we live.

Pests include a wide range of organisms from such microscopic forms as viruses, bacteria, nematodes (small roundworms), and fungi to large woody plants that compete with range grasses and such vertebrate animals as coyotes and deer. Insects and closely related arthropods* are frequent pests. Worldwide, about 10,000 species of insects are important as pests of crops, livestock, humans, and stored products (NAS, 1975). In the United States, there are 150-200 species, or complexes of related species, of serious insect pests, and 400-500 additional species may occasionally cause serious economic or aesthetic damage (NAS, 1969).

Weeds—simply, unwanted plants—are another large and diverse pest category. Worldwide, there are about 30,000 species of plants classified as weeds, and more than 1,800 cause economic losses to agriculture (Shaw, 1971). In addition to the herbaceous and woody species that commonly compete with row crops, lawns, and rangeland, this group includes simple single-celled algae that form the "scum" deposits in swimming pools, parasitic plants that attach to and feed upon crop plants and trees, and such plants as poison ivy and ragweed that cause human allergies.

Plant diseases are also frequent pests. There are probably 100,000 infectious diseases of plants on the North American continent caused by some 8,000 species of fungi, 500 species of nematodes, 250 viruses, and 160 species of bacteria (McNew, 1966).

Genesis of Pest Control

Long before the biology of pests was understood, human beings developed many biological, cultural, and physical methods for the protection of crops, animals, and self. Many of these practices subsequently proved scientifically valid, though originally derived from crude empirical methods (Ordish, 1976).

The earliest reference to the use of chemicals to control pests dates back to circa 2,500 B.C. when the Sumerians used sulfur compounds to control insects and mites. Thousands of miles east of Sumer, and some 1,000 years later, the Chinese developed plant-derived insecticides for protecting plant seeds and for fumigating plants infested with insect pests (Flint and van den Bosch, 1977). Chemicals were also used to control plant diseases at least 1,000 years before the Christian era; at the time of Homer, sulfur was used as a therapeutic agent (Walker, 1950).

Several centuries before Christ, the Chinese developed significant pest control techniques, learning to control insect pest densities by exploiting "natural enemies" and by adjusting crop planting times. By A.D. 300 the Chinese were establishing colonies of predatory (insect-feeding) ants in citrus orchards to control caterpillars and large boring beetles (Flint and van den Bosch, 1977).

The first methods of weed control involved human, livestock, and mechanical energy. From 6000 to 5000 B.C. weeds were controlled by human hands. Crude wooden implements, including hoes, used from 3000 to 2000 B.C. were supplemented by hand sickles and the first wooden plow about 1000 B.C. A wooden spiked-tooth harrow had been invented by 500 B.C., and improved wooden plows became available during A.D. 1600-1800. The first all-steel plows, drawn by horses or mules, were introduced in 1837 (Timmons, 1970).

Foundations of Modern Pest Control in the United States

The latter half of the 19th century and the first part of the 20th marked a significant era in pest control in the United States. As public agricultural experiment stations emerged in the late 1800's, scientists began to discover the biological basis for

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*An arthropod is an invertebrate animal with jointed legs and a segmented body; insects, ticks, spiders, spider mites, scorpions, and crustacea are arthropods.

earlier pest control methods developed largely by "trial and error" (Smith et al., 1976). Partially by intuition and partially because there were no effective alternatives, leading scientists advocated habitat management practices that would maximize the benefits of natural biological and environmental controls. In the late 1800's, for example, Stephen A. Forbes, entomologist at the University of Illinois, adopted the word "ecology" and stressed the broad application of ecological principles in controlling agricultural crop insects (Metcalf, 1930). Other pest control experts of this era advocated an ecological approach that integrated an array of pest suppressive techniques, such as resistant crop varieties, cultural practices, and biological control. From these efforts some of the most ingenious management systems ever developed for agricultural insect pests evolved (Smith et al., 1976; Watson et al., 1975; Newsom, 1975), and the modern approach to pest control known as "integrated pest management" was born (see Chapter III, p. 19).

For example, management of the boll weevil was based on ecological principles well before suitable chemical control technology emerged (Smith et al., 1976). This major cotton insect pest, considered by most pest control specialists to be native to Mexico or Central America, spread into the southern U.S. cotton region in the late 1800's. Within a decade a management system was developed that integrated cotton varieties that matured early, before the weevil populations increased significantly; an array of cultural control practices (such farming practices as planting and harvesting schedules and destruction of postharvest crop residues); and natural biological and environmental controls (Walker and Niles, 1971; Smith et al., 1976). In 1919, when calcium arsenate was discovered to control the pest, scientists recommended that it be applied only if the nonchemical control measures failed to prevent the boll weevil from causing economic damage (Table I-1).

Table I-1 **Guidelines for Controlling the Boll Weevil Developed by USDA Entomologists in 1923 (after Hunter and Coad, 1923)**

Cultural practices, such as selection of proper cotton variety and phytosanitation practices to destroy cotton residues after harvest, are essential.
Use of poison (calcium arsenate) should be supplementary to cultural measures, and its success depends on the cultural measures.
Poison application should be withheld until the weevils have punctured 10-15 percent of the cotton squares (flower buds).
Poisoning is supplementary and should be used only to ensure crop protection.
Do not expect to eradicate the boll weevil.

Plant pathologists also developed important disease management concepts and techniques during the late 1800's and early 1900's. For example, plants resistant to diseases were recognized in the 19th century, and breeding disease-resistant crop varieties was accelerated after the discovery of Mendel's laws of heredity in 1900. Following these breakthroughs, the approach was quickly exploited for the control of important plant diseases of many cereal and some horticultural crops (Apple, 1977; Walker, 1950).

The late 1800's and early 1900's also witnessed major developments in public health and in livestock pest control. In 1893, ticks were shown to transmit Texas fever, a protozoan (single-celled parasitic animal) disease of cattle. This discovery stimulated investigations of disease vectors affecting humans and animals. In the 1890's tsetse flies were discovered to be carriers of the sleeping sickness pathogen; rat fleas, plague bacterium; mosquitoes, malaria protozoa; and flies, typhoid fever (Flint and van den Bosch, 1977).

It soon became apparent that the incidence of many serious diseases could be reduced through control of the insects and ticks that were the disease vectors. A mosquito management strategy that integrated ecological manipulation of the aquatic breeding habitats (draining, filling, impounding, and flushing) and occasional use of kerosene to kill immature mosquitoes in the water had been developed by the early 1900's. Construction of the Panama Canal (completed in 1914) was made possible in part because the United States was able to manage the malaria and yellow fever mosquitoes which had prevented the French from succeeding earlier.

The Shift Toward Chemical Control

Despite the ingenuity and apparent effectiveness of some of the early management schemes developed for agricultural and public health pests, they frequently did not provide satisfactory pest control gauged by present standards. The ecologically oriented approach thus shifted to control by chemical pesticides as effective materials became available. Pesticides were often more effective, were much simpler to use than the more complex and labor-intensive nonchemical approaches, were cheaper, gave greater yields, and provided readily available and inexpensive insurance to the user. Their use displaced many of the earlier control techniques, such as cultural and biological control, pest-resistant crop varieties, and habitat management. The new chemical pesticides could be used by themselves and could achieve higher levels of pest control; they greatly simplified pest control, and the earlier integrated pest control schemes were viewed as obsolete.

Use of chemical insecticides in the United States dates from 1867, when Paris green (an arsenic compound) was used to control outbreaks of the Colorado potato beetle. Within a decade, Paris green and kerosene oil emulsion were being used against a variety of insect pests.

Common salt was apparently the first material used for chemical control of weeds in the United States. It was used extensively to control field bindweed in Kansas in the late 1800's. Copper sulfate was introduced toward the turn of the century for control of weeds in wheat (Timmons, 1970).

Around 1882 the use of Bordeaux mixture (quicklime and copper sulfate) as a fungicide (with some insecticidal properties) was accidentally discovered in France, adding further impetus to use of pesticides. This discovery was soon followed by fluorine-based insecticides and insecticidal compounds derived from plants (NAS, 1969).

There was optimism as early as the turn of the century that chemical pesticides would ultimately control both diseases and insects (Apple, 1977). The introduction of aircraft application in the early 1920's contributed further to the use of pesticides.

Introduction of Synthetic Organic Chemicals

The emergence of effective synthetic organic chemicals—such as the insecticide DDT and the herbicide 2,4-D—after World War II prompted further optimism and seemed to promise a pest-free environment. Although DDT was first synthesized in 1874, it was 1939 when Paul Müller of Switzerland discovered the chemical's insecticidal properties. The U.S. Army classified DDT "top secret," first using it against disease-carrying lice during a typhus fever epidemic in Naples in 1944 and later against a wide variety of insects responsible for spreading malaria, typhus fever, cholera, and encephalitis. During World War II German troops suffered widespread casualties from insect-borne diseases which the U.S. Army and the Allies escaped by controlling the disease vectors with DDT (Ordish, 1976).

After the War, dozens of synthetic organic pesticides* were introduced commercially, and a major chemical industry developed and marketed these new materials. Although agriculture was the primary market for the pesticide industry, pesticide products and equipment for their application were also created for the home, garden, and recreational markets.

The postwar pesticides had a major impact upon control of agricultural pests, particularly insects and weeds. With significant success at a relatively low cost, synthetic organic insecticides and herbicides rapidly became a primary means of pest control in productive agricultural regions. They provided season-long protection for crops and complemented the benefits of fertilizers and other inputs.

The synthetic organic pesticides also had a major impact upon the concept and implementation of the "Green Revolution" by providing a major mode of pest control for the new high-yielding varieties of wheat, rice, maize, and other food grains introduced into the developing countries (Furtick, 1976; Jennings, 1976). They produced equally spectacular results against pests that directly affected human health and comfort. For example, widescale employment of DDT resulted in the temporary riddance from entire countries of serious public health pests, such as malaria mosquitoes (Wright et al., 1972).

Increased Reliance on Pesticides

Chemical pesticides, and particularly the post-World War II synthetic organic pesticides, have brought inestimable benefits in terms of human lives saved, diminished suffering, and economic gain (Smith and van den Bosch, 1967; Metcalf, 1965). Their success has led to widespread reliance upon them, and chemical control has become a significant economic activity.

Of all the chemical pesticides applied worldwide in agriculture, forests, industry, and households, about one-third to one-half is used in the United States, where consumption has risen notably in the past 25-30 years (USDA, unpubl.). Production of synthetic organic pesticides in this country increased from an estimated 464,000 pounds in 1951 to an estimated 1.4 billion pounds in 1977 (Figure I-1).

This increase has occurred for a number of reasons. Herbicides, for example, have been used increasingly to replace hand labor and machine cultivation for the control of undesirable vegetation in agricultural crops; in forests; on the rights-of-way of highways, utility lines, and railroads; and in cities. Agriculture in particular has become dependent on herbicides. Major U.S. farming enterprises now rely almost exclusively on these materials to do the job previously performed by "hoe hands" and mechanical cultivators (Klingman et al., 1975).

Warnings of Pesticidal Hazards

The use of inorganic insecticides in the United States was sufficiently commonplace by the 1920's to cause concern about possible adverse health effects of residues in foodstuffs (NAS, 1969). As a measure to protect humans from the residues, regulations were passed to establish tolerances for arsenic and later for lead in apples and pears. It was thus recognized more than 50 years ago that the regulation of residues of some chemical pesticides was necessary in the public interest.

There were other early warnings of the poten-

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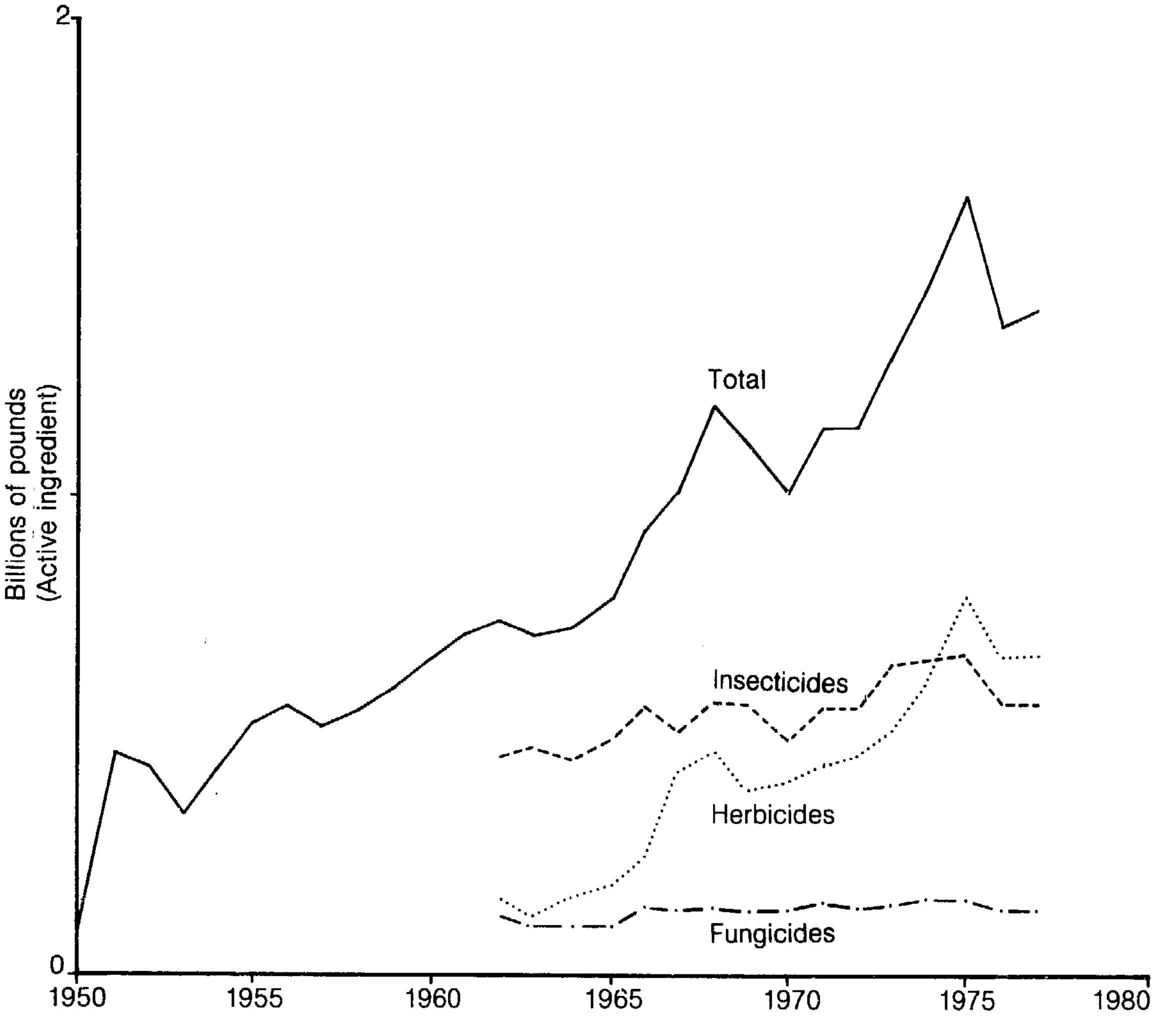
*Synthetic organic chemicals are carbon-based compounds synthesized from petroleum derivatives.

Figure I-1 **U.S. Production of Synthetic Organic Pesticides [1] (USDA, 1957-1965, 1966-1977)**



[1] Includes a small quantity of synthetic soil conditioners; does not include the fumigants carbon tetrachloride, carbon disulfide, ethylene dibromide, and ethylene dichloride, which have many other uses; nor does it include paradichlorobenzene (classed by the International Trade Commission as an intermediate) or inorganic pesticides.

tial hazards. Early 20th century insect control specialists found, for example, that certain insecticides, once nearly 100 percent effective, were totally ineffective because the pests had developed resistant strains. Resistance was first noted in 1908, when the San Jose scale resisted lime-sulfur sprays in Washington apple orchards. Subsequently, three species of scale insects on citrus resisted the fumigant hydrogen cyanide in California between 1912 and 1925. The codling moth, an apple pest, had become resistant to lead arsenate in Colorado by 1928 (NAS, 1969).

Ironically, the success of chemical pesticides created a dilemma. On the one hand, many of our "necessities" have coevolved with pesticide technology to the extent that we eventually became largely dependent upon the technology. Yet there have been ample warnings—first issued more than 50 years ago and since amplified many times—against continuing to rely heavily on pesticide technology, and many pest control scientists are questioning whether this technology can prevent serious pest ravages in the future. Apart from rising concern about the environmental and health hazards of chemical pesticides, their continued use is being challenged by the fact that significant groups of pests have developed genetic resistance because of repeated exposure to (and thus "selection" by) the materials (NAS, 1975). Moreover, despite the economic gains realized from past use of the materials, the price of synthetic organic pesticides has increased significantly in recent years parallel with the increasing costs of petroleum and other chemicals from which they are derived. This increase has created a heavy financial burden for those farmers and others using large quantities.

In the following chapters, contemporary uses of pesticides in the United States, limitations on future use, and the progress and prospects of alternative methods of pest control are discussed.

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Chemical Pesticides: Characteristics, Uses, and Limitations

Chapter Two

"Pesticide" is derived from the words "pest" and "cide," a Latin derivative meaning "killer." A chemical pesticide, then, is a chemical preparation used to kill or in some other way diminish or stop the actions of a pest. Although preparations of disease agents such as viruses and bacteria are commercially available as pesticides, this report treats these living organisms as biological control agents (see Chapter IV, p. 27).

There are several ways to classify a chemical pesticide. One is according to its chemical class. For example, DDT belongs to the organochlorine class of insecticides. Members of this class may retain their chemical identity and biological activity in the soil for more than a decade (Table II-1). Methyl parathion, a member of the organophosphorus class of insecticides, is an example of the so-called nonpersistent pesticides; members of this class may lose their chemical identity and biological activity in a few days or a few weeks following application.

Table II-1 **Persistence of Organochlorine Insecticides in the Soil (compiled by Metcalf, 1976)***

Insecticide	50 percent loss (number of years)	95 percent loss (number of years)
DDT	3-10	4-30
Aldrin	1-4	1-6
Chlordane	2-4	3-5
Dieldrin	1-7	5-25
Endrin	4-8	ND
Heptachlor	7-12	3-5
Lindane	2	3-10
Toxaphene	10	ND

ND = Not determined

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Another way to classify a pesticide is according to the type of pest organism at which it is directed—fungus, weed, insect, etc. DDT is normally classified as an insecticide because it has been used against a wide spectrum of insect pests. Other classes, based upon their primary use against specific pest categories, are fungicides (to control fungi), rodenticides (rodents), nematacides (nematodes), acaracides (mites, ticks), and herbicides (plants).

Although chemical pesticides are commonly identified according to use—fungicides against fungi, herbicides against weeds, etc.—few select only the target pests, and many are broadly toxic, multiple-use materials that operate against numerous groups of organisms. DDT, for example, first used during World War II to control human lice, was eventually used to control hundreds of additional insect pests as well as rodents and other organisms before being canceled for most uses in the United States because of its harmful effects upon wildlife, its persistence in the environment, and its implication as a human carcinogen (cancer-causing agent). Methyl parathion, a replacement for DDT on many crop pests, was discovered by the Germans in their search for human nerve gases in World War II. Less persistent in the environment, methyl parathion and certain related organophosphorus insecticides are even more broadly toxic than DDT to insects and other animals, including humans (Metcalf, 1972).

Use of Pesticides

All analyses of the risks and benefits associated with pest control practices ultimately rely on what is known about their use. Gathering information on use patterns is very difficult because, in contrast to production, use is an activity in the hands of thousands of farmers, homeowners, and industrial and government employees. Because there is no national requirement for these individuals to report pesticide use, estimates are derived from surveys, which are grossly inadequate, and it is impossible to determine accurately the kinds or quantities of chemicals being used in either agricultural or nonagricultural sectors (NAS, 1975).

The Department of Agriculture, in cooperation with the Statistical Reporting Service, has surveyed farm use of pesticides for the crop years 1964, 1966, 1971, and 1976. Various state and federal agencies have conducted use surveys in nonagricultural sectors at various times.

Agricultural Uses

In terms of quantity, agriculture accounts for the single largest use of pesticides in the United States. In 1976, U.S. farmers (excluding those in Alaska and Hawaii) used an estimated 661 million pounds, which is about 65 percent of the total used in this country (Eichers et al., 1978). This was a 38 percent increase over 1971, the year the preceding national survey of pesticide use was conducted for agriculture. Of all pesticides applied to U.S. cropland, use of herbicides has grown most rapidly; the amount used in 1976 was 76 percent more than that used in 1971. Expenditures for all chemical pesticides (excluding their application) in 1976 exceeded \$1.9 billion (USDA, 1977).

Crops accounted for an estimated 98 percent of the pesticides used in U.S. agriculture in 1976; an estimated 40 percent more pesticides were applied to U.S. crops in 1976 than in 1971. Surveys show that 60 percent or more of the U.S. crop acreage (excluding pasture and rangeland) received some type of pesticide treatment in 1976. In addition, U.S. farmers used 11 million pounds of insecticides for livestock pest control in 1976, an estimated decrease of 27 percent over 1971 use (Eichers et al., 1978).

Use varies considerably among crops, pests to be controlled, and geographical regions, depending upon severity of the problems, climate, value of the crops, availability of alternative pest controls, human attitudes, and numerous other factors.

Herbicides accounted for an estimated 60 percent of all crop pesticides used in 1976, insecticides for 26 percent, and fungicides for 6 percent. (The remaining estimated 8 percent of pesticides used on crops included defoliants, desiccants, growth regulators, miticides, and rodenticides) (Eichers et al., 1978).

Only 2 percent of the total U.S. crop acreage (excluding pasture and rangeland) was treated with fungicides in 1976. However, 56 percent of the total acreage was treated with herbicides and 18 percent with insecticides (Table II-2).

Nonagricultural Uses

The limited survey data of pesticide use in nonagricultural sectors show that they may account for one-third or more of the amount consumed in this country (von Rümker et al., 1972, 1974; Eichers et al., 1978; NAS, 1975). Examples of nonagricultural uses include household pest control, control of termites and other pests affecting nonresidential buildings, control of public health vectors, industrial fumigation, control of pests affecting rights-of-way, and control of lawn and garden pests. A substantial portion is dispensed in urban areas by homeowners, businesses, and city governments for a variety of reasons (see Chapter VII, p. 71). According to one study, suburban lawns and gardens receive, per acre, the heaviest applications of pesticides of any land area in the United States (von Rümker et al., 1972).

Table II-2 **Use of Pesticides on Major U.S. Field Crops, Hay, Pasture, and Rangeland, 1976 (after Eichers et al., 1978)**

	Acres grown (millions)	Herbicides (percent of acres treated)	Insecticides and nematicides (percent of acres treated)	Fungicides (percent of acres treated)
All major field crops except pasture and rangeland	340.8	56	18	2.0
All major field crops, including pasture and rangeland	829.0	22	9	1.0

The Chemical Pesticide Industry

A substantial industry has emerged to produce and supply pesticides and application equipment. More than 80 U.S. companies produce the active ingredients for pesticides (NAS, 1975). These chemicals are further processed and packaged for distribution as dusts, wettable powders, granules, emulsifiable concentrates, aerosols, and other formulations. As many as 1,800 companies may be involved in formulating and packaging these materials (NAS, 1975).

The thousands of firms that distribute, sell, and apply pesticides form a major business. For example, commercial pest control operators service homes and other structures; they gross nearly \$1 billion annually (Spear, unpubl.) (see Chapter VII, p. 71). Application of pesticides by aircraft also forms a major business. Approximately 65 percent of all pesticides used on agricultural and forest lands is applied by aircraft (Fowler and Mahan, 1977). Agricultural pilots, who apply pesticides and some fertilizers and seeds, grossed more than \$450 million for their services in 1975.

Benefits from Pesticides

Contemporary pest control by means of chemical pesticides has been successful by a variety of criteria. As discussed in Chapter I, p. 2, it has dramatically reduced vector-borne diseases such as malaria throughout the world, and it has contributed to the currently high agricultural productivity in the United States.

Only rarely have procedures been evaluated in terms of the relative costs of the level of control achieved and the costs of the control practice itself. Information derived from acceptable cost-benefit analyses is very limited. Because most available estimates have relied almost exclusively on opinions of the experts, their accuracy is questionable. Further, few estimates of pesticide benefits have weighed the "external costs" of pesticide use—human health effects, livestock kills, reduction of wildlife and fish populations, destruction and contamination of food crops and natural vegetation, ecological upsets, and destruction of plant pollinators (Pimentel et al., 1978a). Similarly, few have weighed the "hidden" or secondary benefits of pesticides (e.g., the tax revenues provided by pesticide sales and the human nutrition benefits that result from abundant food supplies attributed in part to effective pesticides).

Returns have been estimated at $3-5 for every $1 invested in pesticidal crop control, and gross returns on the nation's investment in chemical pest control are estimated at $10 billion or more (Pimentel et al., 1978b).

It is more difficult to estimate the losses that would occur in the absence of pesticides, but most experts agree that present agricultural production levels depend on these materials and that their removal would cause an immediate drop in food supplies (NAS, 1975). Nobel Prize Laureate N.E. Borlaug (1972) warned that a complete ban of chemical pesticides would cause a 50 percent reduction in current crop yields and a 4- to 5-fold increase in food prices. At the other extreme, Pimentel et al. (1978b) estimated that a ban followed by use of available alternative control methods would reduce the current crop yield value (expressed in dollars) by only 9 percent. Regardless of which estimate is more nearly correct, there is no doubt that economically disabling losses would result in some agricultural sectors if chemical pesticides were not available or were not replaced with effective alternatives (NAS, 1975).

Perhaps the benefits of herbicides are more evident than are those of other crop pesticides. As discussed in Chapter V, p. 51, the use of herbicides is rapidly escalating for agricultural crops. The reasons are:

- Herbicides virtually eliminate the threat of crop loss to weeds during excessively wet weather when mechanical cultivation and hand labor are not effective.
- A substantial reduction in fossil fuel energy is achieved when herbicides are substituted for mechanical cultivators.
- The practice of minimum or no tillage of crops produced on soils with favorable physical properties, made possible by use of herbicides, conserves soil moisture and reduces soil erosion.
- Grower options in choice of crops and crop rotations may be substantially increased by controlling weeds with herbicides.
- Herbicides are usually more cost effective than human labor.

Outstanding benefits have been achieved using chemical pesticides against weeds, plant diseases, and nematodes that affect forests, rangeland, and rights-of-way. The economic benefits derived from increased tourism in recreation areas where chemical pesticides are used to control nuisance insect pests such as mosquitoes and ticks, such poisonous plants as poison ivy and poison oak, and noxious wildlife, although more difficult to quantify, are often quite high.

Limitations to Pesticides

Despite the gains realized from using chemical pesticides, technological and biological limitations are becoming increasingly apparent.

Economic and Energy Costs

In 1971, expenditures for all major agricultural uses of pesticides were an estimated $1.0 billion. Expenditures for pesticides applied to crops averaged $5.39 per treated acre (or $5.23 per treated acre including hay, pasture, and rangeland) (Blake and Andrilenas, 1975). In 1976, expenditures for all major agricultural uses of pesticides were an estimated $1.9 billion (USDA, 1977). Data on average 1976 expenditures per treated acre are not available, but average expenditures per representative acre ranged from $1.30 for wheat to $55.80 for peanuts (Eichers and Andrilenas, 1978). Total agricultural expenditures for pesticides were 93 percent higher in 1976 than in 1971.

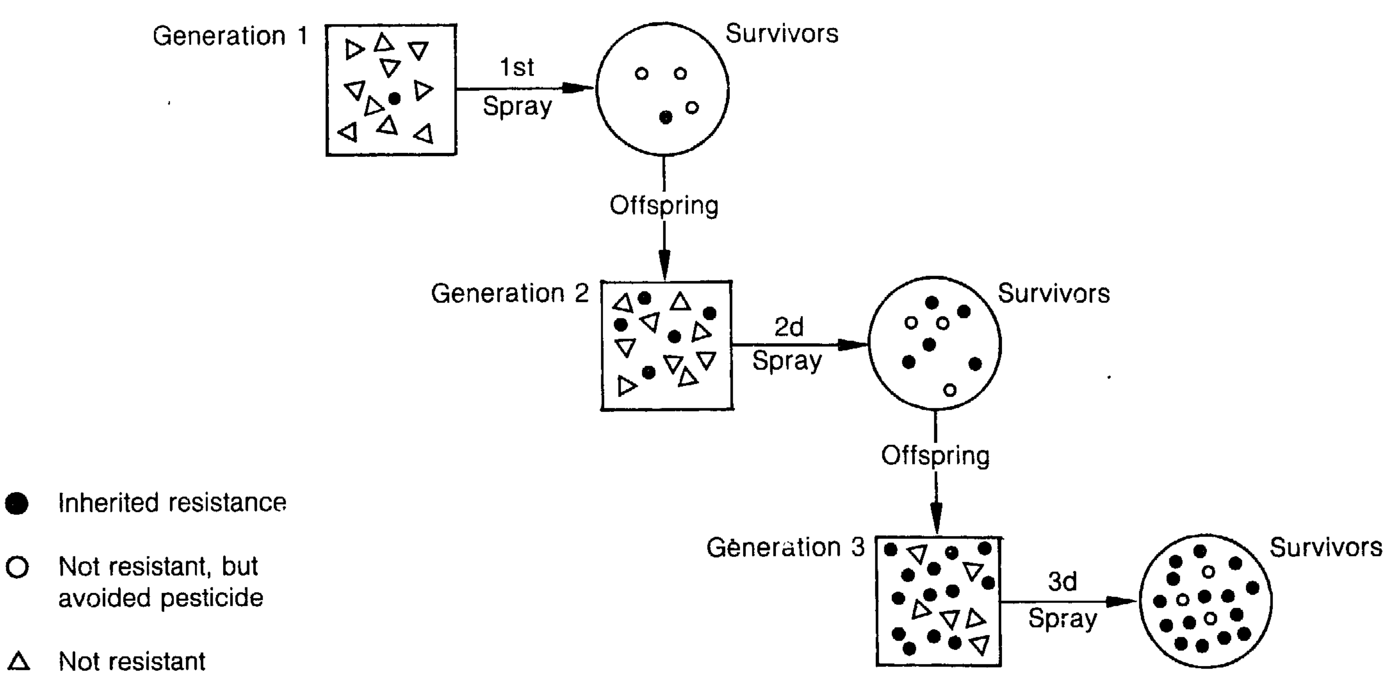
It has been estimated that 1 billion gallons of fossil fuel equivalent is required annually to produce, transport, and apply pesticides in the United States (Pimentel et al., 1977). This amount is small compared to that necessary for heating, cooling, and operating various appliances in U.S. homes, for example, which is estimated at 130 billion gallons of fossil fuel equivalent (Hirst and Carney, 1977). It is less than 0.2 percent of the total energy used in the United States and only about 5 percent of that used in agriculture (USDA, 1976). Nonetheless, use of pesticides may entail highly significant energy inputs for certain agricultural crops. In 1974, for example, approximately 38 pounds of pesticides were used for each acre of apples grown in New York. This amount was the equivalent of nearly 33 gallons of gasoline per acre and represented 30-40 percent of the fossil fuel energy input in the production of that crop (Pimentel et al., 1977).

Continuing energy shortages can be expected to affect the availability of petroleum feedstocks for pesticide production and in turn the cost of pesticide products (NAS, 1975).

Resistance to Pesticides

Genetically acquired resistance is the ability of organisms to evolve strains capable of surviving exposure to dosages to which an earlier generation was susceptible. Surviving individuals of one generation pass the resistance character on to the next generation. Upon repeated exposure to a pesticide, genetically resistant individuals constitute an increasingly larger part of the pest population. Eventually, if every generation is exposed to a pesticide that selects for resistance, the population may contain largely resistant individuals, as illustrated in Figure II-1. The effectiveness of pesticides may be reduced or completely lost because of mutations in the target species.

Figure II-1 **Evolution of Pesticide Resistance (modified from Flint and van den Bosch, 1977)**



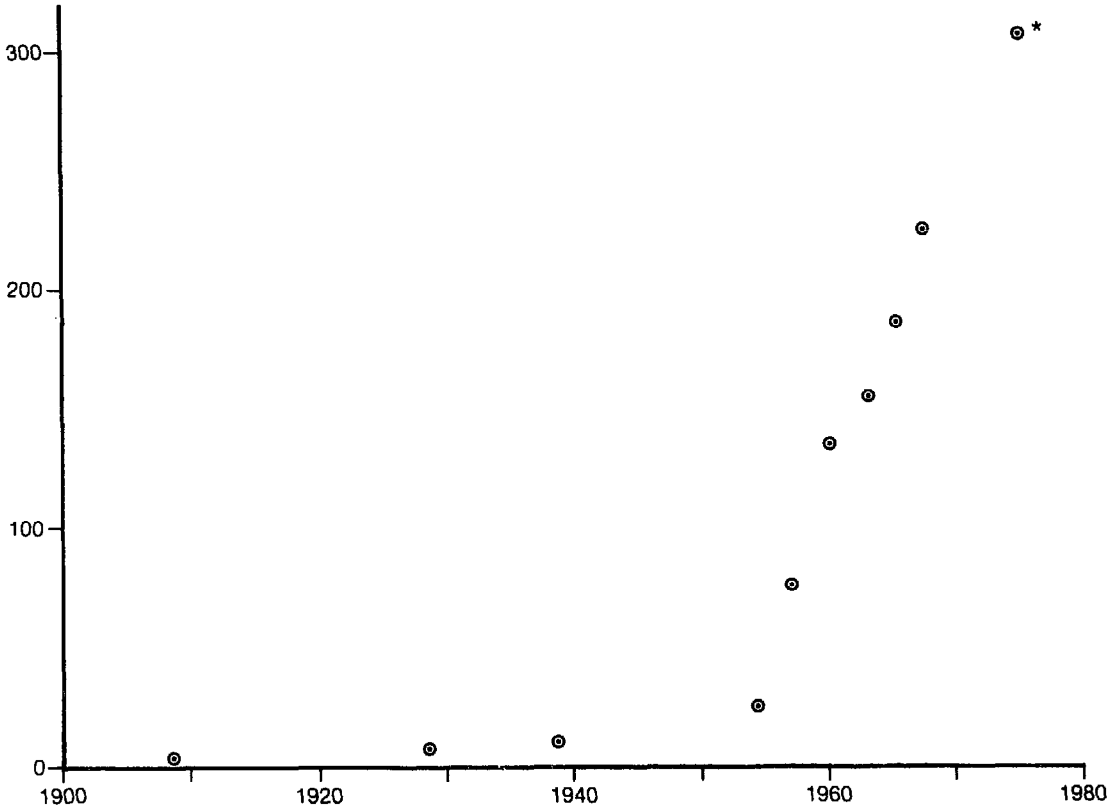
Genetic resistance (NAS, 1969, 1975; Georghiou, 1972; Georgopoulos, 1977) most commonly results from the biochemical capacity of a pest organism to convert a pesticide into products that are not toxic to the organism. For example, DDT-resistant house flies are able to change DDT chemically to a less toxic DDT-ethylene relative.

The potential of a pest population for development of resistance and the rate at which resistance develops depend on the ecological characteristics of the population, past chemical control practices, degree of selection pressure, chemical properties of the pesticide, and other variables (Georgopoulos, 1977; Georghiou, 1972; Georghiou and Taylor, 1977). In a number of cases involving plant pathogens, insects, and mites, the pesticides became ineffective only 2 or 3 years after their first use in the field. However, the fungicide Dodine was intensively used for 9 years before Dodine resistance in the apple scab was first noticed in New York (Szkolnik and Gilpatrick, 1969). Breakdown of the effectiveness of organomercurial compounds against this pest was not reported until after 30 years of widespread use. Other pesticides have been widely used even longer with no evidence of loss in effectiveness.

The development of resistant insect pest strains has become one of the most serious factors limiting insecticide use (Smith, 1970). Resistance to insecticides has a 70-year history (see Chapter I, p. 4), but its greatest increase and strongest impacts have occurred in the last 30 years following the discovery and extensive use of synthetic organic insecticides (Georghiou and Taylor, 1977). Worldwide, in 1975, 305 species of insects, mites, and ticks were known to have developed strains resistant to one or more chemical insecticides, and an additional 59 species were suspected of having developed resistant strains (Georghiou and Taylor, 1977). The increase in resistance among these pests has been almost exponential in recent decades (Figure II-2).

Of the resistant insects, mites, and ticks on record (confirmed or highly suspected), 139 involve pests affecting human beings and livestock (mosquitoes, flies, lice, fleas, ticks), and 225 are pests of agricultural importance, including forest and stored product pests. This resistant group includes some of

Figure II-2 **Number of Insect, Tick, and Mite Species Resistent to One or More Chemical Insecticides, Worldwide (data from Georghiou and Taylor, 1977)**



*Resistance confirmed in laboratory studies; resistance of an additional 59 species not examined in laboratory studies.

the most serious insect pests in the world. Programs for the control of malaria are being seriously jeopardized in some regions because the malaria-transmitting mosquitoes can no longer be controlled with DDT or other previously effective insecticides (see Chapter VIII, p. 82).

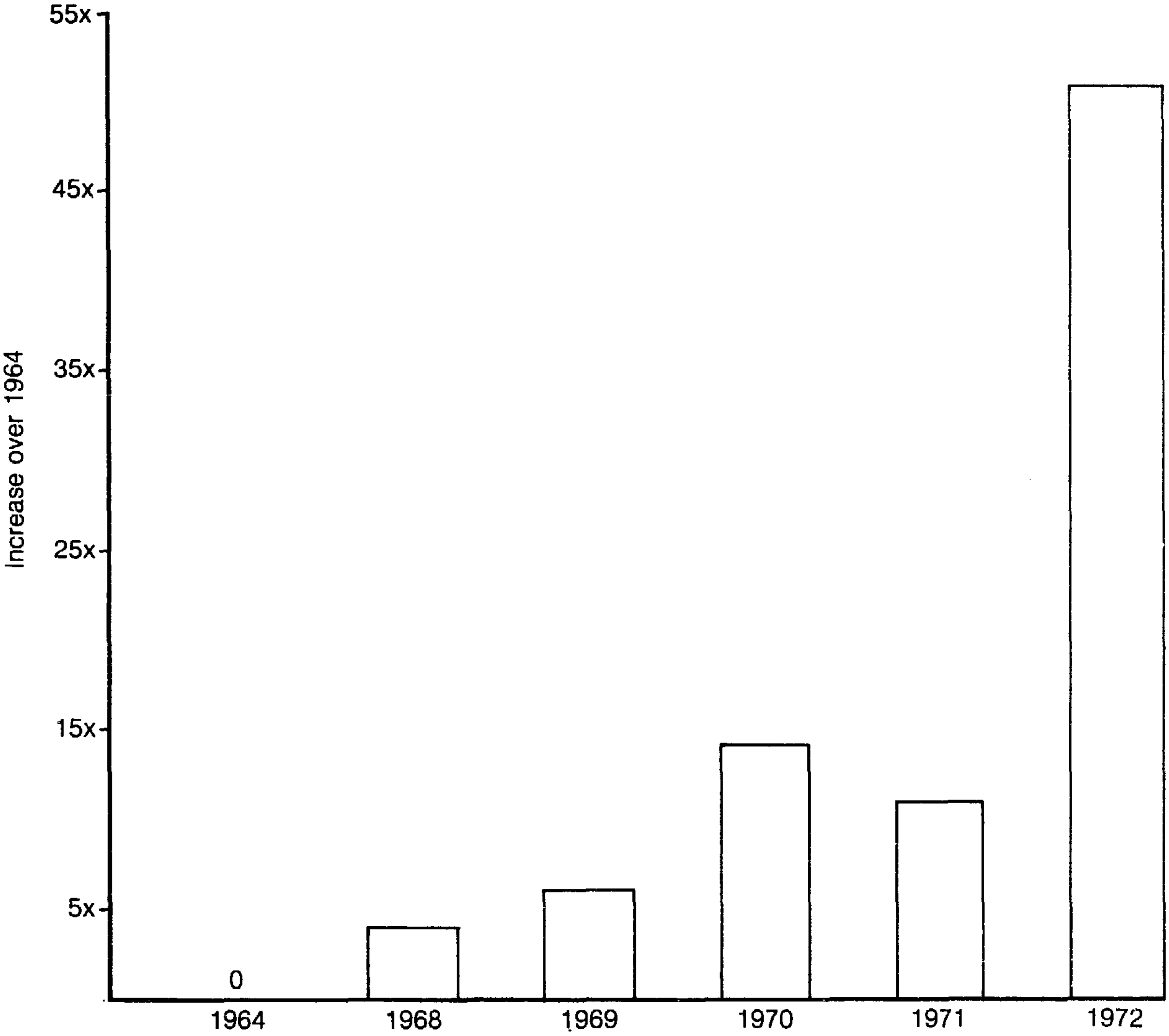
The development of resistance in certain agricultural insect pests has economically crippled crop production, as in the case of the tobacco budworm. Figure II-3 shows the development of its resistance during 8 years of exposure to methyl parathion in Texas cotton fields. The pest became so resistant in south Texas and northeastern Mexico in the late 1960's that it could not be controlled profitably with insecticides, and the entire cotton industry in the area suffered great losses (Adkisson, 1973).

In California, the major agricultural state, 75 percent of its most serious crop insect and mite pests have developed genetic resistance to at least one pesticide, and some are resistant to two or more pesticides (Luck et al., 1977).

It was once thought that resistance to an insecticide could be remedied by switching to an insecticide of a different chemical class. But experience has shown that some insects develop resistance to many closely related insecticides of one chemical class and even to insecticides of several different classes. In some regions the tobacco budworm is resistant to the organophosphorus insecticides (e.g., methyl parathion, as noted above), some of the chlorinated hydrocarbon insecticides, and one carbamate insecticide. Switching, therefore, may offer only a temporary reprieve in the fight against genetic resistance in insects (Georghiou, 1972).

Numerous cases of fungi resistance to fungicides have been reported (Georgopoulus, 1977), but the most serious problems of genetic resistance to chemical pesticides have been encountered in the control of insects, spider mites, ticks, and rodents (NAS, 1975). The development of nematicide resistance in plant nematodes has not yet created serious problems (Van Gundy and McKenry, 1977; Sasser, 1976). However, Smolik (1978) reported that after 4-5 years of exposure, the plant nematode *Pratylenchus scribneri* became tolerant to the insecticide carbofuran being applied to soil in South Dakota corn fields. Because most fungicides and nematicides are used less frequently and on a smaller scale than insecticides, most plant fungi and most nematodes have not been exposed to pesticides to the same degree that

Figure II-3 **Increase in Resistance of Tobacco Budworms to the Insecticide Methyl Parathion, 1964-72 (Adkisson, 1974)**



insects and mites have been. This fact may partially account for the few problems of resistance in fungi and nematodes.

Many species of weeds have been exposed to high levels of herbicide pressure for many years, but herbicide resistance has not become a serious problem, perhaps because weeds typically have much longer generation times than insects (Young and Evans, 1976). In addition, many kinds of weed seeds are mobile, and many can exist dormant in the soil for prolonged periods, so that evolutionary rates tend to be slower, and resistant genes, even when produced, are effectively diluted by a continuous nonresistant input (NAS, 1975).

Nevertheless, weed control literature reports cases of control made difficult by the decreased effectiveness of herbicides and weed strains (ecotypes) that are relatively resistant to various herbicides (NAS, 1975; Young and Evans, 1976). At least three species of weeds, *Senecio vulgaris*, *Amaranthus retroflexus*, and *Chenopodium album*, have developed substantial levels of resistance to atrazine (Holliday et al., 1976). A pest control study committee of the National Academy of Sciences concluded: "We believe that the potential for resistance to herbicides by weeds has been underestimated and recommend that weed scientists maintain a careful watch for resistance development" (NAS, 1975).

Predators and parasites are also exposed to selective pressures of pesticides and may be expected to develop resistance (Georghiou, 1972; NAS, 1975). It would be reassuring if these beneficial species showed the same rate of resistance development as pests, but insect predators and parasites do not, and the reason is not clear. Some insect predators have long generation times compared to prey insect species. Other insect predators and most parasites do not. Because insect predators and parasites are usually highly mobile, local pockets of resistant individuals are much less likely to develop. Insect predators in which resistance has been found have low dispersal powers and a generation time shorter than that of their prey (Georghiou, 1972).

Genetically acquired resistance to chemical insecticides has given impetus to the search for such alternative methods of control as insect hormones, which are discussed in Chapter IV, p. 40. Yet there is no guarantee that pests will not become genetically resistant to some of the alternatives. The potential for genetic resistance to synthetic hormones has already been demonstrated in experimental studies (Georghiou and Taylor, 1977), and new strains of plant pathogens such as the stem rust of wheat frequently appear and cause damage to crop varieties that resisted the earlier strains (NAS, 1975). Pest organisms are highly adaptable to changing environments and can evolve many defensive mechanisms to counter control measures imposed by humans.

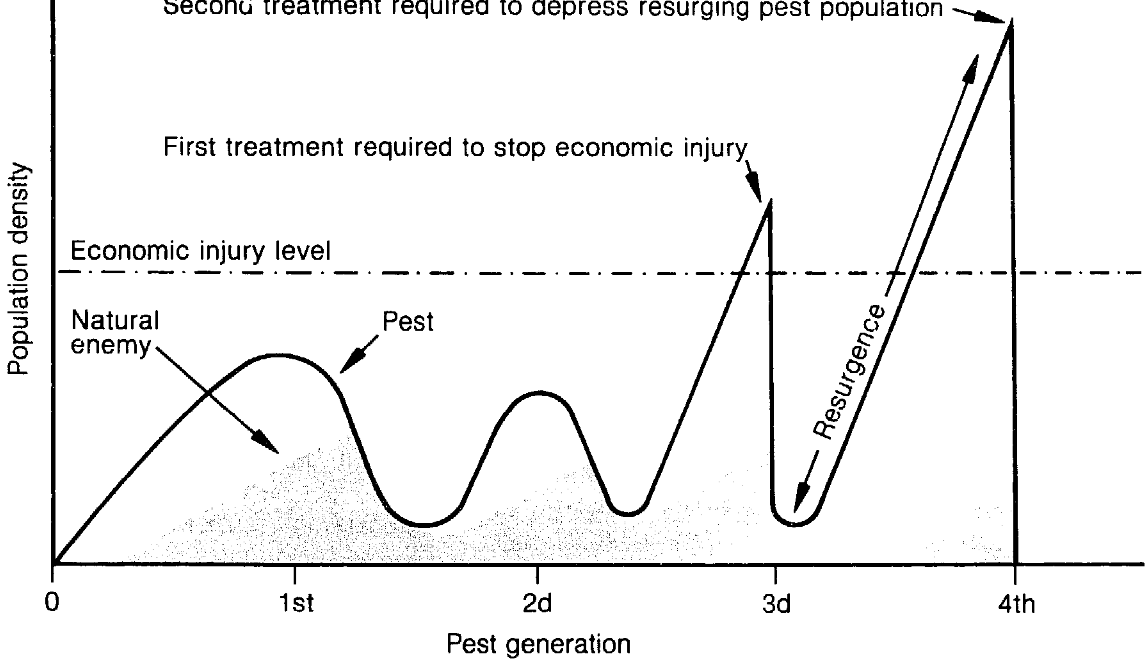
Disruption of Natural Control

Chemical insecticides applied to control insects and mites frequently have deleterious effects on the natural enemies (i.e., beneficial predators, parasites, or disease-causing organisms) that regulate the "target" pests. They may also disrupt the actions of natural enemies that regulate nontarget organisms sharing habitats with the target pests. The resulting effects are referred to as *target pest resurgence* and *induced secondary pest outbreak* (Smith and van den Bosch, 1967; Smith, 1970).

Target pest resurgence is the rapid increase of the target pest population following application of an insecticide, often to a level higher than existed prior to the control measure, as illustrated in Figure II-4. The insecticide may destroy a high percentage (often 99 percent or more) of the target population, but it rarely eliminates all members—and it frequently destroys a large portion of the target pest's natural enemies as well. In addition, the insecticide may disrupt food chains important to the target's natural enemies, thus causing them to starve, migrate, or cease to reproduce. In the absence of its natural enemies, then, the few pests surviving treatment continue to increase as long as environmental factors are favorable or until the decimated natural enemy population recovers. Because the pest's natural enemies usually recover considerably more slowly from pesticide treatment than do the pests, the pest population may reach a much higher level than before treatment. In some cases, it may even be a year or more before the beneficial organisms recover fully from treatment (Smith, 1970).

Induced secondary pest outbreak refers to the flareup of potentially harmful nontarget organisms to pest status following pesticidal destruction of their respective natural enemies which occurred incidentally to the attempted destruction of the primary pest target. Such organisms are sometimes called "potential" pests. The potential for their reaching pest status

Figure II-4 **Hypothetical Example of the Effect of an Insecticide on Target Pest Resurgence**



always exists, but this potential is realized only following an ecological disruption such as that resulting from pesticide use (Smith and van den Bosch, 1967).

The serious consequences of chemical disruption of natural enemies are illustrated by the control of insect and mite crop pests. In efforts to depress resurgence of target insects and mites and to control outbreaks of secondary pests, farmers have often increased the dosages to extremely high levels and the frequency of application. Over the long term, however, this treadmill chemical approach has proved to be self-defeating, only engendering such serious problems as insecticide resistance, human poisonings, and environmental pollution (Smith and van den Bosch, 1967).

Though not as well documented as for agricultural insects and mites, chemical disruptions of natural enemies appear to accentuate if not create many problems with other pest organisms. Certain fungicides used to control plant diseases are known to interfere with insect diseases (pathogenic fungi) that regulate insect pests, and outbreaks of these pests sometimes occur after fungicide use on crops (Johnson et al., 1976).

Fumigating the soil with the nematicide MB has caused destruction of symbionts (mycorrhizal organisms) necessary for the development of most tree and vine crops, consequently reducing plant growth (Gerdemann, 1974). Fumigating the soil with nematicides may also interfere with soil nematode predators or competitors of plant parasitic nematodes, although this effect has not been carefully studied (Van Gundy and McKenry, 1977).

The interactions of herbicides with plant pathogens, insect pests, predators, parasites, and beneficial pathogens are not well known. However, studies have demonstrated that some herbicides may increase the risk of attack by pathogens in many crops (Altman and Campbell, 1977). Treatments of 2, 4-D have been shown to favor the growth of the southern corn leaf blight pathogen and the insect corn leaf aphid (Oka and Pimentel, 1976). Some herbicides may reduce the incidence of plant disease as well (Altman and Campbell, 1977).

Herbicide-Triggered Species Displacement

Somewhat analogous to the pesticide-triggered problems of pest resurgence and pest outbreaks is the phenomenon known as "weed species displacement," which is caused by extensive use of herbicides in crops. The target weed is removed by the herbicide and is replaced by a species of weed not affected by the herbicide. The replacement weed may pose equal or sometimes even more severe problems than the target weed which was eliminated (NAS, 1975).

Human Health Hazards

By virtue of the nature of their use and the fact that they are designed to be biologically active, pesticides often present many potential hazards to human health. The more obvious relate to factory workers in pesticide manufacturing plants, spray plane loaders and pilots, field workers and fruit pickers, and children playing with carelessly stored pesticide products.

Pesticide residues are common in U.S. food and water (Duggan and Duggan, 1973; FDA, 1975), and although the normally low residue levels present no known direct danger to human health (HEW, 1969), the effects of long-term, low-level dosages have not been adequately studied (HEW, 1969; NAS, 1975). Pesticides have been implicated in cancer (Wassermann et al., 1976; Eckholm, 1977). In a recent study by Clark et al. (1977), heavy pesticide use in southeastern U.S. cotton and vegetable crops was associated with human cancer mortality; this association deserves further investigation. Many pesticides are carcinogenic in laboratory animals, but there is no quantifiable evidence that pesticides are human carcinogens (Kraybill, 1975).

Information on direct human poisoning from pesticides is better documented than their chronic effects. The nonfatal human poisoning cases from pesticide exposure are estimated at more than 100,000 per year in the United States (Pimentel et al., 1978a). Many are occupational illnesses; for example, 1,474 cases were diagnosed in California in 1973 (Table II-3).

Table II-3 **Pesticide-Related Occupational Illness in California in 1973 (Yates, 1975)**

Occupation	Systemic	Skin	Eye/ skin	Eye	Total
	(number of cases)				
Ground applicator	187	103	13	121	424
Mixer loader	121	19	3	22	163
Field worker	45	94	0	18	157
Nursery/greenhouse	18	71	1	22	122
Other	294	165	16	141	606
Total	665	452	33	324	1,474

Records from U.S. hospitals during the period 1971-73 showed an average of 65 human deaths per year attributed to pesticides (EPA, 1976). Hayes (1976) reported 87 nonhospitalized deaths caused by pesticide accidents for the year.

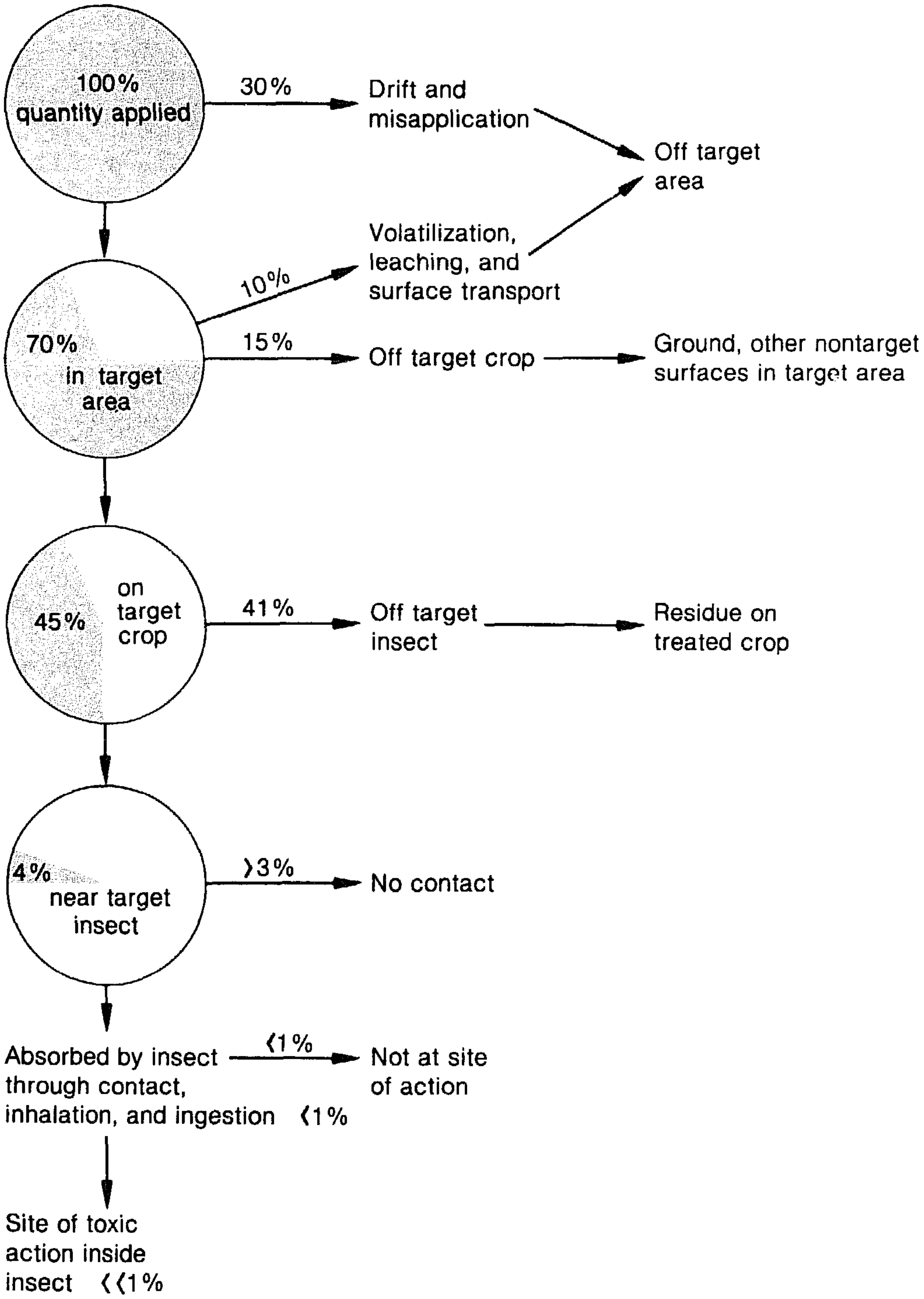
Little is known about the effects of long-term low-level dosages of chemical pesticides on public health, such as those from pesticide residues on food.

Further, the possible interaction of low-level dosages either with drugs, alcohol, etc. or with numerous food additives has not been adequately studied (NAS, 1975; Pimentel et al., 1977).

Environmental Pollution and Effects on Wildlife

Many chemical pesticides are extremely inefficient from an ecological standpoint, either because of the manner in which they are applied or because of their volatility. It has been estimated, for example, that only 1 percent or less of the ingredients of some insecticide sprays applied by aircraft intercepts the target insects (Figure II-5). No more than 25 to 50 percent may even land in the target area (e.g., crop field). The remaining 50 to 75 percent may be lost through volatilization and drift and may be carried

Figure II-5 **The Fate of an Insecticide Discharged by Aircraft (Flint and van den Bosch, 1977, after von Rümker et al., 1974)**



many miles away. These figures point up the need for formulation and application techniques which allow for more selective placement and confinement of the pesticides.

Although many herbicides photodecompose when minute particles move through the air (Santelmann, unpubl.), pesticide application by aircraft has probably contributed significantly to pollution of the environment. Runoff of rain and irrigation water and soil erosion contribute further to the significant spread of pesticides. The discovery of DDT residues in Antarctic seals and penguins shows that even those environments remote from pesticide-use areas may be subject to pesticide contamination (Pimentel and Goodman, 1974).

Persistent pesticides such as DDT and DDD often accumulate in the food chains of both wildlife and humans, and as they progress from the bottom to the top of the food chain, they become more concentrated—a process known as *biomagnification* (Figure II-6). Biomagnification of DDT in fish in Lake Michigan, from approximately 0.000002 parts per million (ppm) in the water to as much as 10 ppm or more in fish, led the Food and Drug Administration to prohibit commercial sale of the fish for human consumption (Metcalf, 1975). Accumulation of other persistent pesticides or their breakdown products in aquatic systems has had similar effects. In 1976, for example, commercial fishing was suspended in the James River and an adjacent portion of the lower part of the Chesapeake Bay because of pollution by the manufacturer of Kepone®, and consumption of Lake Ontario fish was prohibited because of harmful residues of Mirex® in the water (Flint and van den Bosch, 1977).

Chemical pesticides have also seriously harmed many noneconomic species of fishes, birds, and other wildlife. Harmful effects may involve direct kill of desirable species, interference with reproductive performance, or disruption of food chains and resulting starvation of animals that depend on the food chains. These effects have been documented many times (Cope, 1971; Pimentel and Goodman, 1974; Menzie, 1972; Newsom, 1967).

Effects on Pollinators

The honey bee produces honey and beeswax valued at $50 million annually in the United States. More important, honey bees pollinate an estimated 80 percent of the deciduous fruit, vegetable, legume, and oil seed crops grown in this country. Wild bees such as bumble bees, the alfalfa leafcutting bee, and the alkali bee are also very important pollinators. The annual value of bee-pollinated crops is more than $1 billion (Metcalf, 1975).

Modern agricultural methods have seriously aggravated bee poisoning and pollination problems. Many insecticides are highly toxic to bees and are especially harmful if applied during the bloom period when the crops are inhabited by large populations of honeybees and important wild bee pollinators. Herbicidal destruction of bee forage plants may produce even more harmful effects (Johansen, 1977).

Loss of honey bee colonies from pesticide poisonings exceeds losses induced by all other causes in California (Table II-4). Immediate monetary losses are considerable, but long-term losses in insect-pollinated crop yield can be even greater, especially in crops dependent on wild bees for pollination. It may take 3 years or more after a pesticide poisoning for wild populations to return to their original levels, or they may be eliminated (Johansen, 1977).

The seriousness of honey bee kills with pesticides resulted in passage of the Bee Indemnity Program in 1970 (Public Law 91-524), which authorizes compensation of bee owners for their losses. In 1976, the Department of Agriculture, which administers the Program, paid $3.4 million in indemnities (USDA, unpubl.).

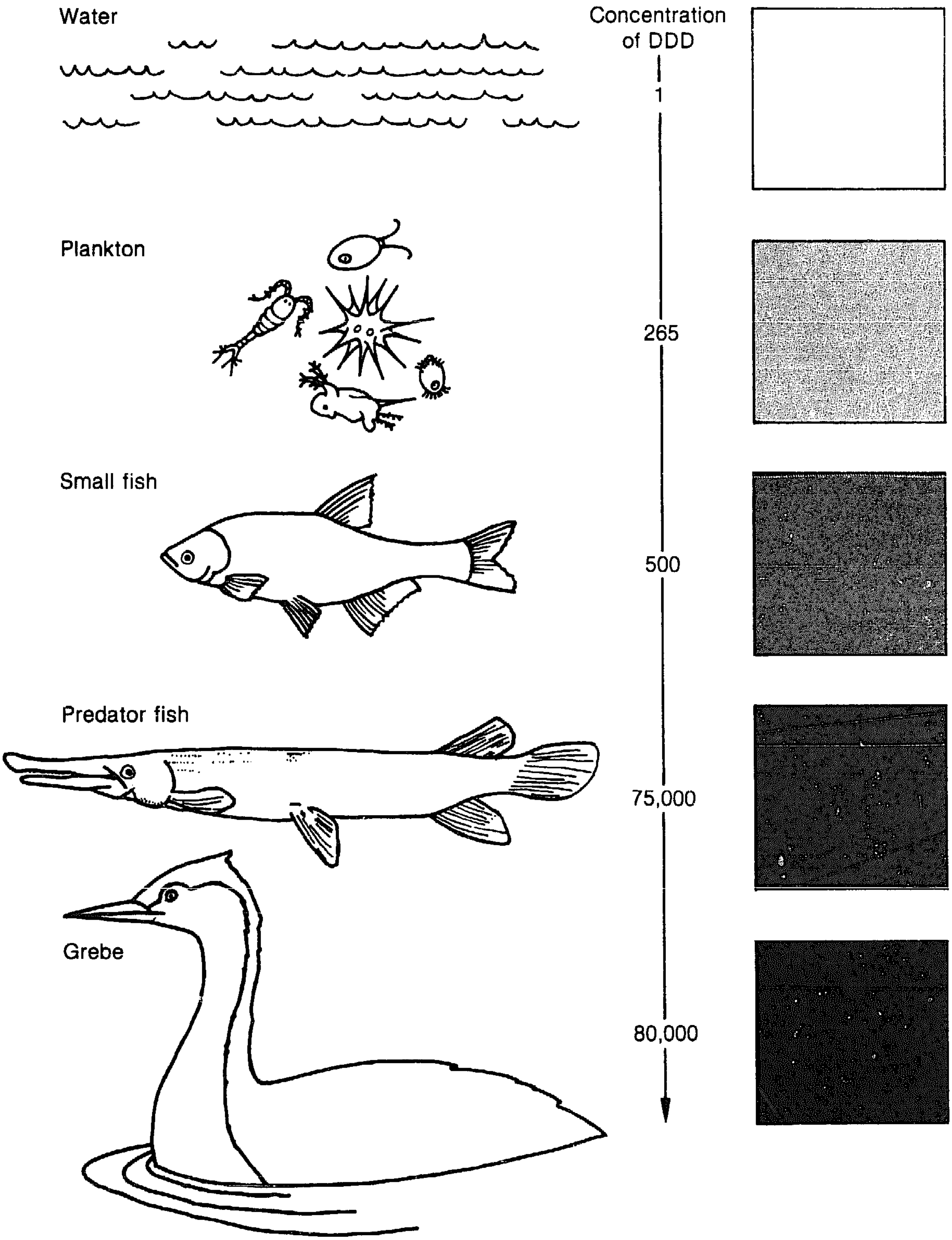
Table II-4 **Loss of Honey Bee Colonies in California from Pesticide Poisonings (after Flint and van den Bosch, 1977)**

Year	Number of colonies (thousands)	Number lost (thousands)	Percentage lost
1969	537	82	15
1970	521	89	17
1971	511	76	15
1972	500	40	8
1973	500	36	7
Average	514	65	13

A Comment

Public concern about impacts of pesticides on health and the environment has led to more stringent regulation of their use and to complete prohibition of specific compounds. Although regulations are necessary to protect society against external costs, undesirable side effects have not been demonstrated for all chemical pesticides, and they will continue to be valuable in integrated pest management, as discussed in the following chapters. The question is not whether their use should be continued; rather, it is how they may be used with minimum undesirable side effects and complications.

Figure II-6 Biomagnification of DDD in the Food Chain at Clear Lake, California (Flint and van den Bosch, 1977)



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Part Two

Pest Control Options

Integrated Pest Management: Definition, Features, and Scope

Chapter Three

Definition

Integrated pest management (IPM) is the selection, integration, and implementation of pest control based on predicted economic, ecological, and sociological consequences. The basic premise of IPM is that no single pest control method will be successful. IPM therefore seeks a variety of biological, physical, and chemical methods integrated into a cohesive scheme designed to provide long-term protection. First consideration is given to use of naturally occurring mortality elements of the pest environment, including weather, diseases, predators, and parasites. Artificial control measures, employed only as required to reduce and maintain the pests at tolerable levels, are based on criteria developed to identify when and where control is justified; measures that pose minimal risks to humans, beneficial nontarget organisms, and the environment are sought. The ultimate objective of integrated pest management is to control pests in an economically efficient and environmentally sound manner.

Integrated pest management is a convenient term sometimes used erroneously to describe any combination of measures for control of pests inhabiting a crop or other resource—even the isolated use of two or more pesticides without an analysis of need or consideration of alternatives. But the meaning of IPM is distinctly different (Huffaker, 1978). It evolved from "integrated control," originally proposed to describe the integration of biological and chemical controls into a cohesive pest management system (Bartlett, 1956; Stern et al., 1959). Subsequently, integrated control was broadened to become synonymous with integrated pest management as defined above (Smith and Reynolds, 1965; Smith and van den Bosch, 1967; FAO, 1967; Smith, 1978). Integrated pest management is also synonymous with pest management, a term introduced by Geier and Clark in 1961 and used by Rabb (1972).

Integrated pest management was first articulated by insect control specialists and insect ecologists. It gained considerable attention and funding as an insect management approach before the concept came to include all classes of pests (Apple and Smith, 1976). The fact that IPM suggests integrated insect-pest management has alienated some weed scientists and plant pathologists although the integrated pest management concept is applicable to all classes of pests and all the pest control disciplines have shared in its development and implementation.

Principles of IPM

The following principles are important in developing a cohesive system for managing pests:

1. Potentially harmful species will continue to exist at tolerable levels of abundance. IPM rejects the notion that the presence of a pest species necessarily justifies action for control. Low-level infestations of some pests may in fact be desirable. Noninjurious levels of agricultural insects and weeds, for example, may provide important sources of food, reproductive hosts, or shelter for natural enemies; complete annihilation of these organisms may have harmful side effects (Smith and van den Bosch, 1967; Croft and McGroarty, 1973). The strategy of eradication may be a desirable goal under special circumstances (e.g., a single weed plant is sufficient to cause a major problem in a field the next year), but the philosophy of pest control based on eradication of pest species is the antithesis of integrated pest management (Smith and van den Bosch, 1967).

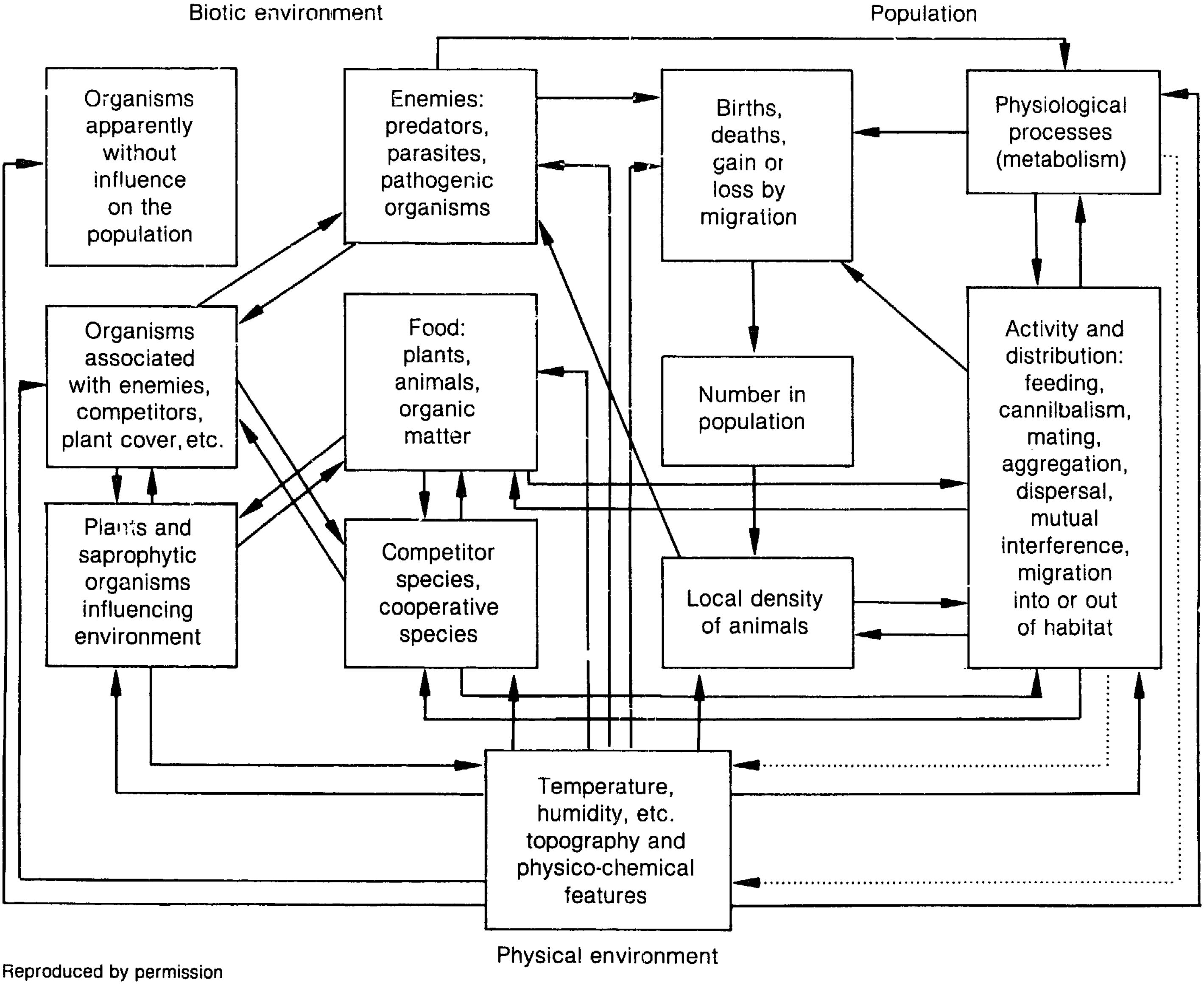
2. The ecosystem is the management unit. Individual organisms of the same species live together as a population, populations of different species live together as a community, and a community is influenced by its physical environment. Such a complex system of biotic and abiotic factors is an ecosystem. Examples of human-managed ecosystems are urban areas, livestock feeding operations, agricultural cropping systems (agroecosystems), and orchards. Woodlands, watersheds, and natural lakes are natural ecosystems.

Any manipulation of an ecosystem may aggravate pest problems while effectively managing other pest populations. For example, the change to a new variety, rotation to another crop, change in fertilizer, modified row-spacing or irrigation schemes, and change in pesticide use patterns may cause a rather drastic shift in the status of pest species in a crop or group of crops in a given agroecosystem. The manipulations may productively affect a damaging pest, but they may also permit establishment of new damaging pest hierarchies. Even subtle manipulations affect the ecosystem. Integrated pest management manipulates ecosystems to hold pests to tolerable levels while avoiding disruptions of the systems (Smith and van den Bosch, 1967).

The resources for research and constraints on time rarely, if ever, permit a total analysis of the agroecosystem, forest ecosystem, or other ecosystem under consideration for IPM. The factors affecting any one organism in an ecosystem (see Figure III-1) may require years of scientific investigation before they can be identified and their significance known. Yet knowledge of the actions, reactions, and interactions of the ecosystem's components is requisite to an effective IPM program. With this knowledge the IPM specialist can design the optimal strategy utilizing the natural forces that control or regulate density of the pests (Smith and van den Bosch, 1967).

Initially, simple pest management programs can be based on limited understanding of the components of an ecosystem. A successful beginning can be made by regarding the ecosystem as a complex of overlapping subsystems, each of which, from the standpoint of pest control, can be analyzed separately, with attention concentrated on the primary pest species (Smith and van den Bosch, 1967).

Figure III-1 **Chief Interrelationships of a Population of One Species with its Environment (Solomon, 1953)**



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The ecosystem is the management unit in integrated pest management, and the migration of the pests usually determines boundaries of the ecosystems to be managed (Apple, 1977). Many pests are strong migrants and are best managed on a large-district basis, as opposed to an individual farm or field basis. For example, a farmer's efforts one day can be canceled by a migrant population from a neighbor's field if the two did not cooperate. Cooperation, and sometimes legislative enforcement locally, nationally, and internationally, is integral to the success of integrated management of some migrant pests (Rabb, 1970).

3. Use of natural control agents is maximized. Integrated pest management emphasizes existing factors in the ecosystem which regulate the pests' numerical growth: limited resources (food, space, shelter), periodic inclement weather or other hazards (heat, cold, wind, drought, rain), competition within the species or with other plants and animals, and natural enemies.

Natural enemies are particularly important for the control of many species of insects and mites. Although resources, weather, and the presence of competitors may provide little control of a pest under some circumstances, the natural enemies of many insect and mite species are almost universally present, often in significant numbers (van den Bosch and Messenger, 1973).

Natural enemies may be insignificant in the control of some species (see Chapter IV, p. 28). However, because the combined actions of various natural suppressive forces are potentially significant against all pest species, an important goal of integrated pest management is to alter pest environments so as to enhance the action of natural forces. The procedures may entail conservation and augmentation of resident natural enemies, introduction of new natural enemies, use of pest-resisting crops and livestock breeds, and other environmental manipulations, discussed in Chapter IV.

4. Any control procedure may produce unexpected and undesirable effects. Use of chemical pesticides has dramatized the point that any single control procedure can have unexpected and undesirable consequences, as discussed in Chapter II. But the unilateral use of any of the alternative techniques, discussed in Chapter IV, can have similar consequences and must be carefully considered in an ecological context both before and after adoption. For example, new strawberry varieties introduced in California because of their disease resistance were highly susceptible to the cyclamen mite, a minor pest on older varieties (Smith and van den Bosch, 1967).

As shown in Chapter IV, there is a wide variety of pest control techniques suitable for IPM programs. The very fact that there is available today a wider array of techniques of much greater sophistication and potency than ever before makes it critical that pest control be approached in broad ecological terms.

5. An interdisciplinary systems approach is essential. An integrated pest management system must be integral to the overall management of a farm, a business, or a forest. Such a system requires interdisciplinary cooperation in the research and development phases and also in its implementation. Cooperating specialists from many disciplines—agronomy, economics, meteorology, engineering, sociology, mathematics, plant and animal physiology, and computer science in addition to the various pest control sciences—are important in collecting the information and formulating the management strategy.

Systems analysis, mathematical models, and computer programming are aids in mapping optimal strategies. But systems analysis is not a panacea, any more than DDT was to all insect pest problems. To quote IPM expert A.P. Gutierrez (1978), "the basic recipe for using systems analysis (or any new technology) in an agroecosystem is enlightened common sense."

Efforts are underway to develop a computer model that simulates all occurrences in a particular crop, forest, or other ecosystem at any given time (from planting through harvest, in the case of a crop ecosystem). Such a model could be used, for example, to determine how to manipulate a crop (use a combination of crop variety, fertilizer, pesticide, etc.) to achieve optimal pest management. Such a model does not exist, but progress is being made. Although the long-term practical value of these computer models is not yet known, the interdisciplinary systems analysis and modeling are providing a better understanding of the ecosystem and more effective ways to manage pest populations (DeMichele, 1975; Huffaker et al., 1978; Gutierrez, 1978; Tummala et al., 1976; Ferris, 1976; Haynes and Tummala, 1978).

Guidelines for IPM Programs

Huffaker (1972) and Apple (1977) outlined general steps for developing IPM programs for insects and plant diseases, respectively. Weed scientists (e.g., Buchanan, 1976) have offered guidelines for developing weed management programs for specific crops. Because development of a specific integrated pest management program depends on many variables—the pest complex, resources to be protected, economic values, and availability of personnel—it is difficult to establish absolute guidelines. The following general guidelines apply to the management of any pest group.

1. Analyze the "pest" status of each of the reputedly injurious organisms and establish economic thresholds for the "real" pests. A given crop, forest, backyard, recreational area, or other resource may be infested with dozens of potentially harmful pest species at any one time. For each situation, however, there are rarely more than a few serious pest species which recur at regular (and fairly predictable) intervals. Dozens of species of weeds may infest cotton fields, for example, but only a few present major problems in any one location (Buchanan, 1974). Serious pests recurring regularly at injurious levels if not controlled are the focal organisms for integrated pest management programs and are known as "key" pests (Smith and van den Bosch, 1967).

Key pests are not the same pests which attain injurious levels irregularly. Sometimes these secondary pests present problems only when provoked by such human disturbances as indiscriminate use of pesticides. For example, the numerous insecticide-induced outbreaks of secondary insect and mite pests of crops (see Chapter II, p. 12) demonstrate the fact that inherently effective natural enemies of many of these pests are present in a given crop ecosystem. If not disturbed by external factors, the enemies generally keep pest populations below economically damaging levels. The arthropod crop pests, both actual and potential, may be likened to an iceberg. The real (key) pests (those which often lack effective natural enemies) are readily recognized above the surface; the potential pests (which may represent 80-90 percent of all pest species) will remain innocuous if their natural enemies are not decimated (DeBach, 1964).

A key pest varies in severity from year to year, but its average density usually exceeds tolerable levels each year. This characteristic is the pest's "equilibrium position."

The population level that determines whether a reputedly harmful species has attained "real" pest status is called the "economic threshold," the density of a pest population below which the cost of applying control measures exceeds the losses caused by the pest (Stern, 1973; Glass, 1975).*

Figure III-2 depicts a simplified economic threshold for a crop pest. The net crop income decreases at an increasing rate as pest density increases above a crop tolerance level (N_1). Control costs to achieve various pest densities are represented by the curved broken line.

The economic threshold (N^*) is the pest density (or amount of plant damage) at which incremental costs of control just equal incremental crop returns. At N^* some crop income is sacrificed (CI_1-CI_2). Above N^* the farmer would fail to get additional crop revenue in proportion to the greater cost of control. If controls are initiated successfully at the tolerance or damage threshold (N_1), zero damage would occur but the costs of control would not be justified (Carlson, 1971).

The concept of the economic threshold is actually much more complex than this illustration; economic thresholds must accurately reflect many

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*"Action threshold," "control threshold," "treatment threshold," "annoyance threshold" (in the case of annoying flies), and "treatment level" are synonymous with "economic threshold." "Aesthetic threshold" has been used in place of economic threshold when control measures are applied for reasons other than economic, e.g., for insect pests affecting house plants (Olkowski, 1973).

Figure III-2 **Hypothetical Economic Threshold (Carlson, 1971)**

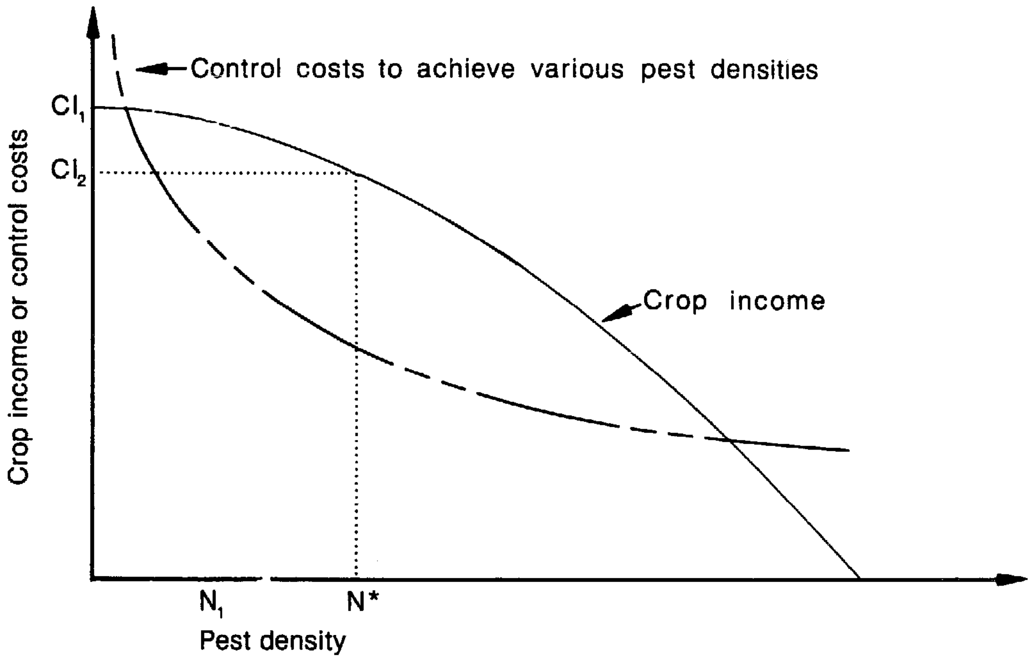

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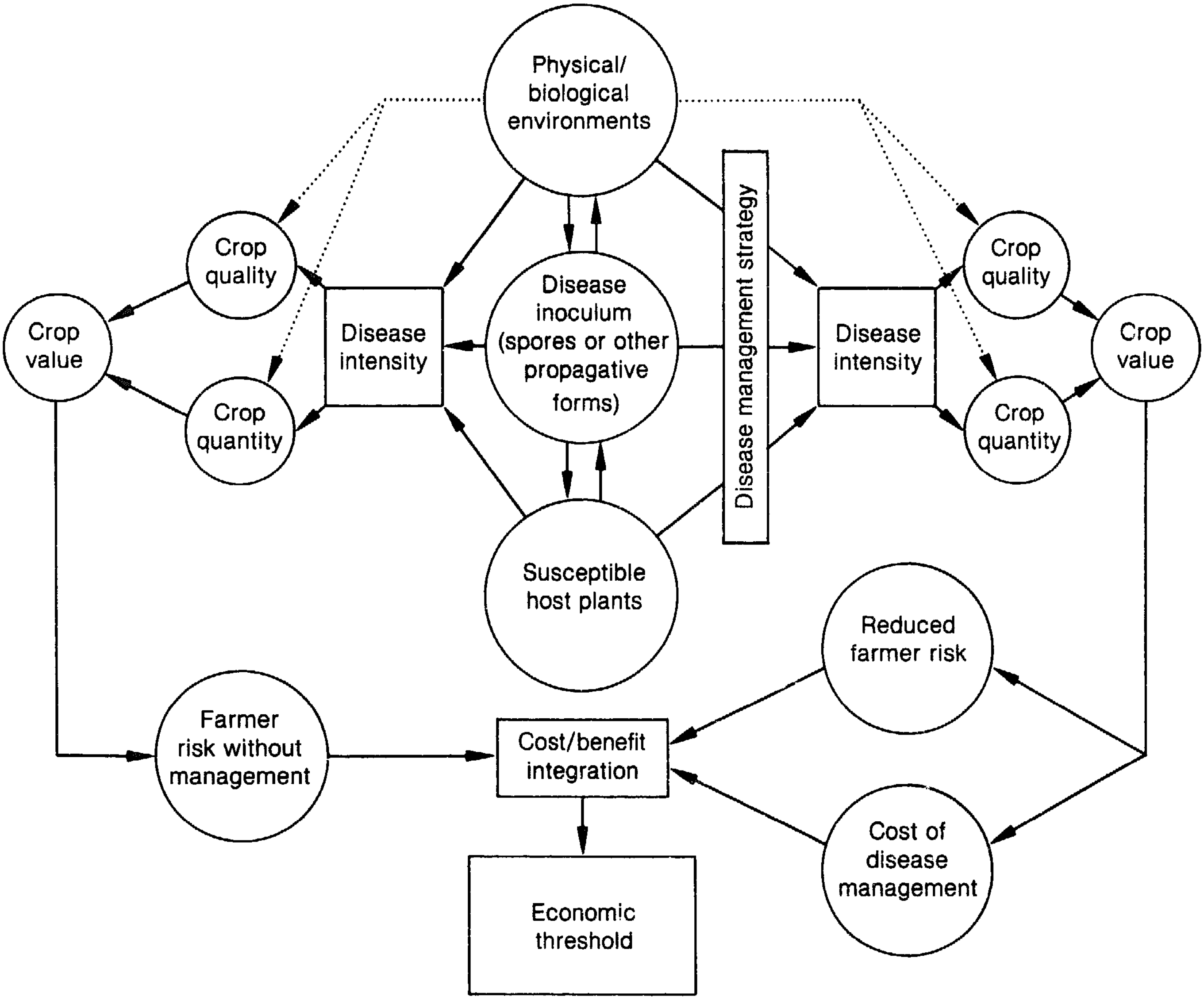
Figure III-3 **Factors that Determine the Economic Threshold for a Plant Disease Pest (after Apple, 1977)**

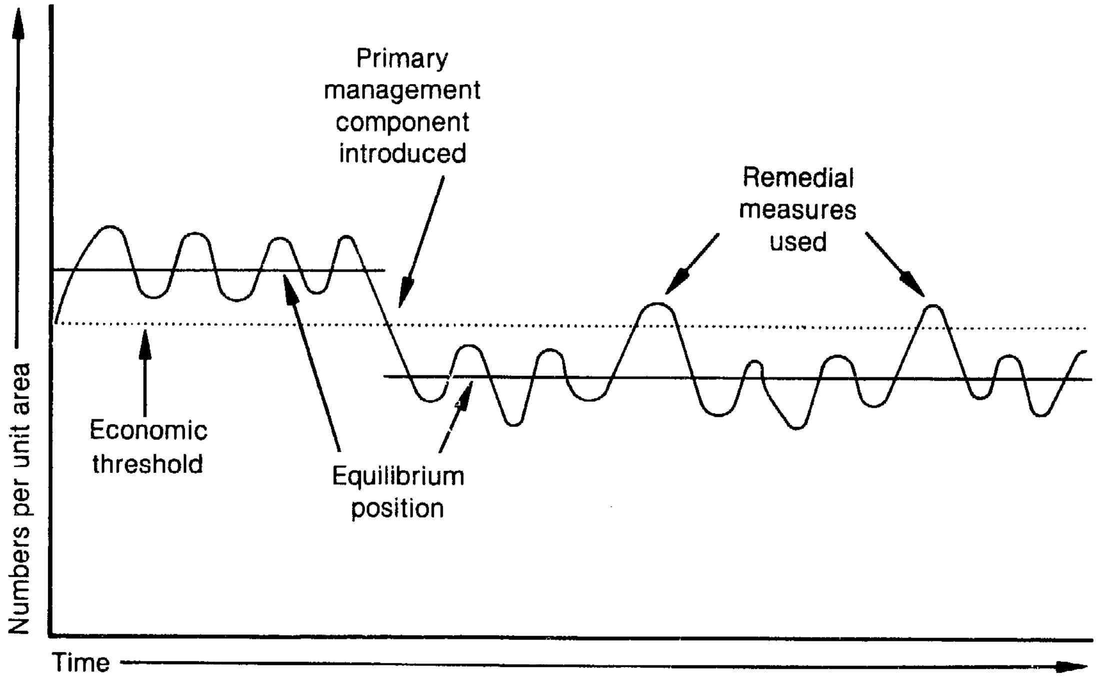


complex and interacting variables (Figure III-3). Ideally, they are based on accurate assessments of the potential damage, the human risks and uncertainties involved, and the ecological, sociological, and external economic costs of control.

Determination of economic thresholds is especially complex when more than strict profit-loss relationships are involved (Stark, 1971). For example, damage that causes nutritive losses or adversely affects the usability or palatability of a food product is far more important than damage that merely affects appearance. Aesthetic values may easily be overemphasized in this regard, for modern marketing and sales promotion of unmblemished fruits and vegetables encourage this error (see Chapter X, pp. 98-99).

Establishing economic thresholds is even more difficult when a crop or other resource is attacked by weed pests or a complex of pests. When a crop is attacked by a pest complex, growers may ask what should be done when the crop is infested by pest species A, B, C, and D, none of which has reached the economic threshold but each of which may be within one-half to three-fourths of it. Are the effects of multiple infestations additive, synergistic, or antagonistic? These basic questions have received far too little attention, and experimental techniques required for research on economic thresholds for pest complexes have not been developed. A substantial research effort is necessary to fill this void in knowledge (Glass, 1975; Main, 1977; Stern, 1973).

Figure III-4 **Lowering the Equilibrium Position of a Pest (after Rabb, 1978)**



2. Devise schemes for lowering equilibrium positions of key pests. Integrated pest management efforts manipulate the environment in order to reduce the key pest's equilibrium position permanently to a level lower than the economic threshold, as illustrated in Figure III-4. This reduction may be accomplished using three primary management components, singly or in combination:

- Deliberate introduction and establishment of natural enemies (parasites, predators, diseases) in areas where they did not previously occur.
- Utilization of pest-resistant or pest-free varieties of seed, crop plants, ornamental plants, orchard trees, forest trees, or livestock.
- Modification of the pest environment in such a way as to increase the effectiveness of the pest's biological control agents, to destroy its breeding, feeding, or shelter habitat, or otherwise to render it harmless. Examples include crop rotation, destruction of crop harvest residues, and soil tillage, effective against numerous agricultural pests; selective burning or mechanical removal of undesirable plant species, pruning, and other silvicultural practices, for many forest pests; avoiding construction of homes in poorly drained sites known to favor pest survival and increase, selection of high-quality building materials and construction to avoid pest attack and entry, and sanitation practices, for pests affecting households and other structures; in public health IPM programs, draining or drenching water impoundments that serve as breeding sites for mosquitoes; and use of predator-proof fences and animal pens, for such predators as coyotes.

Pest management practices can also raise the equilibrium position of a pest. For example, repeated applications of insecticides to crops may destroy natural enemies, thus creating a higher equilibrium position than when the pest was regulated by its enemies. The equilibrium position may also be raised by inadvertent creation of new breeding sites (e.g., uncovered garbage for flies, stagnant pools of water for mosquitoes) (Flint and van den Bosch, 1977).

3. During emergency situations, seek remedial measures that cause minimum ecological disruption. Utilization of the best combination of natural enemies, resistant varieties, and environmental modification may eliminate the need for further action against many key pests except under unusual circumstances. Nearly permanent control of key arthropod and disease pests of some agricultural crops, for example, has been achieved by integrating such cultural practices as plowing and timing of irrigation with pest-resistant crop varieties and conservation of natural enemy populations (see Chapter IV).

For the occasion when the key pests have flared up or the secondary pests are out of control, remedial measures must be taken; pesticides may be the only recourse. In integrated pest management programs, selection of the pesticide, dosage, and treatment time are carefully coordinated to avoid ecological disruptions and the other problems discussed in Chapter II. Economic thresholds serve to identify when and where the remedial measures are truly justified.

4. Devise monitoring techniques. Monitoring is essential to integrated pest management. Pest populations are dynamic, sometimes more than doubling in one day or less or decreasing at a comparable rate. Because weather, crop growth, natural enemies, and other factors that affect population growth and decline are also changing constantly, pest populations and the parts of the environment influencing their abundance must be inspected frequently in order to determine when to apply or relax various control measures. Only through monitoring can the real need for control be known and the natural controls maximized.

How monitoring is conducted depends upon the crop or other resource, the type of pests involved, environmental conditions, and economic resources. Light traps and traps baited with natural or synthetic lures have been used to check some insects. Some soil-borne fungal and bacterial pathogens (Baker, 1970) and nematodes (Barker and Nusbaum, 1971) are detected by soil-sampling techniques. Monitoring weed species involves mapping where the weeds are in a field. More sophisticated IPM monitoring schemes entail the use of computers into which are fed data on pest densities, natural enemies, weather, and other relevant factors. The computers process the information and then alert the farmers to what steps, if any, are necessary to correct a pest problem (see Chapter V, p. 51). Some monitoring procedures designed for the farmer, forester, and home gardener involve no special equipment and very little expense.

Progress in Developing and Implementing IPM Programs

As shown in the chapters that follow, integrated pest management techniques and programs are at various stages of development for pests of agriculture, forests and rangelands, urban areas, and public health. Numerous examples are cited in order to show that IPM promises cost-effective solutions for a wide variety of pests. By using pesticides selectively and judiciously, IPM also promises to prevent needless insult to the environment and human health. In most sectors, IPM is at an early stage, and the full potential of most of the operational IPM programs is still unknown. Yet there are indications that IPM is gaining a foothold in some sectors. For example, farmers in Texas recently organized a nonprofit association explicitly to promote increased use of IPM on crops throughout the state (see Chapters V, p. 52, and X, p. 98).

But integrated pest management is not a panacea for all pest problems; indeed, it may not always be the best approach. For example, reliance on herbicides to control weeds on cropland may be considerably more cost effective than hand labor, mechanical cultivators, and crop rotations—the only alternative methods currently available for IPM programs for weeds affecting most crops. In the case of a recent foreign pest introduction, different values may be assigned to economic and environmental factors. In order to prevent the pest from becoming established and spreading widely, early detection and eradication of low level populations may be preferred to IPM.

The following chapters introduce the techniques available for integrated pest management, review IPM in the agricultural and nonagricultural sectors, identify obstacles to development and implementation of IPM programs, and outline federal government action to overcome these obstacles.

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The Control Techniques of Integrated Pest Management

Chapter Four

The techniques for controlling pests draw from a wide range and history of applied science and technology. Many are suitable for integrated pest management. Some of the most effective techniques, such as pest-resistant crop varieties, crop rotation, biological control, and selective pesticides, have been known and used for many years. Promising alternatives to chemical pesticides, including insect attractant chemicals and weed disease agents, are being developed, but they have not been fully evaluated for use in IPM. All alternatives need continued research directed toward their integration into IPM systems.

A prerequisite to effective integration of various alternatives and chemical pesticides into a cohesive integrated management scheme is a thorough knowledge of the crop or other resource, the biology and ecology of the pests, and the control techniques themselves. Lack of this knowledge is currently hindering development and implementation of many alternatives which have shown outstanding promise in preliminary evaluations (Glass, 1975; NAS, 1975).

Table IV-1 lists examples of alternatives to chemical pesticides. Some of these alternatives are now being used in IPM programs; all have potential value in integrated pest management. Yet for many of the most serious pests, there are no suitable alternatives, and for the foreseeable future, chemical pesticides will remain basic tools in integrated pest management.

There is disagreement among pest control specialists on how the IPM techniques should be categorized; they will be discussed here under the following categories: biological control, host resistance, cultural control, physical and mechanical control, autocidal insect control, chemical behavioral insect control, and selective chemical control. (The following are suggested for more complete discussions of various pest control techniques suitable for IPM programs: NAS, 1968a, b, c; NAS, 1969, 1970, 1975; Anon., 1965; Glass, 1975; and Huffaker and Messenger, 1976.)

Another category, regulatory control, is not available to IPM operators because it is usually a function of government (see Chapter XI, p. 104). Regulatory control is exercised to prevent new pests from invading a quarantined area, to eliminate newly introduced pests from small areas, or to ensure that practices requiring areawide cooperation (e.g., destruction of alternate host plants of a crop pest in a given agricultural area) are adequate. Regulation is essential to certain IPM schemes, particularly those involving migrant pests and requiring uniformity in a large area.

Biological Control

The term "biological control" was first applied by Smith (1919) nearly 60 years ago to the use of parasites, predators, and pathogens* to control insect pests. Over the decades the meaning has changed to suit all the various pest control disciplines. To define biological control as any nonmechanical control method that is biology based, such as host resistance, insect pheromones, crop rotations, and sterile-male insects, tends to obscure the unique functional and ecological basis of biological control as originally intended by Smith (Doutt, 1972).

Here biological control is treated as the science of natural enemies in regulating the numbers of their hosts (Wilson and Huffaker, 1976). In practice, biological control is the use or encouragement of "beneficial" living organisms for the reduction of pest organism populations (DeBach, 1964).

Biological control is a natural phenomemon responsible for regulation of the numbers of plants and animals. It is a major element of the force which keeps living creatures in balance. Successful utilization, then, depends on understanding the biology and the ecology of both the pest and the beneficial organisms operating on it (van den Bosch and Messenger, 1973).

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*A parasite is a small organism which lives and feeds in or on a larger host organism; a predator is an animal which feeds upon other animals (its prey) which are smaller or weaker than itself; a pathogen is a microorganism which lives and feeds parasitically on or in a larger organism (its host) and causes disease to it (van den Bosch and Messenger, 1973).

Table IV-1 **Examples of Alternatives to Chemical Pesticides (Anon., 1965)**

Insects, mites, and other invertebrates	Plant diseases	Weeds	Birds, mammals, and other vertebrate pests
Biological control Parasites Predators Pathogens Plant and animal resistance Environmental manipulations Plant spacing Species diversity Timing Crop rotation Plant hormones Water management Fertilizers Soil preparation Sanitation Induced sexual sterility Physical and mechanical control Window screens Light traps Fly swatters Protective packaging Sifting devices Barriers Flaming and burning Attraction and repellency Attractants Repellents Genetic manipulation of pest populations Lethal genes Male-producing genes	Disease resistance Reduction and losses by manipulations of plants and pathogens Control of plant pathogens by natural enemies Disease- and nematode-free seed and propogating material Crop rotation and soil management Destruction of inoculum sources Vector control Nematode attractants and repellents	Insects and other herbivores Diseases Environmental manipulation Choice of variety Seedbed preparation Method of seeding or planting Seeding rates and row spacing Fertilization Cultivation Irrigation and water management Erosion control Design of irrigation and drainage canals and ponds Managed grazing Sanitation Natural stimulants and inhibitors Plant competition Revegatation of weed- and brush-infested grazing lands Breeding highly competitive forage species	Noise and physical repellents Chemosterilants Chemical repellents Trapping and shooting Behavior Environmental manipulation Exclusion

Although still grossly underused, biological control is gaining world recognition as a primary and often essential component of successful integrated pest management (DeBach, 1964, 1974; van den Bosch and Messenger, 1973; Huffaker, 1971; Huffaker and Messenger, 1976; Maxwell and Harris, 1974; USDA, 1978; Baker and Cook, 1974). There is substantial evidence that long-term suppression of a complex of pests is highly unlikely without the help of natural enemies (Huffaker, 1971).

Yet biological control cannot be expected to work against all pests. It may completely solve problems with one or a few pest species, substantially but insufficiently affect others, and be of little or no use for others (Wilson and Huffaker, 1976).

Classical Biological Control

Classical biological control involves deliberate introduction and establishment of natural enemies in areas where they did not previously occur; the approach is used largely against pests of foreign origin.

Classical biological control is clearly highly effective. In January 1975, there were 213 cases reported worldwide of partial to complete success involving the introduction of natural enemies of important pest insects and arthropod relatives, snails, and weeds where they had not previously occurred (Huffaker, 1975).

The potential of classical biological control against pests of foreign origin is illustrated by an insect pest of walnuts in California and an aquatic weed pest in the southeastern United States.

The walnut aphid had been a serious insect pest of the English walnut in California since the early part of this century. For decades no thought was given to its biological control, and annual outbreaks on thousands of acres were routinely treated with insecticides. Chemical control was costly and it led to repeated pest resurgence and secondary pest outbreaks. Further, the insect pest developed resistance to most insecticides used against it (van den Bosch and Messenger, 1973).

This succession of failures prompted University of California scientists to seek natural enemies for introduction from the Old World, the original home of the walnut and the walnut aphid. In 1968, the tiny parasitic wasp *Trioxys pallidus*, whose immature stages develop within the aphid pest, was obtained from Iran and colonized in several areas of central California. Results were both immediate and spectacular within the release site, and additional colonizations were made in 1969 and 1970. By 1971, the parasite had spread throughout many of the walnut-growing areas of central and northern California, perhaps 50,000 square miles, where it had a generally crushing impact on the aphid pest. Economically injurious infestations of the aphid are now virtually nonexistent in the major walnut growing areas (van den Bosch and Messenger, 1973).

Economic benefits from this biological control program from 1970 to 1973 were conservatively estimated at $1 million annually (savings over previous losses plus pest control costs), shown in Table IV-2. As discussed in Chapter II, page 8, only rarely have control procedures been evaluated in terms of the relative costs of the control practice itself, and information derived from acceptable cost-benefit analyses is very limited. The accuracy of estimates on benefits of alternatives, like those on the benefits of pesticides in Chapter II, then, is questionable.

Table IV-2 **Estimated Agricultural Benefits in California through Major Successful Biological Control Programs, 1928-73 (Huffaker et al., 1976)***

Pest	Crop	Degree of Success	Benefits (million dollars)
Black scale	Citrus	Partial to complete	59.7
Citrophilus mealybug	Citrus, deciduous fruits, and ornamentals	Complete	91.0
Grape leaf skeletonizer	Grape	Partial to complete	2.5
Klamath weed	Rangeland	Complete	66.2
Olive parlatoria scale	Olive	Complete	7.4
Spotted alfalfa aphid	Alfalfa	Substantial	47.6
Walnut aphid	Walnut	Substantial	1.0
Total			275.3†

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†Figures do not add because of rounding.

The alligatorweed, native to South America, was first recorded in Florida about 1894 and by 1970 had infested over 66,000 acres throughout the southeastern United States (Andrès and Bennett, 1975). This aquatic weed grows primarily as an immersed or floating plant, blocking waterways, interfering with fishing, and generally causing water management problems. A small insect, the flea beetle *Agasicles hygrophila*, was discovered feeding on the plant in South America. Introduced in 1964 at the Savannah National Wildlife Refuge in South Carolina, the beetle populations became established but never reached effective control levels at this particular site. When a second release was made near Jacksonville, Florida, in 1965, the insects established quickly and within 15 months destroyed mats of alligatorweed at the release site. Subsequent releases were made in other areas of the United States.

The flea beetle has had its greatest impact in reducing alligatorweed in northern Florida, southern Alabama, Louisiana, and Texas (Andrès et al., 1976). As far as is known, the insect feeds and completes its life cycle only on that weed pest. Promising results here have encouraged scientists to seek out natural enemies of another far more serious weed of the world's waterways, the water hyacinth.

Economic returns from classical biological control programs that have been evaluated were estimated at $30 for every dollar invested (Messenger et al., 1976). This is a rather remarkable accomplishment in view of the fact that about 10 years ago the worldwide annual investment for biological control, including research, development, and implementation, was $10 million (based on 1967 estimates) compared to the $84 million spent yearly (1966 estimates) on the research and development of chemical pesticides (Huffaker et al., 1976).

In California, where classical biological control has received strong support for many years, economic benefits accrued from classical biological control programs for seven major agricultural pests (six insects, one weed) were estimated at nearly $275 million for the 45 years from 1928 to 1973 (Table IV-2).

The most spectacular and the greatest efforts in classical biological control have involved perennial crops (e.g., grape vineyards and orchard crops) and rangeland. For example, of the successful biological control programs in California developed for the pests listed in Table IV-2, all but one (the spotted alfalfa aphid) involved vineyard, orchard, and rangeland pests.

Success with pests of row crops has been limited. There have been no successes with classical biological control of row crop weeds. Of the approximately 110 agricultural insect and mite pest species under partial to complete control by introduced natural enemies reported by DeBach (1964), only 13 involved pests of row crops (including sugarcane). This low figure is partially explained by the lack of vigorous pursuit of classical biological control in row crop agriculture. Further, the constantly evolving nature of the row crop environment may not permit establishment of an effective host-natural enemy relationship such as that which often characterizes the more stable environments of orchards, vineyards, and rangelands (van den Bosch et al., 1976).

A row crop exists for a short time, often less than one year, during which time the natural enemy must discover and move into the crop; find, attack, and begin to build up in numbers; and then be subjected to abrupt habitat destruction at the end of the crop season (van den Bosch et al., 1976).

There has been only limited effort to test classical biological control of nematodes and plant pathogens (Baker and Cook, 1974), and it has not been vigorously pursued for many of the most serious insect and weed pests in the United States. Biological control would appear to offer much promise for some of these organisms considering their origin. Of the 28 most serious insect and mite pests in this country, 17 (60 percent) are of foreign origin. Of the plants considered weeds in California, 63 percent are alien, and generally they are the most serious pests (Glass, 1975; Flint and van den Bosch, 1977).

Conservation and Augmentation

Conservation and augmentation of natural enemies are deliberate actions to protect and maintain natural enemy populations or to increase their beneficial effects, such as

- Applications of supplementary foods to retain, arrest, attract, and sustain natural enemies when natural prey populations are small or when nonprey food, such as plant pollen, is inadequate for the enemies
- Provision or management of shelter utilized by natural enemies in such places as the edges of crop fields or in trees for use by insect-feeding birds
- Selective use of chemical food to increase the effectiveness of natural enemies.

Supplementing food to increase the effectiveness of natural enemies is a relatively new approach and has been attempted for only a few predatory insects and mites in agricultural crops (Hagen, 1976). In irrigated desert areas of California, for example, experimental applications of artificial honeydew (aphid insect excrement) and bee pollen in the form of food sprays have induced early egg deposition of two predatory insects, aphid lions and lady beetles, in treated alfalfa and cotton fields, resulting in significantly smaller aphid and cotton bollworm populations (Hagen et al., 1970).

Augmentation of natural enemies by providing or managing shelter has received limited attention, but it is promising for some pests. In North Carolina, for example, a substantial reduction of the tobacco hornworm, a serious tobacco pest, was achieved by the predatory wasp *Polistes* following erection of nesting shelters for them at field margins (Lawson et al., 1961).

Conservation of natural enemies through the selective use of insecticides has received the most emphasis in the conservation and augmentation category. This technique involves use of the lowest possible dosage of an insecticide for control of the target insect pest, restricting application to part of the crop fields or trees, and timing the treatments to minimize damage to the natural enemy populations (Rabb et al., 1976). Knowledge of the biology, ecology, and behavior of the insect pests often makes possible application of insecticides to very restricted areas that the insect pests utilize for feeding, breeding, or hiding. The technique was demonstrated by Isley (1926) against the boll weevil more than 50 years ago. Isley advocated "spot-dusting," which consisted of applying calcium arsenate only to areas of the cotton fields where the posthibernating boll weevils colonized in the spring, as determined by field scouts who checked the fields routinely. These restricted treatments, made to a very small part of the total field area, effectively controlled the boll weevil while sparing natural enemies in the rest of the field, minimizing both costs for application and adverse effects on nontarget organisms.

This basic technique is currently used quite effectively against the boll weevil in parts of the United States, is also being used against other insect pests, and has great potential against numerous insect pests (Newsom et al., 1976).

Inundative and Inoculative Releases

Inundative and inoculative releases are the colonization of large numbers of a natural enemy to destroy the pest population immediately (inundative releases) or repeated colonization of relatively small numbers of a natural enemy to build up the beneficial organisms over several generations (inoculative releases). Releases of native parasites and predators to control insect pests biologically have been effected in this country for many years on a small scale (Stinner, 1977; Ridgway and Vinson, 1977). Some commercial firms sell parasites and predators for use by home gardeners, farmers, and livestock owners. This approach is quite successful against some agricultural insect pests in the People's Republic of China, where human labor is plentiful (NAS, 1977). Currently, the labor required to manipulate inundative releases of insect parasites and predators is a hindrance in the large-scale operations typical of U.S. commercial agriculture. However, by proper conservation and augmentation of resident natural enemies, frequent releases may not be necessary; periodic colonization shows potential for a variety of high value crops (e.g., strawberry, vegatables, ornamentals), greenhouse culture, city parks, home gardens, grain elevators, dairy barns, livestock feedlots, and small-scale farming. Innovation in production techniques, precise timing of releases, and use of more effective natural enemy species or strains should all contribute importantly to improved efficiency of this control method (van den Bosch and Messenger, 1973).

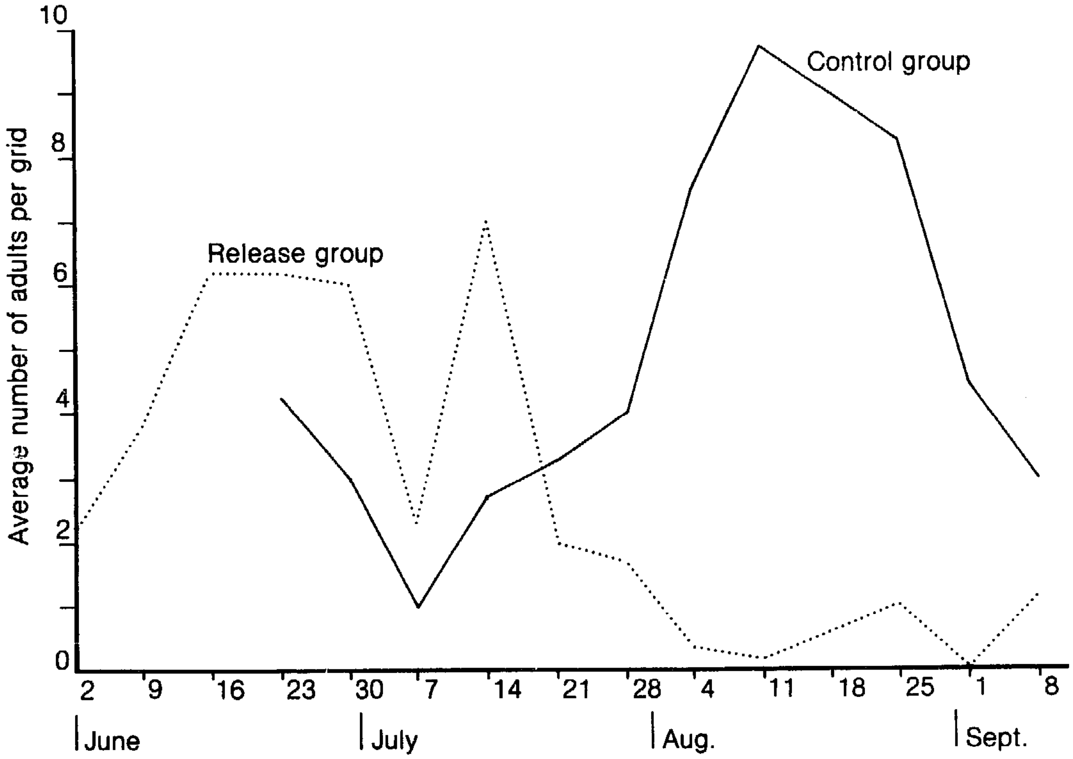
A highly promising technique for control of the common house fly involves inundative releases of the native insect parasite *Spalangia endius*, which develops as an immature parasite in the house fly's pupa (resting stage or cocoon). Sustained releases of laboratory-reared parasites were made three times per week at a poultry farm in Florida, reducing the house flies to nonnuisance levels within 35 days and continuing to suppress the population effectively for the 4-week release period (June 23 to August 25), as shown in Figure IV–1.

The potential for inoculative releases of parasites against insect pests is illustrated by a case involving the boll weevil, the nation's most important agricultural insect pest in terms of quantities of insecticides used.

Inoculative releases of the laboratory-reared parasite *Pteromalus grandis*, procured in Mexico, were made periodically in a small cotton field in Mississippi during the summer; significant control of immature boll weevils infesting the green cotton fruits resulted (Johnson et al., 1973). This control, coupled with that by native natural enemies, may be sufficient to hold boll weevil populations to nondamaging levels in some areas.

Unfortunately, the parasite used in this study did not survive the winter in Mississippi, presumably a victim of the cold weather. It would be desirable to find a cold-resistant strain of parasite. An alternative would be to rear large numbers of the nonadaptable parasite in the laboratory for periodic release during the summer. This approach or any other involving biological control of the boll weevil, however, has not been rigorously pursued.

Figure IV-1 **Effects of Sustained Releases of Small Wasp Parasites on Populations of the Adult House Fly on a Poultry Farm (Morgan et al., 1975)**



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Use of Pathogens

Relatively few pathogens (microscopic disease-causing agents) have been exploited as pest control agents, and the number of potentially useful pathogens is incompletely known. Some of these agents have shown much potential and offer an excellent alternative to chemical pesticides for IPM programs.

There are four general kinds of pathogens considered as biological control agents: fungi, bacteria and rickettsia, protozoa, and viruses. The status, potential, and limitations of these groups in pest control programs were discussed recently in a USDA publication (USDA, 1978).

Bacillus thuringiensis, a bacterial pathogen infecting a wide range of insect pests, is the most common microbial insecticide in use today. This spore-forming pathogen produces endospores which enable it to live in a dormant state in an unfavorable environment. When an insect eats vegetation containing the spores, it remains alive for several days, but its gut becomes paralyzed and it cannot eat. The disease agent is marketed by several companies and is registered for use against the insect caterpillar pests that attack a wide variety of vegetables, flowers (chrysanthemums), and ornamental and shade trees, shown in Table IV-3. It can be used on edible products up to the time of harvest. It is readily available by mail from suppliers and in many garden shops, nurseries, and department stores. The bacterium is quite effective, especially when combined with resistant crop varieties and resident natural enemies (Falcon, 1971, 1973; Maddox, 1975).

Table IV-3 **Approved Uses of the Insect Disease Agent *Bacillus thuringiensis* (as indicated on commercial product labels)**

Insect pests	Plants
Cabbage looper, diamondback moth, imported cabbage worm	Broccoli, cabbage, cauliflower, collards, kale, lettuce, mustard, spinach, turnip greens
Cabbage looper	Beans, cucumbers, melons, potatoes
Cabbage looper, celery looper	Celery
Grape leaf folder	Grapes
Cabbage looper	Flowers (chrysanthemums)
Bagworm, Douglas-fir tussock moth, elm spanworm, fall webworm, gypsy moth, red-humped caterpillar, spring and fall cankerworms, tent caterpillar	Ornamental and shade trees

The only other bacterial pathogen commercially available in the United States for insect control is *Bacillus popilliae,* which has been used extensively since the 1940's against the Japanese beetle, one of the most serious insect pests in this country; it attacks turf, fruits, vegetables, and many ornamental plants. The marketed powder is made from ground inoculated grubs of the pest and is mixed with an inert carrier such as chalk. It is applied to the soil where it is spread by rainwater, insects, and other aminals, thereby affecting the grubs (immature feeding stages) of the beetle which live in the soil.

Bacteria are also useful for nematode control, although as yet not intensively exploited (USDA, 1978). Greenhouse tests using *Bacillus penetrans* to control root lesion and root knot nematodes are very promising (Mankau, 1975). No adverse effects in its use are anticipated, but efficient means of mass-producing it have not been found.

Several species of fungi show potential as control agents against insects and mites, but none is used commercially in the United States. The fungus *Beauveria bassiana* is used widely in the Soviet Union and the People's Republic of China, where it is reportedly highly effective against forest and orchard pests (USDA, 1978). Predaceous (nematode-trapping) fungi show promise against nematodes in integrated pest management schemes; some do not appear to be affected by chemical nematicides (Cayrol et al., 1972).

Three viruses, one for controlling bollworms of cotton, one for controlling the gypsy moth on trees, and one for controlling the Douglas-fir tussock moth on trees, are the only other disease agents commercially available. Because they have been registered for commercial use for only a short time, it is too early to determine how extensively they are being used.

Some 700 species of insects and several species of mites are affected by viruses (USDA, 1978). More than 320 viruses are known to attack over 250 insect and mite species of agricultural importance—pests for which large amounts of insecticides are currently used and which are causing plant protection specialists great difficulty because some have developed insecticidal resistance (Falcon, 1976). At least one species of plant nematode, the Southern root knot nematode, is affected by a viral disease (Loewenberg et al., 1959).

There have been few deliberate attempts to use plant diseases for biological control of weeds. Nevertheless, several native disease agents have recently been studied as possible candidates for controlling weeds biologically (Wilson, 1969; Daniel et al., 1973; Templeton and Smith, 1977). One very promising agent is a fungus (*Colletotrichum)* that causes 95-100 percent mortality in Northern jointvetch, a serious weed of rice (Daniel et al., 1973). The fungus takes about 3 weeks longer than chemical herbicides take to kill the weeds, but control is adequate.

A promising approach to biological control of plant diseases is through inoculations of a variety of naturally occurring microorganisms known collectively as antagonists. Scientists have attempted to increase the antagonists' effectiveness through environmental manipulations (e.g., crop rotations), chemical treatments favorable to the antagonists' increase, and inoculation of the soil or plant surfaces with the organisms. The fungus *Peniophora giganeta* is currently used commercially to compete with and thus reduce the severity of the wood-decay fungus that causes annosus root rot in southern pine forests (see Chapter VI p. 63). The inoculation of seeds, seedlings, seedbeds, or propagatives with antagonists shows much promise experimentally in the control of diseases affecting certain vegetables, grain crops, and fruit trees (Baker and Cook, 1974).

Prospects for further commercial development of pathogens for pest control are not very encouraging. The requirements for their registration are essentially the same as those prescribed for chemical pesticides under the 1972 amendment to the Federal Insecticide, Fungicide, and Rodenticide Act. For registration purposes, there must be laboratory and field/trial evidence that the pesticide product to be marketed is effective and is safe for humans and the environment when used as directed. Like development of chemical pesticides, the development of pathogens requires large capital investments. Unlike broad spectrum chemical pesticides which act on many pest organisms, these agents are generally narrowly selective, and because the potential for economic return is thus limited, private industry is reluctant to invest the money required for research, development, and commercialization (Falcon, 1973, 1976; Tinsley, 1977; USDA, 1978).

Host Resistance

Plants and animals have evolved diverse means to avoid, tolerate, or recover from attacks of other organisms. Plant and animal breeders have used this natural process to their advantage by hybridizing and by deliberate selection of plant varieties and animal breeds resistant to pest attack in a technique known as "host resistance." This is a proven, effective, economical, and safe method of pest control ideally suited for management of plant diseases (Nelson, 1973) and insects (Beck and Maxwell, 1976), and it is compatible with such desirable pest suppression methods as biological control. In weed control, the phenomenon of allelopathy (Rice, 1974), the inhibition of growth of the weedy plants by chemicals released by the crop plants, has not been extensively explored but may have great potential. The development of breeds of animals that show resistance to arthropod attack is not as advanced as the work with crop plants, but some resistant breeds of cattle and sheep have been developed (NAS, 1969).

Plant Resistance

The use of crop varieties resistant to attack or damage by plant diseases and insects has been practiced for many decades (Walker, 1950; Painter, 1951). Early examples of the development of plant resistance by selective breeding include potato varieties resistant to potato late blight, the disease responsible for the Irish famine of the mid-19th century. By the early 1920's selective breeding led to new wheat varieties resistant to the major wheat insect pest in North America, the Hessian fly. Since then, there has been slow but steady progress in the development and use of resistant varieties, and some of the principal devastating insect, disease, and nematode pests have been overcome by this method (Nelson, 1973; Glass, 1975; NAS, 1975; Beck and Maxwell, 1976).

Mechanisms of pest resistance in plants are generally complex and not easily defined (Browning et al., 1977; Painter, 1951; Beck and Maxwell, 1976). The basis for resistance is generally physiological (e.g., the plant produces toxins which inhibit the pest) or mechanical (e.g., the plant leaves have dense mats of hair which deter feeding by insects). Another useful type of resistance is tolerance, in which the plant has the ability to sustain high levels of a pest without severe economic damage. Pest resistance may be due to a single dominant gene or it may involve many genes.

The successful development of resistant crop varieties has been a major factor in increasing and maintaining high levels of crop productivity. From the standpoint of the farmer, pest-resistant varieties are usually the most effective, easiest, and most economical means of controlling insect and plant disease pests (NAS, 1975).

An estimated 75 percent of U.S. cropland utilizes disease-resistant varieties developed during the past 50 years, and 95-98 percent of the vast acreage planted to alfalfa and small grains consists of varieties resistant to one or more diseases (NAS, 1975). Data on major grain crops are shown in Table IV-4.

Development of disease-resistant crop varieties requires a continuing and reasonably expensive research program. The costs, however, are an excellent investment in view of the fact that gains to the farmer now probably exceed $1 billion annually in the United States alone (NAS, 1975).

The availability of pest-resistant varieties is particularly important for crops with relatively low values per acre. On such crops, costly chemicals cannot be used because the profit margin is too narrow.

Plant resistance offers an important form of control of such pests as soil-borne pathogens and is the only known control for certain viruses. Examples

Table IV-4 **Major Grain Crop Pest Suppression by Resistant Varieties, 1973 (Klassen, 1979)***

Crop	Disease or insect pest	Total acres planted (millions)	Percent planted with resistant varieties	Primary locations
Wheat	Stem rust	50	25	Minnesota, Montana, Nebraska, North Dakota, South Dakota
	Leaf rust		20	Illinois, Indiana, Kansas, Minnesota, Missouri, North Carolina, North Dakota, Ohio
	Soil virus		14	Eastern one-half of United States
	Streak mosaic		15	Kansas, Nebraska, Colorado
	Bunt (smut)		13	All
	Hessian fly		8	Kansas, Indiana, Illinois, Montana
	Sawfly		3	Montana, North Dakota
Corn	Stalk rots	67	50	Cornbelt and South
	Leaf blights		75	Cornbelt and South
	Corn earworm		20	All
	European corn borer		80	Eastern one-half of United States
Barley	Yellow dwarf	10	10	California, Minnesota, South Dakota
	Greenbug		10	California, Kansas, Oklahoma, Texas
Oats	Yellow dwarf	25	50	All
	Crown nest		80	Eastern United States
	Stem rust		75	Eastern United States
Grain sorghum	Chinch bug	14	30	Kansas, Oklahoma
	Greenbug		10	Kansas, Oklahoma, Texas
Rice	Blast	2	40	Arizona, Louisiana, Texas
	White tip		50	Arizona, Louisiana, Texas

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are the rust- and smut-resistant cereals; fusarium wilt-resistant tomatoes, cabbages, cotton, and watermelon; mosaic-resistant sugarcane; curly top virus-resistant sugar beets; bacterial wilt-resistant alfalfa; mosaic-resistant beans; and cyst nematode-resistant soybean (NAS, 1975).

Some of the nation's most serious agricultural insect pests are controlled, at least in part of their range, by resistant crop varieties; they are the Hessian fly, wheat stem sawfly, spotted alfalfa aphid, European corn borer, boll weevil, and greenbug (Maxwell et al., 1972; Beck and Maxwell, 1976).

Ideally, multiple resistance to diseases, nematodes, and insects would be incorporated into every crop, but developing plants that resist some pests while maintaining acceptable yield is a slow process. Occasionally, varieties developed to resist one pest may be more susceptible to another that had not previously caused much economic damage. Insects and diseases are continuously evolving strains that may adapt to formerly resistant plant varieties. Development of multiple-pest-resistant plants is clearly a long-term interdisciplinary effort entailing the cooperation of a range of experts.

Despite the time and the costs of developing resistant crops, potential economic rewards are great. The total cost of research conducted by federal and state agencies and by private companies to develop resistant varieties for the Hessian fly (wheat), wheat stem sawfly, European corn borer, and spotted alfalfa aphid was approximately $9.3 million (NAS, 1972), but the savings in reduced losses to the U.S. farmer is estimated at $308 million annually. The net value of the research is about $3 billion over a 10-year period, for a return on each research dollar invested of approximately $300 in reduced crop losses (USDA, unpubl.). As discussed, returns from investments in the development of disease-resistant crop varieties probably exceed $1 billion annually in the United States. The return on investment for research on plant resistance is exceeded only rarely by other methods of control (NAS, 1972).

Allelopathy (defined above) occurs widely in natural plant communities and has been discovered in accessions of several important crop plants. But it is not known if wild progenitors of important crop plants contain high levels of these natural "herbicides" as a mechanism for survival (Rice, 1974).

Some crops have a superior ability to compete with weeds for critical growth factors such as specific nutrients, water, and light. Cultivors specifically bred for more vigorous canopies or root systems should provide at least a partial degree of weed control. Either of the two mechanisms—allelopathy or the superior ability to compete—may provide a valuable new approach to weed management (Klassen et al., 1975).

In some pests, especially those with very high rates of multiplication, mutations are continually occurring which overcome the resistance of the crop. General (nonspecific) resistance and tolerance which have polygenic bases (i.e., genetically diverse) usually provide some protection and are not readily overcome by mutant strains of pests. Thus every effort should be made to use genes for general resistance and tolerance obtained from diverse sources and to add them to the genes for specific resistance (Browning, 1974). The dangers of narrow gene bases in agricultural crops and the need for increasing genetic diversity in these crops are discussed in Chapter V, pp. 48-49. The disastrous outbreak of southern corn leaf blight in 1970 illustrates the fallacy of relying on a single genetic system. The best safeguard against future crop disease pandemics is the implementation of management programs that use broadly based genetic resistance and encouragement of antagonists as the first line of defense (Browning et al., 1977).

Although efforts to develop pest-resistant varieties of forest trees and orchard crops have been relatively slow because of their long generation times, this method has promise for forest (see Chapter VI, p. 62) and orchard IPM systems.

Pest Resistance in Domestic Animals

Compared to plants, the development of resistant animals is not nearly so advanced because manipulation of pest-resistant characteristics is much more difficult. A longer time is required to complete a generation, the animals have relatively few offspring per generation, and only a small number of breeds or lines may be available to the breeder. Nevertheless, development of resistant livestock breeds has promise. For example, some of the best known lines of purebred Hereford cattle have been selected on the basis of light-colored hair coat, because they are less susceptible to the horn fly. Australian sheep ranchers have found that English breeds of sheep are less susceptible to attack by wool maggots (immature forms of calliphorid flies) than are the Spanish-developed Merino breed. Crosses between the breeds show intermediate resistance (NAS, 1969).

Cultural Control

Cultural control is the deliberate manipulation of the environment to make it less favorable for pests by disrupting their reproductive cycles, eliminating their food, or making it more favorable for their natural enemies. Many procedures, such as strategic scheduling of plantings, tillage, irrigation, harvesting, and fertilizer applications, crop rotation, destruction of wild plants harboring pests that migrate to crops, and use of pest-free seed and planting stock, can be employed to achieve cultural control. One of the oldest and most effective methods of pest suppression, cultural control is widely applicable in IPM schemes. The following are just a few examples of the diverse ways in which the method can be used.

Sanitation

Sanitation involves the removal or destruction of breeding refuges or overwintering sites of pests. Prompt disposal of garbage, bread crumbs, pet wastes, and uneaten pet food; enclosure of cereals, bread, cookies, and other food in tight containers; and regular sweeping or vacuuming are basic in preventing infestations of cockroaches and other household pests. Removal of pieces of wood from under houses and other buildings reduces the chance of infestation by subterranean termites. Frequent removal of livestock waste from barns and other quarters is a proven method for reducing house flies, stable flies, and other insects that breed in this material. Storage of garbage in tight enclosures, covering of sewer holes, and frequent removal of garbage, pet feces, and other organic wastes are proven management techniques for the Norway rat and house fly when applied on a communitywide basis in urban areas. Removal of fallen fruit from orchards and destruction of tree prunings are useful in reducing the insect and disease pests which overwinter in these materials (NAS, 1969, 1975).

Removing diseased plants (roguing), pruning infested parts, and removing or effectively treating plant material containing disease organisms (e.g., treating potato tuber piles with chemicals, burning stubble) have been successful in plant disease management (Zentmyer and Bald, 1977).

Destruction of Alternate Hosts and Volunteer Plants

Pest populations may often be effectively suppressed by destruction of their alternate plant hosts (i.e., their secondary hosts, weeds or the volunteer crop plants along the edges of crop fields). This technique, in effect a weed control, has been more effective against plant diseases than other pests. Control of the sugar beet curlytop virus in Idaho involves destruction of Russian thistle, the alternate host of the vector, the western beet leafhopper. A reduction in the vector population results in a measurable degree of control of the disease (Glass, 1975). As discussed in Chapter VI (p. 63), effective management of the white pine blister rust, a serious pest of five-needle pines, has been achieved by destroying the rust's alternate hosts (*Ribes*, e.g., currants, gooseberries) inhabiting the same area as the pines. The rust organism cannot complete its life cycle in the absence of the alternate hosts.

Crop Rotation

Much has been learned about preventing pests from becoming seriously destructive in cultivated fields by following the principles of good crop rotation; a crop of one plant family is followed by one from another family that is not a host crop of the pest to be controlled. Agronomic research and practice, however, have shown that some rotations are advantageous to pest control but may be harmful for other reasons; for example, rotation from sod crops on hilly land may lead to soil erosion. Crop rotation is most effective against pests with a restricted plant host range and, for insects, those with limited capability to migrate.

Crop rotation is one of the oldest and most important measures for controlling plant-parasitic nematodes and is currently the only economical method for controlling some of these pests (Good, 1972). In the Imperial Valley of California, the sugar beet cyst nematode is satisfactorily managed by an enforced rotation program. In fields not infested with this pest, sugar beets may be grown no more than 2 years in succession and not more than 4 years in 10. In infested fields, sugar beets may be grown for only 1 year; for the next 3 years other nonhost crops must be grown. Effective rotation is also widely practiced for control of the golden nematode of potatoes, the soybean cyst nematode, and the root knot nematode (Glass, 1975).

Crop rotation is a long-established practice to reduce the severity of soil-borne fungi and bacteria. Soil pathogens that can be controlled by a 3- to 4-year rotation with nonhost crops include the organisms causing cabbage black rot, bacterial blight of bean, and cabbage blackleg. Several soil-borne pathogens of cereal crops are successfully controlled by a crop rotation period of 2-3 years (Zentmyer and Bald, 1977).

Crop rotation is very effective in reducing weeds, but the effectiveness and economy of herbicides have relieved growers from the strict necessity to practice crop rotation for this purpose. Nevertheless, crop rotations which permit use of different herbicides in different years aid in preventing establishment of herbicide-tolerant species. Where crop rotation is not possible, herbicide rotation may achieve the effect (Shaw and Jansen, 1972).

Corn rootworms in the midwestern United States can be effectively controlled by crop rotation. Until synthetic organic insecticides became available, rotating corn with such crops as oats, clover, and soybeans was a standard procedure for their control. Soil treatments with these materials are now used extensively for rootworm control and have greatly eliminated crop rotation practices in much of the midwestern Corn Belt. Yet in Illinois, for example, the Cooperative Extension Service recommends crop rotation as the most effective method of preventing corn rootworm damage and, if feasible, corn should not be grown 2 years in succession in the same field (Luckmann, 1978).

Like most other pest control techniques, crop rotation has some serious limitations. Often, populations of pests other than the target pest increase on the alternate crop. Some crops used in rotation are often of such low value that they contribute little to farm income. Further, alternate crops may require additional farm machinery. Nonetheless, rotation is frequently a useful pest control technique and has an important place in many IPM schemes (Glass, 1975).

Pasture Rotation

The rotation of livestock among pastures is another effective pest management technique against some pests. Pasture rotation was one of the practices employed in eliminating bovine piroplasmosis, a very serious tick-borne disease of cattle, from the United States. Keeping the pastures completely free of bovine animals (cattle, deer) resulted in starvation of the cattle tick which transmitted the disease (NAS, 1969).

Soil Tillage

Until recently, tillage was the only known method for controlling many weed species. The practice is rapidly being replaced on much U.S. crop acreage with herbicides because they are easier, less energy intensive, and more profitable over the short run. Herbicides also eliminate soil erosion, soil compaction, water loss from the soil, and pruning damage to the crop plants' roots, problems usually associated with tillage (Day, 1978). As a result, some cropping operations are switching to reduced-tillage or no-tillage systems whose success depends on effective herbicides (see Chapter V, p. 48).

With soil tillage, pests are killed by mechanical injury, starvation through debris destruction, desiccation, and exposure. For example, the wheat stem sawfly in North Dakota has been reduced as much as 75 percent by cultivation-caused injury, exposure, and starvation. Summer tillage of wheat destroys not only the volunteer nearby wheat plants but also wheat streak virus reservoirs and the virus's vector, the wheat curl mite. Timing has been an important consideration in controlling the cereal leaf beetle on small grains; the soil was tilled at a time least destructive to natural enemies and least likely to lower preplant spring soil moisture in nonirrigated fields (Flint and van den Bosch, 1977).

Serious side effects of tillage are loss of organic matter, especially in warm soils, and accelerated loss of soil to wind and water erosion if the soil is left bare for an extended period (Glass, 1975).

Trap Crops and Trap Logs

The practice of attracting pests to small plantings of crops which are then destroyed or sprayed with a toxicant has been quite successful against some plant nematodes, parasitic weeds, and insect pests (Flint and van den Bosch, 1977).

In Hawaii, squash and melon fields are often surrounded by a few rows of corn which attract large numbers of melon flies, major pests of melons and squash. Treatment of the corn "trap" plants generally controls the flies, leaves no insecticide residues on the melon or squash crop, and is harmless to natural enemies of the crop plants (van den Bosch and Messenger, 1973).

A somewhat similar approach, using logs as traps, has been effective against Engelmann spruce beetles in the Rocky Mountain region. Because the beetles are more strongly attracted to recently cut logs than to living trees, the logs have been used to attract beetles which are then destroyed (NAS, 1969).

The use of trap crops is effective for controlling witchweed, a parasitic plant that affects corn, sorghum, and some other crops of the grass family. A crop such as sorghum may be grown sufficiently long to induce the germination of witchweed seeds before it is destroyed. Other crops such as soybeans are not parasitized by witchweed but will induce germination of the witchweed seed. Planting such crops on infested fields controls witchweed when the field is not infested with susceptible grass weeds (Glass, 1975).

Some nematodes may also be controlled by trap crops. Highly susceptible crops are allowed to grow in infested fields until the second stage larvae enter the roots and begin to develop. Before the nematodes mature, the plants are destroyed. However, plant destruction must be properly timed and implemented or the nematode population may increase manyfold (Glass, 1975).

A major limitation of the trap-crop technique is the expense of producing and destroying a crop that brings no income.

Habitat Diversification

Increasing crop diversity (i.e., intermixed plantings of several crops, as opposed to monoculture) can sometimes be used to increase predator and parasite populations in a given crop or to attract insect pests away from susceptible crops to nonsusceptible crops. For example, some California growers interplant alfalfa strips between strips of cotton in order to attract lygus bugs from the cotton where they may cause damage to the alfalfa where they cause no damage. Managed properly, the strips of alfalfa are also a source of natural enemies which migrate to cotton (Stern, 1969).

Because wrong intermixes can increase pest problems on one or more of the intermixed crops, the advantages of the practice must be carefully weighed against potential harmful side effects (Smith and van den Bosch, 1967).

Water Management

Water management procedures (e.g., timing of irrigation, loading, drainage) based on a sound understanding of pest biology may provide economical and effective control of some pests. Drainage of irrigated pastures, regulation of water levels in rice paddies, and avoidance of stagnant water buildup in old tires, tree crotches, and other breeding habitats are particularly important mosquito management practices.

Careful control of irrigation water is one of the most effective ways for controlling soil pathogens. Flooding of fields has been used to control some root-infecting fungi. In some cases, reduced irrigation or rainfall prevents root knot nematode eggs from hatching, thereby reducing larval invasion of the crop roots (Van Gundy, 1972). Management of irrigation water can also reduce certain weed problems (Glass, 1975).

Miscellaneous Practices

The list of other cultural methods, some of which are discussed in Chapters V-IX, is almost endless. Selection of the best time to plant, defoliate, and harvest crops will result in a major reduction of some insect pests. Avoidance of dehorning and castration of calves during the screwworm breeding season will reduce infestations of screwworms, which feed in open wounds; use of crop seeds free of weed seeds and pest-free planting stock may be the only methods available for dealing with some pests; and even small changes in row crop plant density or distance between plant rows will reduce certain pest populations.

Many cultural practices are simple, inexpensive, and easily adopted by individual farmers, foresters, ranchers, livestock managers, recreational managers, or homeowners, with only slight modification of routine operations. Yet successful implementation of some cultural practices requires participation over a large geographical area (Stern et al., 1976).

Physical and Mechanical Control

Physical and mechanical controls are direct or indirect (nonchemical) measures to destroy pests outright or to make the environment unsuitable for their entry, dispersal, survival, or reproduction. Like cultural controls, they exploit weak links in the pest's life cycle or specific behavioral patterns. Many mechanical and physical controls require costly equipment and considerable labor and therefore may not be economically justifiable.

Physical controls include temperature manipulations, such as heat and steam sterilization of soil in greenhouses to destroy disease organisms (Raychaudhuri and Verma, 1977). Steam heat is often used to kill insect pests and mildew in furniture and clothing (NAS, 1969). Heat treatment is very important in the production of virus-free plant stock and is routinely applied to seeds, cuttings, sets, tubers, bulbs, and rhizomes (Raychaudhuri and Verma, 1977).

Another technique, flaming, involves hand-carried or power-driven equipment that produces a flame similar to that emitted by a welding torch; the flame is directed selectively at the target weed or brush species or at live plants or plant stubble harboring insect or disease pests (NAS, 1968b; Raychaudhuri and Verma, 1977). Flaming is used to control undesirable plants along roadsides and in abandoned fields. Flaming alfalfa in late fall or winter when the plants are dormant destroys alfalfa weevil adults and eggs in the upper portions of the plants while leaving roots undamaged to resprout in the spring. Limits on the flaming method are that it commonly destroys natural enemies and other beneficial organisms (Flint and van den Bosch, 1977), and it requires petroleum fuel and often substantial labor which may be cost prohibitive.

Fire is sometimes effective in preparing new sites for planting of forest trees; however, this control method may be prohibited because of air pollution restrictions. Prescribed burning is the oldest brush management method in use on rangeland. It may range from only $0.50 to $0.90 per acre and can reduce the herbicide application rate or extend the herbicide's effectiveness (C.J. Scifres, unpubl.).

Alternatives to chemical herbicides in forest and range management include several physical and mechanical methods, e.g., cutting, bulldozing, and chaining in addition to fire. Where terrain and soils permit, these methods may be highly effective. However, their use may cause considerable soil disturbance, erosion, water pollution, and the destruction of wildlife habitat and expense.

Cold storage is used to control many stored-product pests, many of which are tropical in origin and cannot tolerate near-freezing temperatures. Even native stored-product pests are vulnerable to cold temperatures during portions of their life cycles. For instance, the apple maggot and the plum cucurlio in apples can be destroyed by storage at 32° F. Drywood termites in furniture can be effectively controlled by exposure to subfreezing temperatures (NAS, 1969).

Although light traps are effective primarily for monitoring night-flying insects, they have been used to attract night-flying insects away from patios, drive-in restaurants, golf driving ranges, and processing plants where they present a contamination problem (NAS, 1969).

Because of their high energy and cost requirements, light traps used for control are not expected to become a major component of many IPM programs. Similarly, frightening devices (acetylene explosive devices, firecrackers, flashing lights, and other scintillating objects) to repel certain bird and mammal pests have only limited value in control.

The technique of shooting nuisance birds and game animals is an old one. It is time consuming and has limited use (NAS, 1970). Traps and various exclusion techniques are effective against certain vertebrate pests, as discussed in Chapter IX.

If properly installed, metal barriers around buildings effectively deter the subterranean termites. Chemical controls are almost always substituted for this useful physical control method (Flint and van den Bosch, 1977).

Screens are probably the best known physical barrier. Screened windows, doors, tents, and other enclosures are effective barriers to flies, mosquitoes, and many other kinds of hazardous and bothersome insects. Screens placed in irrigation pipes and in ditches can reduce the movement of weed seed into irrigated cropland.

Adhesives are sometimes an adequate and environmentally sound control. Products based on hydrogenated castor oil, natural gum resin, or vegetable wax are common. Fly paper is a well-known application of the technique. Sticky bands around tree trunks are a popular control for gypsy moths, cankerworms, cicadas, ants, and several other insect pests of fruit and shade trees; they have recently been incorporated into a successful IPM program developed for city tree insects in California (see Chapter VII, p. 73).

A simple and well-known mechanical control device is the common fly swatter. Other mechanical controls are more complex. Flour mills and many food processing plants have modern sifting and separating equipment to remove insects and other alien matter. Mechanical delinting of cotton seed greatly reduces pink bollworm problems, and sulfuric acid delinting has provided 100 percent control of these seed-borne pests (Flint and van den Bosch, 1977). Pink bollworms can be reduced in the field by shredding cotton stalks with a flailing shredder pulled behind a tractor (NAS, 1969).

In addition to mice, rats, and other animals, more than 50 insect species attack dry plant products processed for human and animal consumption. Mold and decay organisms also infest human food, animal feed, and numerous other products in storage. Construction of bags, cartons, and other containers to prevent contamination is therefore imperative. A wide variety of specially designed "insect-resistant" containers is available for storing food, animal feeds, seeds, fabrics, and other products which must be stored for long periods (NAS, 1969; Highland and Metts, 1970).

Various electromagnetic radiations have been used to control insects and diseases of harvested fruits, vegetables, and grains in storage (NAS, 1969; Raychaudhuri and Verma, 1977). Laser beams have recently been used to treat wheat and barley seeds for control of insects and disease organisms (Raychaudhuri and Verma, 1977). These and many other physical and mechanical techniques have only limited application and probably will never play a major role in integrated pest management.

Autocidal Insect Control

Autocidal control involves rearing and release of insects that are sterile or are altered genetically in order to suppress members of their own species that are causing pest problems.

Sterile-Male Method

The sterile-male method involves artificially sterilizing large numbers of insects by irradiation or chemical sterilants so that after being released into an area inhabited by a wild population, the sterile males mate with wild females. If the wild population is flooded with large numbers of sterile males and they outcompete the wild fertile males, the wild females produce substantially fewer offspring than they normally would. Repeating this procedure for several consecutive generations may eventually annihilate the wild population. This is one of the most ingenious pest control methods yet developed; it has been widely publicized, primarily because of its successful application against the screwworm fly, discussed in Chapter V (pp. 54-55).

The sterile-male technique has also been successful against other insects. On the small island of Rota, near Guam, two fruit pests, the melon fly and Oriental fruit fly, were eradicated. Procedures for sterilization and rearing have also been developed for several other important insect pests, the stable fly, horn fly, and mosquitoes. Field tests have shown considerable promise, but additional large-scale field tests are required to refine the technique and make it economical (USDA, 1976).

Application of the sterile-male method necessitates procedures for economically rearing and liberating large numbers. To be effective, the released insects must readily mate with the wild members and disperse throughout the area inhabited by tne wild target population.

The possibility that the sterile-male method can literally eradicate an entire pest population from an area, thus providing a permanent solution to the particular pest population under consideration, has attracted a great deal of interest. Consequently, use of this technique in combination with others in IPM schemes aimed only at keeping pests below damaging levels has received little attention. The sterile-male technique may well be practical when used in a way that is somewhat similar to the way inundative releases of insect parasites and predators have been used, i.e., sustained releases directed at selected pest generations. However, difficulties with and the high costs of rearing, sterilizing, and liberating the sterile insects are currently prohibitive except possibly against a few insect pests (Waterhouse et al., 1976).

Genetic Control

Like the sterile-male method, genetic control involves release of reared insects for mating with wild populations. However, whereas sterile males produce inactive or inviable sperm, genetic control involves genetically altered insects whose sperm is active, carrying genes that make the wild populations less vigorous, less prolific, or genetically sterile as a consequence of hybridization.

Many characteristics of insects lend themselves to genetic manipulations. Populations of insects are easily altered by selection, natural or artificial; this genetic plasticity is evidenced by their adaptations to various ecological situations. In addition, their short generation times and relatively high reproductive potential make them excellent subjects for selective breeding and genetic experimentation.

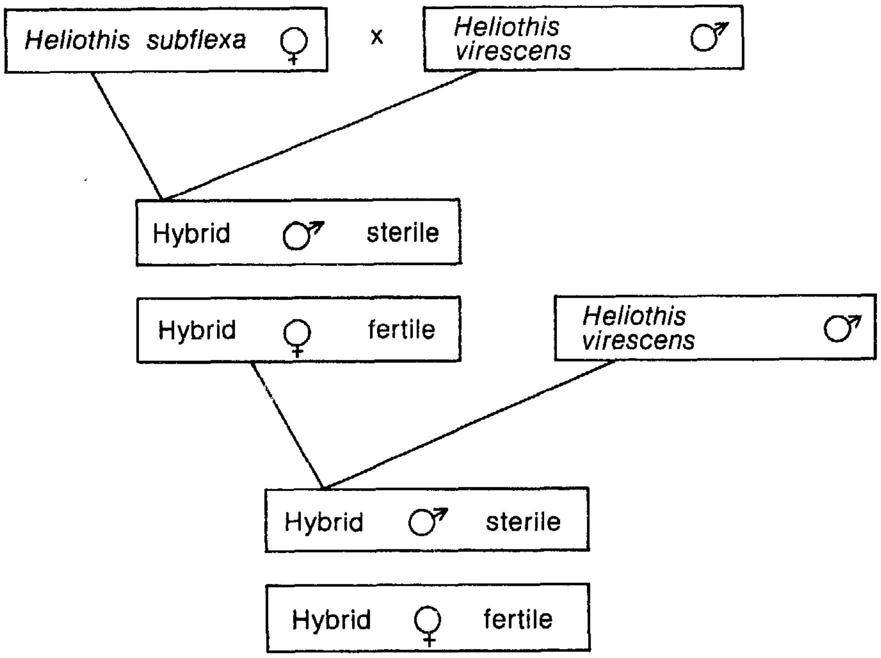
Genetic research on insect pests has centered on hybrid sterility, cytoplasmic incompatibility, conditional lethals, and growth alterations. None has yet reached the stage of practical implementation, and most are in a very early stage of research; however, genetic control has great potential in future management of some insect pests. Only hybrid sterility is discussed to illustrate the principle of genetic control in integrated pest management.

Hybrid sterility is the result of the hybridization of two different but closely related species which produce sterile progeny. When the hybrids are fully viable, they compete with normal individuals, with a consequent reduction in the breeding population.

The best known example of hybridization involving different species that mate to produce sterile progeny is the cross between a male donkey and a female horse. The mule offspring is always sterile.

An example of the potential application of the hybrid sterility principle here involves hybridization of the very serious cotton pest, the tobacco budworm, and a closely related nonpest insect known only as *Heliothis subflexa*, which feeds and breeds mostly on wild noneconomic plants. Laboratory crossings of the two species produce sterile male offspring but fertile female offspring (Figure IV-2). Although the female hybrid is fertile, when she is crossed with a tobacco budworm male, her male offspring are sterile (Laster,

Figure IV-2 **Hybridization-Induced Sterility from Crosses of the Tobacco Budworm *(Heliothis virescens)* and *H. subflexa* (Laster, 1972)**



1972). One possible use of hybrids from tobacco budworm and *Heliothis subflexa* crossings would be the influx of genes of the latter, the nonpests, into tobacco budworm females, the pests, through fertile hybrid females, as proposed by North (1975). This may widen the host-plant adaptation of the tobacco budworm, which currently attacks only cotton in most cotton-growing regions. The tobacco budworm has been exposed to repeated insecticide applications, developing resistant strains which can no longer be controlled by insecticides. The tobacco budworm's extension to wild noneconomic plants used by *Heliothis subflexa* may lessen the degree of insecticidal resistance likely to occur in cotton-growing regions.

Such genetic control techniques need to be researched much more thoroughly. It is especially important that research scientists exercise extreme caution against release of genetically altered insects that breed in nature to produce new strains that may be more harmful than the target pest.

Success of either the sterile-male or the genetic control technique is greatly handicapped in the absence of comprehensive ecological information about natural pest populations. Both depend upon an economic method for rearing and releasing large numbers of insects that are competitive upon release (Waterhouse et al., 1976; Weidhass and Seawright, 1976). Because few current projects have developed comprehensive background information and large-scale mechanized rearing and release techniques have not been developed for many insects appearing amenable to autocidal control, immediate application in integrated pest management programs is not expected for many pest species.

Chemical Behavioral Insect Control

Chemical behavioral control involves the use of chemicals to attract insects to sites where they are destroyed; to distort sexual activity, diverting males or females in their search for mates; or to disrupt the insect's orientation.

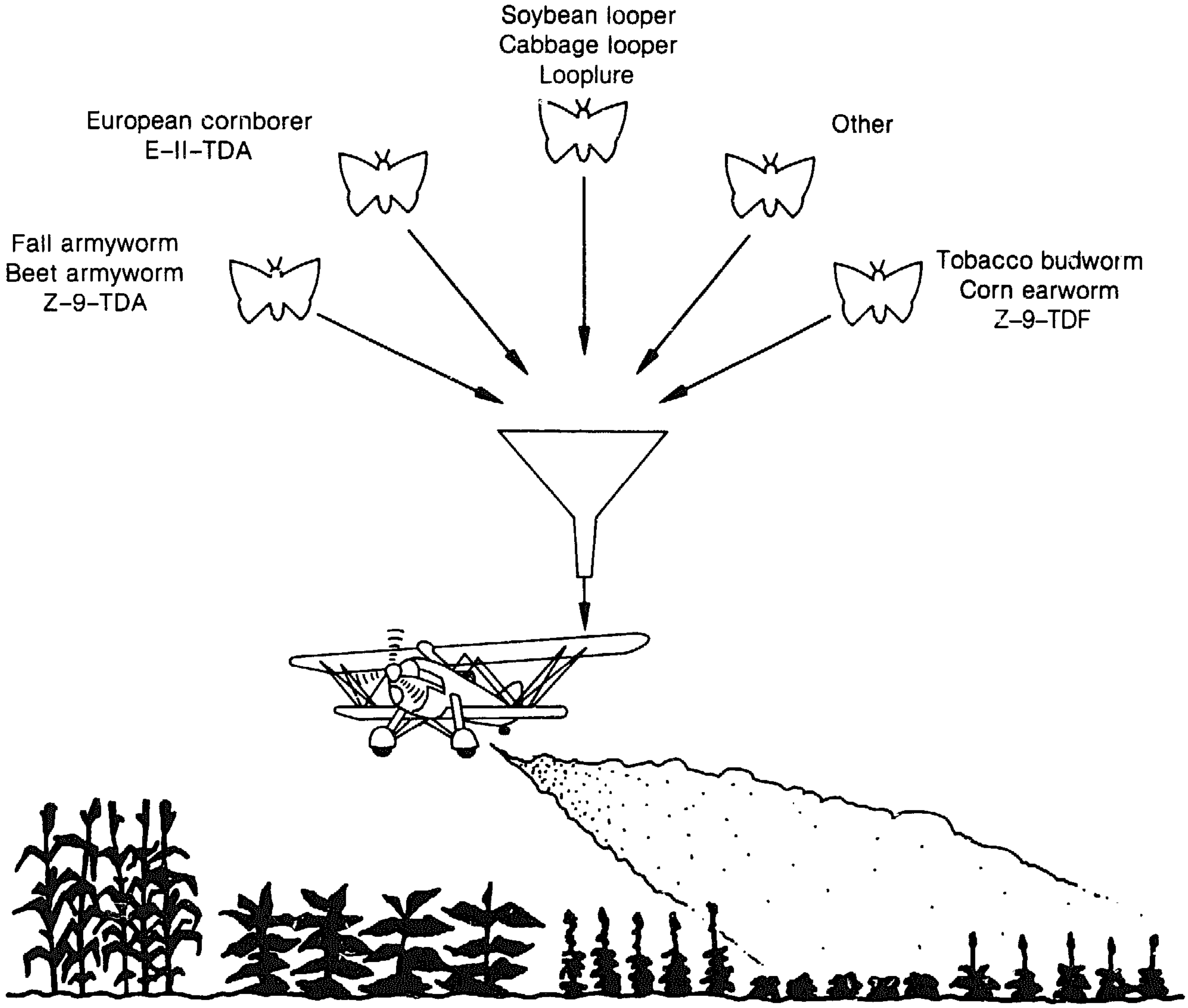
Pheromones

Insects emit and respond to chemicals called pheromones. Pheromones identify members of a colony, trigger fight or flight reactions, or are used to mark a path toward food sources. In many species, the pheromone emitted by one sex attracts the opposite sex of the same species. Pheromones have been identified for many of the nation's most serious insect pests, and there has been much research on utilizing synthetic pheromones in pest programs.

Two approaches have been taken with synthetic pheromones: permeating the environment with the pheromone of the target insect to the extent required for disruption of mating and dispersing the pheromone in traps or restricted sites in a field or forest where the insects are lured and destroyed. The potential for pest suppression based on disruption has been demonstrated for several important pests, e.g., pink bollworm, cabbage looper, red-banded leaf roller, and grape berry moth.

Only one pheromone, "gossyplure," the synthetic pheromone of the pink bollworm, has been

Figure IV-3 **A Pheromone Delivery System Visualized for Future Insect Control Programs (Mitchell, 1975)**



approved as a control device by the Environmental Protection Agency. Gossyplure works by confusing the male pink bollworm moths, preventing their normal attraction to the female moths, thus reducing the females' chances of laying fertile eggs. In terms of both effectiveness and cost of materials used, pink bollworm control was comparable in one experiment to that achieved with conventional insecticides. The experimental pheromone treatments cost $10.50 per acre, about the same as the per-acre cost of the two insecticide applications required in the other fields, but this figure did not include costs of formulating and applying the pheromone (Gaston et al., 1977). Improved production and delivery techniques and large-scale commercial use of synthetic pheromones should greatly reduce their costs (Shorey and McKelvey, 1976; Beroza, 1976).

Scientists believe that the pheromone disruption principle may eventually be directed at whole complexes of insect pests in a manner similar to that shown in Figure IV-3.

The use of insect pheromone traps has received extensive publicity in recent years. Traps often produce spectacular catches, leading some farmers and scientists to believe that the traps are having a major impact on a pest population. But because the traps may be attracting insects from great distances, the catches in themselves are not proof of the traps' effectiveness unless they can be related to a decreased pest population in the area. Problems in designing large-scale trapping experiments have precluded accurate assessment, except perhaps in a few isolated cases (Shorey and McKelvey, 1976; Beroza, 1976). Theoretical evaluation and a limited number of field experiments indicated that both pheromone disruption and pheromone trapping have the greatest potential when directed against very low-density insect populations. These techniques, then, will probably have their greatest value when combined with other techniques that assist in achieving the low-density requirement.

Pheromones have a very narrow spectrum of activity, usually affecting only the target insect pest, and all evidence suggests that they present no hazards to humans or the environment. Nevertheless, they are classed as pesticides under the amended Federal Insecticide, Fungicide, and Rodenticide Act and must be registered as if they were conventional pesticides.

Many types of insect pheromone traps and pheromone compounds are commercially available. Sometimes pheromone trap catches are used to monitor insect populations. For example, data on catches of pink bollworm moths in traps located in cotton fields have been used to plan the timing and to reduce the number of insecticide treatments required (Toscano et al., 1974).

Repellents

Repellents are chemicals that prevent damage to plants, animals, or materials such as fabrics and lumber by rendering them unattractive, unpalatable, or offensive. These chemicals include a wide range of natural and synthetic materials for personal, household, industrial, livestock management, and agricultural use.

Some repellents are effective against bloodsucking and nuisance organisms such as mosquitoes, ticks, chiggers, and gnats. Skin repellents used in the South Pacific during World War II were a chief component of the military's antimalaria program (Metcalf and Metcalf, 1975). Some of the newer repellents look promising against a broad range of pests (Schreck, 1977).

Because repellents must be applied on the human skin or clothing, human health considerations are especially important in the commercialization of new products. However, they present minimal hazards to the environment as generally applied.

The repellent methiocarb was recently registered (under the name Mesurol®) for use on field corn, sweet corn, popcorn, and cherries to protect against bird damage. A short-lived carbamate, it is a potent emetic, and when birds eat cherries or corn treated with the material, they soon learn to associate taste with effect (DOI, 1976).

Repellents applied to foliage actually offer few advantages in IPM programs. The chemicals require very thorough coverage, and those currently available present about the same degree of environmental hazard as conventional pesticides (Metcalf and Metcalf, 1975).

Insect-susceptible packaging materials for certain food products are treated with a chemical repellent on the outer surface to prevent insect penetration. Repellents are also frequently used on kraft paper multiwall bags; they will provide protection against insect attack for as long as 1 year (NAS, 1969).

Selective Chemical Control

Despite the infusion of alternative methods into integrated pest management programs, pesticides will be needed against many pests for which effective alternative methods cannot be found, have not been developed, or are not being implemented. The undesirable side effects of chemical pesticides, discussed in Chapter II, demonstrate the fact that they must be employed judiciously, and those that are narrowly selective against target pests must be sought.

In general, narrowly specific pesticides have not been available, and there has been relatively little effort to develop them. Because broader-spectrum pesticides permit control of several pest species with a single application, they may be more economical in that there may be fewer failures caused by erroneous diagnosis of the pest problem. Further, because of the high volume and the spread of production costs over many units, they are less costly than narrow-spectrum materials (Glass, 1975). However, many pesticides can be used to enhance their own ecological selectivity, involving much less effort and expense than development of physiologically selective compounds.

Perhaps the best known technique to achieve ecological selectivity in pesticides involves timing of applications of minimum amounts of pesticides having the least adverse effects on nontarget organisms. The "reproduction-diapause" method for controlling boll weevils (Brazzel, 1959) is an illustration: insecticides are applied to cotton two or three times during the fall after the crop has matured in order to reduce the boll weevil population going into hibernation in surrounding areas. These applications often eliminate the need to control first and second generation boll weevils the following season, thereby reducing the number of insecticide applications 40-50 percent compared to conventional treatment with insecticides early in the season. Reduction in insecticide use during the growing season results in less harm to natural enemies important in the cotton ecosystem and surrounding areas.

Development of application equipment that precisely directs the pesticide deposits in the habitat of the target pest, thereby minimizing drift and contamination outside the target area, offers great promise for achieving ecological selectivity, but it has not been vigorously pursued. Many insects restrict their activity to portions of the host plants, for example, the pods of soybeans or the heads of sorghum. Plant breeders have succeeded in producing crop varieties uniform in plant height and fruit positions, and it may therefore be feasible to develop equipment which directs the pesticides toward the plant portions most frequently utilized by the pests (Glass, 1975).

Growth Regulators

Chemical growth regulators, used extensively against weeds, are now being developed for insect control.

Many organic herbicides act as plant regulators or synthetic hormones. These are generally used at concentrations which inhibit weed growth but have little or no effect on the crop plant, thus performing as selective herbicides.

A major problem in weed management is the extreme persistence of most weed species resulting from the longevity of propagules (seeds, dormant buds, or other dormant plant parts). Some seeds may survive in a dormant condition for 80 years. Dormancy, germination, and other related plant functions are controlled by hormones. Germination inhibitors to prevent propagule development could provide very effective weed control. Conversely, a germination stimulant to break dormancy in all propagules could be used for weed control during the noncropping season. In either case, a significant link in the life cycle of weeds could be broken to provide a new approach to weed management (Glass, 1975).

Growth and development in insects are regulated by two types of hormones, juvenile hormones which maintain immature status and ecdysones, hormones which regulate molting; a number of both types have been identified for insects and also for plants. Synthetic hormones have been evaluated for use against insect pests. Altosid® has been approved by EPA for control of mosquitoes.

Unlike insecticides, hormone chemicals are not conventional toxicants; rather, they interrupt normal processes associated with growth. They have not been found to be toxic or hazardous to higher animals. Their possible adverse effects on a wide variety of beneficial insects and many other nontarget organisms present in treated and surrounding habitats have not been determined (Staal, 1975).

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Part Three

Status and Prospects of Integrated Pest Management in Specific Areas

Status and Prospects of Integrated Pest Management in Agriculture

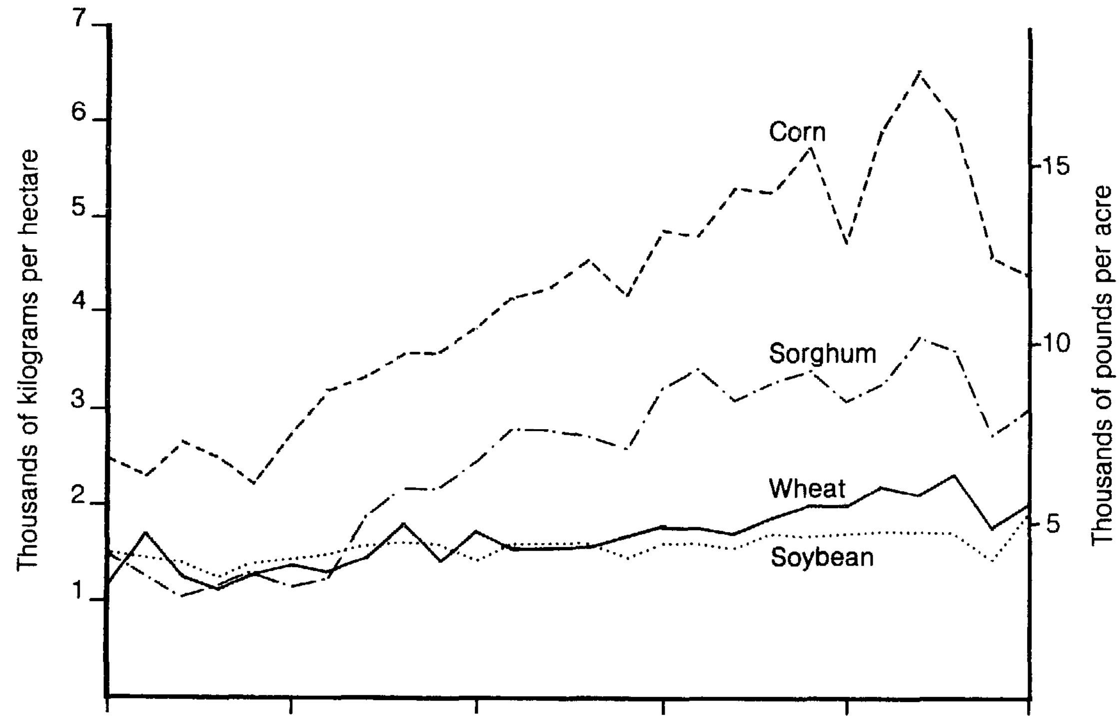
Chapter Five

U.S. agriculture has provided the nation with abundant food, feed, and fiber at moderate prices. It has also contributed significantly in meeting world food needs and maintaining a favorable balance of trade. About 30 percent of the crop products harvested annually are exported. On the average, U.S. consumers use only 17 percent of their disposable income for food (Strohbehn, 1978).

Throughout the 1950's and 1960's, U.S. agriculture was viewed as a cornucopia. Attention was focused on how to hold down production to maintain a balance between supply and demand. It appeared that the agricultural sector could respond to any increase in demand for agricultural supplies. A series of events in the 1970's, however, raised questions about the ability of U.S. agriculture to meet future domestic and world food demands (Strohbehn, 1978).

The National Academy of Sciences addressed the problem of continued agricultural production efficiency in 1975 (NAS, 1975c). The study emphasized the fact that since 1950 crop yields have risen in direct proportion to increased use of fertilizer. But now there is evidence of a leveling of major U.S. crop yields, as illustrated in Figure V-1. Several factors have contributed to these yields: conversion of prime and unique lands; loss of land from wind and water erosion; planting on marginal land with low yield potential; salinization of irrigated land; environmental restraints on use of agricultural chemicals and resistance developed in some crop pests; economic restraints on use of effective pesticides and fertilizers

Figure V-1 **Yield Trends for Major U.S. Crops (NAS, 1977)**



whose cost increases parallel the costs of petroleum; biological limits on the yield capacity of the crop plants; and, possibly, unfavorable weather conditions (NAS, 1975a, 1975c, 1976, 1977).

In a subsequent study (1977), the NAS addressed the problem of world food shortages and the debilitating effects of malnutrition. This study emphasized the need for reliance on new crop varieties with greater efficiency in utilizing water, sunlight, and fertilizer; varieties with new pest-, drought-, and salt-resistant characteristics and new types of varieties with more genetic diversity; and new biological and cultural pest control. Pest management was one of 22 high priority research areas recommended for increased support in order to improve food and nutrition policies, increase worldwide food availability, reduce poverty, and stabilize world food supplies.

Crop Pests

Losses to Crops

Worldwide, annual losses from pests (primarily insects, diseases, and weeds) in preharvested crops are estimated at 33-35 percent of the potential production. World postharvest losses (caused by pests such as fungi, bacteria, insects, and rodents) are estimated at 10-20 percent. When preharvest and postharvest losses are combined, total world food losses caused by pests are estimated at 40-48 percent. In the United States, annual crop losses attributed to pest damage have been estimated at 39 percent, including 33 percent in the field (Cramer, 1967; Pimentel et al., 1975; USDA, 1965). (Current methods for assessing agricultural losses incurred from pest infestations rely almost exclusively on "experts' opinions." Therefore, although these loss estimates are the only ones available, their degree of accuracy is questionable.)

The losses from crop pests do not appear to have declined during the past 30 years despite the estimated 10-fold increase in use of chemical pesticides (Table V-1). Estimates indicate that there may have been a slight decline in crop losses caused by weeds, but losses caused by insects may nearly have doubled (Pimentel, 1978; Pimentel et al., 1977). Of course, crop yields also increased during this 30-year period, and pesticides undoubtedly contributed substantially to the increase. Further, the ratio of losses from pests would probably be much higher than it presently is on many crops if it were not for pesticides or suitable alternatives. The fact remains, however, that pests continue to rob an enormous portion of potential food and fiber crop yield, and increasing the use of pesticides has apparently not decreased the portion of crop loss caused by pests. Further increase in use of available pesticides therefore would not be expected to ensure increased yields of major U.S. crops.

Current Control Practices

The most important pests affecting crops in the field are weeds, pathogens (a mixture of microbial organisms including fungi, bacteria, viruses, nematodes), and insects and other arthropods (e.g., mites). Birds, rodents, and other mammals may create problems in local areas (see Chapter IX).

Weed Control—In crop monocultures, all plants except the crop are considered weeds, largely because weeds often reduce yield or quality by competing for water, sunlight, and nutrients. Some weed species release chemicals toxic to the crop plants, and some (e.g., witchweed) are parasitic on the crop plants. Others interfere with the planting, transplanting, pruning, thinning, harvesting, and processing of crops. For example, weed foliage can clog grain harvesters or foul the spindles on cotton pickers (NAS, 1975a; Klingman et al., 1975).

Weed management is a part of vegetation management, whereby conditions favor the crop or other preferred vegetation and do not favor the weeds. Measures to improve growing conditions for the crop seek to improve its competitive position relative to the weeds. Vigorous, well-adapted crop varieties managed for maximum growth can accomplish much toward the competitive suppression of weeds. Yet the weeds may be equally vigorous and well adapted, and they may respond equally well to

Table V-1 **U.S. Agricultural Crop Losses (billion dollars) Caused by Pests (Pimentel, 1978)***

	Insects		Diseases†		Weeds		Total loss		Potential production
1974	$7.2	13.0%	$6.6	12%	$4.4	8.0%	$18.2	33.0%	$55
1951-60	3.8	12.9	3.6	12.2	2.5	8.5	9.9	33.6	29.5
1942-51	1.9	7.1	2.8	10.5	3.7	13.8	8.4	31.4	26.7
1910-35	0.6	10.5	NA	NA	NA	NA	NA	NA	5.7
1904	0.4	9.8	NA	NA	NA	NA	NA	NA	4.1

NA = Not available

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†Includes nematodes.

the beneficial measures. Other measures must then be taken to suppress the weeds (NAS, 1975a).

Many crop and soil scientists believe that machine cultivation is not necessary for maximum crop yields if herbicides can be used in its place; further, cultivation has many harmful effects: it prunes crop roots, compacts the soil, promotes soil erosion, is energy intensive, and dries out the soil. As a result, some cropping operations have moved toward reduced-tillage or no-tillage systems whose success depends on effective herbicides (Triplett and van Doren, 1977; Day, 1978).

In 1976 some 7.3 million acres of U.S cropland were planted without tillage, and on 52.5 million acres tillage was reduced (218 million acres were conventionally tilled). The Department of Agriculture predicts that by the year 2010 more than 90 percent of the crop acreage in the United States will be managed under reduced-tillage systems and that on more than one-half of the acreage some form of no-tillage farming will be practiced (Triplett and van Doren, 1977). Effective herbicides are doing the job previously done by the cultivators. Reduced tillage and increased use of herbicides will be encouraged if state programs being developed under the Section 208 Nonpoint Water Quality Management Programs emphasize control of erosion and sedimentation without considering the potential increase of pesticides and other toxic substances. Regulations will require soil conservation and agronomic practices that prevent yearly per acre soil loss in excess of a specified amount, depending on soil types and other factors.

Although the long-term effects of reduced tillage have not been studied adequately, some adverse effects are known. For example, armyworms and corn stalk borers often increase in crops grown under reduced tillage, and surface accumulation of crop debris on cropland not being cultivated or being cultivated only infrequently increases the chances for early onset of some crop diseases (e.g., of corn). Further, accumulation of the debris and the successive planting of the same crop may foster the concentration of disease inoculum (e.g., spores), thereby increasing the chances for outbreaks. Soil-inhibiting plant disease nematodes also increase under reduced-tillage systems (NAS, 1975b).

Disease Control—Most agricultural crops are susceptible to attack by many different disease organisms, particularly fungi. Potatoes, beans, and cotton, for example, are attacked by more than 30 species of fungi. They may attack any of the plants' organs; roots, stems, leaves, flowers, fruits, and seeds are susceptible. Both the vitality of the plants and the germinability of seeds may be reduced (USDA, 1953; NAS, 1975a).

Though bacteria cause relatively fewer diseases than fungi, some bacterial diseases are highly destructive; they include fire blight of apples and pears, certain bacterial blight diseases of beans, and soft rots of fruits and vegetables (NAS, 1975a).

Viruses seriously damage crops, especially vegetables and fruit trees. Some viruses are transmitted by plant pathogenic nematodes and insects (NAS, 1975a).

Plant nematodes occur naturally in all soils; some species cause severe diseases to crop plants, alone or in combination with fungi and bacteria. As noted, nematodes transmit viruses, some of which cause serious damage to crops (NAS, 1975a).

By far the largest amounts of chemicals applied for disease control are for diseases caused by fungi (NAS, 1975a).

Most of the fungicide treating is done on a few high-value crops (e.g., citrus and apples). Except for seed treatments, many crops of relatively low value per acre (e.g., cereals, forages) are not treated with fungicides or other disease control chemicals (Eichers et al., 1978; Fry, 1977). As seen in Table II-2 (p. 7), only 2 percent of all major field crops except pasture and rangeland were chemically treated for disease control in 1976.

Although chemical control of plant disease organisms is used much more widely today than 30 years ago, disease control is still primarily managed by disease-resistant crops and such cultural methods as crop rotation, use of disease-free planting stock, and destruction of susceptible plants or diseased plant parts (Horsfall and Cowling, 1977). The application of hot water or air to the soil, to seeds, or to other plant structures is routine for many disease organisms (Raychaudhuri and Verma, 1977).

As discussed in Chapter IV (pp. 33-34), the use of disease-resistant varieties is the most important method for controlling plant fungi, viruses, nematodes, and bacteria. Crop varieties that resist two or more pathogens have been developed. An estimated 75 percent of the U.S. cropland is currently planted to crop varieties that resist one or more plant disease organisms. The successful development of disease-resistant crop varieties has been a major factor in increasing and maintaining high levels of crop productivity in this country (NAS, 1975a). Nevertheless, some plant disease scientists and crop geneticists are concerned that today's important food crops lack the genetic diversity which would be required to resist outbreaks of some very serious diseases (McNew, 1972; Harlan, 1972, 1975; Browning, 1972, 1974; Browning et al., 1977).

The past three decades have witnessed a trend of narrowing the genetic base of crops, that is, minimizing genetic variability within and among crop varieties. Genetically uniform crop varieties have been selected for high yield and other desirable traits (e.g., uniform height to facilitate machine harvesting). This pure-line breeding strategy (for self-pollinated crops like wheat) and the development of single crosses (for cross-pollinated crops like corn) have eroded the genetic diversity of major agricultural crops, eliminating a large proportion of the genes of the old landraces (plants from which modern agricultural varieties originated). Generalized adaption and general resistance to pests with which the old landraces had coevolved were both sharply reduced, leaving the narrow genetic base varieties wide open to disease outbreaks of serious dimensions (Harlan, 1972, 1975).

One example of the risks associated with dangerously narrow genetic bases is the highly publicized outbreak of southern corn leaf blight that developed to pandemic proportions in 1970, causing serious corn losses in some regions. Although a favorable environment allowed the disease organism (a fungus) to surface and spread rapidly, the real cause of the epidemic was lack of genetic diversity in a high percentage of the U.S. corn crop (Browning, 1972).

Broad resistant bases are virtually nonexistent in major food crops. These crops are vulnerable to serious disease organisms now present in the United States at low intensities or to those potentially adaptable foreign pests capable of causing crippling losses upon entry into this country. Unexpected disease problems can explode at any time, with disastrous effects on these crops (NAS, 1975a; Harlan, 1972, 1975; Browning, 1972, 1974; Browning et al., 1977).

Insect and Mite Control—Nearly all agricultural crops are subject to attack by a complex of insects or other arthropods, principally mites. They may injure the crop plants in a wide variety of ways, by chewing or sucking on the leaves, buds, stems, fruits, and flowers; boring or tunneling into the fruits, stems, and seeds; causing cancerous growths (galls) on the plants, within which they live; attacking the roots and underground stem; and transmitting disease organisms.

Following World War II, control of crop insects and mites shifted largely from a biological to a chemical discipline, as discussed in Chapter I, p. 3. Unfortunately, the new chemical methods were often used to supplant rather than to supplement methods such as biological control, host plant resistance, and crop rotations (Huffaker and Smith, 1978).

The new insecticides provided incentives for agriculturalists to develop crop varieties with the highest yield potential and the production technology which maximized this potential. For example, protective insecticide treatments of the plant nurseries where new crop varieties evolved ensured the selection of high-yielding germ plasm. Insect-free plant nurseries in fact became a salient feature of plant breeding programs involving high-value row crops such as cotton on which large quantities of insecticides could be justified. The new high-yield varieties released from the insecticide-shrouded nurseries, therefore, often lacked insect-resistant characteristics that occurred in the earlier varieties and thus were vulnerable to insect pest attack, requiring frequent insecticide treatments for protection against loss. Producers became accustomed to applying chemicals even when insects were below damaging levels because the insecticides were cheap and provided good insurance for the investment in land, machinery, fertililzers, and other resources required to produce the crop (Huffaker and Smith, 1978).

Before World War II, crop rotation, in which a crop of one plant family (e.g., corn) was followed by a crop of a different family (e.g., field beans) that was not a host crop of the pest to be controlled, was routine for a wide range of insects and other crop pests. Rotations of nitrogen-building crops, such as clovers, beans, and peas, with those that required high levels of nitrogen, such as corn, were also a part of the farmer's soil fertility program. The postwar insecticides and other pesticides and improved fertilizers displaced these cultural practices in many cropping regions. Consequently, continuous cropping is increasingly common. Monoculture has disadvantaged some insect pests which seem to thrive best in diverse cropping situations. However, it greatly intensified problems with others, and insecticides have been commonly used in place of rotation to combat the pests favored by the monoculture. A good example of a serious insect problem intensified by continuous cropping involves the corn rootworms in the midwestern United States, discussed in Chapter IV (p. 36). On balance, the emphasis on continuous cropping the past 3 decades has probably favored the persistence and increase of weed and disease problems as well, resulting in the application of increased amounts of pesticides (Luckmann, 1978; NAS, 1975a, 1975b).

The use of insecticides on crops varies considerably among geographical regions and crops. Cotton and corn consume the largest quantities of insecticides, accounting for an estimated 49 and 25 percent, respectively, of the total amount applied to U.S. cropland in 1976 (Eichers et al., 1978). Tobacco, citrus, soybean, and apples also consume large quantities of insecticides (Huffaker and Croft, 1976, 1978).

Some of the nation's very serious crop insect pests (e.g., Hessian fly on wheat, spotted alfalfa aphid, boll weevil on cotton, European corn borer) are controlled, at least in part of their range, by resistant crop varieties (see Chapter IV. pp. 33-35). Biological control has been used successfully against some other serious insect pests of crops (see Table IV-2, p. 29). Various cultural and other nonchemical controls, discussed in Chapter IV, are the primary means of combating other serious crop insect pests. However, chemical insecticides are still the primary control of crop insects (Huffaker and Smith, 1978; Huffaker and Croft, 1976, 1978; Anon., 1978; IPM, 1975; Lawless and von Rümker, 1976; NAS, 1975a).

Farmer Use of IPM

In the past 8 years the Cooperative Extension

Service of the land grant universities and the Department of Agriculture have initiated demonstration programs on integrated pest management, and a growing number of private consultants is offering IPM services to crop farmers.

There is no way to determine accurately how much IPM technology is being used on U.S. cropland. However, farmers of some crops (e.g., citrus, alfalfa, peanuts, tomatoes, potatoes, corn, cotton, grain sorghum, deciduous fruits) in some areas are interested in using the IPM approach, as evidenced by a recent upsurge in the acreage being regularly scouted and serviced by private IPM consultants. In Kansas, for example, 58.9 percent of the corn, 17 percent of the grain sorghum, and 13.5 percent of the wheat acreage received some type of IPM service in 1976, predominantly through private consultants (Mock, 1976). By contrast, only a tiny fraction (1.1 percent) of the Kansas acreage received this type of service 2 years earlier. There were 36 college-trained private crop consultants operating in Kansas in 1976, compared to 3 in 1973. Most offered a wide variety of farm services, including soil analysis, fertilizer recommendations, crop variety selection, and advice on seeding rates and timing, irrigation scheduling, pest infestations, and pesticide applications—all of which may influence client use of pesticides or other IPM technology.

According to Good (1977a), about 50 percent of the nation's cotton acreage was under "some type" of IPM program in 1977. Part of this acreage was serviced by private consultants working independently or employed by farmers or farm cooperatives, and part was included in Extension demonstrations. A high percentage of the acreage of various other crops may now receive a similar service in some regions (USDA, unpubl.).

A distinction should be made between "field checking" and "integrated pest management." The fact that a crop is being serviced by a college-trained IPM consultant or a public service employee is not necessarily proof of integrated pest management. Many of today's so-called IPM services merely involve field checking for pest infestations, usually insects, and scheduling pesticide applications around existing economic thresholds, if these values exist. This approach facilitates more efficient use of pesticides than possible without the field checking, and for that reason it is an important step to integrated pest management. Nevertheless, IPM is more than just field checking, and although reduction in chemical pesticides is often obtained in IPM programs, the ultimate goal is to optimize pest control in terms of the overall economic, social, and environmental values. This goal is achieved only after criteria have been developed to pinpoint those times and places in which efforts to control a pest are truly justified.

There are other basic principles of IPM program development (see Chapter III, pp. 19-21). One important principle is that if pesticides are used, the selection of the chemical dosage and treatment time should be carefully coordinated to minimize the hazards of target pest resurgence and induced secondary pest outbreak (see Chapter II, p. 12).

In fact, there are few true IPM programs now in effect, and most have been developed for single pests (i.e., one species) or for closely related pests (e.g., several insect and mite species attacking a given crop).

Farmers are rarely confronted by a single pest problem but rather by complexes of pests: different kinds of insects, mites, disease-causing organisms, weeds, and sometimes rodents, slugs, and other pests. Measures to control one pest or employment of a desirable agronomic practice may create or intensify pest problems which may also be multiplied by extremes in weather. It is obvious, then, that pest control recommendations cannot evolve independently for insects, weeds, nematodes, diseases, or other pests; nor can optimal control strategies be developed without considering the crop production system as a whole. Multipest integrated management schemes, synchronized with and integrated into optimal crop production systems, are essential for long-term profits. Efforts to develop such multipest IPM schemes have just begun (Luckmann, 1978; Huffaker and Smith, 1978; Anon., 1978).

Potential for Increased Use of IPM

To date, the largest national research effort to develop IPM for crop pests relates to insect and mite pests. The stated objective of "The Principles, Strategies, and Tactics of Pest Population Regulation and Control in Major Crop Ecosystems," sponsored by the Environmental Protection Agency, the National Science Foundation, and the USDA (see Chapter XI, pp. 101-102), is: "to develop ecologically based and structured systems of management of pest populations at noneconomic densities so as to optimize economic returns on a continuing basis consistent with minimal environmental damage and to demonstrate that agricultural research can be done in a more productive way than in the past through unified, interdisciplinary approaches utilizing systems analysis" (Huffaker and Croft, 1976). Conducted from 1972 to 1978, the project focused on insects and mites attacking cotton, citrus, deciduous fruits, soybean, and alfalfa because control of these pests accounts for approximately 70 percent of the insecticides applied annually to U.S. cropland. It is estimated that the prototype plans developed by the EPA-NSF-USDA project could reduce the quantity of insecticides used for control of these pests 40-50 percent in the next 5 years and perhaps 70-80 percent in the next 10 years, with no reduction in present crop yield levels (IPM, 1975). However, many obstacles must first be overcome, as discussed later in this chapter and in Chapter X (p. 98).

The potential for developing effective IPM schemes for plant diseases and nematodes has much promise, but progress has been limited primarily to development of plant-resistant varieties. Genetic-diverse crop varieties that resist complexes of insect, disease, and nematode pests coupled with improved cultural practices (sanitation, crop rotations) that enhance biological antagonists (see Chapter IV, pp. 33-35) offer much promise against disease and nematode pests.

Less reliance on chemical herbicides on cropland currently appears less likely, primarily because of the cost advantages of herbicides over hand labor and machine cultivators. Use of herbicides alone or in combination with cultivation has been estimated to reduce the costs of weed control in Georgia cotton fields by $120-240 per acre (Dowler and Baker, 1975). In Louisiana it is estimated that 74.2 million hours of human hoe labor would be required annually to control weeds on all the state's cotton and soybean acreage. Assuming that each person labored 8 hours per day at $2.65 per hour, 231,750 workers would cost the farmers $197 million, compared to an estimated $57 million for herbicides (Newsom, 1978). Increasing interest in reduced tillage, growing costs of fuel for tractor-driven cultivators, and tillage restrictions which may be imposed under a local "208" nonpoint water quality management program all favor increased use of herbicides. Moreover, there has been minimal effort to seek alternatives to herbicides such as weed biological control agents and weed-tolerant or -resistant crop varieties, and research on crop rotational systems effective in weed management has been deemphasized in recent years. Development of IPM schemes that lead to less reliance on chemical herbicides will necessitate major expansion of research on weed biology and ecology and major efforts to search for alternative methods of control.

Demonstrating IPM Techniques

In 1971 the State Cooperative Extension Services, in cooperation with the Extension Service and the Animal and Plant Health Inspection Service of USDA, began IPM demonstration projects on cotton in Arizona and tobacco in North Carolina. By 1977, 38 projects involving 24 crops in 33 states and 2 projects involving livestock insect pests in Nebraska were funded by federal grants, state funds, and participating farmers. Some were conducted cooperatively with private consultants; in 1978, all 50 states were provided funds to initiate Extension demonstrations (Good, 1977a, b; USDA, unpubl.).

The first Extension demonstration projects were restricted to management of insects. However, the projects were gradually broadened to include other pests. In 1977, several crop projects involved insects, diseases, weeds, and nematodes (Good, 1977a).

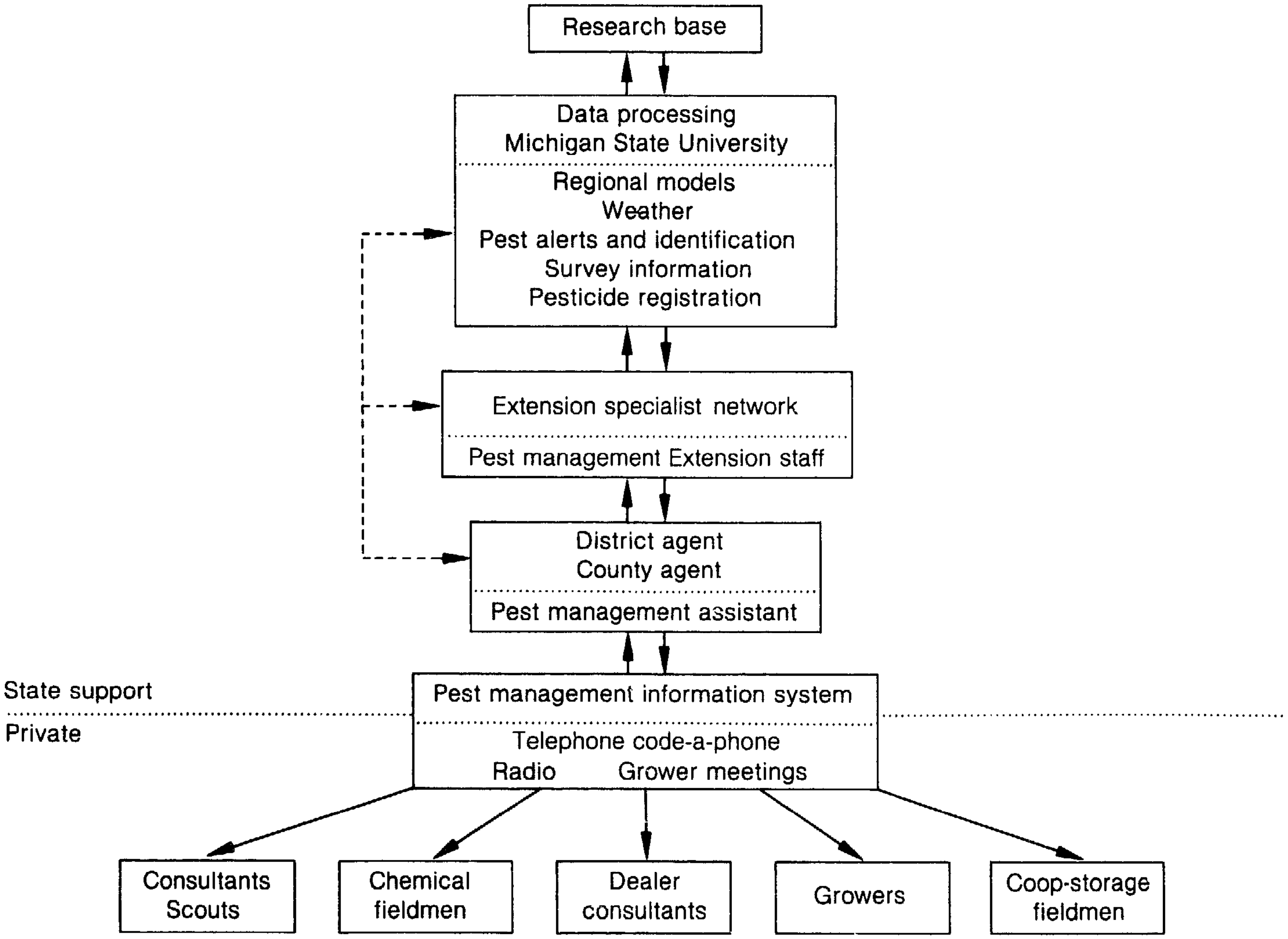
The objective of the Extension demonstrations is to introduce farmers and livestock managers to the concepts and techniques of integrated pest management. Each summer the projects employ several thousand field scouts (mostly college students) who, under the supervision of university Extension personnel, monitor the crop fields or livestock operations, collecting data on pest abundance, natural enemies, crop conditions, and other variables that affect the farmer's or livestock manager's decision on pest control. Participating farmers and livestock managers use these data along with information supplied by Extension personnel in carrying out pest control programs (USDA, 1976b).

Some states have adopted or are experimenting with computer programs to improve the efficiency of the IPM demonstrations. In Michigan, an on-line computer-based delivery system developed by the Agricultural Extension Service is being used to augment the flow of information in IPM demonstrations conducted in deciduous fruit orchards. The PMEX system (pest management executive system, illustrated in Figure V-2) consists of a central computer facility located at Michigan State University and a telecommunications network linked to Extension offices in various fruit-growing areas. Each Extension office is equipped with a small interactive computer terminal which the agricultural agent can use to communicate with the central computer facility. Within minutes the agent can retrieve information from the central computer for use by the growers in their pest control programs (Croft et al., 1976).

A custom-made motorized van equipped with data processing equipment and a slide-tape projector is also used in the Michigan program to aid fruit growers using integrated pest management. Upon request, the van is dispatched to an orchard where a field scout inspects the trees and records information on pest density and natural enemies and other variables which affect the orchard pests. This information is fed into the data processing equipment where it is automatically analyzed. After the analysis is made, a computer terminal in the van prints out a recommendation advising the orchard farmer of the pest situation and the need for control. Simultaneously with these operations, the grower is given a 30-minute slide-tape presentation on IPM concepts and techniques, illustrations of the pests, characteristics of damage, and natural enemies.

The Extension demonstration projects and related projects administered by USDA and the land grant universities illustrate the benefits of systematically scouting the crop fields, utilizing natural controls insofar as possible, and using chemical pesticides at minimum dosages only as needed to prevent economic losses. From 1972 to 1975, for example, cotton growers participating in the Extension demonstrations averaged, per acre, 2-4 fewer insecticide applications per season than nonparticipants for a 35-

Figure V-2 **A Computer-Based Extension Delivery System Used in Fruit Tree Pest Management (after Croft et al., 1976)**



50 percent reduction in insecticide use. In no case did participating growers experience reduced yields that could be attributed to the program (USDA, unpubl.).

In 1974, New York apple growers participating in Extension demonstrations reduced use of fungicides 57 percent and insecticides 11 percent. Participating apple growers in Washington reduced insecticide use by 43 percent, and participating apple growers in Michigan reduced insecticide use by 54 percent but increased fungicide use by 23 percent.

In Texas, a new integrated system of cotton production is based on early maturing varieties that escape boll weevil damage. It has demonstrated that in many areas of the state cotton may be produced with 50-75 percent less insecticides, 80 percent less fertilizer, and 50 percent less irrigation water than the later maturing varieties which must be grown under a higher energy input system. Moreover, increased yields have increased the farmers' profits more than $100 per acre (Sprott et al., 1976). The system is in various stages of implementation by many farmers, who are required to check regularly for insect pests so that they use insecticides very carefully and only as absolutely necessary. Texas farmers recently chartered the Texas Pest Management Association, a nonprofit, farmer-administered organization aimed at increasing the use of IPM on cotton and other crops (Adkisson, 1977).

The University of Arkansas has demonstrated an integrated insect management system for cotton on a 50-square-mile area. In 3 years participating farmers reduced the average number of insecticide applications to the crop from 10 to 2 while maintaining the same yields. Participation by the farmers of the area is virtually 100 percent. They have been provided the technical assistance and trained field scouts necessary to implement the technology (Adkisson, 1977).

Cotton farmers in Texas, Arkansas, and other states where protection depended on routine application of insecticides beginning in early season recently suffered devastating losses from the caterpillars, tobacco budworm, bollworm, and armyworms. Although many incurred insecticide bills of $75-100 per acre or more, they still suffered heavy damage, with disastrous economic consequences (Adkisson, 1977). As a result, some have demanded that the ban on DDT be suspended. The solution to this problem may not be more DDT but more research on integrated pest management systems that would avoid the problem, as illustrated by the Texas and Arkansas programs which did not use DDT.

A California demonstration program for pests of pears has relied heavily on cooperation with private consultants who follow the University of California's recommendations. The program has emphasized natural biological controls of insects supplemented by selective insecticides. For the first time, simple techniques have been made available to consultants and growers for monitoring fire blight, a major pear disease, and some growers have greatly reduced chemical controls which were applied on a preventive, often needless, basis before the monitoring techniques were developed.

One gauge of the success of the California IPM program in pears is the number of growers who continued the program after public subsidies were discontinued. Approximately 50 percent of the pear acreage in the initial demonstration continued under the supervision of private consultants and now 85 percent or more of the state's pear growers are using integrated pest management (Flint and van den Bosch, 1977). Through savings in insecticide costs, growers were generally more than compensated for the costs of the consulting service. Savings (after paying for monitoring) ranged from $49.37 per acre in Sacramento County to $6.21 per acre in Lake County in 1976 (Flint and van den Bosch, 1977). It is estimated that the IPM program on California pears resulted in a $400,000 savings in pesticides in 1976, and the value of the pear crop, by virtue of the program, was increased $750,000 (Good, 1977b).

There is no way to quantify the impact of national Extension demonstration projects on pest control and farming practices outside the immediate demonstration areas. A general evaluation of the economic, environmental, and social effects in representative agricultural regions would be necessary.

Obstacles and Needs

Many barriers must be crossed before integrated pest management is widely used in crop agriculture. As discussed in Chapter IV, an array of new alternative control methods such as insect pheromones, insect diseases, and weed diseases has shown promise against crop pests. Development of some is currently stalemated by government regulations or lack of commercial interest (Chapter IV, p. 33). Preliminary evaluation of other alternatives has shown considerable promise, but they must be researched much more thoroughly before their operational value can be determined. And as noted, efforts to develop multipest IPM schemes, essential for optimal crop production systems, have just begun. Development of these schemes will require a major increase in interdisciplinary IPM research.

Both the development of integrated pest management technology and the demonstration of this technology to farmers depend on publicly supported research and educational institutions. Further, public involvement must continue even after the currently most effective IPM programs have been adopted by the private sector. Improved control technology and practical delivery systems must continually be sought and developed. Once the benefits of IPM programs are known, it is important that individuals in the private sector be encouraged to offer those services so that Extension personnel can initiate programs in new areas and on new crops.

It is therefore anticipated that the demand for private IPM consultants will rise in direct proportion to the increasing availability of effective IPM technology to crop farmers. Much of this technology will be very sophisticated, and adoption will require the supervision of college-trained IPM specialists. Many farmers and farming cooperatives have already hired these specialists. Some grower organizations have formed IPM co-ops which operate under a board of directors and officers much like a cooperative corporation (Good et al., 1977). The co-ops employ one or more IPM specialists and the necessary field labor to supervise the crops of its members and to advise on pest management practices.

The demand for private consultants and IPM cooperatives is likely to be restricted to large farming operations. A question therefore arises about what can be done to elicit the participation of small farming operations, which control a significant portion of U.S. cropland. It may also be relevant to ask how much of the emerging IPM technology can be used by the smaller and often less prosperous farmers.

The farmer's lack of experience with integrated pest management seems to be a real deterrent to increased use of the approach. The farmers are reluctant to adopt IPM systems that they do not understand (often because the control systems are complex) or that require a major time commitment. Many farmers use pesticides on a preventive, often needless, schedule as a form of insurance rather than risk making wrong decisions on their actual needs or spend the time gathering facts necessary to sound decisions. One possible way to encourage acceptance of IPM may be through crop insurance that provides adequate protection against pest losses. Pest-specific risk insurance schemes tailored to the specific pest complexes and specific crops for which effective IPM technology and accurate pest damage assessment procedures have been developed may stimulate further use of IPM (Cutler, 1978; Turpin, 1977).

Livestock Pests

In terms of economic losses by the industry, among the nation's most important livestock pests are several species of biting flies (stable fly, horn fly, horse flies, black flies, gnats, face fly) that are annoying, cause blood loss, or transmit disease. Losses are principally in beef and dairy cattle and to a lesser extent, horses. Mosquitoes are a major problem in coastal and marshy regions. Several serious grub or bot pests (the larvae or immature feeding stages of flies that bore into animal flesh) attack cattle, horses, sheep, and goats, and bloodsucking ticks are very severe pests of these animals. Some species of lice and mites are serious pests of cattle and horses and are the principal pests of swine and poultry. The common house fly occurs anywhere livestock and poultry are found, feeding on animal feed and excrement and the exudate of wounds. Because this insect transmits many organisms that cause disease in domestic animals, it is frequently controlled, although its economic significance in disease transmission is unclear (Steelman, 1976).

Pest losses to U.S. livestock and poultry are estimated at $3 billion annually (the cost of control and of livestock and poultry), approximately 6 percent of the $46 billion received from farm marketing of livestock and poultry in 1973. The pests may damage livestock and poultry by interfering with feed conversion, reducing milk or egg production, and causing hide losses, for example. In addition, they transmit many animal diseases, such as bluetongue, equine encephalitis, pink eye, cattle fever, and anaplasmosis (USDA, 1976a).

Current Control Practices

Control of pests affecting livestock and poultry currently relies heavily on chemical insecticides (USDA, 1976a). Use of these materials accounts for an estimated 94-100 percent of all efforts to control insects, ticks, and mites, considered the primary pests of domesticated livestock (Table V-2). Although the amount of insecticides used on livestock is small compared to that used in agriculture, chemicals may constitute a significant production expense in some areas of the United States. Further, misuse of insecticides in livestock operations has caused serious problems, including environmental pollution, reduction of nontarget species (such as parasites and predators), illegal levels of chemical residues in meat and milk products, and development of resistance in some insect pests (Steelman, 1976).

Some livestock pests (e.g., ticks) also attack wild mammals (e.g., deer, rodents), thus building up large populations of the pests in areas inhabited by both the livestock and the alternate hosts. Control presents a particularly difficult problem when the livestock are being managed under range conditions. It has been approached largely by applying protective chemicals directly on the range animals. Vat dippings, in which individual animals are forced to pass through vessels containing solutions of insecticides, are commonly used for this purpose. In closed environments typical of cattle feedlots, dairy barns, chicken houses, and hog pens, insecticides are commonly applied as surface sprays (in the buildings, at fly resting sites such as under the building eaves, on the ground near the animal pens). Various back-rubbing devices impregnated with insecticides released upon contact by the animal, aerosol or fog sprays, and insecticide-impregnated feeds have also been commonly used to control livestock pests (USDA, 1976a).

Table V-2 **Current Utilization of Various Control Technologies for Insects, Ticks, and Mites Affecting Livestock (USDA, 1976a)**

	Cattle	Swine	Sheep and goats	Poultry	Horses
Insecticides and other chemicals	97%	94%	100%	95%	100%
Biological control	0	0	0	0	0
Physical and cultural control*	3	6	0	5	0
Genetic control	0†	0	0	0	0
Host resistance/ vaccine	0	0	0	0	0
IPM	0	0	0	0	0

* Sanitation and window and door screens

† Excludes screwworm fly eradication (sterile-male release) program in southwestern United States.

Though insecticides are the chief method used to control livestock insect pests, nonchemical control methods have been used successfully against some. For example, the pioneering effort that employed sterile-male insects to eradicate the screwworm fly from Curaçao and Florida involved a livestock pest.

The adult female screwworm lays her eggs in the open wounds of cattle, deer, other large mammals, and occasionally human beings, where the maggot stage feeds and develops. She mates only once prior to laying her eggs, and after mating with a sterile male, lays a normal number of eggs, but they are infertile. Dr. E.F. Knipling of the U.S. Department of Agriculture concluded in the late 1930's that these behavioral characteristics and the pest's naturally low population density (about two adult females per square mile) were ideal for application of the sterile-male principle, discussed in Chapter IV, p. 39. By the early 1950's eradication of the pest was achieved on the Caribbean island, Curaçao, and subsequently in Florida (Knipling, 1967). Massive releases of sterile-male screwworms have been made continuously in the Southwest since the early 1960's in a control program financed by livestock owners and the USDA. This program was extremely effective for about a decade, and it even appeared at one time that eradication of the screwworm pest was feasible throughout the region. During the period of greatest success, the program cost about $5 million per year compared to an estimated savings of $100 million per year (1962 dollars) (Knipling, 1967).

But, beginning in 1972 and continuing through 1976, the program was much less effective, for reasons not entirely known. Perhaps a genetic weakness developed in the screwworm culture being reared under artificial conditions, resulting in diminished competitiveness of the sterile males (Bush et al., 1976).

Unusually large migrations of screwworm flies from Mexico may also have contributed to the increased screwworm problem, leading scientists to believe that effective suppression may be achieved again by extending the release program far into Mexico in an effort to curb migration into the United States. A new screwworm rearing facility was constructed in Tuxtla Gutierrez, Chiapas, Mexico, under a U.S.-Mexican cooperative agreement to provide sterile males for release in Mexico as an adjunct to the U.S. release program administered in Mission, Texas.

Releases of sterile male screwworms were made throughout a large region of Mexico for the first time in 1977, and screwworm infestations in the United States were lower in 1977 than they had been since the program lost its effectiveness. However, it is too early to determine long-term success.

The screwworm program in the southwestern United States and Mexico is the only operational program utilizing the sterile-male method. The other nonchemical approaches used to any degree against livestock pests are physical and cultural controls. Some 3-6 percent of the efforts directed against pests attacking cattle, swine, and poultry involves pest exclusion (e.g., window and door screens) and sanitation (e.g., removal of droppings and soiled hay infested with fly maggots) (Table V-2). Insofar as can be determined, there are few livestock pest control programs that seek a wide variety of control methods and utilize chemicals only as necessary to keep the pests from surpassing economic thresholds.

Needs for and Uses of Economic Thresholds

Economic thresholds have been determined for only a small number of livestock pests. The value of economic thresholds in managing livestock pests is illustrated by the studies of cattle-infesting mosquitoes in Louisiana. Although mosquitoes significantly reduced daily gain of British breed steers, these losses could possibly be curtailed by feeding the animals high concentrate rations during periods of major mosquito activity (Steelman et al., 1972). Subsequently it was determined that purebred Brahman and Hereford x Brahman crossbred steers were more tolerant of mosquitoes than the British breed (Steelman et al.,1972, 1973, 1976). This information was then incorporated into an organized areawide mosquito management program for cattle, operated similarly to abatement programs commonly used to protect human populations from mosquito pests.

Economic threshold levels established for various cattle breeds have been used as criteria for applying insecticides in the mosquito management zone in Louisiana (Figure V-3). Adult mosquito populations are monitored in light traps, and control is initiated only after the mosquito population appearing in the traps exceeds a level considered economically significant (Steelman et al., 1976). Use of this method in an organized areawide control program has provided effective mosquito control at minimal costs to the cattle owners, $0.08-0.27 per animal per year (Steelman and Schilling, 1977).

Other studies of economic thresholds in Louisiana have revealed the value of crossing mosquito-tolerant cattle such as the zebu breed with cattle lacking this tolerance. Crossing promises a significant increase in mosquito tolerance (i.e., raising the economic threshold level) of beef herds, thereby reducing dependency on insecticides for mosquito control (Steelman et al., 1976).

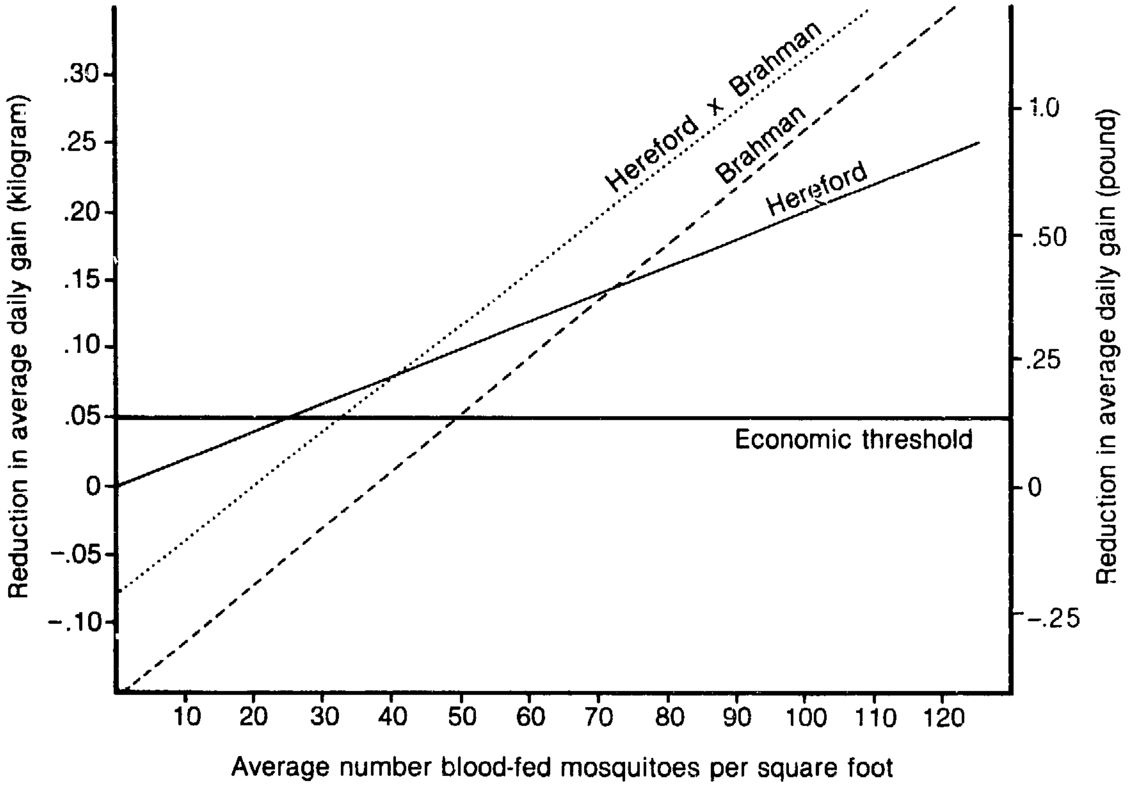
IPM Demonstrations in Cattle Feedlots

An Extension demonstration project conducted in Nebraska in 1976 illustrates the potential benefits of integrated pest management in livestock feedlots where flies (primarily the stable fly and house fly) frequently present difficult problems. The Nebraska program is being conducted by the Cooperative Extension Service and is administered similarly to the IPM crop demonstrations.

The stated objectives of the pilot project in Nebraska are to eliminate, insofar as possible, fly breeding within feedlots, to demonstrate fly breeding management procedures, to use insecticides more efficiently and reduce the quantity needed for control, and to develop a feedlot pest management scout training program (Campbell, 1976).

At the beginning of the fly season in the spring of 1976, a thorough inspection for fly breeding sites or potential breeding sites was made. Six adhesive-coated traps were installed at each feedlot for monitoring the fly populations. During each weekly visit for the rest of the season, an Extension employee examined the traps for house flies and stable flies. Other monitoring determined fly populations residing on the cattle and at known resting places (such as the

Figure V-3 **Economic Thresholds for Mosquitoes *(Psorophora columbiae)* on Three Cattle Breeds (after Steelman and Schilling, 1977)**



walls of buildings). Animal droppings used by the flies for breeding were also examined. The director of the Extension demonstration and the scout supervisor reviewed the weekly information and past history of each feedlot in order to formulate recommendations on fly control. A report and a newsletter were sent weekly to each feedlot manager.

Whenever improprieties (e.g., accumulations of manure serving as fly breeding sites) were noted, written recommendations were sent to the feedlot manager on what practices should be discontinued or altered and, when necessary, recommendations on utilization of chemical sprays for control of adult flies. Depending upon the weekly scouting reports, recommendations were made to increase, decrease, or maintain the frequency of chemical applications. More efficient use of the application equipment, precise timing of the applications, and selective control of flies in restricted habitats such as weeds and shelterbelts were stressed.

Cultural and mechanical control practices recommended to the feedlot manager included cutting weeds around the lots in order to eliminate resting places and to force the flies into more accessible spray areas (e.g., walls of buildings). Recommendations also included stocking the animal pens at densities considered optimal for trampling out the manure (breeding sites) in the pens. When manure deposits were too extensive to be trampled out, they were to be removed.

The project was well received by feedlot managers, it effectively reduced the major fly problems, and it greatly reduced the amount of insecticides formerly employed for control. Some feedlots in the project required no insecticides to keep the fly populations at acceptable levels.

Some efforts by the Environmental Protection Agency to reduce pollution in feedlot areas have compounded the fly problem. Many feedlots have been modified to meet EPA point source regulations in order to reduce stream pollution. Use of manure settling channels and basins or storage of manure in storage mounds, for example, create favorable breeding sites for fly pests (Campbell, 1976).

Needs

Emphasis on finding alternative methods is required for most operations to incorporate integrated pest management systems.

Chapter IV discussed several examples of successful alternative methods used experimentally against certain livestock pests. Sustained releases of a small wasp parasite against populations of house flies inhabiting poultry farms have shown much promise (see Chapter IV, p. 31). The use of biological control agents combined with sanitation measures (removal of manure and other wastes) appears to have great promise against poultry and livestock confined to pens, as do use of pasture rotation schemes against some livestock pests and breeding for pest-resistant livestock varieties (see Chapter IV, pp. 35, 36).

A recent rather novel technique appearing extremely promising in preliminary field studies is a trapping system that employs a pyrethroid insecticide (very low toxicity to people and animals) against stable flies. Insecticide-treated fiberglass traps, found attractive to the flies, have reduced 84-90 percent of a native population inhabiting a cattle feedlot in Florida (Meifert et al., 1978).

Because these and other alternatives such as the sterile-male method are largely in an early experimental stage and because economic thresholds have been established for very few livestock pests, immediate adoption of IPM in the livestock sector is not likely.

Pests of Postharvest Products

Pests affecting harvested foodstuffs and other agricultural products in storage and in transit present problems quite different from those affecting crops in the field or living animals. These products may be subjected to pest depredation at every step from field to consumption—during storage, in transit, in processing plants, in the wholesale grocers' warehouses, in the supermarket, and, finally, in the home.

The most serious pests attacking stored agricultural products and creating the greatest problems in processed food establishments are insects and disease organisms. Harvested agricultural products and their byproducts are commonly attacked by 25-30 species of insects, 50 less common species may cause severe damage, and 100 others create problems in given regions or under special circumstances. Insect damage to harvested agricultural and horticultural products and to animal products amounted to approximately $2 billion in 1973 (Table V-3). In addition, viruses, bacteria, mites, birds, and rodents may cause significant damage to stored agricultural products. More than 100 species of fungi may cause decay and blemishes to harvested fruit, and more than 150 species of fungi may spoil harvested vegetables (USDA, 1953). Storage of some grains and nuts under conditions that favor development of fungi may result in accumulation of substances toxic to animals. For example, aflatoxins produced by species of the fungus *Aspergillus* are known to occur in significant quantities on peanuts, cottonseed, and several nut crops. The fungal infection of cottonseed is predisposed by injury of the insect pink bollworm in the field. Feed prepared from cottonseed infested with *Aspergillus* has caused liver cancer in laboratory animals (NAS, 1975a).

The stored-product pests are usually confined to closed environments, permitting use of some nonchemical controls that are not applicable under field conditions. For example, window and door screening and other exclusion techniques to prevent pest entry and the regulation of temperature and humidity in buildings are effective for some pests. Closed environments also constrain use of pesticides because they often have to be applied in close proximity to foods and animal feeds (USDA, 1978).

Table V-3 **Postharvest Losses of Field and Horticultural Crops and Animal Products Caused by Insects, 1973 (USDA, 1978)**

Commodity	Value (billion dollars)	Loss* (billion dollars)
Field crops	45.00	1.75
Horticultural crops	0.69	0.04
Animal products	8.67	0.27
Total	54.36	2.06

* Includes damage losses plus control costs incurred to all postharvest products (raw and processed) in storage and in transit.

To meet current demands of consumers and the Food and Drug Administration, food entering commercial markets must be free not only of pest infestation or contamination but also of harmful pesticide residues, hence a narrow margin of operation between the two requirements if pesticides are employed. In addition to the domestic requirements for quality, safety, and residues, foreign markets impose rigid requirements. Presence of certain pests or pesticide residues, for example, may be sufficient reason for grain to be rejected by the buyer. Therefore, preventing pests from entering areas where agricultural products are stored is essential, and infestations must be stopped before they cause appreciable damage and contamination (USDA, 1978).

Very few chemical pesticides are approved for use around human food and animal feed; however, substantial quantities of atmospheric fumigants and surface sprays are used, especially to protect stored grain and feeds from insects and rodents. Some stored grain and feeds may receive two or three pesticide treatments per year; the total quantity used for this purpose is estimated at 4 million pounds per year. An estimated 85 percent of the grain stored in commercial facilities is protected with pesticides, but by contrast a very small percentage of the soybeans is treated. In addition, at least 1 million pounds of pesticides may be used yearly to control pests in grain mills, bakeries, canneries, slaughterhouses, breweries, soft drink bottling plants, dairies, and other food or beverage establishments (Lawless and von Rümker, 1976).

Malathion, one of the most commonly used insecticides approved for use around human food and animal feed, is no longer effective against insects which have developed a high level of resistance. Certain fungicides have also become ineffective because of resistance in some fungi that attack harvested agricultural products. Widespread resistance in stored-grain pests could have very serious consequences. Without alternative solutions, the pests may seriously jeopardize export markets and reduce domestic grain supplies. In addition to the problem of pesticide resistance, some grain fumigants are facing increasingly stringent regulation because of their potential adverse effects on human health.

Integrated management of pests affecting agricultural products in storage and transit has not received the emphasis that it deserves, considering the magnitude of the problem. One reason is that the grain and food industries apply minimal pressure on public institutions responsible for research. The industries are reluctant to acknowledge pest problems and the losses that occur because of fear of jeopardizing sales and increasing government regulation. Consequently, some of the larger industries have developed independent research programs for control of certain pests that affect them. Yet most research on agricultural pests in storage and transit is publicly sponsored; the Agricultural Research Service of USDA has primary research responsibility in this area (USDA, 1978).

To some, management of pests in most commercial storage and transportation facilities involves an "integrated" approach. Managers of these facilities recognize the importance of good construction and sanitation, and they practice pest prevention insofar as possible. Nevertheless, basic prevention is not duly stressed; the use of pesticides partially reflects faulty building technology and poor sanitation (Whitney, 1974).

The management of pests affecting agricultural products in storage and transit includes an extremely wide diversity of economic, biological, and physical conditions existing in the marketing channels, and there are many regulations affecting the design of pest control programs. Hence, an interdisciplinary systems approach is necessary, one that involves close collaboration of architects and engineers who design and build storage and transportation facilities, human nutritionists and health sanitation experts, agriculturalists and biologists who develop technology for producing and protecting plant and animal products that enter storage and market channels, and transportation and legal experts.

Promising alternatives include biological control, atmospheric modifications which raise the carbon dioxide content or lower the oxygen content, improved cold storage, irradiation procedures, insect pheromones, release of sterile-male insects or genetically altered insects, improved storage containers (pest-resistant packages, insect-repellent coatings), and selective chemical control (Anon., 1974). Most are in an early developmental stage, and there has been virtually no effort to seek optimal combinations for a single cohesive system of integrated pest management (USDA, 1978).

Research and education related to pests affecting agricultural products in storage and in transit must be broadened, with emphasis on integrating nonchemical methods of control, including such basic preventive measures as good construction and sanitation. In addition, there is need for improved coordination between scientists working on postharvest programs and scientists working on preharvest programs. Some stored-product pests enter storage facilities on infested plant or animal products.

FDA regulations to minimize pest contamination in foodstuff and food establishments may unnecessarily encourage pesticide treatment. Although the consumer must be protected from adulterated foods and beverages that present hazards to health, perhaps current FDA regulations are more stringent than they need be to protect human health (see Chapter X, p. 99).

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Status and Prospects of Integrated Pest Management in Forests, Rangelands, and Rights-of-Way

Chapter Six

Forests and rangelands are vital because of the products that they furnish and because their natural resources are renewable. Of the 2.3 billion acres of land in this country, one-third is forested and almost one-half is used for pasture and grazing (USDA-FS, 1975). Well managed, these resources are a perpetual source of food, fiber, shelter materials, water, and aesthetic diversion.

Growing demands for forest products and nontimber uses of forest land during the past 3 decades have increased the need for better pest management. Similarly, a growing demand for grass-fattened beef and mutton and the increased use of rangelands for recreation have necessitated attention to increasing the productivity of rangeland pastures through improved pest management systems.

Pest Management in Forests

Pest and Management Problems

There are no recent estimates of loss and mortality in the nation's forests. The last, compiled in 1952, showed total losses by fires, animals (including insects), and pathogens at 29 percent of the lumber produced annually (cited in NAS, 1975, based on U.S. Forest Service data). Insects and diseases are generally recognized as the most important pests affecting U.S. forests (USDA-FS, 1973; Waters and Cowling, 1976).

Insects and disease-causing organisms (fungi, bacteria, viruses, nematodes, such parasitic plants as true mistletoes and dodders) attack living trees in all their life stages from seed to harvest (or natural demise). Their actions directly influence the composition, structure, growth, and regeneration of forest lands. Some can cause irrevocable, or at least very long-term, changes in forest systems. Three pests of foreign origin, chestnut blight, Dutch elm disease, and red-pine scale, for example, have seriously jeopardized entire tree species in some areas. Other insects and diseases (e.g., balsam woolly aphid, white pine blister rust) may deform or kill a large portion of the trees in a given area, greatly modifying the composition and age-size structure of affected stands. Epidemics of, insects such as the Douglas-fir tussock moth, spruce budworm, forest tent caterpillar, and southern pine beetle can cause damage in a short time, but their effects are not irreversible. Affected stands often regenerate the same tree species, and only the developmental time sequence of the stand is altered (Waters and Cowling, 1976).

Various species of plants, trees, brush, herbaceous weeds, and parasitic plants may conflict with a forest manager's objective. Whether a given plant is classified as a pest depends on the particular management objective. For example, certain brushy species that compete with forest trees managed for harvest of lumber are viewed as pests. The same species may be desirable in forests of wildlife management areas, serving as important habitat for wildlife (NAS, 1975; Newton, 1967).

The impact of undesirable vegetation on lands managed for timber production may be substantial but it is difficult to quantify. Undesirable vegetation may reduce potential annual growth of forest trees being grown for timber by as much as 55 percent, according to some estimates (Walker, 1973; NAS, 1975).

Some wildlife species (e.g., birds, squirrels, deer, bears, porcupines, mice, rabbits, beavers) and domesticated livestock may also damage forest trees (see Chapter IX, p. 84).

The problems of forest pest management are usually much different from those in row crop agriculture. Because growing a tree to commercial size may take 25-100 years, the benefits of protecting seedlings from pests may not be realized for a long time. In addition to pest damage, trees are exposed to a multitude of other environmental stresses which may render them more susceptible to pest attack. Unless managed, for example, forests become overstocked, which is a natural process that ensures elimination of the less vigorous trees. Weaker trees may become more vulnerable to pest attack than vigorous trees, and their presence can increase pest populations to levels that also damage the latter (Stark, 1975). Correcting such pest problems entails continuous monitoring of individual trees and selective control of the weaker, which may require much different pest population surveillance procedures and more labor-intensive management than are required of agricultural pest management systems.

The multiple use of forests and their mixed ownership by private parties and public agencies place constraints on forest management not found in agriculture. Individuals and corporations own approximately 73 percent of the commercially productive forest land of the United States; the remainder is in federal, state, and other public holdings (USDA-FS, 1975).

Social values are increasingly important to pest management in public forests. The National Environmental Policy Act of 1969 has placed constraints on pest control practices, for example, the use of pesticides and clearcutting of trees, practices which had been almost exclusively at the discretion of federal agencies. The use of 2,4,5-T and other herbicides containing dioxin (TCDD), a chemical that has produced tumors and birth defects in laboratory animals, on public forests has caused considerable controversy and legal action (USDA, 1978).

Pesticide Use in Forests

In much forest land pest infestations and losses are simply accepted. Unless the value of the trees is quite high or the expected damage quite severe, attempting artificial control of forest pests may be uneconomic.

The use of fungicides and nematacides is confined primarily to specialty forests (e.g., Christmas tree plantations, forest tree nurseries) and highly individual trees of high value (e.g., shade trees). On millions of acres of commercial and noncommercial forests, stresses caused by plant disease organisms (including nematodes) are either left unattended or controlled by silvicultural practices such as pruning and thinning the infested trees and destroying other plant hosts of the disease organisms (NAS, 1975)

Insecticides have been used occasionally by the Forest Service on very large acreages of commercial and noncommercial forests; however, the treatments were generally restricted to a few pests. Between 1954 and 1974, treatment of four insect species, the western spruce budworm, eastern spruce budworm, gypsy moth, and Douglas-fir tussock moth accounted for 96 percent of the acreage sprayed for insect control by the Forest Service (NAS, 1975).

The Forest Pest Control Act of 1947 (16 U.S.C. §§ 594 et seq.) has greatly influenced the direction of forest insect and disease pest control programs. The Act provided subsidization for cooperative pest control programs on private land by cost sharing with federal funds. It authorized the Forest Service to conduct surveys of destructive insect and disease pests and to execute control programs against these pests as demanded. The Act stimulated control programs that relied exclusively on chemical destruction of insect pests and, to a lesser degree, plant pathogens, with little or no emphasis on incorporating a variety of control methods. Chemical control was emphasized because the programs were structured to deal with emergencies that required only short-term remedies (NAS, 1975).

The most commonly used herbicides in forests are, in descending order: 2,4-D; 2,4,5-T; 2,4-D/2,4,5-T mixture; MSMA; and a mixture of picloram and 2,4-D. Other imporant herbicides are cacodylic acid, amitrole, and dicamba (Flamm, 1976). The quantity of herbicides now used on U.S. forests is not known, but it has increased considerably in recent years. Although National Forests and Grasslands account for less than 1 percent of all herbicides used in the United States, the acreage treated on National Forests increased over 10 percent in the 2 years 1972-74 (based on Forest Service data, cited in Flamm, 1976). Herbicide use on private forests is also thought to have increased recently (NAS, 1975).

Alternative Methods

Cultural and silvicultural methods, which may include any manipulations designed to maintain the overall health and vigor of the trees, have been used extensively in managing forest diseases and, to a lesser degree, insects. Examples are planting seedlings genetically resistant to diseases, selective removal of trees heavily infested with disease organisms or insects, timing tree harvest, and mixing tree species optimally suited for the region (Waters and Cowling, 1976; Graham, 1963; Knight, 1976; NAS, 1975).

The value of planting pest-resistant forest trees in managing plant pathogens is illustrated with fusiform rust in southern pine forests. Fusiform rust is the most economically damaging disease of southern pines. Native stands of slash and loblolly pines are very susceptible; the longleaf pine is highly resistant and the shortleaf pine is essentially immune to the disease. Affected trees frequently are deformed, are predisposed to wind breakage, or are killed by the pathogen. The disease is most severe in plantations less than 15 years old (Waters and Cowling, 1976).

Planting genetically resistant seedlings is the most promising method of minimizing loss. Since the late 1960's, special orchards of highly resistant selections of loblolly and slash pines were established by the Forest Service in North Carolina and Florida. By 1980 there should be enough seed to satisfy the demand for resistant seedlings in the area of the South where damage is great (Waters and Cowling, 1976).

Because of the long generation life of forest trees, the selection and breeding of pest-resistant strains require efforts over a very long period. However, the development of pest-resistant tree varieties, though only in its infant stage, offers tremendous potential in future forest insect and disease management programs and deserves much greater emphasis than it currently commands (Waters and Cowling, 1976).

Biological controls utilizing antagonists (microorganisms that control plant disease pathogens) of forest disease pests are very promising (NAS, 1975; Rishbeth, 1975). One antagonist, the fungus *Peniophora giganeta,* is now used as a commercial treatment to compete with and thus reduce the severity of the wood-decay fungus that causes annosus root rot in southern pine forests (Rishbeth, 1975; Waters and Cowling, 1976).

An example of a successful disease management program achieved by destroying a disease organism's alternate host involved the white pine blister rust caused by a fungus of foreign origin that attacks five-needle pines. First detected in the United States in 1906 at Geneva, New York, the fungus had established itself in the Pacific Northwest and California by the late 1930's (NAS, 1975).

The fungus requires an alternate host of the species *Ribes* (e.g., currants, gooseberries) to complete its life cycle. The disease, therefore, can be controlled by suppressing the alternate host plants inhabiting the same area as the susceptible pine trees.

For several decades, complete eradication of the pest organism (by mechanical destruction of the alternate hosts) was attempted on about 2 million acres of the western United States. The eradication effort failed although it did provide substantial control of the disease organism. Eventually it was found that the fungus could be effectively managed at a great savings over the eradication effort by restricting control of the alternate hosts to certain areas with high densities of susceptible pines and using selective tree harvest methods (Vaux, 1954).

Other alternatives to chemical pesticides have been used with varying success. Three insect disease agents were recently approved by the Environmental Protection Agency: a virus was registered for use against the Douglas-fir tussock moth, another virus was registered for control of the gypsy moth, and the bacterium *Bacillus thuringiensis* was registered for use against the Douglas-fir tussock moth.

Some of the most serious insect pests of U.S. forests are of foreign origin, and not all have natural enemies here that regulated them in their homelands. Classical biological control involving the importation and establishment of parasites, predators, and diseases of these nonnative pests therefore may hold special promise. However, this approach has been vigorously pursued with few forest insect pests (Pschorn-Walcher, 1977; Anderson and Kaya, 1976; Turnock et al., 1976; Waters et al., 1976; NAS, 1975).

Insect pheromones presently have no practical value for control of forest insect pests other than for use in detecting and monitoring their activity. However, the feasibility of baiting traps with pheromones and other attractant chemicals to suppress insect populations has been demonstrated with bark beetles and the gypsy moth (NAS, 1975; Wood, 1976). The gypsy moth pheromone disparlure is being tested in a system integrating pheromone-baited traps, minimal use of chemical pesticides, and spray applications of *Bacillus thuringiensis* and a virus (NAS, 1975). If proven effective, this integrated management system would offer immense benefits. The gypsy moth, a serious defoliator of hardwood trees, has extended its range significantly in the past decade (Figure VI-1). It was introduced into Medford, Massachusetts, from Eurasia in 1869 as a possible candidate for silk production. Several of the insects escaped from the laboratory and eventually became established in the northeastern United States. The pest is now a serious threat to hardwood trees throughout New England and other states in the East and has been found in small numbers as far west as California (NAS, 1975).

Alternatives to chemical herbicides in forest management include mechanical methods (e.g., hand cutting, bulldozing, chaining) and fire. Where terrain and soils permit, mechanical methods can sometimes be substituted for herbicides. But these methods generally involve considerable soil disturbance, and in places they increase the risk of soil erosion. Because mechanical means are actually more effective but are less selective in controlling competing vegetation, they may lead to a less diverse and desirable wildlife habitat than herbicides. Mechanical control is more effective than herbicides in preparing sites for seedlings, but it may cost more per acre ($20-60) than use of herbicides ($10-30 per acre) (Flamm, 1976).

Fire may be effective in preparing new sites for planting; it requires dry weather and may succeed only if preceded by application of a desiccant herbicide to facilitate drying of the vegetation to be burned. This control method may be prohibited because of smoke pollution (Flamm, 1976).

Biological control of undesirable forest vegetation is not sufficiently refined to be a viable alternative to herbicides or the mechanical and fire methods. Insects have been effective in reducing herbaceous weeds of rangelands (see p. 67). Proper manipulation of deer and livestock can reduce the competition of grass or brush to favor conifers or other tree species. But the situations in which biological control is practical are few.

IPM Systems*

Integrated pest management is largely in the experimental stage in forestry, but forests are ideally suited for IPM systems. The long life of forests makes them amenable to efficient management of their destructive agents and allows continuous, long-term measurements and analyses of the interactions of pest

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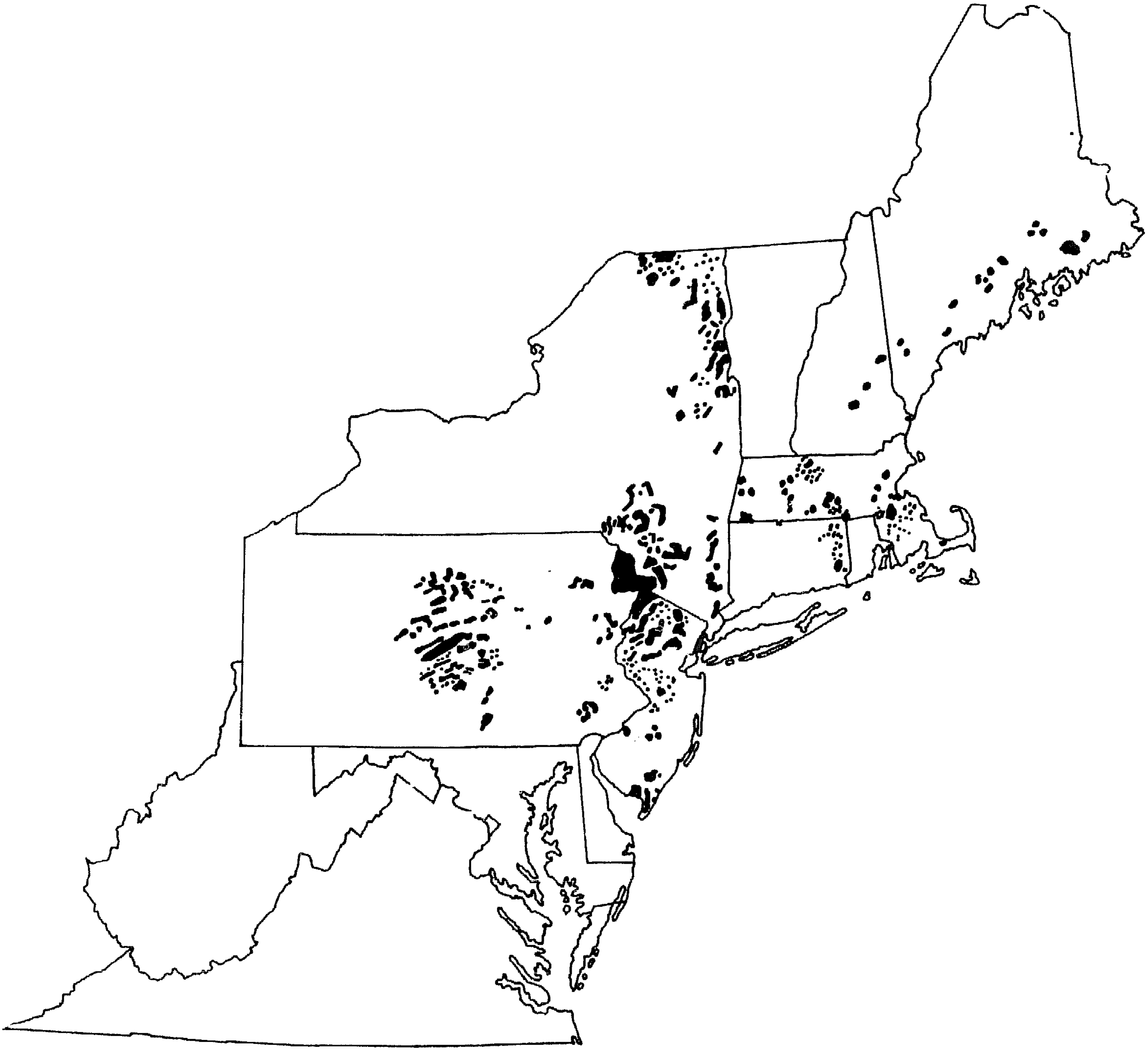
*Recent developments related to integrated management schemes for forest pests are discussed in Stark (1973, 1975), Waters and Cowling (1976), NAS (1975), Anderson and Kaya (1976), and Campbell (1973).

Figure VI-1 **Gypsy Moth Defoliated Areas, 1978 (USDA, 1979)**



populations and their environment. Continuous feedback from and adjustment of applied control or population regulation allows development of an optimal strategy (Stark, 1973).

Recently there have been two especially notable IPM efforts with major forest pests of the United States. One, initiated in 1972 and terminated in 1975, was part of a federally sponsored multi-university project, "The Principles, Strategies, and Tactics of Pest Population Regulation and Control in Major Crop Ecosystems" (Huffaker and Smith, 1973). The forest component of this interdisciplinary research project focused on developing principles and techniques for managing pests of pines, the most important of coniferous trees.

A complex of three pine bark beetles is among the most destructive forest insect pests: the southern pine beetle, affecting shortleaf and loblolly pine forests; the western pine beetle, affecting ponderosa pine forests; and the mountain pine beetle, affecting lodgepole pine forests.

As noted, managing a forest differs from managing a short-lived agricultural crop because trees may not be harvested for many years after application of a given pest control measure. Thus, bark beetle specialists have sought ways to provide long-term planning and management advice to forest managers. Early warning of bark beetle outbreaks would give a manager more flexibility, ultimately reducing the amount of insecticides currently used preventively as a result of not being able to predict outbreaks and not knowing how to use alternative methods.

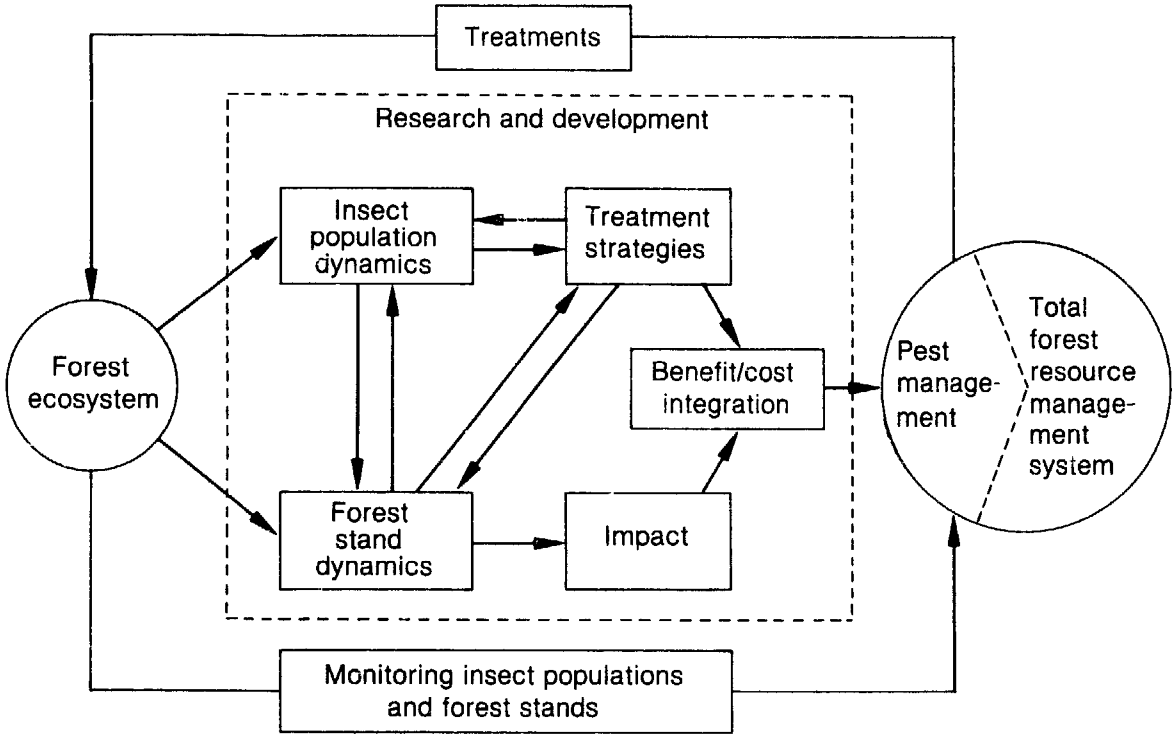
Forest pests and forest environments encompass a wider range of ecological conditions than most agricultural systems. It is envisioned that a computerized management system model (see the flow diagram, Figure VI-2) may eventually guide the forest manager in selecting pest control and forest management strategies for these complex systems. Pine bark beetle specialists believe that the model would lead to more precise pest control and better management than are currently possible. A major goal of the project was to formulate concepts and computer techniques for a management model to be used by forest managers (Huffaker and Croft, 1976).

Project participants also looked for ways to use pheromones and other attractants to trap beetles in a given forested area or to interrupt normal mating behavior, to increase the effectiveness of natural enemies, and to improve silvicultural practices and selective pesticide treatments.

A somewhat related project, the "USDA-Combined Forest Pest Research and Development Program," was initiated in fiscal year 1975 by the Department of Agriculture to develop and implement technology for management of the gypsy moth, Douglas-fir tussock moth, and southern pine beetle, three of the nation's most serious forest insect pests (Ketcham and Shea, 1977; Leuschner et al., 1977). The project entails collaboration of disciplines, universities, four agencies in the Department of Agriculture, state organizations, and private forestry. Its major objective is to find, evaluate, and implement environmentally safe management systems for the three insect pests and to provide the knowledge necessary to prevent or suppress future outbreaks. Also a project goal is the development of computerized management models for forest managers (Shea and Bayley, 1976). Registration of the disease agents for control of the gypsy moth and Douglas-fir tussock moth was accelerated through field evaluation in this project (Ketcham and Shea, 1977).

These two interdisciplinary projects are the largest coordinated national effort to develop comprehensive IPM systems for major forest pests. Both have utilized pest control specialists, economists, systems analysts and computer experts, and silviculturists, working as a team to develop the concepts and technology leading to improved pest control through optimal forest management. Although the impact of these projects on control practices in private and public forest lands has not been determined, the research and operational advances represent a trend toward more rational management of forest pests.

Figure VI-2 **Optimizing Pest Control Strategies in Forests (after Huffaker and Croft, 1976)**



Special Problems with Aquatic Plants

Aquatic plants of lakes and streams are important to the manufacture and provision of food and shelter for insects, fish, and various forms of wildlife. But some aquatic plants frequently become overabundant and create problems by obstructing water flow and navigation, by interfering with swimming, fishing, and boating, and by increasing water loss through evaporation.

In North America over 170 species of aquatic plants are classified as weeds, of which 40-50 species are considered major. Of particular significance in resources being managed for fishing and recreation are the emersed and floating weeds with underwater roots and most of their vegetation abovewater. Prime examples are the alligatorweed and water hyacinth, both introduced species that form floating mats on the surface, sometimes completely choking waterways, streams, and small lakes. These and other aquatic weeds are commonly removed by chemical herbicides and by mechanical destruction which, in addition to other drawbacks, provide control of only limited duration (Andrès and Bennett, 1975).

A very promising method for managing alligatorweed and the water hyacinth involves insects imported from their native regions in South America. As discussed in Chapter IV, p. 29, a flea beetle, native to Argentina, that feeds and develops only on alligatorweed has effectively controlled this plant in parts of its range in the southeastern United States. More recent introductions of another insect from Argentina that attacks only the water hyacinth have shown promise. By themselves these biological control agents may not permanently solve the alligatorweed and water hyacinth problems throughout their entire range in this country; nor are permanent solutions necessarily desirable because the plants may also be beneficial (e.g., the alligatorweed is reportedly important food for white-tailed deer in Louisiana, and it protects stream banks from erosion during flooding) (Andrès and Bennett, 1975). In many situations, however, biological control of these and other problem plants offers great potential. Further, the technology is available for converting some kinds of mechanically harvested lake weeds into mulch, compost, or high protein animal feeds (NAS, 1975).

Pest Management in Rangelands

Years of overgrazing, the reduction in naturally occurring fires, the introduction of undesirable plants and animals of foreign origin, and periodic drought have precipitated undesirable vegetation shifts from grassland to brushland on much of our native rangelands. Most U.S. rangeland is privately owned, but under a permit system grazing privileges are granted to ranchers on forest ranges within the National Forest System, including 3.8 million acres of National Grasslands (USDA-FS, 1975).

Weed and brush control is often routine in range management which aims to improve productivity of livestock through vegetation improvement. The manipulation of range vegetation to enhance the recreational value of the land may also require weed and brush control. Improvement practices that focus on preservation of game animal habitat have become an integral part of rangeland management. In addition to the direct benefits from increased livestock productivity and improved wildlife habitat, effective brush and weed control provides some important indirect benefits. Moisture use efficiency is improved when water is directed toward production of valuable forage instead of undesirable brush (Scifres et al., 1977). Further, livestock is distributed over the range, facilitating their handling and care (Scifres and Merkle, 1975).

Problems have been created on grazing lands by the introduction of exotic plant species and by the shift of nonforage native species to positions of major importance. The Macartney rose, a native of China evidently introduced into the United States in the early 1800's for use as a windbreak, is a good example of a rangeland problem caused by an exotic pest. This brush species infests approximately 500,000 acres of highly productive rangeland in Texas, where it must be controlled in order to prevent its outcompeting desirable forage grass (Scifres, 1975). Changes in vegetation communities of vast noncrop rangeland areas are constantly occurring through the undesirable introduction of the Macartney rose, diseases, insects, and various other organisms and because of other environmental factors. Where desirable vegetation is disturbed or removed, the species remaining or introduced tend to increase and become dominant (NAS, 1968). More often than not, these remaining species have little if any value to grazing animals.

Brush, a term applied here to various types of undesirable woody plants that compete with forage grasses used by livestock, is the primary pest problem of U.S. rangelands. Of approximately 630 million acres of rangeland in the United States, brush dominates an estimated 320 million acres, including 70 million acres of mesquite, 75 million acres of juniper, and 96 million acres of sagebrush. More than 80 percent of the grazing land in Texas alone is infested to some extent with brush deemed undesirable to grazing (NAS, 1968).

Some herbaceous weeds (such as bitterweed) are very poisonous to livestock. Damage from poisonous range plants varies from a high percentage of mortality to retardation of growth or abnormalities in livestock (Klingman et al., 1975). The total economic loss caused by poisonous plants is hard to estimate, but it is probably small compared to brush-caused forage grass losses. Controlling heavy infestations of some brush species has increased forage yields from two- to eightfold (Klingman et al., 1975) and has increased the amount consumed by livestock (by virtue of this increased availability) from two- to fivefold (Scifres et al., 1977).

In one south Texas study, forage yields were increased from 640 to over 1,600 pounds per acre (oven dry) in only 1 year following control of mixed brush (Scifres et al., 1977). Not only does brush cover reduce the quantity of forage produced, but the quality of the forage is reduced by the elimination of key species for grazing. Once the woody plants have gained competitive advantage, brush control must be incorporated into the management strategy for range restoration.

Brush control accounts for most of the chemical pesticides used on rangelands, but the quantities of herbicides used annually are not known. Six are commonly used for herbaceous weeds and brush on rangelands: 2,4-D, 2,4,5-T, MCPA, silvex, dicamba, and picloram (Scifres and Merkle, 1975).

In some years substantial amounts of insecticides are applied on large acreages of western rangelands to control range caterpillar and grasshoppers. Other insects, small mammals (rats, rabbits, prairie dogs), deer, and other wild animals may be pests in localized areas. High densities of pocket gophers can severely damage mountain rangelands. But the use of chemical pesticides for control of rangeland pests other than brush, the range caterpillar, and grasshoppers is quite low in most years and is generally confined to small areas.

Economics dictate the control method and treatment sequencing for manipulating the range vegetation so that optimal production of desirable forage grasses results. An investment in herbicides is budgeted over several years and must be carefully considered in view of alternatives. For example, a treatment cost of $5.50 per acre on land that can support only one animal unit (one mature cow and one calf) per 20 acres would be prohibitive if considered as an annual cost. If the treatment doubles the carrying capacity (i.e., to one cow-calf unit per 10 acres) and lasts for 5 years, however, the investment may be justified (Scifres and Merkle, 1975).

Various range scientists have advocated integrated brush management as one component of the overall range improvement strategy. It entails systematic integration of prescribed burning (the oldest brush management method in use), bulldozing, root plowing, chaining and cabling, selective use of herbicides, and, to some extent, biological control (Scifres, 1977; Scifres and Merkle, 1975; NAS, 1968).

But the high costs of fuel required for bulldozing and other mechanical controls and the shortages of ranch labor have made synthetic herbicides increasingly attractive economically. In order to safeguard against overreliance on these materials, it is important that range and forest scientists take a systems approach to weed and brush management whereby economically feasible alternatives are available to the resource manager. Burning, which may range from only $0.50 to $0.90 per acre, can reduce the herbicide application rate, or it can extend its effectiveness (C.J. Scifres, unpubl.).

Biological control of both weeds (DeLoach, 1977) and insects (Hagen et al., 1976) has shown some promise for rangelands. Although no exhaustive biological weed control program has failed to yield some beneficial results (NAS, 1968), the limited work that has been done has not often led to any measurable success. The cases judged as failures should not lead to the premature conclusion that biological control does not have merit in weed management on rangelands. The success achieved with biological control of Klamath weed, a pest of foreign origin, in the western rangelands of the United States is an example of this technique's potential.

Two species of leaf-feeding insects from Australia (*Chrysolina hyperici* and *Chrysolina qualrigemina*) were introduced in 1944 to suppress Klamath weed, which had spread over 4.6 million acres in California and adjacent states. In a relatively few years, these biotic agents successfully checked further spread of the weed. Unaided by supplementary means, they reduced Klamath weed to the extent that it was no longer of economic significance. The investment for control was only $200,000-300,000. The benefits (aggregated savings over previous losses plus pest control costs) from the program up to 1973 were estimated at $66.2 million (Huffaker and Kennett, 1959; Huffaker et al., 1976).

A constraint to expanded efforts in biological control of range plant pests is conflict of interest. For example, species of brush (e.g., oaks and honey mesquite) which are considered deterrents to range livestock production are sometimes of high value to the homeowner and recreationist. This conflict curbs use of insect and plant disease organisms that would be spread beyond the rangeland area.

The use of classical biological control against insect pests affecting rangelands has been attempted relatively few times. Completely successful results have been obtained only for the Rhodes grass scale, a pest of Rhodes grass in Texas. Effective biological control of the pest was achieved over a 45,000 square mile area (Hagen et al., 1976).

Vegetation Management in Rights-of-Way

Nationwide there are over 60 million acres of rights-of-way, including those of roadside, electric and telephone lines, railways, natural gas lines, and firebreaks (NAS, 1975). The control methods for unwanted vegetation in these areas are similar to those used in forest and rangeland situations although the objectives are quite different.

A large portion of rights-of-way is located in forested or formerly forested areas where the primary concern of pest management is to eliminate vegetative growth that entangles in overhead lines, interferes with sight lines along road sides, or presents fire hazards. In nonforested areas, the objective of managing vegetation in the rights-of-way may simply be a neat appearance.

Herbicides have been widely used on rights-of-way in the United States. In 1969, almost one-half the 2,4,5-T consumed was applied to over 2 million acres of rights-of-way (not including those treated by federal agencies) (NAS, 1975). With the most widely used phenoxy herbicide treatment, a 2,4-D/2,4,5-T mixture, a grassland cover is often obtained upon repeated applications. However, in most forested regions with moist summers, the right-of-way areas are invaded by brush seedlings, especially if the grassy cover is discontinuous, so that the herbicides must be applied every year.

An alternate approach is use of management techniques (e.g., selective herbicides, mechanical removal of the large woody plants) that foster a low shrub cover which arrests tree reproduction and growth. The fact that some utilities (in Connecticut, for example) have essentially converted to such a selective approach with good results indicates that it is commercially feasible in some regions (NAS, 1975). The initial costs of this approach are high, but once the low shrub cover becomes established, costs of maintenance are minimal. Yet it has not been widely accepted commercially. Inadequately trained maintenance personnel not familiar with ecological principles of vegetation management tend to perpetuate heavy use of herbicides in rights-of-way.

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Status and Prospects of Integrated Pest Management in Urban Areas

Chapter Seven

Urban expansion during the past 3 decades has created many pest problems and has intensified some others (Ebeling, 1975). Part of the growth occurred in the absence of comprehensive building laws and zoning regulations, and many of the less expensive houses and apartments created environments particularly favorable to pests.

Green lumber used in many of these structures was not properly dried before the structures were enclosed. Further, the use of air conditioning and humidifying equipment in structures not designed for such equipment results in increased humidity in internal wall spaces. As a result of lumber "sweating" and high humidity behind wall panels, for example, the growth of mold is stimulated and nuisance insects (e.g., fungus beetles, booklice) that feed on mold are attracted. The cracks and crevices resulting from poor construction facilitated entry of nuisance insects and related organisms (e.g., oriental cockroaches, springtails, earwigs, sowbugs, spiders).

Modern house design, even of expensive homes, favors some pest problems. Many houses are built on concrete slabs and their interiors are generally more humid than those with raised foundations typical of earlier construction (Ebeling, 1975). This high humidity has aggravated problems with mildew and such insects as fungus beetles, booklice, and springtails, which subsist on the mildew spores (Scott, 1966). Urban encroachment on agricultural lands and the resulting proximity of large human populations to cattle and poultry operations have created fly problems (Ebeling, 1975), and the construction of homes in wooded areas where mosquitoes, chiggers, and ticks commonly abound has added to human pest problems. The increasing popularity of apartments and townhouses has created an almost new facet of pest problems—difficult because the pests move from one unit to another. Further, the significant increase in home gardening, houseplant culture, and lawn care has contributed to the variety of urban pest problems in the past decade.

Diversity of Urban Pest Problems

If there is a single property that characterizes urban pest problems, it is diversity. Most cities provide habitats in which complexes of agricultural pests, forest pests, public health pests, wildlife pests, and structural pests can thrive.

Urban environments abound with plants that attract a large variety of insect and plant disease pests. In Austin, Texas, for example, 332 species of woody ornamentals have been recorded: 132 species of trees, 147 shrubs, and 53 species of ground cover and vines (D. Cole and E. McWilliams, cited in Frankie and Ehler, 1978). Some 120 species of trees are found in Berkeley, California (Olkowski et al., 1976). Outdoors or indoors, all species of trees, shrubs, flowers, grasses, vegetables, and plants are subject to pest attack.

Insects and diseases normally regarded as forest pests may present problems in urban areas, especially near forests. For example, during spruce budworm population outbreaks that occur in forests, the nearby ornamental conifers may be attacked, and the fall cankerworm, an important forest pest, often attacks urban shade trees (Olkowski et al., unpubl.).

Favorable habitats for a wide range of pest organisms are numerous in urban environments: birds (pigeons, house sparrows, chimney swifts) are nuisance pests which may create fire hazards when they nest in wooden buildings; cockroaches survive with great success in and around human domiciles, as do mice and rats; any structure that contains wood may be vulnerable to heavy loss by termites and other wood-destroying insects and fungi if it is not treated; a wide variety of insects infests carpeting, clothing, fabrics, paper, and other materials; and foods and seeds kept in homes, stores, and eating establishments may become contaminated with some 140 species of insects and mite marauders (Strong and Okumura, 1958), many of which reproduce in the indoor environment (Ebeling, 1975).

Many public health pests thrive in urban environments. Some species of mosquitoes colonize containers that catch and hold water (e.g., empty food cans, tires, rain barrels, flowerpots) (Ebeling, 1975). Open dumps (which are to be prohibited by federal law) provide a suitable habitat for rats and various species of flies and "filth" organisms, and dog

Table VII-1 **Pests Most Commonly Encountered by Commercial Pest Control Operators (after NAS, 1975a, based on a National Pest Control Association, Inc. survey)**

- American cockroach
- Bee
- Black carpet beetle
- Brown-banded cockroach
- Brown dog tick
- Carpenter ant
- Casemaking clothes moth
- Clover mite
- Common carpet beetle
- Confused flower beetle
- Cricket
- Fleas
- German cockroach
- House ants
- House fly
- House mouse
- House sparrow
- Indian meal moth
- Lawn ant
- Norway rat
- Oriental cockroach
- Pigeon
- Powder post beetle
- Saw-toothed grain beetle
- Silverfish
- Sow bug
- Subterranean termite
- Wasp
- Webbing clothes moth

excrement is often a productive source of flies. Sewage outfalls and drainage ditches may also harbor pests affecting human health (Ebeling, 1975; Frankie and Ehler, 1978).

Weeds along railroad tracks and utility rights-of-way and on vacant lots, city parks, golf courses, athletic fields, cemeteries, and industrial and municipal property require control.

Table VII-1 lists the primary pests encountered by commercial pest control operators (PCO's) specializing in structural pests. The German cockroach, house mouse, Norway rat, and the subterranean termite are the four most important structural pests. The major pests encountered by PCO's specializing in tree and lawn pest control are insects, vertebrates, and weeds (NAS, 1975a).

Commercial Pest Control Service

A substantial commercial pest control industry has emerged to serve the needs of homeowners and commercial establishments. As of 1975, an estimated 7,500 firms were engaged full time in pest control operations (see Table VII-2); approximately 2,000 are members of the National Pest Control Association. Some 30,000 pest control service personnel make an average of 200 calls per month, for a total of 4.4 million services to the public in just one month. Pest control operators gross more than $1 billion annually (Spear, unpubl.). In addition, many firms and individuals not engaged in commercial household and industrial pest control apply pesticides in doing "maintenance" work in apartments or employers' places of business.

The PCO industry initially formed primarily to meet the needs for structural pest control (termites, other understructure pests, pests inside dwellings) but expanded to include much wider needs, including control of exterior pests, i.e., those affecting lawns, trees, and outdoor recreation areas. Some PCO firms offer a comprehensive pest control service to homes, eating and lodging establishments, other businesses, and public facilities; service includes regular inspection and guaranteed treatment.

Most NPCA business may be categorized as general pest control involving cockroaches, ants, fleas, ticks, and other insects that infest food, fabrics, and human inhabitants in the home. This service is provided by 97 percent of all NPCA firms and probably contributes 40-50 percent of NPCA's annual gross (Spear, unpubl.).

Termite control is the second most important category of NPCA business, accounting for 35-40 percent annually and grossing an estimated $500 million (Spear, unpubl.).

Urban Pesticide Use

Surveys indicate that substantially more pesticides are dispensed in urban areas than is generally recognized (von Rümker et al., 1972, 1974). One-third or more of the total annual quantity of pesticides marketed in the United States may be for nonagricultural purposes. Although there is no way to determine their disposition, a substantial percentage is used by homeowners to beautify their lawns and gardens, protect valuable trees, prevent structural damage to their homes by wood-destroying pests, and control cockroaches and other noxious organisms inside their homes (NAS, 1975a).

The home and garden pesticide market is

Table VII-2 **Estimated Operations of the Commercial Pest Control Industry (Spear, unpubl.)**

Number of full-time firms	7,500
Number of employees	46,000
Service personnel	30,000
General pest control	(22,000)
Termite control	(8,000)
Number of monthly service calls per serviceman	
General pest control	200
Termite control	25

significant. In 1970, the estimated retail value of all pesticides sold in the United States was $1.545 billion, of which $298 million (19 percent) was in the residential category (Anon., 1972). The percentage actually used in the home and garden market is probably considerably less because the materials are sold in small packages at a higher unit rate. Further, the homeowner frequently does not use the entire package (NAS, 1975a).

One of the most thorough surveys of home use of pesticides was conducted for the Environmental Protection Agency in Lansing, Michigan, Dallas, and Philadelphia by von Rümker et al. (1972). An estimated 759,000 pounds of active pesticide ingredients (130,000 pounds of herbicides, 509,000 pounds of insecticides, and 120,000 pounds of fungicides) were used in the suburban areas of these three cities in 1971. Homeowners accounted for 80 percent of the use, and the other 20 percent was applied by commercial firms or public institutions to control mosquitoes and pests affecting recreational areas. Lawn and garden improvement was the major objective of residential use. The most commonly used herbicide was 2,4-D, and dicofol, dimethoate, chlordane, and malathion were the insecticides used in largest quantities. The survey did not name a specific fungicide used in large amounts.

The survey showed that 92.5 percent of the homeowners used pesticides from time to time. Somewhat surprising, it also showed that homeowners used more pesticides per acre than farmers did in the surrounding agricultural land (Table VII-3).

Table VII-3 **Estimated Quantities of Pesticides Used by Homeowners in Lansing, Dallas, and Philadelphia and by Farmers in Nearby Agricultural Areas (von Rümker et al., 1972)**

	Herbicide	Insecticide	Fungicide
	(pounds per acre)		
Homeowners	1.4	5.0	0.8
Farmers	0.5-2.3	1.5-3.0	Negligible

Pesticide Hazards in the Urban Environment

Studies indicate that most homeowners generally rely on commercial advertisements, pesticide salespeople, and product labels for information and, notwithstanding these sources, have difficulty interpreting information on the correct use of pesticides (NAS, 1975a; von Rümker et al., 1972, 1974; Levenson and Frankie, 1978). A high percentage of homeowners who use pesticides is unaware of or indifferent to potential hazards and may apply them carelessly, often unnecessarily, or at much higher dosages than the labels recommend. Some admit to the unsafe practice of flushing leftover pesticides down the drain (von Rümker et al., 1972).

The characteristics of pesticide use patterns in the urban home and garden play a significant role in incidental human exposures and environmental pesticide pollution. A study of the role of economic class and DDT pollution in Dade County, Florida, demonstrated significant correlations of DDT and DDE (a DDT metabolite) levels with social class; higher levels were found in the less affluent (Davies et al., 1972). Overcrowding, inadequate fly screenings, garbage accumulation, and the resulting problems of flies and other insects contributed to increased use of DDT by the less affluent.

Homeowners' use of pesticides resulted in atmospheric contamination in Florida, where the pesticides dichlofenthion (VC-13) and dursban, used to control horticultural pests, were identified in all six air samples in residential areas of Dade County; diazinon was identified in four of the samples. Near Miami, DDT and its metabolites were regularly identified in the air prior to the 1972 cancellation of DDT for most uses (J.W. Davies, cited in NAS, 1975a).

Pesticides have also been identified as water pollutants. Diazinon, one of the insecticides most commonly used by urban homeowners, was present in 80-100 percent of the water samples taken from rivers in metropolitan Houston from 1971 to 1976. Although sales of the insecticide dieldrin were greatly restricted by EPA in 1973 and its major uses suspended in 1974 because of its potential cancer-causing properties, residues of this persistent material were detected in rivers in metropolitan Houston in 1976 (CEQ, 1977).

Pest Resistance

The appearance of pest strains resistant to pesticides has created problems in controlling some urban pests. The German cockroach is almost universally resistant to organochlorine insecticides once used extensively for its control. However, other insecticides (e.g., diazinon, malathion, propoxur, chlorpyrifos) currently provide satisfactory control (Ebeling, 1975). Since 1971, scattered populations of the Norway rat have developed high levels of resistance to some anticoagulants (poisons that cause internal bleeding) (Jackson et al., 1975). Such resistance has also appeared in populations of roof rats and house mice (Spear, unpubl.).

Homeowner Use of Alternative Methods

The Cooperative Extension Service (located at state land grant universities) offers (often at no cost) helpful pamphlets, bulletins, and control guides pertaining to common household, lawn, and garden pests. They frequently describe the pests' habits and known natural controls.

CES personnel are equipped to advise on disease- and insect-resistant varieties of ornamental plants and garden vegetables, on garden and lawn mulches to arrest weed growth, and on such cultural practices as rotation of garden vegetables and planting dates when they are known to lessen pest damage. Some public institutions also provide illustrated material on pests, on insect predators and other natural controls, and on building materials and construction designs that most effectively resist pest attack.

Some urban pests can be controlled by the homeowner without chemical pesticides. For example, control of insect populations on deciduous fruit and nut trees grown on a small scale can be achieved by carefully monitoring the insect pest populations, mechanically removing (by hand, shaking the plants, hosing the plants with water) those that cause damage, and avoiding insecticidal destruction of insect predators and parasites (Schwartz, 1975). Other nonchemical approaches can be taken against pests of ornamental plants (Henneberry et al., 1972) and insect pests that commonly infest households (Piper and Frankie, 1978; Henderson, 1973).

Many homeowners have experimented with a wide variety of nonchemical controls which range from such commonsense means as use of a fly swatter to the more sophisticated interplanting of aromatic herbs (e.g., garlic) among garden vegetables in an attempt to repel insect pests. However, the level of satisfaction among those using these methods is relatively low (Levenson and Frankie, 1978), a fact that is not surprising because few of these methods have been adequately researched or developed. Most homeowners who have attempted nonchemical control have discovered the method themselves or have learned about them through friends. Only a very few, perhaps 10 percent or less, use the Extension Service as a source of information (Levenson and Frankie, 1978; NAS, 1975a).

If all available information on the correct use of pesticides and all available information and technology on nonchemical alternatives were put to use immediately, there would undoubtedly be a drastic drop in pesticide use and pesticide-related problems in urban areas. However, truly effective integrated management schemes have been developed for only a few urban pests, and a much larger research effort would have to be followed by a well-planned program of public education. The only major efforts to develop and implement urban IPM schemes relate to city-owned trees.

IPM on City Trees

The potential for integrated pest management of tree pests in urban environments is illustrated by the model programs developed for city-owned shade trees in Berkeley, San Jose, Palo Alto, Modesto, and Davis (Olkowski et al., 1976, 1978). The University of California, Berkeley, cooperated with the cities in all aspects of program development. Previously, the city governments had relied exclusively on chemical insecticides for control.

Under the IPM programs the management procedure consisted of the following: establishing populations of parasites to control biologically several nonnative insect pests; using various mechanical methods such as high-pressure water sprays to wash insects from the tree foliage, sticky adhesive barriers around the tree trunks to prevent the insects from reaching the foliage, and selective pruning to remove tree parts that harbored pest infestations; and careful monitoring and application of pesticides only after the nonchemical methods failed (Olkowski et al., 1976, 1978).

Significant reductions in insecticide use resulted in all five cities. The year before any of the programs was initiated, approximately 16 percent of the total tree population (462,000) was treated for pests. Six years later only 0.08 percent was treated with chemical insecticides and approximately 1 percent was treated with the insect disease agent *Bacillus thuringiensis*. With the number of treatments reduced to 7 percent of the preprogram days, the pests were effectively managed, and at the same time citizen concern about pesticide pollution was lessened (Olkowski et al., 1976, 1978).

Trees managed by city governments are generally subject to regular insecticide treatments, in large part because professional integrated pest management specialists do not participate in developing the control programs. Alternatively, city employees could be trained in integrated pest management sciences to enable them to advise and service urban and suburban communities (Olkowski et al., 1976).

Special Rodent Problems in Urban Slums

Rats present particularly difficult problems in urban ghettos. Rats bite as many as 60,000 people each year in this country, mostly children and the elderly and almost always in urban slum areas (NAS, 1975b). Rat bites rarely cause death, and commensal rats seldom actually transmit disease but sometimes cause rat bite fever. The psychological trauma of being bitten can be significant (NAS, 1975b).

Only a few types of poisons are used against rats; anticoagulants are the most common. Used by both the general public and commercial operators, anticoagulants are mixed into baits which must be replenished frequently; anticoagulants represent about 95 percent of the rodenticide market in the United States (NAS, 1975b). But rats have become resistant to some anticoagulants in several cities.

Rodents that occasionally enter suburban and small-city homes and other structures are not generally a major problem. Sanitation and exclusion techniques usually suffice to prevent a continual problem, and traps are also quite effective.

The problem of rats in slum areas of large cities is much more complex. There the management program must cover a large area. Because rats are migratory, one building may be freed of all members only to be reinfested in a short time unless the same control is applied throughout the rodents' range. Satisfactory long-term management is based on a thorough understanding of the pests' habits and dynamics for the particular area.

The basic principles for urban rat management were established over 30 years ago, primarily from work done in Baltimore (Davis, 1972). Studies of the population dynamics and behavior of rats in Baltimore revealed that uncontrolled rat populations will increase to the capacity of a given environment and essentially remain at this level indefinitely unless their habitats are modified. Poisoning or trapping has only temporary effects because the population rebounds quickly to the capacity level soon after these controls are relaxed if the food and breeding habitats remain stable. The only known permanent solution to the rat problem is by modifying these habitats as required to lower the capacity level.

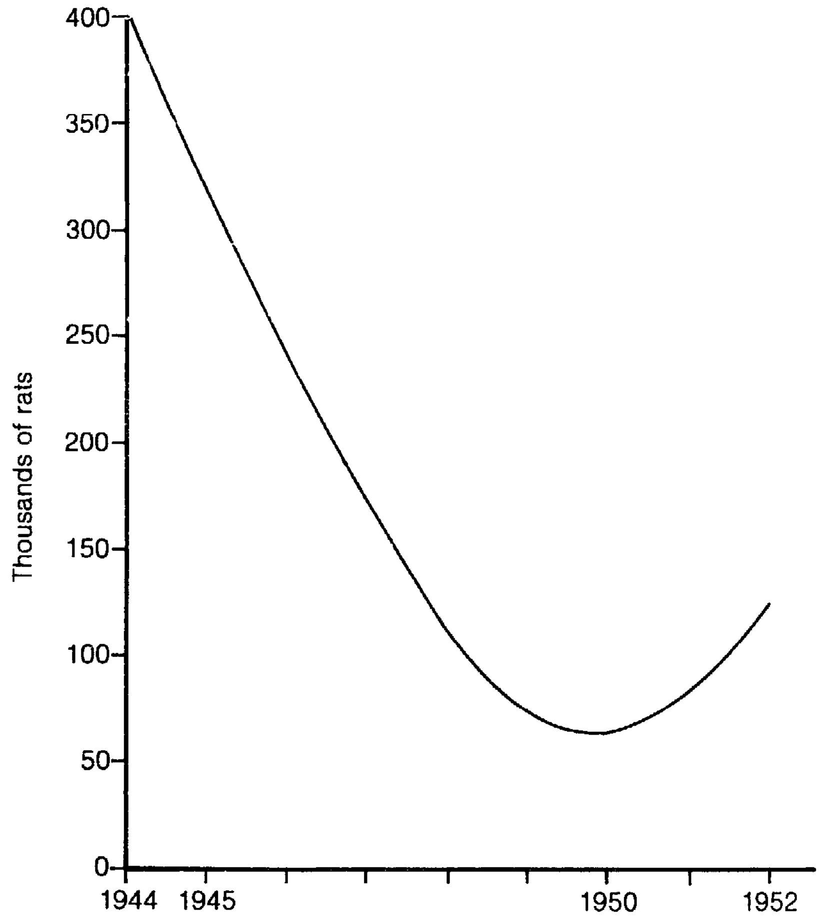
A very successful integrated rat management system based on habitat management principles was developed in Baltimore in 1944 prior to the availability of synthetic organic rodenticides. The system included a careful coordination of sanitation and habitat modification (removal of garbage from alleys, covering entrance holes into sewers), rehabilitation of dilapidated buildings, and major educational and monitoring efforts. The slum rat problem was effectively reduced in just a short time and remained so as long as the habitat modification continued (Figure VII-1). But when synthetic anticoagulants were used intensively in Baltimore and the habitat management procedures discontinued, the rat population rebounded.

Urban rat problems and the need for habitat management practices to deal with them are certain to command increasing attention as pesticide-resistant strains of rats become more prevalent, as the trend suggests (Jackson et al., 1975).

Needs in Urban Integrated Pest Management

Integrated pest management promises to reduce the use of chemical pesticides, which currently is

Figure VII-1 **Estimated Rat Population in Baltimore during and after a Habitat Management Program Initiated in 1944 and Discontinued in the Late 40s (after Davis, 1972)**



alarmingly high in urban areas. It has broad application and offers the only known long-term solutions to some of the most severe urban pest problems, e.g., pesticide-resistant slum rats. However, development and implementation of urban IPM systems will require a vastly expanded, publicly sponsored, and carefully coordinated research and education effort. Although the knowledge and techniques from other applied fields can be related to urban pests, much of the technology will have to be tailored to urban conditions (Olkowski et al., unpubl.; Frankie and Ehler, 1978; Ehler, 1978). Experience with large-scale agricultural monocultures, for example, may have only limited utility for the typically small-scale, more labor intensive, and diverse urban vegetable gardens (Ehler, 1978).

Education at all levels—federal, state, and city officials, workers, and citizens—is a key ingredient of urban IPM. City dwellers are often unaware of the role of beneficial insects and assume that all are pests, and they often cannot distinguish plant pest damage from, for example, wind burn or nutrient deficiency. In addition, they know little about pesticides and associated hazards of their use.

The development and application of IPM technology in the urban environment are an ambitious undertaking, one that requires the cooperation of public and private institutions.

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Status and Prospects of Integrated Management of Pests Affecting Human Health

Chapter Eight

Many organisms affect the health and comfort of humans. These "pests of public health" may inflict painful bites or stings, cause annoyance, worry, or allergies, or transport pathogenic diseases.

Envenomization (injury from venoms produced by insects and other animals) is a common public health problem in the United States. Each year, venomous organisms, particularly bees, wasps, yellow jackets, and ants, sting or bite many thousands of people, causing death in a few. Of 460 human deaths by venomous animals recorded during 1950-59, 30 percent were attributed to snakes, 1.7 percent to scorpions, 14 percent to spiders, and 50 percent to insects, primarily bees and wasps (Parrish, 1963).

Rats are a common public health problem in urban slums. Although they seldom cause death, rats inflict painful bites which occasionally produce rat-bite fever (see Chapter VII, p. 73).

The most important public health pests are arthropod disease vectors, insects and ticks which transmit organisms such as viruses and bacteria. Arthropod vectors have been involved in some of the most serious disease epidemics. Plague is one example. A disease of rodents and humans, plague is usually transmitted to humans by rodent fleas. In A.D. 542-94, it killed about one-half the population in the Roman Empire, as did the "Black Death" in England in 1348-49. Typhus, which is transmitted by lice, mites, and fleas, was a dreaded enemy of early warriors because it quickly spread among the high concentrations of people characteristic of large armies. The fall of the Roman Empire is sometimes attributed in part to the malaria transmitted by mosquitoes breeding in the marshes outside Rome (Southwood, 1977).

Malaria and yellow fever, transmitted by mosquitoes, prevented the French from constructing the Panama Canal prior to U.S. success in the early part of this century. Vector-borne disease remains a major deterrent to human settlement and agricultural development in areas of Africa and Asia (NAS, 1975).

In 1976, an estimated 300 million people suffered from filariasis (a condition which is caused by threadlike worms transmitted by mosquitoes and which invades lymphatic vessels and lymphoid tissue) (Southwood, 1977), 120 million from malaria (WHO estimates, provided by Newton, unpubl.), and 10 million from trypanosomiasis (Southwood, 1977). The latter disease, transmitted by flies or bugs and caused by a protozoan (single-celled animal), induces sleeping sickness, among other symptoms. Approximately one in seven people in the world had one of these three arthropod diseases as late as 1976 (Southwood, 1977).

Although arthropod-borne diseases continue to present a serious problem, human health and well-being have markedly improved throughout the world since organic insecticides appeared in the 1940's; serious diseases like yellow fever and malaria have been virtually eliminated from many developed countries and the number of cases significantly reduced in other parts of the world (NAS, 1975).

Major Pest Problems in the United States

Mosquitoes, ticks, black flies and other biting flies (stable fly, horse flies, deer flies, biting gnats), lice, fleas, and house flies are the most important public health pests in the United States. Annual monetary losses (including costs of control) attributed to arthropods of public health importance have been estimated at $500 million for mosquitoes, $500 million for black flies and other biting flies, $150 million for filth-breeding flies, $100 million for ticks, mites, and lice, and $25 million for wasps and yellow jackets (USDA, 1976).

Mosquitoes

Eighty to 90 percent of all control efforts against public health pests is directed against mosquitoes, nuisance pests in all 50 states. The most significant mosquito-borne diseases in the United States have largely disappeared from public consciousness, but as late as the early part of this century, malaria, yellow fever, and dengue were significant public health problems here (NAS, 1975).

Mosquito-borne encephalitides (eastern equine encephalitis, western equine encephalitis, California encephalitis, and St. Louis encephalitis) have occurred periodically in recent years, but outbreaks have been limited to relatively small areas (NAS, 1975). In 1975, some 2,000 cases were confirmed in the United States, with approximately 30 deaths (USDA, 1976). The recent resurgence of malaria in Asia, Africa, and Latin America is discussed on page 82 of this chapter.

Ticks

The most serious human disease transmitted by ticks in the United States is Rocky Mountain spotted fever. Principal carriers are the Rocky Mountain wood tick in the West and the American dog tick east of the Rockies. There has been a considerable increase in the number of cases of Rocky Mountain spotted fever in recent years, from under 200 in 1959 to over 800 in 1975 (cited in Newson, 1977).

Aside from their role as disease vectors, ticks are a real nuisance in parts of the United States. High tick densities in rural areas may hamper outdoor activities such as camping and fishing.

Black Flies and Other Biting Flies

Black flies and biting gnats and other species of biting flies (the stable fly, horse flies, deer flies) are not involved in the transmission of human disease in the United States. But because of the bites that they inflict, these insects present a serious problem in some areas. For example, late in spring and early summer in some areas of the northern United States, giant swarms of the small bloodsucking black flies may attack people in the vicinity of the flies' breeding places. The flies frequently restrict fishing, camping, and other outdoor activities and may reduce the productivity of agricultural and forest workers (USDA, 1976).

Lice

Three species of lice (body louse, head louse, and crab louse) attack humans. Only the body louse is a significant disease vector. Also called "cootie," "grayback," and "mechanized dandruff," this insect transmits typhus, trench fever, and relapsing fever. In the United States, the principal louse problems are caused by head lice and crab lice, which are spread by physical contact with infested individuals or by use of infested toilet seats and blankets, for example (NAS, 1975).

Fleas

Because of their abundance, worldwide distribution, irritating bites, and ability to transmit disease, fleas are among the principal pests of public health. The last occurrence of a major flea-borne disease, urban plague, in the United States was in Los Angeles in 1924. From 1924 to 1972, 72 cases of human plague were reported in the United States (NAS, 1975). Sylvatic plague is present in rodent fleas in 15 western states where the colonial prairie dog is a principal reservoir for the disease agent.

The greatest potential danger from plague in this country is transmission of the causal organism from wild rodents to rats or other mammals commonly found in major cities. Several years ago it was found in the fox squirrel in Denver, causing much concern among public health officials because the squirrel is common in many western and southern cities. Further, pesticide-resistant urban rats (see Chapter VII, p. 72) may harbor potentially vectorial fleas. Plague is not a serious problem, but the situation requires continued attention (NAS, 1975).

House Flies

House flies are filth organisms, breeding in human excrement, garbage, and domestic animal wastes. They transmit the organisms that cause human diseases, such as salmonella (food poisoning), cholera, shigellosis (dysentery), and poliomyelitis, but their real significance as disease carriers in the United States is not known. Most action against house flies and related species of filth-breeding flies is prompted by the fact that people find them repugnant (James and Harwood, 1969).

Imported Fire Ants

Imported fire ants, two closely related species of ants accidentally introduced into the United States from South America, are a public health nuisance in the South. Entering at Mobile, the pests adapted well to the southern United States. One species, introduced 55-60 years ago, spread only into a relatively small area in northwestern Alabama and northeastern Mississippi. The other, introduced about 35 years ago, spread much more widely, from the Carolinas to Texas, and apparently is still extending its range (Lofgren et al., 1975).

The public health significance of these ants is the subject of much debate. Some scientists, doctors, and others believe that the pests are not a serious public health hazard. However, of 1,336 physicians surveyed in selected areas of Mississippi, Alabama, and Georgia in 1971, 901 reported treating patients for fire ant stings or for complications from stings. They reported treating 9,224 and 11,937 patients for fire ant stings in 1969 and 1970, respectively, and had seen 12,438 patients for stings in the first 7-9 months of 1971. Average medical costs for each patient treated in 1971 were $28.32 (survey by R.F. Triplett, described in Lofgren et al., 1975).

Occasionally a stung individual has systemic reactions, including nausea, vomiting, dizziness, perspiration, asthma, and other symptoms of severe allergic reactions; if medical assistance is not received, the individual may die (Triplett, 1973).

Potential for Arthropod-Borne Disease

A recent study committee of the National Academy of Sciences concluded that given the current life style, economic standards, and general well-being of the U.S. public, it seems unlikely that major epidemics of arthropod-borne disease could occur or could long be sustained except under most unusual circumstances (NAS, 1975). Nevertheless, the committee report emphasized that the potential for a major epidemic of several arthropod-borne diseases, including malaria, yellow fever, dengue, filariasis, plague, murine typhus, and various encephalitides, may be present at any given time. This potential exists so long as the vectorial arthropods thrive in this country and the causative pathogens are active in any part of the world (Reeves, 1972). The rapid intercontinental mobility of people made possible by jet aircraft has theoretically increased the chances of introducing foreign vector-borne disease here. The speed of air travel is such that an infected person may arrive in a foreign land well before the incubation period of a vector-borne disease ends and thus before any symptoms appear (NAS, 1975).

Current Control Practices

No centralized effort has been made to compile national statistics on quantities of pesticides used against public health pests, but organized mosquito control probably accounts for the bulk of them. Nationwide, the estimated 2.15 million pounds of chemical insecticides (active ingredient) used in organized mosquito control programs in 1972 (NAS, 1975) is less than 1 percent of the estimated 278.8 million pounds of insecticides (including nematacides, rodenticides, miticides, and repellents) used for all purposes in the United States in 1972 (von Rümker et al., 1974).

Mosquitoes

Mosquito annoyance, possible wherever people reside, varies among regions only in severity and by season. By and large, control programs are organized on the community level by public agencies or on the local level by mosquito abatement districts. States heavily involved in mosquito control have designated agencies (for example, a health department, agriculture department, or university) to promote, regulate, or advise on mosquito control practices (NAS, 1975).

The American Mosquito Control Association, Inc., parent organization for the United States and Canada, is nonprofit, scientific, and educational and is operated by professional mosquito workers for the benefit of the public. One of AMCA's primary objectives is dissemination of information. The association's quarterly, *Mosquito News*, is circulated worldwide. In addition to the AMCA, the most common sources of technical information for mosquito district personnel are their state and regional organizations (NAS, 1975).

For fiscal year 1975-76, the AMCA had on record 535 U.S. and Canadian agencies with operational mosquito control programs; their total budget was over $69 million. The agencies employed 3,218 permanent personnel and 2,938 part-time personnel. More than one-fourth of the agencies were involved in the control of public health pests other than mosquitoes (e.g., gnats, flies, ticks, wasps, rodents) (Anon., 1977).

Organized mosquito districts of the United States have always stressed "integrated pest management" in one sense of the term. The underlying concept of IPM was visualized and put into practice from the beginning of California's first organized mosquito control program in 1904 (Mulhern, 1973a; Fontaine and Schaefer, 1978). University of California pest control specialists working with community sponsors of antimalaria projects evaluated and advocated various combinations of chemical control (use of petroleum oils to spray the water in which the mosquitoes bred), physical control (elimination of beeding areas through drainage, flushing, or dredging), and biological control (using the predatory mosquitofish). Similarly, Florida's first organized mosquito control program, in the early 1920's, also involved a combination of methods (NAS, 1975).

Leading pest control specialists of the pre-DDT period of about 1900-1945 acknowledged that biological control agents and other natural factors provided adequate control in only a limited number of situations; each presented the mosquito problem as a complex combination of natural and manmade situations, not susceptible to simple control but to be attacked with both preventive and corrective measures. They proposed that control programs employ natural enemies by modifying the environment from one favorable to mosquito production to one favoring natural enemies and inhibiting production. Chemicals (petroleum oils and inorganic pesticides) were only a temporary supplement to natural control and source reduction (deliberate habitat modifications of aquatic environments, rendering them unsuitable for immature mosquitoes) (Mulhern, 1973a).

But this integrated approach was overshadowed by DDT and other synthetic organic insecticides after World War II. Because the compounds initially produced spectacular results against virtually every kind of mosquito and mosquito-borne disease, some of the earlier nonchemical methods were replaced by the quick and easy solutions offered by the new materials (Fontaine and Schaefer, 1978). Of the total expenditures for 59 organized control districts, chemical control (against both adult and immature mosquitoes) averaged 67 percent, and less than 20 percent was spent on the previously popular physical control techniques in the late 1940's. By comparison, in 1912 expenditures for chemical controls (largely with petroleum) accounted for a fraction of the total control budget (Loomis, 1972).

Despite the popularity of the organic insecticides, most mosquito control districts did not completely abandon the earlier nonchemical methods of control, such as source reduction by habitat modification and use of mosquitofish predators. Source reduction by filling, dredging, or vegetation management, though effective against mosquitoes, is very difficult and costly in natural wetlands and may disrupt local ecosystems. In addition, locating the breeding sites over vast wild terrain is difficult, making it impossible to rely totally on chemical treatments to control larvae. Thus the use of predators is an important control.

In arid environments like California, mosquito problems are predominately the result of human activity; breeding is confined to such places as manmade lakes and flooded agricultural land. Source reduction is more feasible under these conditions; however, use of insecticides to control the larvae is cheaper, though less permanent. Fuel oil, kerosene, the inorganic insecticide Paris green, and the plant-derived pyrethroid insecticides had been effectively used in larviciding before organic insecticides became available. New materials such as temephos (Abate) and malathion were added to the larvicidal arsenal (Metcalf, 1975).

Today some mosquito control agencies advocate and practice, insofar as is economically possible, scientifically planned mosquito control programs based on a sound understanding of integrated pest management. The California Mosquito Control Association, for example, promotes "the use of all acceptable control methods, applied selectively, singly or in combination, to obtain mosquito control most effectively and economically, with the least possible damage to nontarget organisms or to other elements of the environment." Preventive measures, principally natural biological and environmental controls, are emphasized, but chemical control is integrated with other measures as necessary (Mulhern, 1973b).

Figure VIII-1 shows components of integrated management of mosquitoes in California. Not only must an IPM program incorporate the principal elements here, but it must also integrate mosquito control with land uses. Often many technical specialties are required. Although hindered by a lack of adequately trained personnel, inadequate budgeting, lack of alternatives to chemical pesticides, and other constraints, comprehensive IPM such as that advocated by the CMCA is gaining increased acceptance in California and other state mosquito districts. Reliance on insecticides for mosquito control is fading appreciably in certain regions, and the trend has shifted toward integrated pest management.

Insecticide resistance in mosquito populations has forced attention to alternative methods and integrated schemes in California. Mosquito control experienced a crisis in that state in the early 1970's when encephalitis-transmitting mosquitoes developed resistance to the organophosphorus insecticides used extensively for their control (NAS, 1975). In search of a solution, most of the state's mosquito control agencies accelerated research on developing new control technologies and correcting deficiencies of existing ones. The result is gradual adoption of new control strategies throughout the state.

The shift to IPM is directly reflected in recorded insecticide use by California mosquito control agencies; in 1962, the peak year, 615,000 pounds of insecticides were used, compared to approximately 63,000 pounds in 1976. Much of the reduction is attributed to more judicious and efficient use of chemicals and a shift in oil applications. Instead of applying 20-50 gallons of oil per acre of mosquito-breeding area, control is equally effective at an average 2 gallons per acre. As a result, labor and material costs have been cut and environmental pollution is negligible (Fontaine and Schaefer, 1978).

Ticks

Fairly effective personal protection against ticks is provided by application of repellents to one's skin and clothing. As a precaution against ticks in parks and other recreational areas, mowing of tall grass, which shelters the ticks and their small mammal hosts, has been recommended (Ebeling, 1975). Sporadic applications of insecticides (primarily Gardona) have been made to roadside parks and other areas of frequent recreational use to reduce tick populations. However, there are no major organized tick control programs in the United States (NAS, 1975).

A parasitic wasp (*Hunterellus hookeri*) from France was introduced into Massachusetts in 1926 to control the American dog tick. It significantly reduced the tick population of Naushon Island within one year (Larousse et al., 1928). Biological control agents are not being used to any degree in operational tick control programs.

Black Flies and Other Biting Flies

Control of black flies was originally effected by DDT and other organochlorine insecticides. Currently, the insecticide Abate is used in recreational areas where black flies are a problem. There it is sprayed (usually by aircraft) to control the adult flies, or it is introduced into streams to control the immature forms (USDA, 1976; Jamnback, 1973). Nonchemical methods of control (elimination of breeding sites, use of parasites) are being investigated, but none is employed in operational control programs (Jamnback, 1973).

Control of stable flies, deer flies, horse flies, and biting gnats is limited. The immature stages (eggs, larvae, pupae) of these species exist over large areas, frequently in water, and the adults are strong fliers. It usually is too costly or it is environmentally unsound to apply insecticides over their large habitat areas. Water and land management practices that reduce their numbers are costly and may be impractical. Repellents developed for protection against mosquitoes have some value against these pests (USDA, 1976).

Figure VIII-1 **Components of Integrated Mosquito Pest Management Emphasized by the California Mosquito Control Association (after Mulhern, 1973a)**

Integrated pest management
Inclusive of all known control methodology as applicable

Natural control
Employs various biological and physical factors similar to those found in nature

Biological control (a major element of Natural control)
- Predators, principally fish and aquatic insects
- Parasites
- Pathogens
- Plant inhibitors of mosquito production

Abiotic factors (physical natural forces) which may affect the mosquitoes, the biological enemies, or the sources
- Natural runoff
- Percolation
- Evaporation
- Transpiration
- Turbulence, wave action, currents
- Alkalinity
- Salinity
- Acidity
- Sunlight
- Shade

Physical control (source reduction)—elimination or manipulation of the breeding places
- Water management
  - Regulation
  - Circulation
  - Drainage
  - Reuse
  - Impoundment
- Land preparation and management
  - Filling
  - Grading
  - Draining
- Crop selection and management
- Weed control

Temporary control

Chemical control
- Ovicides or mosquito egg control (not usually practicable)
- Larvicides (smaller areas treated to control mosquitoes which affect larger areas)
- Pupicides to control pupae (infrequently employed)
- Adulticides (particularly useful in emergencies and where larval resistance to chemicals occurs)
- Repellents
- Weed Control
- Growth regulators
- Attractants

Mechanical barriers
- Screens
  - Screening [illegible] buildings
  - Use of temporary barriers as bed nets, mosquito-proof clothing

Landholder motivation to cooperation
- Public information and education
- Individual persuasion and cooperation
- Legal action and enforcement
- Interagency cooperation

Lice

Lice are most likely to spread under unsanitary, crowded living conditions. Frequent bathing and laundering of clothes are largely effective against lice, although once well established, lice may be hard to eliminate (James and Harwood, 1969).

Various insecticides (e.g., Abate, malathion) are sometimes applied under the supervision of health authorities to suppress louse outbreaks in cities. The amount used for this purpose is not known (NAS, 1975). Shampoos, ointments, and lotions containing various insecticides (e.g., malathion, pyrethrins) are available without prescription for personal use against head and body lice (Ebeling, 1975).

Fleas

Rodent fleas are controlled, particularly when plague or murine typhus threaten, by controlling the rodent hosts. Insecticides are sometimes applied in rodent habitats as additional measures.

Flea infestations in homes are nearly always associated with pets. The immature fleas develop in debris found in such places as floor boards. Keeping debris to a minimum is usually effective against infestation in the home (James and Harwood, 1969).

House Flies

In the United States house fly control is achieved principally with insecticides and sanitation practices. Nationwide, an estimated 30 percent of the total control effort directed against house flies and related filth-breeding flies (e.g., little house fly, latrine fly) is noninsecticidal (USDA, 1976).

Sanitation practices such as burying manure, garbage, and other organic wastes or spreading the wastes to facilitate drying are very effective. The use of sanitary landfills in municipal solid waste management programs has greatly reduced fly problems in urban areas. Screening, an effective means of excluding flies from homes and food, is widely used (James and Harwood, 1969; Ebeling, 1975).

A large number and variety of parasites and predators attack house flies and other filth-breeding flies. Some have been used effectively in operational integrated fly pest management programs on poultry farms in California. Flies breeding on poultry and livestock farms can present a real problem for nearby urban areas (Ebeling, 1975).

A variety of insecticides and application methods has been used to control these pests. Slow release devices or strips impregnated with an insecticide (dichlorvos or DDVP and related products) and suspended from room fixtures are effective against flies and some other insects and are popular with homeowners and businesses. Fly baits and sprays are also used by homeowners and businesses. Communitywide aerial spraying of insecticides is sometimes practiced by cities in areas infested with very high fly densities, typical of poultry farms, for example (Ebeling, 1975). There is a need, however, for increased concern about the continuous exposure of the public to such pesticides released in this way.

House flies have shown remarkable resistance to insecticides. In some areas, they can no longer be controlled chemically because of resistance to registered insecticides (USDA, 1976; Metcalf, 1975).

Imported Fire Ants

Of all public health pest control programs the most controversial was the imported fire ant program. In late 1957, the Congress authorized a massive federal-state program to eradicate the fire ant. Control initially involved the insecticides heptachlor and dieldrin, later suspended by the Environmental Protection Agency after laboratory tests indicated that they were carcinogenic. In 1962, the insecticide Mirex was introduced and used.

Three large-scale trials in Georgia, Florida, and Mississippi in 1967 showed Mirex to be effective for control, but eradication of the fire ant was not achieved. The trials also demonstrated important operational and technical problems, among them the inadequacy of survey and detection methods to monitor effectiveness. Later, in 1971, the Department of Agriculture rejected an eradication program for the 126 million infested acres. Its position was based on conclusions that although eradication may be technically feasible, it is no longer a program objective because of "financial and logistical limitations." Although USDA also expressed concern about possible adverse environmental effects resulting from large-scale use of Mirex, the eradication program continued using Mirex (USDA, unpubl.).

In 1971, EPA canceled registration of Mirex. Subsequently registration was reinstated but with severe restrictions, and the federal-state program was limited to areas infested with heavy populations of the ants (Lofgren et al., 1975). EPA has since issued another notice canceling all uses of Mirex as of June 30, 1978.

Mirex baits and chlordane are the only chemicals available for control of imported fire ants. More than 3,000 chemicals have been evaluated, but none has proved effective (USDA, 1976). There has been much effort to find alternative insecticides but little to develop an integrated pest management program.

Major Needs

Development of ecologically sound schemes for controlling arthropod vectors of human diseases will require a long-term program with a much expanded interdisciplinary research effort. Because in all probability no single method alone (with the exception of insecticides) can satisfactorily control the pests in question, integrated schemes must be developed and the organization/agency personnel taught how to effect them. The primary pests to be considered are mosquitoes, ticks, black flies, and fleas, of which mosquitoes have the most potential for spreading a wide range of disease.

Research on Biological and Other Control Methods

Over more than a half-century, a wide variety of biological controls has been studied for use against mosquitoes. The predatory mosquitofish has been used in operational mosquito control programs for decades (NAS, 1975). It remains the chief predatory control although other species of fish, especially killifishes, have been used (Wright et al., 1972).

As a control technique, stocking with mosquitofish is often less costly than repetitive larviciding with oil or insecticides. Several control districts in

California found use of mosquitofish profitable even at the height of DDT's effectiveness and low cost (NAS, 1975).

A variety of mosquito disease organisms, including fungi, nematodes, protozoa, bacteria, and viruses, offer promise in the control of mosquitoes as well as of other medically important arthropods. Some species of nematodes (roundworms) enter the mosquito larvae and kill them. One species has been cultured in large numbers and is in preliminary field testing, providing infection rates ranging from 50 to 85 percent (Chapman, 1974). The bacterium *Bacillus thuringiensis* is especially effective against mosquito larvae, but it is not yet registered for such use. Another bacterium, *Bacillus sphaericus*, has shown promise in experimental studies.

Biological control of public health pests has essentially been limited to mosquitoes and some fly pests. Biological control agents have been identified for many other major public health pests, and some have shown promise on small-scale control attempts. Their full potential is unknown, however, and further development of biological control of the pests will require a significant research undertaking (Bay et al., 1976; NAS, 1975). Two insect growth regulators, Altosid® and Dimilin®, compounds interfering with normal growth, are available for controlling mosquito larvae. The use of these and other insect growth regulators, various genetic controls, and sex attractants have much potential against mosquitoes and other important public health pests. The development and implementation of these alternatives require a major expansion of research efforts at public institutions. Parallel with the increased use of alternatives, improved pest surveillance and increased emphasis on "annoyance" or economic thresholds are required before alternative methods can be integrated into cohesive pest management systems.

Although many traditional chemical insecticides have fallen into disfavor because of mosquito resistance, EPA restrictions, and high costs, chemicals are currently indispensable in mosquito control. There is substantial need for research on selective application techniques with these materials. Repellents are valuable for protection against mosquitoes, ticks, biting flies, and other public health pests and should be further investigated.

Ecological Studies

Knowledge of the pests' behavior and ecology is requisite to successful IPM programs. Lack of this information is currently slowing progress in integrated pest management in much of the public health field.

As more is learned about the ecology of pests of public health importance, control through habitat modification could become increasingly more feasible. Although this approach often leads to permanent control of the pest species, it can have extremely negative impacts on vegetation and wild creatures. All care must be taken to avoid undesirable habitat modifications and to weigh their benefits against their costs and against the costs of alternate solutions. Further investigations of the pests in their natural and manmade environments and of the ecological effects of various habitat-modification procedures are urgently needed.

International Cooperation

There is a pressing need to develop stronger unified programs with medical teams and pest control specialists in other countries, especially the developing countries currently experiencing difficulties with malaria mosquitoes. The recent resurgence of malaria, a disease that appeared to have been conquered a decade ago, is alarming in Africa, Asia, and Latin America. In Pakistan, for example, the number of reported malaria cases rose from 9,500 in 1968 to more than 10 million in 1975 (Anon., 1975). Worldwide, an estimated 1 million people died from malaria in 1976 (information supplied by UN Environmental Programme).

The resurgence of malaria in the developing countries stems partially from the very success of the attempts to eradicate it. After 20 years of concentrated exposure to attack, in some areas the malarial parasite became resistant to what were the most effective antimalaria drugs. Further, more malaria mosquitoes are becoming resistant to insecticides. However, both developments have not yet occurred in the same geographical areas (information provided by UN Environmental Programme).

In some developing countries, the growth of agriculture and insecticide use in agricultural areas has caused malaria to spread. Heavy use of insecticides on cotton in Central American coastal areas has so enriched the mosquito habitat as to result in the evolution of insecticide-resistant malaria mosquitoes. A similar situation is occurring in areas of the Third World where Green Revolution crop varieties have been introduced, stimulating increased use of chemical pesticides (NAS, 1975).

There are many opportunities for the U.S. and the developing countries' scientists and medical teams to cooperate in combating the growing problem of malaria. Besides the obvious humanitarian benefits, cooperative efforts would help safeguard against future malaria problems in the United States.

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Status and Prospects of Integrated Management of Wildlife Pests

Chapter Nine

Agricultural, industrial, and urban encroachment on natural habitats has reduced the populations of many birds, mammals, and other vertebrates. Other wild creatures, finding the habitat alterations to their liking, have established new balances and have substantially increased in density, often in direct conflict with people. In addition, some exotic (foreign) wildlife species introduced into this country conflict with humans, either directly by harming agriculture and public health, for example, or indirectly by competing with native wildlife species.

Types of Vertebrate Pests and Management Problems*

A wild animal that is a pest by one person's judgment may be desirable by another's. The coyote, which the sheep rancher views as a threat, is prized by the pleasure coyote hunter and may have aesthetic value to the naturalist. What one person considers a trash fish, for example, the carp, may be sought by another for sport or food. Thus, control of wildlife "pests" is a subjective matter. Pest situations can become conflicts when they bring these divergent views together.

Pest situations involving wildlife species are not only controversial but also diverse, spanning the range of vertebrates.

Small Mammals

Small mammals, rodents, bats, hares, rabbits, and some carnivores (meat-eaters), are involved in a variety of pest situations. Rodents comprise the largest group, frequently creating problems in orchards, crops, rangelands, forests, homes and other buildings, ships, and recreational areas. Orchards, cultivated crops, and home gardens are damaged by native rats and mice, squirrels, woodchucks, pocket gophers, raccoons, and rabbits (Table IX-1). Occasionally they cause heavy losses in individual orchards or fields in a given region, but they seldom require large-scale control campaigns.

Forests everywhere are subject to injury by small mammals. Loss of tree seed is the least apparent form of damage but is one of the most serious problems. Millions of acres of artificially and naturally seeded forest lands fail to regenerate because of seed lost to various species of mice, chipmunks, squirrels, and birds. Seed caching by rodents; rodent damage to newly emerged seedlings; clipping and browsing damage to established seedlings by rodents, rabbits, and hares; and bark injuries by meadow mice, porcupines, beavers, squirrels, rabbits, hares, and pocket gophers can all result in heavy losses. Small mammal pests also include several very serious exotic species (e.g., nutria) which displace or attack native animals or inflict damage to agriculture (NAS, 1970).

Big Game Animals

"Big game" refers to the large wild herbivores (plant-eaters) which are hunted for sport. Usually hoofed, they include deer, pronghorn, moose, wild goats, and wild and feral pigs. In the United States, these animals legally belong to the citizens of the particular state in which they are found, and thus their conservation and management are a function of state government (NAS, 1970).

Competition between big game and domesticated livestock occasionally reaches a level at which the livestock operator suffers significant economic loss. Principal examples are elk and cattle in the northern Rockies, mule deer and sheep in the central Rockies and Great Basin, and white-tailed deer, sheep, and goats in Texas (NAS, 1970). White-tailed deer may seriously damage small orchard trees, and several North American big game, particularly deer, severely damage young timber trees by nipping terminal buds or by stripping the bark. Some also damage cultivated crops, especially when the fields are small and are in close proximity to big game cover.

Some big game animals serve as reservoirs for parasites and diseases that affect other big game species, livestock, or human beings. For example, of the 66 or more known parasites of white-tailed deer, at least 36 are transmissible to domestic livestock (NAS, 1970).

Nationwide, perhaps the greatest conflict between people and big game animals is motor vehicle

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*See Chapters VI (p. 61) and VII (p. 73) for discussion of other vertebrate pest problems.

Table IX-1 **Small Mammal Damage to Orchards and Cultivated Crops (compiled by NAS, 1970, after Eadie, 1954)**

Animal	Problem	Current controls
Meadow mice	Remove bark in orchard trees; destroy vegetable and forage crops	Poison baits, habitat control, traps, mechanical and chemical repellents
Pine mice	Eat roots and bark from orchard trees; damage root crops, bulbs, and seeds	Poison baits, habitat control, ground sprays
Muskrats	Damage gardens, pond dikes, and irrigation ditches	Traps, poison baits, dike barriers
Cotton rats	Destroy sugar cane, cotton, truck crops, grain, and planted seeds	Poison baits, seed repellents
Rice rats	Attack vegetable crops cotton, rice, fruit trees	Poison baits, habitat control
White-footed mice	Destroy planted seeds, corn in shocks, standing grain in field borders	Poison baits, seed repellents, modified farming practices
House rats and house mice	Destroy and contaminate stored fruits, vegetables, and grain; damage sugar cane and other field crops	Rat-proofing storage areas, poison baits, traps, fumigation
Kangaroo rats and pocket mice	Eat range forage and seeds; damage contour dikes in irrigation	Poison baits, modified range management, seed repellents
Ground squirrels and chipmunks	Damage or destroy vegetables, grain, forage plants, nut and fruit trees, seeds, bulbs	Poison baits, fumigation, traps, habitat manipulation, repellents
Woodchucks (marmots)	Destroy gardens and field crops; burrows and soil mounds affect harvesting and irrigation structures	Poison baits, fumigation, trapping, shooting
Tree squirrels	Damage garden crops, nuts, and fruits	Trapping, shooting, mechanical repellents
Pocket gophers	Destroy root crops, range forage; damage orchard trees, underground cables, irrigation structures	Poison baits, traps, habitat manipulation, herbicides
Cottontail rabbits	Damage fruit trees, gardens, tree nursery stock	Repellents, fences and tree guards, trapping, shooting
Hares and jackrabbits	Damage fruit trees, range forage, garden crops	Repellents, poison baits, shooting, fences and guards, trapping
Raccoons	Destroy garden crops, especially corn	Shooting, trapping, electric fences

collisions with deer, and the most dangerous situation is the high-speed highway running through heavy vegetation harboring large populations of deer. During the 4 years 1963-66, an estimated 404,100 deer-automobile collisions resulted in about 10,000 human injuries and in over $100 million in property loss and medical costs (NAS, 1970). Fortunately, few human deaths resulted.

Predatory Animals

Wherever there is a pastoral industry, conflicts with predators arise. In the United States, problems arose with the settlers. The first bounty law was passed by colonial lawmakers of Massachusetts in 1630 (Cain, 1971). Bears, lions, wolves, coyotes, and eagles preyed upon the pioneers' livestock, especially the kids, lambs, and calves and the sick, injured, and strayed. Except for the coyote, the number of these large predators has been greatly reduced.

The sheep industry is hit hardest by predation, but there are also losses in calves, small pigs, goats, and poultry. The coyote is the single most important predator, and it is the principal target of organized predator control, primarily on western rangelands. In some years individual sheep producers suffer severely from predation by the coyote (and to a lesser extent, the eagle). Sheep herds in the western United States are larger than those in the East and are often pastured on more open range where exposure to coyotes is greater.

Estimates of sheep losses from coyote predation vary considerably. They should be viewed with some reservation because they are based on interview data and not on mortality statistics (Cain, 1971). In a recent Department of Agriculture report, predators, principally the coyote, were listed as the major cause of sheep losses in the western states. In [illegible] coyotes killed an estimated 728,000 lamb [illegible] 229,000 adult sheep, representing about one-[illegible] and one-fourth, respectively, of the total lamb and adult sheep losses in those states. The losses cost sheep producers an estimated $27 million in 1974 (USDA, 1977). Some losses would have occurred in the absence of predators. Overgrazing weakens some of the animals, causing them to die prematurely for other reasons (Cain, 1971; Evanson, 1967).

Wolves, puma, and bears still prey on livestock where their ranges overlap those of domesticated animals, but losses by these predators are very small except locally. Skunk and raccoon predation on poultry and gamebirds varies widely in location and intensity; the same is true for otter and mink predation on fishery resources. The predators occasionally kill poultry, young farm animals, and game animals, but their primary diet is field rodents (NAS, 1970). Other primary predators of domesticated animals are shown in Table IX-2.

Fishes

Some species of freshwater and marine fishes interrupt commercial and sport fishing and damage fish and waterfowl habitats. Some sharks cause heavy losses by biting and tearing trawl nets and other commercial fishing gear; the small spiny dogfish shark is probably the most destructive saltwater fish pest. Abundant in the North Atlantic and North Pacific during the summer, this pest damages nets and lines, eats catches in the nets or on the lines, and drives shoaling food and game fishes from fishing grounds (NAS, 1970).

In freshwater the sea lamprey is probably the most destructive. This pest invaded the Great Lakes in the 1940's, harming the trout and whitefish, which are important to both commercial and sport fisheries. The U.S. and Canadian governments initiated a major eradication campaign, using chemicals and electric control devices in lamprey breeding habitats. However, the pest was not eradicated and continues to cause great losses to the Great Lakes fishery (NAS, 1975).

Alewives (another Great Lakes pest), carp, goldfish, and gars are among the other most serious pests of freshwater environments. More than 30 other freshwater species prey on fish sought for human food, compete with these desirable species, serve as alternate hosts for parasites of edible species, and prey on cultured shrimp, for example (Table IX-3).

Amphibians and Reptiles

North America has relatively few species of amphibians (e.g., toads, salamanders) and reptiles (e.g., snakes, turtles, lizards) compared to tropical regions of the world. Problems with these organisms are also few by comparison, and rarely do they conflict with the interests and welfare of people.

No amphibians seriously harm humans by biting, and all but a few species are always beneficial, feeding on insects and other small organisms. Two introduced species, the African clawed frog and the giant or marine toad, are competitors with some small native vertebrates.

Alligators in parts of the southern United States and crocodiles in Florida occasionally disrupt recreation areas by scaring people, or they crawl into towns or onto airstrips where they are a nuisance, but they cause little harm to human welfare (NAS, 1970).

Birds

Many bird species feed on agricultural crops, roost in cities and other places where they are not wanted, and interfere with air travel. Economic losses are usually concentrated in limited areas or single holdings. A 1967 estimate showed annual crop loss at between $50 and $100 million (Miller, 1967).

A major bird problem occurs in the cereal grain-growing areas of the Canadian prairie provinces and the northern U.S. prairie states where waterfowl breeding marshes are adjacent to grain fields. The grain harvest coincides with the joining of young and adult ducks for the southward migration. Losses to the grain crop have been so severe that major relief and organized control have been undertaken (NAS, 1970).

Soft fruits are particularly vulnerable to some birds, and bird depredations may be the chief limiting factor in the production of cherries, grapes, blueberries, strawberries, and tomatoes in localized areas.

In western feedlots starlings and blackbirds consume so much cattle feed that serious losses may occur. Invasion by millions of birds has created very serious problems to crops and to people in Kentucky and Tennessee, where redwing blackbirds, common grackles, brown-headed cowbirds, and European starlings roost in trees. The malodorous layer of their fecal material is a medium for growth of the fungus that causes the human lung disease histoplasmosis. Incidence of the disease has apparently increased locally along with the increased number of blackbirds, and several cases have been fatal (USDI, 1974-1975; McElwain, 1976).

A 20th century development is human competition with birds for air space, and collisions have resulted in both human death and costly damage to aircraft. In 1960, for example, an airliner crashed at Boston's Logan Airport after flying into a flock of starlings; 62 people were killed. Collisions have also occurred with gulls, sandhill cranes, whistling swans, herons, and geese (NAS, 1970; Murton and Wright, 1968).

House sparrows, pigeons, and starlings are a common nuisance in urban areas. Pigeon and house sparrow nests may be fire hazards in wooden structures, and they may create maintenance problems by obstructing water downspouts, for example (NAS, 1970).

Table IX-2 **Primary Predators of Domesticated Animals (compiled by NAS, 1970, from information supplied by Milton Caroline)**

Species	Prey	Time	Degree
Coyote	Sheep, lambs, goats, and kids	All year	Moderate to severe
	Calves	All year	Slight to moderate
	Poultry and big game (young)	All year	Slight
	Melons	Spring	Slight
Wolf (red)	Calves	Spring	Slight
Wolf (gray)	Livestock	All year	Slight
	Big game	All year	Moderate
Fox (gray)	Lambs, kids, and pigs	Fall, winter, spring	Moderate
	Poultry	All year	Slight
Wolverine	Trapped fur animals, trappers' caches	Fall, winter	Slight
Bear (grizzly)	Sheep and livestock	Summer, fall	Moderate (drought)
Bear (black)	Sheep	Summer, fall	Moderate (drought)
	Pine seedlings	Spring, summer, fall	Slight
	Apiaries	Spring, summer, fall	Slight to moderate
	Orchards	Fall	Slight to moderate
Raccoon	Lambs, kids, poultry, truck crops	All year	Moderate
	Ground and tree nesting birds	Spring, summer, fall	Slight to moderate
	Stored grains	Fall, winter	Slight to moderate
Weasel	Poultry	All year	Slight to moderate
Mink	Poultry	All year	Slight to moderate
Skunk	Poultry	Spring, summer, fall	Slight to moderate
Badger	Poultry and lambs	Spring, summer, fall	Slight
River otter	Fish (hatcheries)	All year	Slight
Mountain lion	Sheep and lambs	All year	Moderate
	Goats, kids, horses, colts, big game	All year	Slight
	Livestock	Unusual	Slight
Bobcat	Lambs	Spring, summer	Slight to moderate
	Kids, poultry	All year	Slight to moderate
	Big game (young)	Spring, summer	Slight to moderate
Jaguar	Livestock	All year	Slight
Ocelot	Lambs and kids	Spring, summer	Rare

Table IX-3 **Freshwater Fish Pests (NAS, 1970)**

Species	Problem	Loss	Location	Season
Sea lamprey	Predation on food fish	$8 million per year	Upper Great Lakes	All year
	Predation on food fish	Economic	Chesapeake Bay	Winter
	Predation on food fish	Salmon	Maine	Spring
Longnose gar	Predation	Game fish	Eastern, southwestern United States	All year
Shortnose gar	Predation	Game fish	Eastern, southwestern United States	All year
Alligator gar	Predation	Game fish	Southern United States	All year
Bowfin	Predation	Game fish	Northeastern, southeastern United States	All year
Alewife	Abundance, die-offs	Economic, nuisance	Great Lakes	Spring
	Clogs intake lines	Nuisance	Chicago, New York	Spring
Gizzard shad	Abundance, competition	Game fish	Oklahoma	All year
Brown trout	Competition	Game fish	California	All year
Dolly Varden trout	Predation	Salmon	Western Canada, Alaska	Summer
Brook trout	Disease carrier	Hatchery fish	Canada	All year
Chain pickerel	Predation	Trout	Maine	All year
Northern pike	Predation	Trout	Canada	All year
	Predation	Ducklings	Canada	Summer
	Host for tapeworm	Cysts in whitefish	Manitoba, Alberta	All year
Stoneroller	Competition on redds	Spawn of rainbow trout	Great Smoky Mountains National Park	Spring
Goldfish	Competition	Trout	California	All year
Carp	Competition, destroy habitat	Game fish, waterfowl, water quality	United States, Canada, Victoria, Australia	All year
Hitch	Competition	Trout, bass	California	All year
Sacramento squawfish	Predation	Pacific salmon	United States, Canada	Spring, summer
Northern squawfish	Predation	Pacific salmon	United States, Canada	Spring, summer
White sucker	Competition	Game fish	United States	All year
Longnose sucker	Competition	Game fish	Canada	All year
Largescale sucker	Competition	Game fish	United States, Canada	All year
Catfish spp.	Clog water lines	Economic	Texas, Missouri	All year
Walking catfish	Predation	Game fish	Florida	All year
Black bullhead	Competition	Game fish	Southern United States	All year

Table IX-3 **Freshwater Fish Pests** *(continued)*

Species	Problem	Loss	Location	Season
American eel	Competition	Trout	Eastern Canada	All year
	Clog water lines	Economic	New York, Nova Scotia, Massachusetts	Autumn
Japanese eel	Predation	Cultured shrimp	Taiwan	All year
Mosquitofish	Predation on spawn	Cultured carp	India	Summer
Green sunfish	Predation	Game fish	Southern, western United States	All year
Pumpkinseed	Competition	Game fish	Eastern, midwest United States	All year
Bluegill	Stunting	Game fish	California	All year
Largemouth bass	Exotic	Native fish	South America, East Africa	All year
Yellow perch	Predation	Game fish	Michigan, Wyoming	All year
	Competition	Game fish	Wisconsin	All year
	Stunting	Game fish	New Hampshire	All year
Freshwater drum	Competition	Game fish	Wisconsin	All year
Coastrange sculpin	Predation	Pink salmon	Alaska	Summer
Torrent sculpin	Predation	Coho salmon	Washington	Summer

Special Problems with Exotics

In the past 150 years, many wildlife species have been introduced into the United States either accidentally or intentionally. Some are detrimental to public health, agriculture, and native wildlife and remain among the nation's most serious vertebrate pests (Table IX-4). Like the serious agricultural insects, weeds, and plant diseases of foreign origin, these alien organisms reproduced freely in this country in the absence of the biological controls and other natural constraints that kept them in check in their native lands. In addition to their economic and control costs, exotic species compete with native wildlife, sometimes destroying habitat.

Recent action taken by the President (Executive Order 11987, May 24, 1977) to restrict the introduction of exotic animals and plants into natural ecosystems of lands and waters managed by the federal government will help safeguard against increasing problems with exotic species. Nevertheless, many species already established in this country will continue to present perplexing problems.

Current Control Practices

Most wildlife pests have been approached with borrowed technology developed for agricultural pests. Prior to development of the compound TFM, specifically designed as a lampricide in the 1960's, for example, chemical control of undesirable fish was accomplished by insecticides such as rotenone, endrin, and toxaphene. But often a problem is so unique that special control technologies must be developed (NAS, 1975).

Much of the research on control of wildlife pests has entailed a narrow, unilateral approach to population destruction by single methods such as chemical toxicants, trapping, and repellents rather than an integrated management approach entailing a thorough ecological, behavioral, and physiological assessment of the pest and the problem (Howard, 1966, 1967; McCabe, 1966). Sometimes a single preventive or reductional method may correct a problem with no harm to the environment, for example, fencing to exclude deer and other large mammals from gardens, orchards, and game management areas. Trapping may be all that is required for occasional foxes in small areas where poultry is being raised on the open range.

Few long-term solutions for wildlife pests are provided by the single-method approach, and it has created many unexpected problems. Use of the poison Compound 1080 (sodium monofluoride), thallium, and sodium cyanide for coyotes provoked public furor over potential environmental hazards. The materials were canceled as predator controls by

Table IX-4 **Selected Pests Introduced from Foreign Countries (from Lawless and von Rümker, 1976)**

Introduced species	Method of introduction		
	Accidental	Biological control agent	Other
Black rat	Arrived from England 1609		
Burros	Escaped from domesticated herds 1800		
Feral hogs	Domesticated hogs which escaped		
Norway rat	Arrived from England 1778		
Nutria	Escaped from a furrier in Louisiana circa 1930		
House sparrow		Several pairs brought to control the linden looper circa 1850	
Carp			Introduced as a game fish circa 1850
Starling			Forty pairs brought from England were released 1890
Walking catfish	Brought by the aquarium trade circa 1967		

the Environmental Protection Agency in 1972. Subsequently sodium cyanide was reregistered for use against predators of livestock and poultry.

Other controversial control measures were the airplane gunning of coyotes, eagles, and wild horses and the dynamiting and gunning of bird roosts. Use of broad-spectrum insecticides and other toxicants to destroy rough or trash fish has also been challenged by the public because of serious ecological disruptions.

Opportunities for Integrated Pest Management

Increasingly, the problems have led pest control and game management specialists to seek integrated management approaches, with emphasis on finding environmentally sound control methods. Although the concept of integrated pest management has not advanced far in the field of wildlife, there are many opportunities for applying experience from other areas to numerous wildlife pest categories.

Small Mammals

Habitat management is the key to correcting most small mammal problems. It has been successful many times. In orchards, for example, cultivating to remove weeds and debris from around the trees usually eliminates problems with bark-eating meadow mice, but this practice may not be possible where sod is maintained. Even where sod is not maintained, complete removal of weeds and debris may be undesirable because in winter they shelter some enemies (e.g., predatory mites that prey on mite pests of apple foliage, Croft, 1975). Protective metal or wire barriers affixed to the trees combined with chemical removal of vegetation immediately surrounding the trees may be more desirable than cultivating the entire orchard (NAS, 1970). As shown in Table IX-1, a variety of nonchemical methods is available for common small mammal pests.

A very effective integrated program was developed for the muskrat in Arkansas (Miller, 1974). This native animal is distributed throughout most of the

United States. Since World War II crop acreage in bottom land along streams where the animals live has increased, thereby increasing muskrat damage to rice crops and fish culture in managed ponds. An organized muskrat management program administered by the Arkansas Cooperative Extension Service was initiated in 1967. Designed to teach farmers to manage their own problems, it emphasized the point that muskrat eradication was not feasible and recommended only those techniques known to present minimal damage to humans and other nontarget organisms: habitat alteration, including control of cattails (muskrat food) around farm ponds, use of a conibear trap in ponds and other waters inhabited by muskrats (the trap is considered humane and is simple to use), and placement of "lollipops," bait containing rolled oats mixed with the chemical poison Pival, near the pest's habitat.

The program was accepted by Arkansas farmers and proved to be extremely cost effective. In the 20 counties affected, crop damage by muskrats dropped from an estimated $900,000 in 1967 to less than $20,000 in 1970. Although the integrated program does rely on a chemical poison, chemical control is only one component (Miller, 1974). Investigation of muskrat ecology and behavior and research on additional alternatives may lead to reducing dependency on this chemical.

Big Game Animals

Controlling a big game population is often a function of recreational hunters. Success varies according to species, particularly with regard to how easy it is to hunt and how attractive it is to the hunter. At one extreme, the pronghorn is quite easy to control by manipulation of hunting pressure, and the elk is kept almost stable by hunting. At the other extreme, stabilizing the mule deer population would require an estimated doubling of the present annual kill by hunters (NAS, 1970).

Direct control methods for big game or any other animal offer only temporary relief, however, and they must be applied continuously and usually over a very large area in order to be effective. Research has been conducted on chemical inhibitors of reproduction as an alternative to such direct controls of big game as hunting, but there is no practical application available. The size of the offending animals and their large territories often make physical control (e.g., fencing) too costly and impractical. Better methods are needed to deal satisfactorily with the special big game problems for which hunting is not a solution and there are no good alternatives.

Predatory Animals

Predator management specialists use several criteria for evaluating various predatory animal controls, as illustrated in Table IX-5. The extent to which a control meets these essential criteria depends in part on the skill and effort of the users. For example, trapping can be a selective and humane method of capturing individual predators, but when some kinds of traps are used and they are not checked daily, unwarranted suffering of the trapped animals results. If used improperly, the traps may also cause harm to beneficial nontarget species.

The "Extension trapper system" of Kansas, patterned after an earlier program in Missouri (Sampson and Brohn, 1955), is a successful predator management system employing selective trapping techniques carried out by farmers and ranchers. It has effectively reduced the coyote problem in much of Kansas without using poisons. The "Conservationist of the Year" award was presented by the Kansas Wildlife Federation to the Kansas Cooperative Extension Service for its efforts in the coyote management program (Henderson, 1972).

The Kansas program emphasizes use of coyote-proof fencing, housing, and other procedures that individuals can employ to avoid predation combined with selective trapping. The program strives to teach livestock owners that damage is caused by a relatively small portion of the total predator population. The educators' role is to help owners locate the relatively few problem predators and to take the most effective steps to stop them.

One state wildlife specialist and the county agricultural agents have distributed educational materials to the livestock owners and have shown them how to use the traps employed in the program. In 1975-76, an estimated 52 percent of the livestock owners who requested training assistance stopped all losses caused by coyotes. Sheep producers reduced sheep losses by 79 percent compared to previous years. Calf losses were reduced 76 percent; swine losses, 89 percent; and poultry losses, 53 percent (Anon., 1977).

Of the livestock owners who received training through the Kansas Extension trapper system, 42 percent showed other livestock owners how to correct their predator problem, thus contributing to the program's effectiveness. The program cost Kansas taxpayers $40,000 in 1976, a low figure relative to less effective programs in other western states (Anon., 1977). Although a management program based on the one in Kansas may not be as successful where the livestock herds are much larger, are kept on more open terrain, and are subject to heavier predator pressure, the program has potential in many areas of the United States.

A potentially significant development in predator management is a special electric fence which generates a shock that repels but does not harm coyotes, dogs, sheep, or people who brush against it. It has been 100 percent effective in protecting sheep from coyotes. The design originated in Australia and was refined and tested in Idaho by the Department of

Table IX-5 **Evaluation of Predatory Animal Control (Cain, 1971)**

Technique	Effectiveness[1]							
	Prophylactic	Trouble-shooting	Economy	Safety (man and livestock)	Selectivity (takes only target species)	Specificity (takes only offending individuals)	Humaneness	Lack of environmental impact
Aerial shooting	+	+ + +	-	+ + +	+ +	+	+?	+ + +
Ground shooting	-	+ +	+	+ + +	+ +	+ +	+?	+ + +
Den hunting	-	+ +	+	+ + +	+	+ +	-+	+ + +
Steel trap	+	+ +	+ +	+ +	-	+	+ +[2]	+ + +
Cyanide guns	+ +	-	+ +	-	-	+	+ +	+ + +
Poisons								
Strychnine	+ + +	+	+ + +	-	-	-	--	+?
Thallium	+ + +	+	+ + +	-	-	-	-	-
1080	+ + +	+	+ + +	-	-	-	-	-
Zinc phosphide	+ + +	+	+ + +	-	-	-	-	+
Starlicide	+ + +	+	+ + +	-	+	-	+ +	+ +
Gophacide	+ + +	+	+ + +	-	-	-	-	-
Reproductive inhibition	+ +		+ +?	+ + +	+	-	+ + +	+ +
Live trap and transplant	-	+ +	-	+ + +	+ +	+ +	+ + +	+ + +
Repellents	-	+ + +	?	+ + +	+ + +	+ + +	+ + +	?

–	Very bad
-	Poor
+	Fair
+ +	Good
+ + +	Very good

[1] Effectiveness is highly subjective. Highly effective methods tend to be nonspecific, hence are judged on basis of general control. Ineffective methods may be very efficient at removing specific animals.

[2] Steel traps properly used are humane; improperly used are inhumane.

Agriculture. The fence costs considerably less than the sheep fences now in use, and it can be powered by a small wind charger. In addition to repelling predators, the new fence confines sheep and other livestock. It could provide immediate protection to approximately 55 percent of the U.S. sheep population (Cutler, 1977).

Fishes

Fish toxicants have been used extensively on undesirable species in ponds, lakes, and streams for 60 years. Most were broadly toxic, affecting both target and nontarget fish species and many aquatic invertebrates. Currently, four fish toxicants are registered with EPA: antimycin and rotenone as general toxicants and TFM and Bayluscide® for lampreys. When used in small closed bodies of water, such as ponds, they may reduce the pest populations to acceptable levels for several years.

TFM and antimycin exhibit relatively high levels of selectivity. TFM has been used to control the sea lamprey in the Great Lakes with apparently only minor effects on nontarget fishes. Antimycin, if used in very low concentrations, is effective against several species of problem fishes (NAS, 1970). The two materials have only limited application, however, because they do not affect the vast majority of problem fishes. Further, with industry's lack of interest, prospects for additional selective fish toxicants are not promising.

Some of the alternative methods that have been used against various fish pests and their relative levels of success are listed in Table IX-6.

Among the earliest methods were biological controls. Large predatory fishes have long been stocked to reduce unwanted populations, but with relatively few successes (NAS, 1970). Compared to development of chemical toxicants, biological control efforts have been minor, and no major attempts have been made to seek biotic agents for some of the most serious introduced freshwater pests. Introducing a specific biological control agent from a pest's native habitat appears to have promise in terms of its being specific to the target pests. Ecological studies of introduced problem fishes and their natural enemies in their native habitats should pay high dividends.

Dams, weirs, and diversions are effective in denying some undesirable fishes access to given waters. Other physical control methods employed with varying degrees of success include seines, trap nets, gill nets, explosives, manipulation of water levels, and light and sound devices to attract or repel (NAS, 1970, 1975).

Various electric devices have been used against problem fishes in both freshwater and marine environments for several decades. Electric shocking devices temporarily stun the fish, forcing them to the surface where they can be collected. Electrobarriers installed in streams to prevent upstream spawning migration have been used against the sea lamprey. These and other electrical devices in conjunction with chemical control of the young have been effective against this pest (NAS, 1970). Although some fish management specialists believe that electrical control methods can be developed for many problem fishes with minimal hazards to humans and other nontarget organisms, fear and high costs deter their development.

Present fish control efforts are relatively unsophisticated, depending largely on pesticides, and for many fish problem situations there simply are no solutions in sight (NAS, 1970).

Birds

Two general approaches may be taken to bird problems: first, direct control by trapping, shooting, biological control, dynamiting roosts, using repellents, poisoning, inhibiting reproduction by chemical means, and frightening and, second, indirect control through habitat modification (destruction of feeding, breeding, or nesting habitat) or resource protection (shielding plants, using bird-resistant crop varieties, or using screens to prevent entry). With the possible exception of biological control agents which reproduce on or inside their hosts, direct controls always provide only temporary relief, and they have to be applied continuously if the problem involves birds established in a given location or recurring flights or migrants returning to a given location.

Poisons often cannot be used because of legal constraints or because of public refusal to destroy birds chemically. Numerous repellents, reproductive inhibitors (chemical sterilants), and fright-producing chemicals have been used on a small scale. The repellent methiocarb is a potent emetic, recently registered under the name Mesurol® for use on field corn, sweet corn, popcorn, and cherries (see Chapter IV, p. 42). Sticky repellents have been used to keep roosting birds off sheltered edges of buildings, but sometimes these compounds deface the buildings more than the birds do (NAS, 1970).

Noise, light moving objects, and electrical shocking devices have been used with mixed success. The birds' habituation to sounds (or their inability to hear) and to moving devices limits the usefulness of most fright techniques (Frings and Frings, 1967; Howard, 1967).

Attempts at biological control of birds have been few and discouraging. But because the number of debilitating bird diseases is quite large, use of bird-disease organisms from the pest's native regions may have potential against some exotic bird pests. However, introduction of a contagious or infectious disease may be hazardous to humans, domestic animals, and nontarget birds, narrowing the possibility of this approach to a few special cases (Howard, 1966).

Development of bird-resistant crop varieties has great potential, especially against birds which feed on cereal grains, but it is not being pursued to any degree (Howard, 1967; NAS, 1970). Many cultural practices may also reduce bird damage; deep planting of the crop seed often reduces loss of sprouted seed. Delaying planting until after the birds' seasonal migration, timing the planting so that the crop matures when natural foods are abundant, and using quick-ripening varieties of grain reduce the period of time when the crops are exposed to bird attack (Buckley and Cottam, 1966). Feeding programs on migratory bird refuges, aimed to divert migratory populations from surrounding agricultural areas, have helped reduce waterfowl damage to some crops. Extensive thinning of the trees at roosting sites offers some degree of permanent starling control in towns. Sanitation around warehouses, grain elevators, and other commercial establishments is very effective in correcting problems with house sparrows (NAS, 1970).

Since the 1960 plane crash at Boston noted earlier, much emphasis has been placed on managing birds around airports through habitat modification (Murton and Wright, 1968; NAS, 1970). Low, flat areas ideal for airports are frequently associated with water or marshland vegetation, which may be the breeding or roosting sites of large water birds or of smaller flocking or perching birds. In these areas, surface water is sometimes drained from ponds and associated marshland to eliminate roosting places, but at the expense of valuable wetlands. Where crops are grown near airports, those that attract large numbers of birds are to be avoided (NAS, 1970).

A fairly effective way to reduce air strikes is to avoid the times and places where encounters are likely (Murton and Wright, 1968; NAS, 1970). The use of radar and closed-circuit television to determine location of bird flights or concentrations will aid in avoiding flight paths and movement patterns of potentially dangerous birds (NAS, 1970).

Although there have been few efforts to integrate the promising and ecologically acceptable techniques into a management program for a serious bird

Table IX-6 **Evaluation of Fish Control Methods (NAS, 1970)**

Species	Control program	Success[1]
Sea lamprey	Mechanical weirs	+
	Electromechanical weirs	+ + +
	Barrier dams	+ + +
	Downstream traps	+ + + +
	Selective toxicants	+ + + +
Man-eating sharks	Explosives	–
	Shark fences	+
	Patrols, watches	+ +
	Repellents	+
Spiny dogfish	Increased exploitation	–
	Explosives	–
Gars	Seining	+
	Explosives	+
	Electrofishing	+
	Toxicants	+ + +
Indian tarpon	Toxicants	+ + +
	Water level manipulation	+
Alewife	Increased exploitation	+
	Stock predator fish	+ +
	Curtain of air bubbles	+ +
	Barrier nets and screens	+ +
Gizzard shad	Toxicants	+ + +
Dolly Varden trout	Bounties	–
	Weir-trapping	+ +
	Gillnetting	+ + +
Piranha	Warning service	+ +
	Toxicants	+ + +
Carp	Commercial exploitation	–
	Electrofishing	+
	Water level manipulation	+ +
	Netting	+ + +
	Toxicants	+ + + +

Table IX-6 **Evaluation of Fish Control Methods** *(continued)*

Species	Control program	Success[1]
Squawfishes	Explosives	+
	Toxicants	+
	Gillnetting	+ + +
Suckers	Toxicants	+ + +
Bullheads	Toxicants	+ + +
	Water level manipulation	+ + +
Catfish (*Clarius* sp.)	Toxicants	+ + +
Candiru	Protective sheaths	+ +
American eel	Barrier weirs	+
	Baited traps	+
	Screens on intake lines	+
Sunfishes	Toxicants	+ + +
	Water level manipulation	+ +
Largemouth bass	Toxicants	+ + +
Yellow perch	Toxicants	+ + + +
Snakeheads	Toxicants	+ + +
Striped mullet	Toxicants	+ + +
	Water level manupulation	+ +
Puffers	Regulations, inspection	+ + +
Parasitized freshwater food and game fishes	Cook fish thoroughly, prevent raw sewage in water, poison infected snails and fish	+ + + +

++++ = Highly successful, ranging to –, unsuccessful

[1] Success of control is more often estimated than assessed.

pest or bird pest complex, the potential appears high for many agricultural and urban situations.

Quite a different approach to agricultural losses caused by birds is pest-specific risk insurance against heavy financial losses inflicted by migratory fowl. Provincial governments in Canada, for example, have provided crop loss insurance to grain farmers in areas near waterfowl breeding marshes where heavy grain losses often occur. There are no control measures effective with this pest problem; hence, the insurance program is the only means for averting severe monetary losses to the farmers (NAS, 1970).

Research Needs

Integrated management of many wildlife pest species is hampered by lack of knowledge of their behavior, physiology, ecology, and dynamics. Management of these organisms must be based on regulation of population levels, not necessarily on destruction of individuals, which has been heavily emphasized in many past control efforts. This approach requires a research input that appears lacking in existing programs (NAS, 1975). For exotic species, the ecological and biological investigations will necessarily take place in the lands of their origin.

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Part Four

Obstacles to Overcome

Constraints and Limitations

Chapter Ten

As illustrated by the many examples in the preceding chapters, integrated pest management promises cost-effective, environmentally sound solutions for a wide variety of pest problems. Yet IPM is not being used extensively in agriculture, forestry, urban areas, the public health sector, or any other sector.

Even on agricultural crops where IPM has progressed furthest, there are few truly operational IPM programs. As discussed in Chapter V (p. 50), a high percentage of one or more crops in a given region may now be scouted routinely by Cooperative Extension personnel or by private consultants. These individuals regularly check the crops for various pests and offer information on pesticide use, such as selection of a chemical and dosage and timing of application. They may also advise, for example, on crop variety selection, crop seeding rates and timing, fertilizer use, and irrigation scheduling—all of which are important to integrated pest management. However, research scientists have not even begun to collect the information and perfect the control and pest monitoring techniques required for integrated management on many crops.

Although research in integrated pest management has been vastly expanded in recent years, much greater effort is needed (Glass, 1975). This research must embrace the coordinated efforts of scientists from economics, agronomy, plant physiology, entomology, weed science, nematology, plant pathology, ecology, engineering, mathematics, computer science, and perhaps other disciplines. Coordination is critical to integration of the research results. The use of systems analysis, discussed in Chapters III (pp. 21-23) and V (p. 55), is valuable in unifying the interdisciplinary research efforts and will certainly play an increasing role in IPM research (Huffaker et al., 1978).

The lack of understanding and support for interdisciplinary research projects and companion educational and demonstration programs at the public institutions is a major impediment to IPM. Researchers, educators, and administrators who understand the concept—that is, who are well informed in ecology, systems science, and allied biological sciences that are the backbone of the IPM strategy—are a distinct minority. Furthermore, the public agricultural research and extension institutions are frequently required to produce quick, simple answers to complex problems that are not well understood because of pressure from commodity groups or from elected federal and state officials. As a result, vast research and extension efforts are expended in frantic attempts to solve pest problems instantly. Integrated pest management technology develops slowly, usually step by step, and it is shunted aside when solutions must be developed quickly (Luck et al., 1977; Flint and van den Bosch, 1977; Glass, 1975).

Even when an IPM strategy exists, it is often extremely difficult to sell to farmers and others who are accustomed to the simpler chemical control strategy. These individuals must first be shown that the IPM strategy will adequately control the pests at lower costs than those for chemical control. Then they must be taught how to acquire and apply information necessary to IPM implementation. Many IPM systems can be implemented by farmers, livestock owners, and homeowners although initially they may feel awkward in doing something new. For this reason individuals may continue using a chemical control until they have been instructed on how to use an IPM alternative even though the latter may be less costly and more effective.

An additional impediment to the adoption of existing IPM systems involves the agriculture loan requirements of some financial institutions. As a condition of obtaining a loan, some farmers are apparently required to agree to follow a "spray schedule"—the routine application of pesticides to a crop regardless of whether the pest population has exceeded its economic threshold. Although an IPM alternative may be less costly and more effective than such a conventional strategy and may be a more prudent approach to crop protection by being sufficiently flexible to deal with unforeseen contingencies, financial institutions making agricultural loans have not been sufficiently encouraged to examine the potential adverse financial effects of current loan requirements.

Pesticide use is further encouraged by those who customarily provide the information which farmers and others use to make a decision. A study in California, the nation's richest agricultural state, makes this point. There farmers receive most of their pest control advice from pesticide salespeople. For California cotton farmers, only 1 percent of the information that they use to control insect pests originates with farm advisors from the Cooperative Extension Service. In 70 percent of the cases, insect problem-solving decisions originate with chemical company employees. Independent pest management advisors are consulted in only 17 percent of the decisions (Luck et al., 1977; R.F. Luck, unpubl.).

Other studies have also shown the importance of industry salespeople and advertisements as sources of pest control information (NAS, 1975; Levenson and Frankie, 1978; Anon., 1974). That farmers and homeowners use information provided directly by the chemical industry far more often than that provided directly by the Cooperative Extension Service or by independent pest management advisors is to be expected; there are typically few CES pest control specialists and independent advisors compared to the number of chemical industry representatives. In Iowa, for example, an estimated 4,000 or more persons were involved in retail sales of agricultural pesticides in 1973—compared to 119 Extension personnel working full time or part time on educational programs in agricultural pest control (Anon., 1974).

Nationwide, an estimated 200,000 commercial pesticide applicators are presently certified, including aerial applicators, pest control operators, and other commercial applicators. By comparison, specialists with the Cooperative Extension Service assigned to crop and animal health, including IPM, totaled only about 1,120 in 1977 (see Chapter XI, p. 103). In addition, some 500 private consultants work independently or for farm service firms and farmers' cooperatives to advise and make recommendations on IPM; most of them have been in business less than 5 years (Good, 1977).

Although IPM consultant fees are nearly always lower than the costs of pesticides and their application (Blair, 1976), a broad-scale IPM industry is not likely until integrated pest management gains wider recognition, IPM technology is improved for more crops and other resources, and is proved more profitable to use than pesticide-dominated schemes.

The publicly sponsored Extension demonstrations discussed in Chapter V (pp. 49-50) have been instrumental in demonstrating the feasibility of IPM for a variety of crops and a few livestock operations. With the limited funding available, however, they cannot reach the majority of growers in need of information. The advantage of the Extension programs is the low cost factor in enlisting the initial cooperation of growers who are apprehensive about trying new approaches to pest control. But once the benefits of the pilot programs have been shown, it is important that the private sector continue the services so that Extension personnel can demonstrate the new IPM programs elsewhere (Flint and van den Bosch, 1977).

Some states have established minimum educational standards for private pest control advisors and require that they be licensed. The 1972 amendment to the Federal Insecticide, Fungicide, and Rodenticide Act established standards and procedures for certification of commercial pesticide applicators.

No state prevents the licensing of pest control advisors who have a financial interest in the manufacture, sale, or distribution of pesticides. In 1977, California State Senator Arlen Gregorio introduced a bill (SB 669) to prohibit the State Food and Agriculture Department from licensing any such person; the bill did not pass, however. At least one-half the licensed farm pest control advisors in California also sell pesticides (Gregorio, 1977).

The chemical industry contends that pesticide salespeople are more qualified than anyone else to advise on use of their products and therefore should not be prohibited from advising clients on use of these products. Not all farmers agree. The president of the farmer-administered Texas Pest Management Association has said: "It is important to recognize that it is extremely difficult for a chemical field man or a pesticide dealer to serve as an unbiased integrated pest management consultant. If their income is principally derived from the sale of chemical pesticides, it would likely be difficult for them to recommend an IPM protocol that did not include a chemical product, or their particular product line" (Anderson, 1977). The Texas Pest Management Association, formed in 1977, is probably the largest farmer organization formed specifically to further use of integrated pest management on agricultural crops.

As discussed in Chapter XI, many universities now offer bachelor's or master's degree programs specializing in integrated pest management. Students are exposed to both the theoretical and practical aspects of integrated pest management as preparation for Extension work at the universities or for private consulting.

As state and federal governments move toward certification of pest control operators and IPM consultants, the demand for university-trained IPM specialists will increase.

Education must extend far beyond the needs of IPM practitioners and their clients to reach government officials and the consumer. Some government regulations encourage use of conventional chemical pesticides. An example of government regulations that favor pesticides at unnecessary costs to the consumer is the Food and Drug Administration's regulations on insects and insect parts in food.

Since the 1930's the FDA has generally reduced the defect action levels—the allowable quantities of insects and insect parts found in foods—although there is no apparent health hazard from ingesting small plant-feeding insects (FDA, 1974). In addition, food processors, wholesalers, and retailers have given increasing emphasis to the cosmetic appearance (i.e., insect blemish-free) of fruits and vegetables. Reducing the number of small insects and insect parts and emphasizing cosmetic appearance have had two results: increased losses because a larger proportion of the crop is now classified as unsuitable for commercial use and use of an additional 10-20 percent in insecticides on fruit and vegetable crops to meet the FDA and cosmetic appearance standards (Pimentel et al., 1977).

FDA regulations are the primary determinant of pest control practices with some vegetable crops, especially those largely sold to frozen food processors or canners. The growers of brussels sprouts in some areas of California, for example, use chemical pesticides solely to ensure that the harvested brussels sprouts meet FDA standards. They do not believe that satisfactory crop yields require pesticide applications (NAS, 1975).

The risks and costs associated with the FDA regulations and cosmetic appearance standards include increasing health hazards from the insecticides, reducing environmental quality, and increasing farm production and food costs (Pimentel et al., 1977). Although the consumer must be protected from adulterated foods that are hazardous to health, it may be that the regulations here are more stringent than necessary. Some other government regulations, policies, and programs currently favor increased use of chemical pesticides and constrain the expansion of IPM, as discussed in Chapter XI.

Although integrated pest management may not be progressing as rapidly as one may desire, several factors may accelerate progress. The increasing costs of pesticides put farmers in an economic squeeze. Increasing problems of pesticide-resistant pest strains and public concern over the hazards of the pesticides to human health and the environment should also hasten the transition to IPM.

Yet integrated pest management is not a panacea for all pest problems; indeed, it may not always be the best approach (Glass, 1975). For example, treating seed with a fungicide is a low-cost protection measure for which there may not be an alternative. In the case of a foreign pest introduction, different values may be assigned to economic and environmental factors. In order to prevent the pest from becoming established and spreading widely, early detection and elimination of low level populations are emphasized over the criterion of economic thresholds.

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The Current Federal Role

Chapter Eleven

Through regulatory action, education, and research, the federal government is deeply involved in activities related to integrated pest management. Many of these activities involve cooperation with nonfederal institutions.*

Research

Public research on pest control is conducted or funded by many federal, state, and local agencies. Federal efforts involve the Departments of Agriculture, Interior, Defense, and Health, Education, and Welfare, the National Science Foundation (NSF), and the Environmental Protection Agency (EPA). Research at the state level is conducted by the land grant universities; state departments of health, natural resources, agriculture, fish and game, and forestry; and various state and local educational institutions and operating agencies. Funding and management of research are frequently shared among agencies and levels of government. Funds come from foundations, industry, and individuals.

The nature of research at a given public agency reflects both the diversity of the pest control problems and the responsibilities mandated to the agency. Some agencies, such as the Forest Service, Animal and Plant Health Inspection Service, Bureau of Reclamation, Bureau of Land Management, Corps of Engineers, and the Tennessee Valley Authority, manage pests on public lands and waterways. EPA is concerned primarily with regulation and enforcement for the public safety and welfare, but the Agency supports research related to integrated pest management. The Science and Education Administration in the Department of Agriculture and the land grant universities are responsible for basic and applied research and for general education about pest control.

Planning and funding for public research tend to be based on the agencies' individual responsibilities and interests. Yet there are formal and informal mechanisms for coordinating research efforts. Joint planning of pest control research between the Department of Agriculture and land grant universities, the two institutions responsible for most research expenditures, has been formalized. The State Agricultural Experiment Station at each land grant university receives federal funds through Cooperative Research (CR) of USDA under provisions of the Hatch Act.

The CR approves all state projects, and federal funds must usually be matched with funds from the states. Some Hatch Act funds (approximately 25 percent), designated Regional Research Funds, are restricted to joint projects, of two or more states (NAS, 1975).

State pest control research is also funded under the McIntyre-Stennis Act for forestry, under Public Law 89-106, and to a minor extent under other laws. The McIntyre-Stennis Act provides federal funds for research to all schools of forestry, including those that are not affiliated with land grant universities (NAS, 1975).

USDA-Land Grant University Complex

The agricultural research establishment in the public sector is the largest and most significant element in the development of new technologies and practices in U.S. agriculture. Each State Agricultural Experiment Station has a central facility at the land grant university and one or more branch stations in outlying areas. The branch stations service specific geographic areas or specific commodity needs. There are more than 300 branch stations and field laboratories (NAS, 1975). The USDA has several major national and regional research laboratories throughout the United States and many small research laboratories and centers.

In FY 1978, an estimated $208.3 million was devoted to pest control research at the principal USDA research agencies and the State Agricultural Experiment Stations (Table XI-1). It is difficult to determine what portion of the USDA or the SAES's research funds is allocated to integrated pest management because research projects usually are categorized by commodity (e.g., cotton), pest organism

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* The National Academy of Sciences publication, *Pest Control: An Assessment of Present and Alternative Technologies* (1975), was a major source of information for this chapter. The federal agencies cooperated in compiling information on their roles and levels of funding.

(e.g., house fly) or groups of pest organisms (e.g., insect pests), and specific research area (e.g., biological control) and not as IPM or non-IPM. The USDA estimates that of approximately $122.9 million allocated for basic research on pests and pest control methods by its principal pest control research agencies (AR, CR, and FS) in FY 1978, 1-6 percent supported interdisciplinary study of the interactions of various pests. In addition, the USDA and SAES's spent a substantial portion of their total pest control research funds on basic biology of pests, alternative methods of control, selective pesticides, systems science, and other areas with direct or indirect application to IPM programs (USDA, unpubl.).

The Secretary of Agriculture formalized USDA's current policy on integrated pest management in 1977:

> It is the policy of the U.S. Department of Agriculture to develop, practice, and encourage the use of integrated pest management methods, systems, and strategies that are practical, effective, and energy-efficient. The policy is to seek adequate protection against significant pests with the least hazard to man, his possessions, wildlife, and the natural environment. Additional natural controls and selective measures to achieve these goals will be developed and adopted as rapidly as possible (USDA, 1977).

The SAES's of the land grant universities have not issued a unified policy statement on IPM, but they generally support the USDA policy statement.

The Department of Agriculture

The USDA is the major federal institution involved in pest control research.

Agricultural Research—Agricultural Research is the Department's largest research agency. AR was allocated $81.1 million, about two-thirds of USDA's total pest control research budget, in FY 1978 (Table XI-1).

Table XI-1 **Estimated Pest Control Research Support by the Principal USDA Research Agencies and the State Agricultural Experiment Stations, Fiscal Year 1978 (USDA, unpubl.)**

Agency	Funding (millions)
USDA	$122.9
Agricultural Research	81.1
Cooperative Research	20.8
Forest Service	21.0
SAES's	85.4
Total	208.3

Among AR's most notable research efforts in integrated pest management is a pilot research program initiated in 1972. Its primary objective is development of new techniques of pest suppression and detection through large-scale field trials. It is largely a series of AR in-house projects, but some projects are extramural. In FY 1978, 31 projects were in progress, and the program was funded at $1.6 million. AR is currently developing a special research program, Integrated Pest Management Systems.

Cooperative Research—Cooperative Research has no in-house research program, but it administers research funds to the land grant universities and state forestry schools. In FY 1978, a $0.5 million competitive special grant program supported interdisciplinary projects on IPM (USDA, unpubl.).

Forest Service—The Forest Service has a substantial program of research on control of insects, plant diseases, and undesirable vegetation. In FY 1978, FS's research budget on pest control was approximately $21 million; 87 percent supported in-house research conducted by FS personnel, and the remaining supported extramural projects at the universities and state schools of forestry. More than one-half of this budget supported research on IPM systems for forest pests. The largest FS research effort on IPM is the "USDA-Combined Forest Pest Research and Development Program," which involves the gypsy moth, Douglas-fir tussock moth, and southern pine beetle, discussed in Chapter VI, p. 64. Begun in 1975, it was funded at $6.2 million in 1978 (FS provided $3.2 million; AR, $1.0 million; CR, $1.3 million; and the Animal and Plant Health Inspection Service, $0.7 million). FS, AR, CR, and APHIS are cooperating with State Agricultural Experiment Stations, universities and colleges, state forestry organizations, and private industries on the project.

Other USDA agencies engaged in pest control research but not shown in Table XI-1 include the Economics, Statistics, and Cooperatives Service (ESCS) and APHIS. Research participation by ESCS and APHIS is very small, however, compared to that of AR, CR, and FS (USDA, unpubl.).

The Environmental Protection Agency

A variety of research, monitoring, standardsetting, and enforcement responsibilities was given to EPA when it was established in 1970. Most EPA research efforts in the area of pest control center on the effects of pesticides on nontarget organisms, including human beings, but some are designed to create new methods for controlling pests. Until fiscal year 1972, these efforts were small. Of the $790,000 funded in FY 1972, $700,000 was the agency's share of an EPA-NSF-USDA comprehensive IPM research project, "The Principles, Strategies, and Tactics of Pest Population Regulation and Control in Major Crop Ecosystems." EPA participation in pest control research and development continued to grow, and of the almost $2.4 million expended in FY 1973, $1.3 million was allocated to the joint project. Subsequently EPA participation has ranged from a high of $1.8 million in 1974 to a low of $1.2 million in FY 1978 (EPA, unpubl.). The Congress has made it clear that EPA should continue to be involved in research and development of pest control technologies.

The National Science Foundation

NSF supports basic research that is applicable or related to integrated pest management, although the level of funding is small compared to that of the USDA and land grant universities. In FY 1978, the IPM budget was $542,000; of this, $287,000 was allocated to the EPA-NSF-USDA research project on integrated pest management. From FY 1972 to FY 1978, NSF participation in the project varied from a low of $287,000 in FY 1978 to a high of $1.3 million in FYs 1973 and 1974. In addition, some NSF-sponsored basic research in ecology, physiology, and other fields indirectly benefits integrated pest management (NSF, unpubl.).

NSF was the lead agency for the IPM project in major crop ecosystems noted above. EPA contributed between $1.8 and $1.2 million per year from 1974 to 1978. USDA contributed $911,500 in FY 1972 and with the SAES provided substantial cooperative research effort. NSF generally directed the project.

Coordinated by the University of California at Berkeley, the project involved the cooperation of 18 universities, Cooperative Research, Agricultural Research, Forest Service, and private industry. Grants from NSF, EPA, and USDA totaling $5.48 million during the 6 years represented only a portion of the total cost because each participating institution provided substantial support.

Although commonly referred to as an integrated pest management project, it focused principally on insect and mite pests of major crop and forest ecosystems in the United States. Mathematical modeling and systems analysis provided the research planning matrix through which critical ecosystem relationships and interactions were discovered, data voids identified, and research priorities established.

Research accomplishments of the project were recently evaluated by an outside committee sponsored by two executive offices, the Council on Environmental Quality and the Office of Science and Technology Policy. The evaluation committee concluded that overall accomplishments of the project were excellent. However, accomplishments varied considerably among the crops included (alfalfa, citrus, cotton, pome and stone fruits, and soybean). The alfalfa project, for example, was determined clearly superior to the citrus project. Despite its generally unfavorable rating of the citrus project and other overall criticism (e.g., domination by entomologists), the committee concluded that "the money was well spent and the project's influence on the development of IPM technology in the United States was enormous. IPM will never again be the same because of the project's having been visualized, requested, approved, funded, and carried out." The committee strongly recommended subsequent work on development of a systems approach to integrated crop management in agroecosystems (Anon., 1977).

The Department of the Interior

Interior has wide-ranging responsibilities in the areas of conservation and resource management, including jurisdiction over timberland, wildlife, fisheries, and water located in many geographic areas of the United States. In managing these resources, the Department uses pesticides and other methods of controlling organisms interfering with its objectives. Interior also supports research to develop new control technologies.

Innovative efforts include testing chemicals for specific uses and integrating a variety of pest management techniques. Sometimes the Department gathers data necessary to register a specific chemical for a specific use. In FY 1978, the Department spent approximately $5.2 million for research on pest control technologies, most of it ($4.0 million) by the Fish and Wildlife Service. The next largest amount, $0.9 million, was spent by the Geological Survey. The remaining funds were expended by the Bureaus of Land Management and of Reclamation.

The Department of Health, Education, and Welfare

HEW has major responsibilities for assessing the effects of pesticides and other environmental toxicants on human health and maintains a research program designed to produce new methodologies for controlling pest organisms. Its pest management budget in FY 1978 was $22.6 million: $4.7 million in the National Institutes of Health for research on the biological regulation of disease vectors and studies of the mechanisms of pesticide action and modes of action and metabolism of organic toxicants; $13 million in the Center for Disease Control on its urban rat control program in 68 communities; and $4.9 million in the Food and Drug Administration for the detection of pesticide residues in and on all foods except meat and poultry, which are the responsibility of USDA.

The Department of Defense

DOD policy is to utilize integrated pest management techniques to the maximum extent possible. The Department's pest management program covers 26 million acres of land, wooden buildings valued at $100 billion, and 3 million people, their equipment, and subsistence items. DOD supports both in-house and extramural research efforts which, in FY 1978, were funded at $550,000. In addition, USDA conducts pest management research for DOD with annual funding of $2.3 million (DOD, unpubl.).

Education

Development and successful implementation of integrated pest management very much depend upon education at all levels—research scientists developing the technology, Extension personnel teaching and demonstrating use of the technology, farmers and others demanding the technology, and government regulators, elected officials, and others imposing laws and regulations to constrain its use.

The Cooperative Extension Service

The Cooperative Extension Service (CES), created in 1914 by the Smith-Lever Act, is the established public institution for transferring new technologies from centers of research and development to the public. Financing, planning, and conducting the educational programs of the CES are responsibilities shared by USDA and the land grant universities. Extension personnel are located in all urban and all but a few nonagricultural counties of the United States, on the campuses of the land grant universities, and in Washington, D.C.

CES is active in such diverse areas as agricultural and natural resource management, home economics, community improvement, and youth development (the 4-H program). Much of its agricultural management information is on how to grow, protect, market, process, and use farm products and is for the farmer. Information and educational programs are provided to rural and urban homeowners, farm cooperatives, wholesalers and produce distributors, and professionals such as veterinarians, high school agriculture teachers, and bankers.

CES is engaged in various phases of pest control education, including

- Training applicators of restricted pesticides who must be certified under the provisions of the Federal Insecticide, Fungicide, and Rodenticide Act
- Providing information on the description of pests and control procedures to farmers, homeowners, and other users
- Teaching and demonstrating to farmers and other users the concepts and techniques of integrated pest management.

In 1977, employees of CES working on all phases of pest control education contributed a total of 1,120 scientific years, which represents an increase of 771 scientific years since 1974. Most of the increase was attributable to the Pesticide Applicator Training Program, in which county Extension personnel trained private applicators: county agricultural agents (664 SY's) who carry out all pest control-related Extension programs, specialists in integrated pest management (119 SY's) charged with education and demonstration programs in IPM, and the Washington, D.C. staff (4.5 SY's), which is involved in various Extension programs on pesticides, pest control, and integrated pest management (USDA, unpubl.).

The CES has primary responsibility for administering the Extension IPM demonstration projects on agricultural crops and livestock operations, discussed in Chapter V (pp. 51-53, 55-56).

These projects represent the largest effort to date to demonstrate the IPM concept and techniques to crop and livestock producers. The USDA provided approximately $4.4 million in FY 1978 to the State Extension Services for the pilot projects and ongoing IPM programs. In addition, the participating State Extension Services matched the federal funds from state, county, and other fund sources. Participating crop and livestock producers contributed approximately $10 million for the services of field scouts hired by private consultants in grower-operated organizations that were cooperating with the Extension-supported program (USDA, unpubl.).

Begun in 1971, the Extension program on crops and livestock has been very successful, resulting in generally less pesticide use on most commodities in the demonstration areas at no sacrifice in yield or quality. The influence of this program on pest control practices beyond the immediate areas has not been determined.

An evaluation of the economic, environmental, and social impacts of CES programs on various agricultural regions is important. As discussed in Chapter X (p. 98), studies have shown that farmers and homeowners generally rely on the sellers of pesticides, on commercial advertisements, and on neighbors—not the Cooperative Extension Service—as the source of information on pest control. Without an evaluation of the Extension IPM projects, a very real benefit of the demonstration may be lost.

University Training in IPM

The modern concept of integrated management did not evolve because of philosophical advances by students or teachers. Rather, it evolved from new approaches by researchers, individuals who frequently have no responsibility to teaching. Formal training programs in IPM, therefore, have lagged compared to research programs in IPM (NAS, 1969; Browning, 1972; Tammen and Wood, 1977).

About one-half the land grant universities offer undergraduate curricula in either plant protection or integrated pest management, and several have M.S. programs (Apple and Smith, 1976). Some non-land grant institutions also offer curricula in those fields.

Some undergraduate programs are interdepartmental and include plant pathology, entomology, and weed science, for example. A national workshop, "Systems of Pest Management and Plant Protection," sponsored by the Resident Instruction Committee on Policy of the Division of Agriculture, National Association of State Universities and Land-Grant Colleges

(Browning, 1972), was a major stimulus for broader disciplinary integration in pest management curricula and for development of team-taught interdisciplinary courses at several institutions.

Pest management and plant protection at the undergraduate level have not attracted many students primarily because there presently are few operational IPM programs and employment opportunities are limited.

NSF is currently sponsoring an undergraduate program in integrated pest management at three land grant universities (Michigan State University, Cornell University, and Kansas State University), one state university (California State University at Fresno), and an 1890 college (Tennessee State University at Nashville). With FY 1978 funding of $100,000, the objective is to develop a model interdisciplinary curriculum for B.S. training programs in integrated pest management for adoption by other universities and colleges.

Various reports (Glass, 1975; Apple and Smith, 1976; Browning, 1972; Tammen and Wood, 1977) have emphasized the point that the interdisciplinary nature of IPM necessitates training for IPM personnel in a wide range of subjects. Yet nearly all undergraduate and graduate programs in "integrated pest management" typically lead to specialization even within the selected major—entomology, plant pathology, or weed science, for example. As the demand for college graduates trained in IPM increases, new interdepartmental programs must be developed to provide the necessary broad interdisciplinary training not only for new students but also for county agents and others demanding refresher courses and supplemental training in IPM.

Pesticide Regulations

Over the past 68 years, a wide variety of federal laws has been enacted to regulate pesticides. Their overall purpose was to control the quality, sale, and production of pesticides through labeling, registration, and other means.

The first law regulating pesticides was the Insecticide Act of 1910, written to ensure the buyer of product quality. Regulations were developed to establish tolerances for specific insecticides (arsenic and later lead on apples and pears), but the Act was broadly written so that fungicides and additional insecticides could be regulated. USDA had primary responsibility for enforcement. The Federal Insecticide, Fungicide, and Rodenticide Act of 1947 (FIFRA) was the first comprehensive effort to regulate "economic poisons." The Act defined a number of terms, established strict labeling requirements, and for the first time designated registration requirements and procedures.

FIFRA was amended in 1959, 1961, 1964, 1972, 1975, and 1978. The most significant amendment was in 1972; it created a most ambitious and comprehensive regulatory structure for chemicals. Known as the Federal Environmental Pesticide Control Act (FEPCA), the 1972 amendment placed pesticide regulation in an environmental context, taking into account the economic, social, and environmental costs and benefits of pesticide use. One significant feature of FEPCA is its requirement that commercially prepared insect disease agents (viruses, bacteria, fungi), sex attractants, and insect hormones, for example, are treated like conventional chemical pesticides and subject to the same general testing procedures prior to registration by EPA. This requirement has discouraged commercial development of some alternatives which are desirable for integrated pest management programs. Unlike broad-spectrum chemical pesticides, alternatives such as insect disease agents, sex attractants, and hormones are usually narrowly selective, and because the potential for economic return is therefore limited, industry is reluctant to invest the money required for research, development, and commercialization (see Chapter IV, p. 42).

The 1975 amendments stated that certification of applicators must include provisions for making instructional materials concerning integrated pest management available to individuals at their request (FEPCA has required that pesticides in the "restricted" category be applied only by or under the supervision of certified applicators).

The second major piece of legislation affecting pesticides was initially enacted as the Federal Food, Drug, and Cosmetic Act of 1938, subsequently amended in 1954, 1958, and 1960. The 1958 amendment was especially significant. Although specifically excluding pesticide chemicals from its provisions, it has nevertheless been used extensively in pesticide regulation. Despite the fact that Section 201(s) states that pesticide chemicals are not to be considered food additives, the so-called Delaney Clause (§409(c)(3)(A)), which applies solely to "food additives," has been used to prohibit the presence in foods of residues of pesticides considered carcinogenic. The conflict between legislative authority and regulatory action has not been resolved. Nonetheless, this amendment must be cited as having strong influence on pesticide regulation.

The most recent legislation affecting pesticides is the Toxic Substances Control Act of 1976, which is administered by EPA. The potential impact of the Act in pesticide regulation is not known, but it could be significant.

The Role of Regulatory Control and Eradication Programs

Preventing the entry and establishment of foreign plant and animal pests in a country or area or eradicating or confining newly introduced pests to limited areas is important to pest management.

Quarantine programs at U.S. ports of entry aim to prevent the entry of harmful pest species. The Animal and Plant Health Inspection Service of USDA has primary responsibility for port inspections and quarantines under the Plant Quarantine Act of 1912, as amended. Thousands of specimens of potentially harmful pest species are intercepted every year at the ports of entry, and thousands of shipments of pest-infested grain, animal products, plants, and other materials are denied entry. But even with the enforcement of quarantine procedures, the cereal leaf beetle, witchweed, face fly, and other important pests have been introduced into the United States in the last 3 decades.

A study by McGregor (1973) identified some serious deficiencies in the present pest inspection and quarantine programs: "There is no objective evidence that U.S. quarantine actions are having any significant impact on this flow [introduction of pests of foreign origin]. That doesn't mean the program is without effect, but rather that the haphazard use of sampling during inspection and the lack of certain biological information precludes a quantified evaluation." The study recommended actions to minimize future introductions of foreign pests.

McGregor listed 760 insect species, 551 plant disease organisms, and 22 animal disease organisms of foreign countries that are thought to be a significant threat to the United States. Considering the potential economic and environmental impacts of the introduction of these pests and the control programs that they would require, it is important that the APHIS inspection and quarantine programs be realigned as needed to minimize the risks of introduction.

In FY 1978, APHIS allocated approximately $25.4 million to its pest inspection and quarantine programs (USDA, unpubl.). In addition, APHIS and the states administer a variety of regulatory programs designed to retard the spread of pests of foreign origin or to eradicate them. Quarantines and pest suppression measures have been used extensively, successfully eliminating several important pests from the United States (e.g., cattle tick, Khapra beetle, Mediterranean fruit fly, screwworm) (NAS, 1969).

In FY 1978, APHIS participation in programs to retard the spread of pests of foreign origin in this country was approximately $25.1 million. APHIS allocated an additional $7.1 million for programs aimed at eradicating plant pests of foreign origin in the United States: $1.73 million for insect eradication, $0.5 million for plant disease eradication, $0.87 million for nematode eradication, and $3.96 million for weed eradication (costs for eradication of pests affecting people and animals are excluded) (USDA, unpubl.).

Eradication of a pest is difficult and costly and must be repeated with each new reinvasion of the pest. Nevertheless, attempted eradication of a newly introduced, highly damaging pest species confined to a limited geographic area may be justified. The quantity of chemical pesticides and the costs of such an eradication program may be much less than if the pest spread throughout its ecological range (NAS, 1969).

APHIS has designated the boll weevil—a pest of U.S. cotton for some 85 years, spread widely throughout the eastern cotton-producing states—as a leading candidate for eradication. Costs to eradicate the boll weevil from the United States are estimated at $0.6-1.9 billion (USDA, unpubl.); further, an unknown amount would have to be spent on preventing reinvasion of the boll weevil from Mexico, where it also occurs (NAS, 1975). A NAS study committee seriously questioned whether current technology could eradicate the boll weevil. Knipling (1978), on the other hand, presented an opposing view. In any case, a very effective IPM strategy has been developed to combat the pest throughout part of its range, as discussed in Chapter V (p. 52).

Need for Improved Interagency Cooperation

No single government program or public or private institution can make integrated pest management work. All concerned must contribute and cooperate fully in fostering a cohesive national pest control policy and in initiating programs to implement an IPM approach. There are roles appropriate to USDA, EPA, NSF, Defense, Interior, State, the Executive Office, other federal agencies, the universities, and various state and private organizations. These collaborative and cooperative efforts must also provide for strengthening relations between U.S. and foreign pest control programs and policies. There are many opportunities for U.S. and foreign scientists and agencies to cooperate on pest problems and on development of cohesive international policies in pest control and pesticide regulation.

Two or more federal agencies may have formalized cooperative agreements for effecting improved communication and cooperation, and the federal agencies may have similar arrangements with state universities and other state institutions. But there is presently no formal mechanism for improving the communication and cooperation among all public institutions engaged in research, regulatory, and educational programs in pest control at the national level.

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Policy Initiatives

Chapter Twelve

Integrated pest management promises to provide practical, effective, and energy-efficient solutions to significant pest problems of agriculture, forestry, public health, and other human and natural resources while minimizing potential hazards to humans, their possessions, and the environment. Despite its many benefits, however, IPM is not widespread. A variety of obstacles contributes to its slow development and implementation, and no single government program or public or private institution can overcome these obstacles. All concerned agencies must contribute and cooperate fully in fostering a new national pest control policy and in initiating programs to implement an integrated pest management approach.

The following initiatives should be taken by the federal government as steps toward a cohesive national pest control policy which will lead to increased development and use of integrated pest management.

1. Requiring Federal Agency Implementation of IPM. The Department of Agriculture, in cooperation with the Executive Interagency Group on Integrated Pest Management (see Initiative 2 below) should draft an Executive order or other Presidential directive which would require each federal agency

- To adopt the most suitable integrated pest management technology available on all lands, facilities, and structures owned, managed, or leased by the federal government.
- To utilize all fiscal, budgetary, programmatic, and regulatory mechanisms within the scope of its responsibility to encourage the development and utilization of integrated pest management in all sectors.

2. Establishing Interagency Coordination. An Executive Interagency Group on Integrated Pest Management should be established to examine the coherence and effectiveness of current programs and future plans, to seek Presidential decision on matters in dispute, if necessary, and to coordinate national and international policies and programs in pest control. The Group should consist of representatives from the Council on Environmental Quality, Office of Management and Budget, Environmental Protection Agency,Department of Agriculture, National Science Foundation, Department of Defense, Food and Drug Administration, and the State Department.

The Executive Interagency Group, its member agencies, and the universities should actively encourage the exchange of or cooperative working arrangements between U.S. and foreign scientists engaged in:

- IPM research, development, and implementation (with priority given to agricultural and public health sectors).
- The study or control of the same pest or similar pest complexes.
- The control of pests affecting harvested agricultural products in transit and storage.

3. Monitoring and Initiating Research and Development. The USDA, EPA, and the universities should cooperate to

- Initiate a national monitoring program to detect changing levels of herbicide resistance in weed species exposed to frequent applications of herbicides.
- Determine the feasibility of establishing an "early warning system" to identify present or anticipated problems in the control of significant primary pests with chemical pesticides.
- Determine the feasibility of initiating IPM research programs when chemical pesticides previously effective against significant pests are becoming less effective or have been removed from the market by regulatory action and there is no reasonable pesticide alternative or effective IPM technology.

4. Developing Information Systems. The USDA, EPA, and the universities should develop computer and other information systems for use in integrated pest management. The USDA and EPA should cooperate in studying the feasibility of coordinating, integrating, and disseminating IPM information from automated and manual information systems. Existing information systems that are site/pest/pesticide specific should be revised to provide complete listings of pest distribution, management recommendations (including all IPM tactics), and the legal status of and restrictions upon relevant pesticides.

5. Encouraging Registration of Alternative Methods. EPA, in cooperation with USDA, the universities, and the pesticide industry, should explore ways to accelerate the registration process for pest disease agents, insect pheromones, and other alternative methods of pest control and should sponsor needed developmental research leading to their registration.

6. Establishing Criteria for Extension Pest Management Pilot Projects. The Secretary of Agriculture, in cooperation with the Executive Interagency Group on Integrated Pest Management (see Initiative 2), should appoint a work group consisting of federal, state, and university integrated pest management specialists not affiliated with Extension Pest Management Pilot Projects to develop criteria for approval, funding, review, and evaluation. Current Pilot Projects should be reviewed and evaluated under the new criteria. Among other items, the criteria should include the following requirements:

- The USDA should fund the Extension Pest Management Pilot Projects on a meritorious competitive basis. Projects should be located only where there is provision for close collaboration with research teams and where procedures for properly evaluating the projects can be effected.
- Certified IPM consultants should be encouraged by the USDA and the participating universities to participate in the Pilot Projects.
- The USDA should make a special effort to ensure that small farmers are given the same opportunity to participate in the Pilot Projects as farmers with large holdings.

7. Evaluating Exterior Appearance and Quality Standards for Food Commodities. The Food and Drug Administration should commission the National Academy of Sciences to evaluate government regulations and tolerance standards and the standards set by the food marketing and processing industries on both pest parts in food and the cosmetic appearance of fruits and vegetables. The NAS should submit its report within 9 months. This evaluation should

- Determine how FDA regulations and standards are to be amended to decrease pesticide residues which may pose a risk to human health.
- Determine how tolerance limits for residues from pesticides applied to meet superficial damage or exterior appearance standards can be modified to prevent unnecessary residues which may adversely affect human health over the long term.
- Determine whether standards set by the food marketing and processing industries exceed those necessary to preserve taste, nutrition, and storageability, thereby encouraging unnecessary use of chemical pesticides, and what minimum standards are necessary for protection of human health and consumer preference. Upon receipt of this report, the FDA and EPA should implement the study findings through rulemaking procedures.
- The USDA should commission the NAS to evaluate marketing orders under the Commodity Benefits Law to determine whether the cosmetic standards under a majority of such marketing orders result in the use of pesticides which are not needed to preserve a commodity's taste, nutrition, and storageability.

8. Establishing Criteria for Pest Eradication Programs. The USDA should commission NAS to review all pest eradication programs currently administered by USDA. The review should include a cost/benefit analysis of the long-term benefits (economic and other) compared to the cost (monetary costs as well as external costs, such as harm to the environment, if any) and develop for each program a report and recommendations for consideration by the Secretary of Agriculture, the Executive Interagency Group on Integrated Pest Management, and the Director of OMB. The Secretary of Agriculture would be responsible for distribution of the reports, posting notice of receipt of the reports in the *Federal Register* and seeking comment from other government agencies and the public.

The NAS committee should also develop criteria for approval, funding, review, and evaluation of future eradication programs.

9. Developing Model Certification Requirements for Independent Pest Management Advisors. The USDA, universities, and the Environmental Protection Agency should cooperatively develop a Model Act for certification requirements for private consultants and firms offering any commercial service in pest management and should work with the states to urge adoption and enforcement of these requirements. The certification requirements should

- Specify that applicants for certification possess the requisite education and field experience in integrated pest management.
- Prohibit any certified person or firm from engaging in the sale of any pesticide or receiving any compensation, reimbursement, or commission for any sale or application of any pesticide resulting from the person's or the firm's pest control recommendation.

Once these certification requirements have been established, the USDA and the Small Business Administration should cooperate to assist certified individuals in establishing IPM consulting firms.

10. Reviewing Agricultural Loan Procedures. The Department of the Treasury, USDA, and EPA should investigate lending procedures used by banks making agriculturally related loans to determine whether excessive pesticide treatments are being encouraged by conditions specified in the loans.

These agencies should publish their findings and develop recommendations on how the procedures may be modified, if necessary, to increase the farmers' options for using IPM techniques.

11. Determining the Feasibility of Crop Insurance. The USDA and the universities should conduct a pilot program to determine the feasibility of pest-specific risk insurance schemes for farmers to be available through the Federal Crop Insurance Corporation.

Only those crops for which effective IPM technology and accurate pest damage assessment procedures have been developed should be considered in the pilot programs. They should be restricted to farmers participating in IPM programs through the USDA Extension Service or using certified private IPM consultants. The pilot program would serve to determine the feasibility of expanding IPM through pest-specific risk insurance programs and would also create a basis for refining premium schedules and increasing program acreage and crop coverage.

12. Expanding Foreign Exploration for an International Exchange of Natural Enemies. The USDA and the universities should

- Expand their foreign exploration for natural enemies of pests affecting U.S. agriculture, forestry, and rangeland.
- Develop an international exchange program to encourage exchange of natural enemies with foreign countries where important U.S. pests of foreign origin occur.
- Increase the pest and natural enemy identification services and quarantine facilities required for the foreign exploration and international exchange program.

13. Preserving Breeding Material. The USDA and the State Department should collaborate in establishing and maintaining natural ecosystem and plant germ plasm preserves for scientific study and conservation in foreign regions where U.S. crops and their serious pests originated and continue to coevolve or where potentially serious pests occur.

14. Developing Educational Materials. In cooperation with the USDA, EPA, and the universities, NSF and the Department of Health, Education, and Welfare should develop curricula and educational materials which communicate the ecological principles related to integrated pest management to the public.

15. Sponsoring Urban Programs. EPA and USDA, in cooperation with the Department of Housing and Urban Development, NSF, and the universities, should sponsor IPM research, demonstration, and public information and education programs in urban areas; they should also sponsor national workshops on IPM, focusing on the ecological principles of plant and animal health and structured primarily for city officials, urban planners, citizen action groups, and urban educators. The objectives of these programs should be:

- Accelerating the development of research programs leading to practical IPM schemes for urban pest problems.
- Increasing general public awareness of ecological approaches to managing plant and animal health problems.
- Increasing the diagnostic capability to identify urban pests on a multitude of hosts.
- Providing readily available information on pest problems, plant and animal health problems, and environmentally safe methods of managing these problems.
- Demonstrating IPM technology in urban areas through pilot projects.

16. Improving Pesticide Surveys. The USDA and EPA should cooperate in coordinating and implementing efforts to improve both the methodologies and the frequency of national pesticide use surveys. The surveys should be conducted biennially and the results published within 6 months of completion of a survey. The surveys should be planned and coordinated in conjunction with universities at the state, regional, and national levels and should include pesticide use and pest infestation levels in all agricultural and nonagricultural use categories. The results should be enumerated to show pesticide use and pest infestations by specific crop or other specific use category (e.g., household use, use on rights-of-way) and by geographical region.

17. Determining the Environmental Effects of Pesticides. The USDA, EPA, and the universities should initiate an interdisciplinary research project to determine, for several major crops in several different climatic regions in the United States or other countries, the immediate and long-term effects of pesticides on pests of those crops, on the crop-soil ecology, and on the surrounding aquatic and terrestrial ecosystems.

18. Studying Livestock Pests. The USDA should commission and publish an independent study of the status of livestock pest control, with recommendations for research and implementation.

19. Studying Stored Product Pests. The USDA should commission and publish an independent study of the control of pests affecting harvested agricultural products in transit and storage, with recommendations for research and implementation.

20. Supporting IPM Research on Forests, Rangelands, and Rights-of-Way. The USDA and the universities should

- Support interdisciplinary forest pest management projects which take a broad systems approach and emphasize finding and developing alternatives to conventional pesticides.
- Determine the adequacy of ongoing integrated pest management research on pests of rangelands and rights-of-way and develop needed IPM research programs.

21. Developing Techniques and Procedures for Safe Application of Pesticides. The USDA and the universities, in cooperation with the pesticide industry, should initiate a program to develop pesticide application equipment, application techniques, and improved pest monitoring procedures that minimize the environmental and human health hazards of chemical pesticides employed in integrated pest management programs.

22. Supporting Basic Ecological Studies. The USDA, NSF, EPA, and the universities should commit significant research funds and assign a high priority to basic ecological studies of pests and to interdisciplinary research leading to unified integrated systems of pest management that focus on multipest categories (i.e., insects, weeds, plant diseases, and nematodes and vertebrates). The studies should focus on unstudied or inadequately studied ecosystems, including agro-, stored-product, aquatic, and urban ecosystems. Through population studies of the pest species, models should be developed to predict the effects of manipulations in the ecosystems on the pests' dynamics. Evolutionary and genetic studies should be conducted to determine the mechanisms involved in the development of genetic resistance in the pests to chemical, biological, and physical population controls.

23. Supporting Disease Vector Projects. USDA, in cooperation with the Department of Health, Education, and Welfare, the Department of Defense, and the universities, should initiate an interdisciplinary research program to develop ecologically sound integrated mosquito management approaches.

The Center for Disease Control and the Public Health Service, HEW, should determine the need, if any, for stockpiling various insecticides for the control of disease vectors during public health emergencies which have shown resistance to some insecticides now in use.

24. Supporting Foreign Studies. The USDA, NSF, and the universities should expand support for basic ecological studies of serious U.S. pests of foreign origin in the pests' native ecosystems.

Common and Scientific Names of Organisms and Diseases[1]

APPENDIX A

Chapter I

Common Name	Scientific Name	Common Name	Scientific Name
Boll weevil	*Anthonomus grandis*	Poison ivy	*Rhus radicans*
Coyote	*Canis latrans*	Ragweed	*Ambrosia* sp.
Codling moth	*Laspeyresia pomonella*	San Jose scale	*Quadraspidiotus perniciosus*
Colorado potato beetle	*Leptinotarsa decemlineata*	Tsetse fly	*Glossina* sp.
Deer	Cervidae		
Field bindweed	*Convolvulus arvensis*		

Chapter II

Common Name	Scientific Name	Common Name	Scientific Name
Alfalfa leafcutting bee	*Megachile pacifica*	Poison ivy	*Rhus radicans*
Alkali bee	*Nomia melanderi*	Poison oak	*Rhus toxicodendron*
Apple scab	*Ventura inaequalis*	Redroot pigweed	*Amaranthus retroflexus*
Bumble bees	*Bombus* sp.	Seals	Pinnipedia
Common groundsel	*Senecio vulgaris*	Southern corn leaf blight	*Helminthosporium maydis*
Common lambsquarters	*Chenopodium album*	Tobacco budworm	*Heliothis virescens*
Corn leaf aphid	*Rhopalosiphum maidis*	Wheat stem rust	*Puccinia graminis*
Honey bee	*Apis mellifera*		
Penguins	Spheniscidae		

Chapter III

Common Name	Scientific Name
Cyclamen mite	*Steneotarsonemus pallidus*

Chapter IV

Common Name	Scientific Name	Common Name	Scientific Name
Alfalfa weevil	*Hypera postica*	Bovine piroplasmosis	*Babesia*
Alligatorweed	*Alternanthera philoxeroides*	Bunt (smut)	*Tilletia* sp.
Annosus root rot	*Fomes annosus*	Cabbage black rot	*Pseudomonas campestris*
Ants	Formicidae	Cabbage blackleg	*Phoma lingam*
Aphid lion	*Chrysopa* sp.	Cabbage looper	*Trichoplusia ni*
Apple maggot	*Rhaguoletis pomonella*	Cankerworms	*Paleacrita vernata,* *Alsophila pometaria*
Bacterial blight of bean	*Pseudomonas phaseoli*	Cattle tick	*Boophilus annulatus*
Bagworm	*Thyridopteryx ephemeraeformis*	Celery looper	*Anagrapha falcifera*
Black scale	*Saissetia oleae*	Cereal leaf beetle	*Oulema melanopus*
Boll weevil	*Anthonomus grandis*	Chiggers	Trombiculidae
Bollworm (cotton bollworm)	*Heliothis zea*	Chinch bug	*Blissus leucopterus*
		Cicadas	Cicadidae
		Citrophilus mealybug	*Citrophilus* sp.
		Corn earworm	*Heliothis zea*
		Corn rootworms	*Diabrotica* spp.

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[1] If no common name exists, an organism cited by its scientific name in the text is not included.

Common Name	Scientific Name
Corn rootworms	*Diabrotica* spp.
Curly top virus	No Latin name
Currants	*Ribes* spp.
Cyst nematode	*Heterodera* sp.
Diamondback moth	*Plutella xylostella*
Douglas-fir tussock moth	*Orgyia pseudotsugata*
Drywood termites	Isoptera
Elm spanworm	*Ennomos subsignarius*
Engelmann spruce beetle	*Pissodes strobi*
European corn borer	*Ostrinia nubilalis*
Fall cankerworm	*Alsophila pometaria*
Fall webworm	*Hyphantria cunea*
Flea beetle	*Agasicles hygrophila*
Fusarium wilt	*Fusarium* sp.
Gnats	Diptera
Golden nematode	*Heterodera rostochiensis*
Gooseberries	*Ribes* sp.
Grape berry moth	*Endopiza viteana*
Grape leaf folder	*Desmia funeralis*
Grape leaf skeletonizer	*Harrisina americana*
Greenbug	*Schizaphis graminum*
Gypsy moth	*Lymantria dispar*
Hessian fly	*Mayetiola destructor*
Horn fly	*Haematobia irritans*
House fly	*Musca domestica*
Imported cabbage worm	*Pieris rapae*
Japanese beetle	*Popillia japonica*
Klamath weed (St. Johnswort)	*Hypericum perforatum*
Lady beetle	Coccinellidae
Leaf rust	*Puccinia* sp.
Lygus bugs	*Lygus* spp.
Melon fly	*Dacus cucurbitae*
Mildew	Various fungi
Mosaic	No Latin name
Mosquitoes	Culicidae
Northern jointvetch	*Aeschynomene virginica*
Norway rat	*Rattus norvegicus*
Olive parlatoria scale	*Parlatoria oleae*
Oriental fruit fly	*Dacus dorsalis*
Pink bollworm	*Pectinophora gossypiella*

Common Name	Scientific Name
Plum cucurlio	*Conotrachelus nenuphar*
Potato late blight	*Phytophthora infestans*
Red-banded leaf roller	*Argyrotaenia velutinana*
Red-humped caterpillar	*Schizura concinna*
Root-knot nematode	*Meloidogyne* sp.
Russian thistle	*Salsola kali*
Rust	Uredinales
Sawfly (wheat stem sawfly)	*Cephus cinctus*
Screwworm	*Cochliomyia hominivorax*
Smut (bunt)	*Tilletia* sp.
Soil virus	No Latin name
Southern corn leaf blight	*Helminthosporium maydis*
Southern root-knot nematode	*Meloidogyne incognita*
Soybean cyst nematode	*Heterodera glycines*
Spotted alfalfa aphid	*Therioaphis maculata*
Spring cankerworm	*Paleacrita vernata*
Stable fly	*Stomoxys calcitrans*
Stem rust (wheat stem rust)	*Puccinia* sp.
Streak mosaic	No Latin name
Subterranean termites	*Reticulitermes* spp.
Sugar beet curlytop virus	No Latin name
Sugar beet cyst nematode	*Ditylenchus schachtii*
Tent caterpillar	*Malacosoma* spp.
Ticks	Acarina
Tobacco budworm	*Heliothis virescens*
Tobacco hornworm	*Manduca sexta*
Walnut aphid	*Chromaphis juglandicola*
Water hyacinth	*Eichornia crassipes*
Western beet leafhopper	*Circulifer tenellus*
Wheat curl mite	*Eriophyes tulipae*
Wheat stem sawfly	*Cephus cinctus*
Wheat streak virus	No Latin name
White pine blister rust	*Cronartium ribicola*
Witchweed	*Striga lutea*
Wool maggots	Calliphoridae
Yellow dwarf virus	No Latin name

Chapter V

Armyworm	*Pseudaletia unipuncts*
Black flies	*Simuliidae*
Boll weevil	*Anthonomus grandis*
Bollworm	*Heliothis zea*
Corn rootworms	*Diabrotica* spp.
Corn stalk borers	*Papaipema nebris*
European corn borer	*Ostrinia nubilalis*
Face fly	*Musca autumnalis*
Fire blight of apples, pears	*Erwinia amylovora*
Gnats	Diptera

Hessian fly	*Mayetiola destructor*
Horn fly	*Haematobia irritans*
Horse flies	Tabanidae
House fly	*Musca domestica*
Screwworm	*Cochliomyia hominivorax*
Southern corn leaf blight	*Helminthosporium maydis*
Spotted alfalfa aphid	*Therioaphis maculata*
Stable fly	*Stomoxys calcitrans*
Tobacco budworm	*Heliothis virescens*
Witchweed	*Striga lutea*

Chapter VI

Common Name	**Scientific Name**
Alligatorweed	*Alternanthera philoxeroides*
Annosus root rot	*Fomes annosus*
Balsam-woolly aphid	*Adelges piceae*
Bark beetles	Scolytidae
Bears	Ursidae
Beavers	*Castor canadensis*
Bitterweed	*Helenium* sp.
Chestnut blight	*Endothia parasitica*
Currants	*Ribes* spp.
Deer	Cervidae
Dodders	*Cuscuta* spp.
Douglas-fir tussock moth	*Orgyia pseudotsugata*
Dutch elm disease	*Ceratocystis ulmi*
Eastern spruce budworm	*Choristoneura* sp.
Forest tent caterpillar	*Malacosoma disstria*
Fusiform rust	*Cronartium fusiforme*
Gooseberries	*Ribes* sp.
Grasshoppers	Acrididae
Gypsy moth	*Lymantria dispar*
Juniper	*Juniperus* sp.
Klamath weed (St. Johnswort)	*Hypericum perforatum*
Macartney rose	*Rosa bracteata*
Mesquite (honey mesquite)	*Prosopis* sp.
Mice	Muridae
Mistletoes	*Phoradendron flavescens*
Mountain pine beetle	*Dendroctonus ponderosae*
Oaks	*Quercus* spp.
Pocket gophers	Geomyidae
Porcupines	*Erethizon dorsatum*
Prairie dogs	*Cynomys* spp.
Rabbits	Leporidae
Range caterpillar	*Hemileuca oliviae*
Rats	Muridae
Red-pine scale	*Matsucoccus resinosae*
Rhodegrass scale	*Antonina graminis*
Sagebrush	*Artemisia* sp.
Southern pine beetle	*Dendroctonus frontalis*
Spruce budworm	*Choristoneura* sp.
Squirrels	Sciuridae
Water hyacinth	*Eichornia crassipes*
Western pine beetle	*Dendroctonus brevicomis*
Western spruce budworm	*Choristoneura* sp.
White pine blister rust	*Cronartium ribicola*

Chapter VII

American cockroach	*Periplaneta americana*
Bees	Apidae
Black carpet beetle	*Attagenus megatoma*
Booklice	*Liposcelis* spp.
Brown-banded cockroach	*Supella longipaipa*
Brown dog tick	*Rhipicephalus sanguineus*
Carpenter ant	*Camponotus* spp.
Casemaking clothes moth	*Tinea pellionella*
Chiggers	Trombiculidae
Chimney swifts	*Chateura pelagica*
Clover mite	*Bryobia praetiosa*
Common carpet beetle	*Anthrenus serophulariae*
Confused flour beetle	*Triblium confusum*
Cricket	Gryllidae
Earwigs	Dermaptera
Fall cankerworm	*Alsophila pometaria*
Fleas	Siphonaptera
Fungus beetles	Erotylidae
German cockroach	*Blattella germanica*
House ants	Formicidae
House fly	*Musca domestica*
House mouse	*Mus musculus*
House sparrow	*Passer domesticus*
Indian meal moth	*Plodia interpunctella*
Lawn ant	Formicidae
Mosquitoes	Culicidae
Norway rat	*Rattus norvegicus*
Oriental cockroach	*Blatta orientalis*
Pigeons	*Columba livia*
Powder-post beetles	Lyctidae
Rats	Muridae
Roof rat	*Rattus rattus*
Saw-toothed grain beetle	*Oryzaephilus surinamensis*
Silverfish	*Lepisma saccharina*
Sow bug	Isopoda
Spiders	Araneae
Springtails	Collembola
Spruce budworm	*Choristoneura* sp.
Subterranean termites	*Reticulitermes* spp.
Termites	Isoptera
Ticks	Acarina
Wasps	Hymenoptera
Webbing clothes moth	*Tineola bisselliella*

Chapter VIII

American dog tick	*Dermacentor variabilis*
Ants	Formicidae
Bees	Apidae
Black flies	Simuliidae
Body louse	*Pediculus humanus*
Colonial prairie dog	*Cynomys* sp.
Crab louse	*Pthirus pubis*
Deer flies	Tabanidae
Fleas	Siphonaptera
Fox squirrel	*Sciurus niger*

Common Name	Scientific Name
Gnats	Diptera
Head louse	*Pediculus humanus*
Horse flies	Tabanidae
House fly	*Musca domestica*
Imported fire ants	*Solenopsis* spp.
Killifishes	Cyprinodontidae
Latrine fly	*Fannia scalaris*
Little house fly	*Fannia canicularis*
Mosquitoes	Culicidae
Mosquitofish	*Gambusia affinis*
Rats	Muridae
Rocky Mountain wood tick	*Dermacentor andersoni*
Scorpions	Scorpionida
Stable fly	*Stomoxys calcitrans*
Ticks	Acarina
Wasps	Hymenoptera
Yellow jackets	Vespidae

Chapter IX[2]

African clawed frog	*Xenopus laevis*
Alewives	*Pomolobus pseudoharengus*
Alligator	*Alligator* sp.
Bats	Chiroptera
Bears	Ursidae
Beavers	*Castor canadensis*
Blackbirds	Icteridae
Brown-headed cowbird	*Molothrus ater*
Carp	Cyprinidae
Cattails	*Typha* sp.
Chipmunks	*Tamias* sp.
Common grackles	*Quiscalus quiscula*
Cougar	*Felis concolor*
Coyote	*Canis latrans*
Crocodiles	*Crocodylus* sp.
Deer	Cervidae
Ducks	Anatidae
Eagles	Accipitridae
Elk	*Cervus canadensis*
European starlings	*Sturnus vulgaris*
Feral hog (pig)	Suidae
Foxes	*Vulpes* sp.
Gars	*Lepisosteus* sp.
Geese	Anatidae
Giant toad (marine toad)	*Bufo marinus*
Goldfish	*Carassius auratus*
Gulls	Laridae
Hares	Leporidae
Herons	Ardeidae
House sparrow	*Passer domesticus*
Lampreys	Hyperoartia
Lion	*Felis concolor*
Lizards	Lacertilia
Meadow mice	*Microtus* spp.
Mice	Muridae
Mink	*Mustela* sp.
Moose	*Alces* sp.
Mountain lion	*Felis concolor*
Mule deer	*Odocoileus hemionus*
Muskrat	*Ondatra zibethica*
Nutria	*Myocastor coypus*
Otter	*Lutra canadensis*
Panther	*Felis concolor*
Pigeons	*Columba livia*
Pocket gophers	Geomyidae
Porcupines	*Erethizon dorsatum*
Pronghorn	*Antilocapra americana*
Puma	*Felis concolor*
Rabbits	Leporidae
Raccoons	*Procyon lotor*
Rats	Muridae
Redwing blackbirds	*Agelaius phoeniceus*
Salamanders	Urodeles
Sandhill cranes	*Grus canadensis*
Sea lamprey	*Petromyzon marinus*
Skunks	*Mephitis* sp.
Snakes	Ophidia
Spiny dogfish shark	*Squalus acanthias*
Squirrels	Sciuridae
Starlings	*Sturnus vulgaris*
Toads	Bufonidae
Trout	*Salmo* sp.
Turtles	Chelonia
Whistling swans	*Olor columbianus*
Whitefish	Coregonidae
White-tailed deer	*Odocoileus virginianus*
Wild goats	Bovidae
Wild horse	*Equus caballus*
Wolves	*Canis lupus*
Woodchucks	*Marmota monax*

Chapter XI

Boll weevil	*Anthonomus grandis*
Cattle tick	*Boophilus annulatus*
Cereal leaf beetle	*Oulema melanopus*
Dogulas-fir tussock moth	*Orgyia pseudotsugata*
Face fly	*Musca autumnalis*
Gypsy moth	*Lymantria dispar*
Khapra beetle	*Trogoderma granarium*
Mediterrean fruit fly	*Ceratitis capitata*
Screwworm	*Cochliomyia hominivorax*
Southern pine beetle	*Dendroctonus frontalis*
Witchweed	*Striga ludens*

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[2] For Chapter IX, if organisms are listed in tables but are not discussed in the text, they are not included.

Acknowledgments

APPENDIX B

The following individuals and organizations played a significant role in reviewing drafts of this document and advising the Council on Environmental Quality on integrated pest management.

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U.S. Department of Health, Education, and Welfare
U.S. Department of the Interior
Intersociety Consortium for
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National Academy of Sciences–
National Research Council,
Committee on Biology of
Pest Species
National Science Foundation
Office of Management and Budget
U.S. Department of State

*Dr. van den Bosch died in November 1978.

Memorandum from the President, August 2, 1979

Appendix C

Memorandum for the Secretary of Agriculture, the Secretary of Commerce, the Secretary of Defense, the Secretary of Health, Education, and Welfare, the Secretary of Housing and Urban Development, the Secretary of the Interior, the Secretary of Labor, the Secretary of Transportation, the Administrator of the Environmental Protection Agency, the Administrator of the General Services Administration, the Chairman of the Council on Environmental Quality

In my Environmental Message of August 2, 1979, I recognized that integrated pest management (IPM) has both economic and environmental benefits and should be encouraged in both research and operational programs of federal agencies. Therefore, I am directing that each of your agencies:

- Modify as soon as possible your existing pest management, research, control, education, and assistance programs to support and adopt IPM strategies wherever practicable within the limits of existing resources.
- Review your pest management research, control, education, and assistance programs to assess the potential for increased emphasis on intergrated pest management.
- Report actions taken to implement IPM strategies and the results of this review and assessment to the IPM coordinating committee in six months.

I am establishing an interagency IPM Coordinating Committee to assure implementation of this directive and to oversee further development and implementation of integrated pest management practices. The Committee shall be chaired by the Council on Environmental Quality. Your agency should appoint one representative to serve on this Committee who is an Assistant Secretary, Assistant Administrator, or the equivalent. The Committee is to report to me by June 30, 1980 on progress made by federal agencies in the advancement of IPM and on any institutional barriers thereto.

The Committee may request any Executive agency to furnish such information, advice, and service as may be useful for the fulfillment of the Committee's functions. Each of your agencies shall cooperate with and furnish support to the Committee as needed to carry out its functions.

Please give these assignments your immediate attention.

JIMMY CARTER

August 2, 1979.

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