PEST CONTROL AND

WILDLIFE RELATIONSHIPS

PART III

RESEARCH NEEDS

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A Report by the
Subcommittee on
Research Needs
of the Committee on
Pest Control and Wildlife Relationships
Division of Biology and Agriculture
National Academy of Sciences—National Research Council

Publication 920-C
National Academy of Sciences—National Research Council
Washington, D. C.
1963

Library of Congress
Catalog Card Number 61-60097
Price $1.25

FOREWORD

This is the third report prepared by experts with diverse training and background in the various phases of pest control and wildlife relationships. The information in this publication was assembled, evaluated, and compiled by the Subcommittee on Research Needs. Similar material has been assembled by other Subcommittees for Part I, a report on Evaluation of Pesticide-Wildlife Problems, and for Part II, Policy and Procedures for Pest Control. It should be noted that the three reports were prepared independently by three separate subcommittees of the Committee on Pest Control and Wildlife Relationships. No individual was a member of more than one of the three subcommittees. No subcommittee member, except those who were also members of the main committee, bears any responsibility for the report of any subcommittee other than his own.

Cooperation of many industrial organizations, trade and scientific associations, agencies of Government, and individuals made this report possible and is gratefully acknowledged. Without the generous voluntary participation of the following committee members, this work could not have been accomplished.

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INTRODUCTION

Pest control to protect human health, food, fiber, forest and other biological resources is essential by whatever means necessary. Cultural, biological, chemical and other methods of control are in use. New and expanded research to develop safer and more effective methods of pest control is urgently required.

During recent years, however, many people have been increasingly concerned about the widespread use of nonspecific and accumulative chemicals in pest control and their possible harmful effects on wildlife. The term wildlife, used in its broad sense, includes fish and other aquatic organisms. The subject has been discussed at length without uniform conclusions by informed individuals responsible for pest control or for wildlife conservation and articles bearing on it, both pro and con, are appearing more and more frequently in the press. Concern persists that in the widespread use of chemical pesticides other valuable resources, notably wildlife, are being seriously threatened. As a result, many have opposed the widespread use of these chemicals until more is known about them and how they may be applied more safely. Because of the controversy surrounding the subject and the obvious advantage in knowing the facts, an objective research program is imperative.

There have been few studies of the effects of fungicides, herbicides, growth regulators, and nematocides on wildlife. Many of these materials are less toxic than most insecticides or rodenticides. Therefore, this report deals primarily with the use of pesticides for the control of insects and other arthropods and undesirable vertebrates and the effects on wildlife. However, in the future development and use of fungicides, herbicides, growth regulators and nematocides, attention should be given to their possible adverse effects on wildlife, especially to possible inimical effects of changes in vegetation resulting from their use.

Originally it was intended to review and evaluate the technical information available on pest control and wildlife relationships, the research being done, and the research needs. However, in the interest of brevity it was decided to concentrate on the development of a research program to meet future requirements.

This report is directed primarily to those concerned with planning and facilitating research in this important and controversial field. It should serve to assist them in determining whether pest control and eradication programs are based upon sound technical information. It should also serve as a basis for planning additional research to (1) develop alternative methods of control, (2) improve upon and develop safer and more specific control materials and methods of application, and (3) determine allowable levels of pesticides in wildlife environment and dosages which may be applied without exceeding these levels.

INSECTS

Losses from insect depredations to agricultural crops, forests, ranges, livestock, and products in transit and storage are a major hindrance to production and utilization. All plants, animals, and products derived from them are susceptible to attack by one or more of the estimated 10,000 injurious insect species in this country. These insects cause damage by feeding on the host, contaminating products, or transmitting diseases to plants, animals, or man. The many species with their varied habits reduce yields of crops, lower quality, increase cost of production and harvesting, and require heavy expenditures for control materials and equipment. Insects transmit debilitating or deadly diseases, reduce labor efficiency, and spoil the pleasure of persons seeking rest and relaxation.

Insects comprise the greatest abundance and variety of animal life on earth. One or more species is to be found in practically every possible environmental niche. They attack practically all species of plant and animal life. They are plastic enough to adapt to new environments; to change their feeding habits as new hosts become available. Some of them possess incredible capacities for survival and are able to overcome extreme hazards such as that posed by various insecticides. Because of the great number and variety of species and the ever-present potentialities for increase of destructive forms, insects pose a continuing threat to man and his natural resources. The discovery of effective, safe, and economical ways to control old and new pest species is a challenge which will tax the ingenuity of man to the utmost, and which can be met only by a well-supported nationwide research program.

Many serious insect-control problems face America today. These problems are compounded by insecticide residues on food and feed, hazards to wildlife, insect resistance to insecticides, and by public demands for more effective, longer lasting, and safer control methods.

The study of insects in this country has involved thousands of species over a period of a century. For many years federal and state workers have cooperated with industry, farmers, and others to develop effective, economical, and safer methods for controlling major insect pests.

Although progress has been made in the development of ways to control insects, it has become increasingly apparent that insect problems do not remain static. Important insect problems constantly arise or change as the result of new introductions and establishments, further spread of established species, and changing agricultural and forestry practices. Moreover, standards for satisfactory control are constantly changing because of demands by growers for greater efficiency in the production of crops, timber, livestock, and other commodities. The public is not willing to accept heavy losses of commodities, possessions, and valuable natural resources, or to tolerate insects that affect their comfort or health. These constantly changing insect conditions and standards of efficiency in insect control place heavy pressure on researchers. Simultaneously, higher standards of safety are also demanded.

The problem is how to control these various insect pests and to meet the desired standards of efficiency and safety within a reasonable time, when only limited funds, facilities, and scientific resources are available.

The thousands of species of destructive insects conflict with man's interests in many ways. They involve man himself and his home. They also involve livestock, industrial establishments, forests and ranges, wildlife, field crops, fruits, soil, and water--all essential to his welfare. Satisfactory solutions to insect problems are difficult and complex, and conflicts of interest are to be expected.

No single approach to control will be the most practical or desirable under all circumstances or for all species. The control of each insect pest must take into account its biology, habits, and relationship to its environment. Satisfactory solutions, providing both effectiveness and safety, pose a challenge that will demand not only the best efforts of entomologists, but also the full cooperation of pharmacologists, animal toxicologists, plant scientists, wildlife biologists,

chemists, soil scientists, engineers, and other specialists in different disciplines.

Given adequate support and facilities for research, scientists ultimately should achieve desired standards of effectiveness in insect control and also the essential standards of safety to man, animals, wildlife, beneficial insects, and other values that the public desires. It must be acknowledged, however, that these two goals--effective insect control and complete safety to man and beneficial animals—will be difficult to achieve. More efficient insect control or eradication with the types of insecticides now available may require high dosages, frequent applications, or the treatment of large areas. In some instances, at least, such usage might be expected to increase hazards to man, wildlife, beneficial insects, and other organisms.

Many opportunities exist for productive research leading to more effective methods of insect control that will at the same time avoid or greatly minimize hazards to wildlife. Such opportunities exist whether the method of control involves the use of well-established procedures such as chemicals, biological control agents, and insect-resistant plant varieties, or the newer approaches now under investigation.

The areas of entomological research, both basic and applied, that most urgently need increased attention and support are discussed below.

A. Basic Investigations on Insects

A strong basic research program on insects is needed to lay a firm foundation for new developments in the future and for applied research on practical control procedures. Such a program is required whether the methods involve the use of biological control agents, cultural practices, insect-resistant crop varieties, the use of sterile insects; or various chemicals such as conventional insecticides, systemic insecticides, attractants; or other chemical methods.

Some of the areas of basic investigation most urgently in need of more attention are as follows:

1. Classification of Insects

Precise information regarding insect identity and distribution is a prerequisite to undertaking research on insects, to the initiation of insect-control programs, and to the development of effective quarantine practices against insects. Such information can be obtained only by a critical and systematic appraisal of the kinds of insects that are potentially damaging or beneficial, including criteria for distinguishing each of them from the many other similar but unimportant species. Present knowledge of insects is far from adequate for this purpose, and the task of acquiring and organizing such knowledge is enormous and exceedingly complex; yet the number of insect taxonomists in this country today is no greater than of 30 years ago.

Entomologists in the United States who devote full time to taxonomic entomology are called upon to spend an increasing part of their efforts in identifying routine samples of insects. To meet this demand, and at the same time to develop essential fundamental research in systematic entomology, an urgent need exists for a marked increase in the number of insect taxonomists and supporting personnel, and for adequate work facilities.

2. Research on Insect Biology, Ecology, and Behavior

Efficient and intelligent application of insect-control measures depends on knowledge about insects in their environment. The natural population densities, manner and rate of dispersion, factors responsible for and rates of increase from one generation to the next, and relationship of injurious insects to other organisms such as hosts, parasites, predators, and insect diseases, are all important aspects that may determine the best approaches to pest control. A determination of the causes of insect outbreaks is essential both to the development of practices for reducing or preventing them and to forecasting their occurrence.

The role of various aquatic or terrestrial insects as food-chain organisms for other animals is not well known. Yet this is a vital question that needs answering in many situations to determine the true effect of insect control operations on wildlife.

3. Insect Physiology and Toxicology

A better understanding of these disciplines is necessary in order to ascertain the mode of action of specific insecticides, attractants, or repellents. Likewise, a need exists for a more thorough understanding of the nature of the insecticide-resistance mechanism so that the problem may be avoided or overcome. The physiological differences between insects and higher animals need to be known so as to develop specific chemicals for insect control without hazard to other organisms.

4. Insect Nutrition and Reproduction

Successful mass rearing of insects requires basic knowledge of insect nutrition. Several new and potentially safe approaches to insect control may be totally dependent on the success that can be achieved in the economical mass production of insects under controlled conditions. The release of sterile males, the availability of certain insect pathogens, parasites, or predators in adequate numbers for direct control of specific insects, a sufficient supply of insects for extraction of sex attractants for survey or control purposes, all depend on the ability to rear adequate numbers of insects of particular species.

Basic information on the nutritional requirements of insects is also needed to open the way for other possible approaches to insect control. For example, studies on the nutritional requirements of tropical fruit flies led to the development of the protein hydrolysate-malathion bait-spray, used in the eradication of the Mediterranean fruit fly in Florida.

5. Biochemical and Metabolic Investigations of Insects

Basic biochemical research on insects should be expanded. Limited research has already provided promising leads in new approaches to insect control. For example, certain insect hormones play vital roles in connection with insect growth and reproduction. The opportunities for controlling insects effectively and safely by utilizing such hormones or by otherwise interfering with their normal activity appear to be great. Studies are also needed to obtain more basic information on normal metabolic processes in insects and the metabolic fate of chemicals used for insect control. By relating results from such studies with results of similar investigations on plants and higher animals, it might be possible to develop types of chemicals biologically active against certain insects but harmless to man, plants, wildlife, and other organisms.

B. Biological Control of Insects

1. Exploration, Introduction, Conservation, and More Effective Utilization of Parasites and Predators of Destructive Insects

Without predatory and parasitic insects, many insect outbreaks would be much more frequent and intense, but parasites and predators often do not provide the level of insect control required. When biological-control organisms do provide effective control of insects, the problem of chemical residues and other hazards to wildlife and beneficial insects is avoided.

Additional biological control agents should be introduced and established in the United States to help control some of our worst pests from foreign countries. More attention should be given to the ecological conditions under which beneficial insects live in the country of origin, as compared with those into which they may be introduced. Likewise, adequate follow-up studies in this country, after introductions are made, are required to learn the reasons for success or failure. Genetic studies are needed to select strains of parasites and predators that will survive and function as effective natural control agents.

Studies are needed on the mass production of these agents and the possibilities of releasing them in large numbers for the control of certain major destructive species of insects. By this method it has sometimes been possible to achieve the required level of insect control without supplementary chemical control measures.

Another promising line of research relates to investigation and development of the best possible integrated control program based on the maximum utilization of these agents along with a minimum use of insecticides. Finally, it appears

possible to improve the efficiency of certain parasites and predators of forest insects by determining the optimum environmental conditions for their maximum abundance, and by developing management practices designed to produce and maintain these conditions.

2. Investigations on the Use of Insect Pathogens Such as Viruses, Bacteria, Fungi, and Nematodes

Several lines of investigation should be expanded, including the discovery and identification of new insect pathogens, studies of their cultural requirements, methods of propagation, methods of separating and purifying the agents, and factors governing infection and spread of diseases under laboratory and field conditions. Ways of utilizing diseases for effective and economical control of various insects should be investigated, including the release of contaminated adult insects, strip or spot spraying of pathogens, and the adoption of cultural practices that favor insect diseases. Further emphasis is also needed on the integration of microbial and chemical control. As with other control methods, the influence of weather and other environmental factors on the effectiveness of microbial agents must be determined. Since the effective use of insect pathogens may often require repeated applications, it will be necessary to develop economical methods for pathogen production on artificial media or on insect hosts that can be reared in large numbers at low cost. An important step in connection with viruses would be the development of tissue-culture methods for propagation.

C. Development of Plant Varieties Resistant to Insect Attack

Sufficient research has been conducted to show that it is practical to develop plant varieties highly resistant to attack by some insects; such studies should be greatly accelerated. Plant varieties that possess resistance to major pests and are also agronomically or silviculturally desirable do not cost any more to grow than susceptible varieties and are not hazardous to other organisms. However, it may take from 10 to 15 years or longer to develop insect-resistant varieties of plants. An adequate program of basic studies to determine the precise nature of resistance in selected varieties of different plants is needed. Programs on insect-resistant plant varieties could be greatly facilitated by research on methods of rearing insects, which emphasizes again the importance of basic studies on insect nutrition.

D. Research on the Application of the Sexual-Sterility Approach to Insect Control

The successful use of male screw-worm flies, sterilized by exposure to cobalt-60 radiation, to eliminate the screw-worm from the southeastern United States has elicited worldwide interest in additional research to determine the value of this control procedure against other insects. This method of insect control represents the ultimate in specific action. The successful use of reared and released sterile males to control or eliminate well-established insect infestations can be expected only after the natural population has declined or been reduced to a point at which it is economically feasible or advantageous to release dominating numbers of sterile insects. Much basic research will be required before the limitations and potentialities of the technique can be determined for any specific insect. Studies are needed on mating habits of the insect and on methods of producing sexual sterility without adversely affecting the sexual vigor and length of life of the males. In addition, successful methods of rearing the species economically in large numbers, and practical ways to release and distribute the insect must be developed. The potential advantages of the release of sterile males as a means of insect control, from the standpoint of effectiveness, economy, and safety to man, animals, wildlife, and beneficial insects, justify greatly increased research effort.

Chemosterilants, another means of utilizing the sexual-sterility approach to insect control, are being investigated in a limited way, and with encouraging results. Suitable sterilizing chemicals incorporated in baits which when fed upon would sterilize males and females of the native insect population appear to offer the most feasible approach. Inducing sterility in a high percentage of the natural population would avoid the necessity of rearing large numbers of insects in the laboratory and of treating and releasing them. Much research will have to be done, however, to develop effective and safe chemosterilants, but the potential advantage of this approach over conventional killing agents warrants a major effort.

E. Chemical Control

Chemical control will for some time continue to be a principal means of controlling most of our major insect pests. The benefits are of major importance throughout the world. On the other hand, the application of insecticides is generally a repetitive operation and often has adverse side effects, such as harm to other forms of life.

Chemicals furnish a ready means of controlling or eradicating destructive insects introduced into the United States from abroad. They can also be employed to prevent or restrict serious damage resulting from unexplained and unanticipated outbreaks of local insect pests. Thus, it is essential that research effort on chemical control methods be maintained and strengthened.

The effectiveness of many chemicals currently in use should be improved and more selective and highly effective chemicals developed to provide maximum safety to man, animals, and wildlife. Emphasis should be placed on developing insecticides that are as specific as possible. The following lines of investigation in chemical control are increasingly important.

1. Attractants

The recent identification of the structure of the chemical substance occurring as a natural product in virgin female gypsy moths, which attracts the male, plus the synthesis of a related and powerful attractant, plus the success achieved in finding highly effective and specific male lures for several species of tropical fruit flies, is ample justification for more research on insect attractants.

Research on specific attractants, whether sex lures, food attractants, or other agents, offers the possibility of achieving control of certain insects without hazard to other organisms. An intensification of research in this field should be given high priority.

2. Systemic Insecticides

Sufficient progress in research on these insecticides has been made during recent years to emphasize their advantages in the chemical control of insects. Introduced into plants or animals, they offer more uniform biological effectiveness and specific action against the insect to be controlled. Use of these materials might not completely eliminate hazards to beneficial insects such as bees, parasites, and predators, or to wildlife, but there is every indication that these hazards would be greatly reduced. Increased support should be provided for investigations on systemic insecticides.

3. Search for Safer Conventional Insecticides

More and more attention is being given to the development of insecticides possessing a high degree of insecticidal activity with a minimum of toxicity to higher animals, including wildlife. Efforts to achieve these objectives should be maintained and intensified.

4. Development of New Chemicals Possessing Different Modes of Action

Research on insecticides for many years has emphasized rapid action in destroying insects, and techniques for discovering new insecticidal chemicals also have emphasized this type of action. However, for many insects high speed of kill is not always essential. Studies are needed to develop new evaluation procedures for determining adverse effects on feeding, survival, and reproduction of insects irrespective of the period of time required to kill them. Such tests might broaden the opportunities of developing effective insect-control chemicals. Search should also be made for chemicals possessing slow toxic action or antimetabolic activity not detectable by current screening procedures.

F. Equipment for Applying Insect-Control Materials

There is need to test and improve existing equipment and to design new equipment for the application of insecticides and insect pathogens to various agricultural and forest crops. Such research should include dispersal equipment of various types for use in small and large aircraft and in ground equipment. Further research is needed to improve the spray patterns and droplet sizes produced by different nozzle sizes and arrangements on different types of equipment, with special emphasis on the penetration of the spray through the canopy of different types of vegetation. In addition to sprays, much research is needed on the proper dispersal of dusts and granular insecticides. There is also need for the development of better aerosol devices to disperse regulated quantities of several insecticides within airplanes for control of insects. Better methods are needed for pilot guidance in widespread aerial spray programs so as to insure proper placement of insecticides in the target area and to avoid overdosing and its attendant hazards. Improved equipment for applying insecticides can contribute to safety of wildlife as well as man and livestock, and to economy by permitting the use of a minimum amount of insecticide for satisfactory insect control.

VERTEBRATES

With the exception of marine fishes, most wildlife share habitats serving other purposes such as: water conservation, recreation, agriculture, forestry, and livestock grazing. Some of these uses complement one another, resulting in the widely accepted multiple-use concept. For example, wildlife can use the intervening herbaceous and browse shrub cover to the advantage of an early-stage coniferous plantation, each approaching the maximum production attainable by exclusive use of the habitat by either. Natural checks and balances rarely if ever achieve this goal. However, the reproductive potential sometimes enables vertebrates first to severely damage the vegetative cover and, in turn, to fall victim to the multiple consequences of overcrowding. Only to the extent that man can provide more immediate checks and balances, including effective and judicious harvesting through hunting and fishing, can the optimum return from the land be realized. This obviously requires planning.

When land is to be subjected to the dual use of economic plants and wildlife, the habitat must be managed with these objectives in mind. Wildlife must be manipulated so as to regulate the number of species and individuals, just as plant societies have been molded to sustain and complement man's welfare. Where the two uses conflict, adjustments must be made that will best serve the long-range needs of mankind.

Both in agricultural areas and in wildlife habitats, the better food plants tend to be replaced by unpalatable or less desirable species when wildlife populations exceed the carrying capacity of the land. On the other hand, wildlife numbers can be measurably increased on lands devoted primarily to crop, livestock, and timber production by developing techniques that permit the realization of plant productivity through management of feeding behavior.

Interspecific strife in wildlife populations sometimes results in very undesirable changes in the faunal community.

For example, the aggressive herring gull competes more successfully than black and eider ducks, terns, and shore birds that share the same nesting islands off the coast of New England. Without corrective measures, the populations of the latter species decline sharply. Similarly, the more adaptive carp may dominate warm-water streams, ponds, and lakes to the detriment of fish species more important to man.

Some species of wildlife disperse widely during most of the year (or most of their lives) only to congregate in huge numbers for limited periods, as illustrated by the winter roosts of as many as 20 million blackbirds, the breeding colonies of the fur seals, or the spawning migrations of salmon. These concentrations may conflict sharply with economic pursuits in adjacent areas, such as rice growing near a blackbird roost or lettuce crops astride the northern migratory routes of certain species of small passerine birds. Other wildlife concentrations pose very real problems. The presence of the Laysan albatross on Midway Island, its principal nesting site in the Pacific, presents problems in the establishment and operation of strategic airfields in that area. Concentrations of a still different type bring woe to irrigated farming when mammals such as the jackrabbit abruptly appear by the tens of thousands from adjacent drought-plagued range and desert lands.

Lastly, means must be available for quick defensive action against vertebrates found to be involved in the transmission of communicable diseases such as rabies, sylvatic plague, Rocky Mountain spotted fever, encephalitis, and tularemia.

Thus, while considering how wildlife and wildlife habitats can be protected from possible adverse effects of pesticides used in agricultural pursuits, it is equally important to consider how other pesticides can be employed to enhance and perpetuate this same resource, to solve some of the perplexing problems of retaining the prefix "wild" in the flora and fauna. Natural forces never succeeded in maintaining a status quo. Ninety-nine percent of all plant and animal species once present on this globe are now extinct.

There is widespread interest and participation in research on management of vertebrate populations; thus little difficulty is experienced in either staffing or financing of short-term studies of immediate urgency. However, greater attention should be given to long-term studies that are basic for dealing with the sporadic, brief, severe-to-catastrophic increases in animal numbers and diseases. Moreover, manipulation of vertebrate populations and habitats with pesticide chemicals should not terminate with the initial demonstration of utility and safety, but should be programmed to follow the cumulative effect of the practice.

A. Chemicals

Data on the side effects of pesticides on wildlife are urgently needed at an early stage in the development program. Limiting factors would thus be revealed at a time when such information would aid in decisions affecting further development, marketing, and use. Adverse information that becomes available after a chemical is marketed not only initiates antagonisms but also often results in economic losses. Active participation by Government, industry, and conservationists in the early evaluation of chemical pesticides is deemed necessary to achieve mutual understanding.

In connection with pesticides intended primarily for vertebrate and habitat management, the wildlife interests would be well counseled to share with industry and public and private institutions the responsibility for research into the biological activity of these chemicals. Without such a cooperative program, wildlife scientists may largely be limited to adopting pesticides designed entirely for other purposes.

Research on repellent-type chemicals should be intensified. Of particular interest to the operators of 56 million acres in tree farms is the development of systemic repellents—chemicals that can be translocated into the plant to follow the growth pattern and reduce palatability for browsing or gnawing animals. A systemic seed treatment is yet to be found that will translocate through the intact edible hull and provide protection from vertebrates for both the seed and subsequent seedling.

Since aerial applications of pesticides to both terrestrial and aquatic habitats is an established practice, it is essential that chemicals be developed that have inherent species

selectivity. Although the aquatic biologists will have some use for a general fish toxicant that is rapidly transitory, the species-selective toxicant is the ultimate tool.

Much greater use of anesthetizing and stupefying chemical agents could be made in the handling of localized wildlife problems. Candidate chemicals of this class should be included in all evaluation programs.

B. Mechanical

The continuing developmental projects in trap design, fencing, frightening devices and other mechanical means of controlling vertebrate movements and habits should be supplemented by studies on the effect of different wavelengths of energy on the behavior of animals. Radar and ultrasonic sound have been repeatedly proposed as a possible means of moving or otherwise repelling birds and mammals. Several electronic devices are currently being marketed for this purpose in the United States, although the efficacy of the method has not been established by any recognized authority.

C. Cultural

Although control of vertebrate populations by cultural practices is not suited for handling crises, it is nevertheless the "method of choice" wherever applicable. It includes the manipulation of cover so that damaging populations of rodents have no chance to become established, or the selection of earlier or later maturing crops to avoid harvests during a migration period or before birds congregate in winter roosting colonies. A corollary to the latter would be the combining and kiln-drying of cereal grains. The selection of plant varieties for fruiting behavior less susceptible to animal damage would be a valuable contribution. An effective solution may be as obvious as avoiding landscaping of new airports so as not to attract concentration of resident birds that are a hazard in a jet age.

D. Attractants

Several mammal-control problems are presently at an impasse, not for lack of an acceptable toxic agent, but because the animals have to be dealt with individually. The rabbits and porcupines are good examples. Attractant odors that could draw animals from as short a distance as 100 feet would be valuable indeed. Certainly chemicals with this property should be regularly solicited from all known sources and their action against specific vertebrate species evaluated. This investigation must include natural products extracted from animal tissues, chemically isolated, and subsequently synthesized.

E. Reproductive Inhibitors

This relatively new field of vertebrate population control should be progressively expanded as techniques for evaluation of compounds are perfected. Since killing of adult birds meets with much public disfavor, candidate reproductive inhibitors should be regularly solicited from all sources for evaluation of their effects upon avian species.

EFFECTS OF PESTICIDES ON WILDLIFE

Unless chemical pesticide programs are soundly based and properly planned and executed, they may cause serious damage to wildlife. In contrast, when they are carried on with understanding and consideration of all resources, they may even be beneficial to wildlife. Waterfowl environment, for example, is often improved by the use of herbicides. Control of spruce budworms helps to keep forests green and thus helps to prevent forest fires that often occur following the widespread killing of forest trees by this insect.

Wildlife and fisheries comprise an important part of renewable natural resources. They are of great value esthetically, recreationally, socially, and culturally, as well as economically. The spiritual and health benefits derived from a day afield enjoying wildlife help to build a stronger, more appreciative, and better-balanced citizenry.

Wildlife is the basis for great economic values in hunting and fishing. In 1960 some 50,000,000 people, 12 or more years of age, went fishing, hunting, or both. An estimated 25,323,000 fishermen took 412 million fishing trips, and spent some 466 million man-days fishing. Similarly, 14,637,000 hunters made 178 million hunting trips. Such popular forms of recreation as these add greatly to the economy in all sections of the country.

Participation in bird watching and other natural history activities is increasing at a more rapid rate than is national population growth.

In all states, tourism is of great economic importance and in many it ranks among the major economic resources. The presence of wildlife in a locality is one of the attractions that draws visitors. The large number of tourists who travel each year to Texas to see 25 or 30 whooping cranes, the remnants of a once-large population, which winter near the Aransas National Wildlife Refuge, is an illustration.

The annual commercial fishery harvest, including coastal commercial fisheries, approaches five billion pounds. This is a valuable source of high-protein, high-mineral, low-fat food.

Wildlife resources cannot successfully be managed apart from the management of soil, water, forests, farms, and ranches. Wildlife is an important element in the over-all renewable natural resources base, and all of these resources are interrelated. Wildlife is as much a product of the soil as any crop. Sound management must appropriately consider all values.

The complexity, scope, and importance of pest-control problems require close cooperation of many agencies and scientific disciplines. Control of pests is essential, and those undertaking control programs must be guided by adequate knowledge and maturity of judgment in weighing all values involved. Without factual information, mistakes are likely to be made even though all concerned consider the interrelations with a wholesome spirit of cooperation.

Investigations needed to meet the problems of the effects of pesticides on wildlife may be outlined as follows:

A. Testing the Toxicity of Pesticides

1. In the Laboratory

Tests of acute toxicity using laboratory animals are required by present regulations. Without making these regulations unnecessarily stringent, testing should be expanded to include more wildlife species because their reactions are often different from those of standard laboratory animals and there may be a wide range in the toxicity of a material to different species. The limitation in this sort of work will be the present inability to handle many species of wildlife under controlled laboratory conditions. This laboratory testing will be dependent therefore on the development of methods for holding and rearing the test organisms required. The testing of the most important species is essential because it provides needed basic information.

2. In the Field

Only by extensive field tests can the actual performance of a pesticide be determined. The effects on wildlife will depend not only upon (1) the absolute toxicity of the materials, but also upon (2) the chance that it will be contacted by the animals, (3) whether the toxicant decomposes quickly, (4) whether it becomes bound on the surfaces of colloidal particles (clay, humus, etc.), (5) whether it influences the ability of a species to compete favorably with other organisms in the environment, or (6) whether it is concentrated in the bodies of one species that is fed upon by another one less resistant to the poison. An example of the last is provided by robins feeding upon earthworms that have accumulated DDT.

B. Decreasing the Hazard to Wildlife

1. Safer Formulations and Applications

Some of the pesticides in common use, especially the chlorinated hydrocarbons such as DDT, dieldrin, aldrin, and heptachlor, have proved to be harmful to wildlife under some conditions such as those involving high concentrations. Every possible effort should be made to develop means whereby these substances can be applied safely, either (1) by carefully controlled dosages of the least harmful formulations, (2) by avoiding certain habitats such as water areas, or (3) by placing the toxicant in locations where the pest will be reached but where wildlife cannot be contacted. For example, the special equipment on planting machines to inject pesticides for the protection of the crop against white grubs and the reduced dosages and improved application techniques for mosquito control are advances that have been made along this line.

2. Safer Materials

Safer materials, especially those with low toxicity to vertebrates and a unique toxicity to specific arthropod pests are needed. It is essential that research be directed toward the development of organic pesticides which decompose or are broken down into harmless materials in the soil and water.

C. Biological, Cultural and Integrated Controls

Where biological controls can be utilized effectively and under adequate safeguards, the need for pesticides is correspondingly reduced. High priority should therefore be given to research for the development of all types of biological controls. Cultural practices to effect pest control should be employed whenever possible. Cooperative studies to develop these and similar practices are needed.

D. Fate of Pesticides After Application

1. In the Terrestrial Environment

Some pesticides decompose promptly after application and become harmless, whereas others, such as certain of the chlorinated hydrocarbons, are comparatively stable and tend to accumulate. Although some studies of what happens to chemicals in soil and water have been made, particularly on the accumulation and breakdown of chlorinated hydrocarbons in the soil, much research remains to be done on many pesticides, both old and new.

Research is needed to determine how pesticides that accumulate in the soil affect (1) plants growing in the soil, (2) the micro fauna and flora, and (3) the associated animals.

Studies are needed to determine the relationship between the amount of pesticide applied and the residual amounts in the habitat under a variety of conditions, different formulations, methods of application, the effects of weather conditions and amount and kind of vegetative cover should be taken into consideration. The relation between the amount of different pesticides on the forage or in the drinking water, and concentrations in the bodies of wildlife should be determined. This will require extensions of research on needs of determining residual concentrations.

2. In the Aquatic Environment

Studies are badly needed to determine the pattern and extent of water pollution that occurs through direct application of pesticides, through drift during treatment operations, and by pesticide in runoff water from treated lands.

Studies are also needed to determine the relation between the amount of pesticide applied and that reaching watercourses. This will vary with formulation, time and method of treatment, vegetative cover, soil, slope, and weather conditions. Studies will thus have to be made in a variety of situations and will require several disciplines if this relation is to be established.

Of prime importance are studies to determine the effects on the aquatic biota of sublethal concentrations of the pesticides. This can be accomplished through physiological, biochemical, histological, toxicological, ecological, and other studies to determine maximum concentrations of the various pesticides which are not detrimental under conditions of intermittent or continuous exposure. When these data are used with information on the ratio between the amount of pesticide applied and that reaching the aquatic habitat, it will be possible to indicate safe levels of treatment. Without such data recommendations for the prevention of harmful pollution cannot be established.

Those familiar with both terrestrial and aquatic wildlife and those chiefly concerned with the control of pests need to study these matters from the ecological viewpoint. The importance of cooperative research cannot be overemphasized. Success will depend upon careful planning, a spirit of cooperation, adequate financial support, and competent overall guidance.

E. Wildlife Movements in Response to Pesticides

Evidence indicates that some animals can and do move away from areas treated with pesticides. Whereas others, especially the less mobile species, do not. When animals which cannot or do not move out of the treated areas are decimated, the species will again invade the area if a surrounding population exists. Evidently the movements out of and into a treated area, are related to the mobility of the animal, the size and shape of the treated area, and the character of the environments in both treated and adjacent untreated areas.

The long-term effects of a decimating pesticide call for intensive research that is largely ecological in nature involving population dynamics, population estimates, and biological studies of the organisms involved. Research of this sort can be done effectively only on a long-term basis, with replication under numerous different conditions, and calls for careful direction and supervision by experienced personnel. Only on the basis of such studies can an accurate judgment be made as to whether the effects of a certain decimating treatment will be transient or relatively permanent.

F. Environmental Changes Caused by Pesticides

Any pesticide application is likely to change environmental conditions to a greater or lesser degree. However, some pesticidal applications that cause damage to wildlife environment could doubtless be avoided if more were known about them. Such environmental changes may be striking or may escape detection. Careful research is needed to disclose subtle effect upon the environment and, if undesirable, how they can be ameliorated.

ECONOMIC EVALUATIONS

In many instances the use of pesticides will inevitably result in a certain amount of damage to wildlife. In cases of this sort an evaluation must be made that is economic in nature. To use or not to use a pesticide hinges upon the analysis of a complex set of conditions and the balancing of expected good on the one side against the bad on the other.

This balancing process calls for knowledge of the factors involved, expressed in quantitative terms. To collect and evaluate such data calls for cooperative research in which competent economists work cooperatively with biologists and land managers who are interested in pest control, public health, and wildlife protection and crop production. Economic measurement techniques and the methods by which these measurements are analyzed and evaluated need to be developed or improved.

SUMMARY

Since many of the chemicals used for control of pests are indispensable to efficient crop production and forest management but have recognized potential for adversely affecting desirable plants and wildlife, much more comprehensive research is needed. Intensification of research on pesticide use, especially for control of insects and mammal pests, would be clearly indicated along the following lines without connotation of priority:

(1) Study better methods of application and modified scheduling of treatments with known pesticides so as to avoid, as far as possible, contact with valuable wildlife or impairment of the environment essential to their survival and healthy reproduction.

(2) Initiate intensive research on new types of pesticides to replace those causing the more severe types of injury to wildlife. This includes the synthesis and evaluation of materials that will be highly specific for the pests to be controlled, ephemeral in the environment to be treated, or capable of detoxication by the wildlife that is likely to come in contact with them.

(3) Determine the fate of commonly used pesticides after application, and set up procedures for comparable evaluation of experimental new materials, including: rate of volatilization, detoxication, adherence to soil colloids and organic matter, leaching and mobility in soil water, and storage in plant and animal tissues likely to serve in the food chain of wildlife.

(4) Develop alternative methods of pest control by intensification of research on: improved cultural practices, biological controls such as use of parasites, predators, and disease agents of the pests, development of resistant and pest-escaping varieties of crops, search for specific repellents and attractants for use in control, and induction of

sterility in the pests by irradiation or chemicals. Success in developing these alternative methods will be dependent in large measure upon increased support for basic research on different pests, including studies on their taxonomy, biology, ecology, nutrition, physiology, biochemistry, and toxicology.

(5) Make more effective use of the knowledge now available on items listed immediately above in coordinating chemical and non-chemical control measures so as to capitalize on the distinct benefits from each in a carefully coordinated program.

(6) Intensify research into the habits and movement of wildlife with particular attention to its proclivity to exposure to different pesticide applications and capacity for regeneration and dispersal in case of marked reduction or decimation by chemicals or other adverse forces in the environment.

These six lines of research obviously call for (1) development of the very best techniques for detecting pesticides in the environment and inside plants and animals, (2) determining the tolerance of wildlife to pesticidal compositions, and (3) appraising the relative harmfulness of pesticides when ingested and in bodily contact by either direct or indirect exposure. Even under the most favorable circumstances, it will be difficult to appraise, and much more difficult to predict the hazards wildlife is being exposed to in the control of economically important pests of the woodland, forests, pastures, orchards, and fields. The very best skills of specialists in the several fields of knowledge will be required to develop principles that will permit attaining maximum benefits from pesticides with minimum hazard to desirable forms of wildlife. A constant process of consultation and gathering of data will be required since the problem will be a continuing one for many years to come.

This accelerated research program will be exceptionally expensive and time-consuming because of (1) the complexity arising from study of many types of chemicals and formulations in a multitude of uses on different crops and trees, (2) the modifying influence of different factors of soil and climate in the several environments, (3) the diversity of wildlife likely to be affected, and (4) the many combinations of treatments that inevitably will be tried. The investment in scientific research facilities, manpower and resources will be tremendous.

Industry might assume the major responsibilities in the search for effective new chemicals, the basic measurements on toxicology to pests and mammals, and perfection of formulations and methods of application to secure effective control of pests with a minimum of hazard. The public institutions might be responsible for studies on the reactions and habits of pests and wildlife, tolerance of wildlife for chemicals, development of alternative methods of pest control, and their integration with chemical methods. With teamwork, mutual understanding, and trust, and provided adequate support is forthcoming, the problems can be solved.