ment, and the fishing industry what must be done to accomplish this goal. The gains can be substantial but only after long-term, painstaking research, which should be started without delay if we are to compete with other countries or even maintain our present position among the fishing nations.

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The Effects of Pesticides on Sport Fisheries

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Abstract

Pesticides for agricultural use are being applied at such great rates in the United States that they must be considered as a major factor in the welfare of our fishery resources. It has so far been impossible for fishery research to keep up with the growing use and increased potency of these chemicals, but recent legislation directing the Secretary of the Interior to undertake comprehensive research on the effects of pesticides on fish and wildlife has dramatized the need for careful study. The insecticides pose the greatest threat to fish; of these, the chlorinated hydrocarbons are most dangerous because of chemical stability and slow detoxification. The Bureau of Sport Fisheries and Wildlife has organized a laboratory at Denver, Colorado, for research on the complex of fish, water, fish food, and pesticides, involving both biological and biochemical studies. The laboratory's program will include cooperative work with entomologists and chemical industry scientists to develop more specific and less toxic pesticides and improved methods of application.

THE MANAGEMENT of the inland sport fisheries has always had to consider the factors which tend to reduce fish populations. The effects of exploitation by fishermen, the survival of planted fish, and the improvement of the environment have been intensively studied, and progress has been made in maintenance of sport fish populations as a result of understanding these factors and applying improvements. Fishery science has made good progress in fresh water in providing fish for the creel, and in maintaining fish populations at safe levels. This has been possible because of long experience, long-term research, and hard work.

A relatively new threat has been added to the list of influences which adversely affect fish populations. Pesticides, including insecticides, weed killers, and other economic poisons, have come into such widespread use since World War II and have proven to be so poisonous to fish that they must now be ranked as a major factor in the welfare of sport fish in nature. Fishery biologists have been aware of the threat from pesticides for a long time; but it has been impossible to keep pace with the growing use of these toxicants in so many situations and in such widespread applications in the face of the augmented number of new agents, and with the increased potency of the newer insecticides.

Over 200 pesticides and more than 6,000 brand-named products are now marketed.

Extent of Pesticide Use

The use of economic poisons in the United States has undergone a phenomenal development from the days of the initial improvements in older botanical and inorganic pesticides. Just before World War II, advances were made in the areas of synthetic organic herbicides and fungicides. During the war, hormone-type selective herbicides, synthetic organic rodenticides, and chlorinated hydrocarbon insecticides were developed, and since the war, organic phosphate and systemic insecticides, anti-coagulant rodenticides, and antibiotics for plant use have been discovered and improved to an astounding degree. In more recent years, new and amazingly toxic halogenated hydrocarbons have evolved and have been marketed for mass application over widespread areas. The list is not complete without mentioning defoliants, plant growth regulators, nematocides, fungicides, and evaporation control agents. Truly, the term "chemical age in agriculture" is most appropriate in describing the latter-day methods of managing plant resources. Secretary of Agriculture Ezra Taft Benson points out that America's farmers need weed killers to prevent $4 billion per year in weed damage and enough rodenticides to prevent damage amounting to $1 - $2 billion per year. It is said that enough insecticides must be used to save seven billion board feet of timber in the United States each year. The farmers of the U. S. spent $400 million for pesticides in 1956; one can visualize the anticipated growth of this industry by noting that, by 1975, $1 billion worth of agricultural chemicals is expected to be used each year.

The growth of research on the effects of pesticides on sport fish populations has been very much slower than the development and use of new economic poisons. With the advent of DDT, fishery biologists became concerned about the consequences of field treatments near aquatic environments. Studies were conducted at the end of World War II to measure effects of DDT on fish and fish foods, and enough information was collected to make recommendations to reduce hazards to aquatic life. An increasing amount of investigation was done in subsequent years, but it was still difficult to keep pace with the strides of industry in their production of new and greater quantities of toxicants. Fishery science in the United States is responsible for the management and protection of sport fishery resources worth $2 billion per year, so we are discussing something that approaches in value some of the agricultural resources that are being protected by the pesticides. Industry is now spending $20 million per year on research and development in pesticides, and the Federal Government is dedicating $5 million per year to work with pesticides. Of course, only an insignificant fraction of this Federal money has been spent on fish studies, despite the desperate need for such investigation.

Considerable relief from this situation was afforded in 1958 with the passage of Public Law 85-582. This directed the Secretary of the Interior to undertake comprehensive studies on the effects of insecticides, herbicides, fungicides and other pesticides on the fish and wildlife resources of the United States. A small portion of the appropriated funds was applied to studies on fresh water fisheries, beginning in January, 1959. Some of the money was also used for marine fishery investigation. Construction of laboratory facilities was begun in Denver, Colorado, and I am happy to report that the specialized facilities needed for this work are now operating. The assembling of our staff of biologists and chemists was completed by the end of June, so the Fish-Pesticide Research Laboratory is an operating unit.

The directive for "comprehensive" work was nullified to a large extent by Congressional limitation on expenditures, so that no more than $280,000 could be appropriated in any one year. Congress recognized the deficiency during the past session and amended the 1958 Act to allow appropriations of not to exceed $2,565,000 a year for this work. We do not have any such appropriations now, but at least there is more room for budgeting realistically in accordance with the size of the problems involved.

Control Programs

Of all the pesticides, the insecticides pose the greatest threat to fish. This is so because of the magnitude of the spray programs against insects, because of the relatively high toxicity of insecticides as compared with weed killers and other economic poisons, because insect life is a major fish food and because of the variety of ecological situations in which insecticides are dispersed. Two chemical groups are the most important in the insecticide realm, the chlorinated hydrocarbons and the organic phosphates. The chlorinated hydrocarbons are characterized by moderately to extremely high toxicities to fish and by chemical stability that results in slow detoxification and prolonged danger to fish and fish foods. DDT is the most familiar insecticide of this group; aldrin, dieldrin, endrin, and heptachlor are examples of newer, long-lasting, and highly-toxic chlorinated hydrocarbons in widespread use today.

The organic phosphorus insecticides have a wide range of toxicity to fish, are generally less toxic to fish than many chlorinated hydrocarbons, and lose their toxicity much more quickly than most chlorinated hydrocarbons, especially in aquatic environments.

The method of application of the insecticide and the formulation in which it is applied are of decided importance in the effects on fish. Airplane spraying, although cheap and fast, is often difficult to control, and is generally less safe in the vicinity of water than ground spraying or dusting which features lower dosage rates and better control over distribution. Oil solutions are very popular as formulations for many insecticides, and are favored from the fish standpoint because of their lower toxicity compared with xylene emulsions and because of their fast dissipation compared with dusts and wettable powders.

The herbicides represent the second greatest threat among the pesticides, especially those that are used to control aquatic weeds. When some weed-killers are placed in drainage and irrigation canals for aquatic weed suppression, there is often a danger to fish in the ditches and to waters into which the canals may feed. The dinitrophenol compounds, the aromatic solvents, and the chlorinated benzenes are herbicides that are particularly hazardous to fish; the 2-4D and 2-4-5T weed killers have proven to be somewhat less toxic for fish and fish food animals.

Some recent insect control programs in the United States have been so large and have attracted so much attention that some remarks about them may be in order here. The larger programs include spruce budworm in the forest areas of the north, gypsy moth in the northeast, mosquitoes in nearly all parts of the country, grasshoppers in the west, and imported fire ant in the southeast. In the past four years, approximately 26 million acres of forest and agricultural land have been treated for these pests alone, and projected plans call for augmented control programs for control of some of these insects. Spruce budworm and gypsy moth programs feature aerial application of one pound per acre of DDT, a procedure that has resulted in cases of substantial losses of trout in

New Brunswick and Montana. In the fruitfly eradication effort, malathion bait spray is dispersed by airplane and ground equipment at the rate of ½ to ¾ pounds per acre of the poison. Here again, actual control operations have produced extensive mortality to shallow-water fish populations in Florida. Insecticides of various kinds are in common use for grasshopper control in the west —dieldrin, heptachlor, endrin, chlordane, aldrin, and toxaphene in relatively low dosage rates. In 1958 and 1959 several instances of significant mortalities among bass, bluegill, crappie, and perch populations in lakes in Colorado were observed following airplane spraying of aldrin, toxaphene and endrin. Alarming as these documented episodes have been, we are faced with a still stronger possibility of damage to fish and fisheries in parts of the southeastern U. S. adjacent to areas to be treated for the protection of agricultural crops. Massive doses of insecticides are the treatments of choice for cotton and other crops, and heavy doses of dieldrin (2 pounds per acre) and heptachlor (1¼ pounds per acre) are being used and are planned for future, expanded imported fire ant eradication. Our knowledge of toxicity of these agents against fish causes us much concern about the consequences of these field programs, since these chemicals are among the most lasting and the most toxic in use today.

Damage to Fish

The damage rendered to fish by pesticides can act in one or more of several ways. Some poisons strike directly at the fish, causing acute toxicity and quick death. The mode of action may be on the central nervous system of the fish, as with chlordane, which stimulates the system, or with some isomers of benzene hexachloride, which depress the system. Organic phosphorus compounds are believed to act through irreversible cholinesterase inhibition by irritation of surface tissues, by stimulation and depression of the central nervous system, or by degeneration in the central and peripheral nervous system. Parathion, malathion, Chlorthion, and Guthion are poisons of this group. Chemicals of the pyrethrum type may be lethal to fish by causing convulsions leading to respiratory failure. Sometimes the solvents, as well as the insecticides, are toxic to fish. Kerosene has a narcotic action causing depression and can damage liver and kidneys. Xylene irritates nervous membranes and the skin, and affects red blood corpuscles.

Death to fish may be caused by the accidental or careless introduction of the chemical into waters during spray operations. Other chances for lethal amounts may be provided when long-lasting chemicals are washed into the water by rain runoff from adjacent ground or vegetation, sometimes long after the actual spray operation. Dieldrin, for example, has maintained its potency for more than two years in some instances and has poisoned fish over that period.

The presence in fish waters of invertebrates dying or dead from pesticide treatment can seriously affect fish. During such episodes, fish feed vigorously, engorging themselves with food animals that contain more toxicant than the water. It has been demonstrated that fish can die from acute toxicity after receiving chemicals from this source.

Another important influence pesticides may have on fish comes through destruction of the food supply. Aquatic invertebrates succumb to pesticides to various extents, and the effects on fish populations can obviously be serious. Starvation in fish can result in diminished growth rates and various deficiency maladies, or, when demands are placed on stored nutritive materials, may mobilize toxicants retained in adipose tissues.

The possible significance of chronic effects of pesticides must be emphasized here. The earliest concern for fish was naturally felt in terms of acute mortalities, but as fishery biologists worked on these toxicity problems, they developed an awareness of the possible import of chronic effects—effects which may well prove to influence fish populations more seriously than the quick deaths of whole segments of the populations. Since it has been established that low levels of some chlorinated hydrocarbons can reduce reproductive efficiency in gallinaceous birds, it seems possible that similar influences could occur in fish. As pointed out earlier, growth rates can be affected, either through elimination of the food source, or perhaps in a more direct way, affecting the physiology of the fish itself. Changes in behavior might come about through exposure to sublethal amounts of pesticides, and other life processes may be profoundly influenced by prolonged contact with small amounts of chemicals accumulated in food organisms.

Research to be Done

The foregoing remarks have been intended to reveal the magnitude of pesticide use, the diversity of programs which may affect fish, and the variety of ways in which the poisons have been shown to act on fish. We have only begun to scratch the surface in our search for an understanding of the complex involving fish, water, fish food, and pesticides. An intensive and extensive long-term program of basic research constitutes the task of the Fish-Pesticide Research Laboratory in Denver. Biological and biochemical studies are being initiated in an integrated program designed to furnish bases for predicting the immediate and long-term effects of pesticides on fish.

One important segment of the Denver program pertains to the determination of toxicities and tolerances of commonly used insecticides and fish. In this project we shall compare different chemicals, formulations, species of fish, sizes of fish, chemistries of water inhabited by fish, physical features of the environment, and other variables known or suspected to influence the welfare of fish populations subjected to exposure to economic poisons. These data are required as a starting point for more penetrating inquiries, and will be approached through controlled experiments in aquaria. Identical studies will also be made on important fish-food animals to help our view of some possible indirect effects on fish.

Concurrent with this will be basic studies in the chemistry laboratory, where we shall investigate characteristics of the toxicants and their biochemical effects on fish. This will include analyses of water, bottom sediments, aquatic vegetation, fish tissues, and invertebrate animals for presence of poisons and their metabolites after contact. Thus, we hope to trace the fates of poisons through water, food chains, and fish to determine the breakdown or buildup of toxic substances. This, of course, will be related to morbidity and mortality in the fish. The approaches in this program will be through chemical analysis, bioassay, and radioisotope tracing.

The program outlined above will gradually lead into fundamental studies on chronic effects on fish. We shall investigate influences on fish growth, on reproduction, on behavior, and on tissues and systems in the fish. With outdoor holding ponds, we can keep fish for extended periods and measure slow changes over long periods.

While this laboratory work is in progress, contact will be kept with actual control programs being carried on by other agencies in the field. By carefully planning field work in connection with these projects, much valuable information and material for examination in the laboratory will be gained, and will thus bolster our laboratory results. Moreover, by participating in these projects, we are able to render services by giving advice and information to the control operators.

An important part of the program will include cooperative work with entomologists and members of the chemical industries to try to develop more specific and less toxic pesticides to help bring about effective pest control but with minimum hazards to fish.

We feel that this projected program, carried out carefully and vigorously, will be a major contribution to sport fishery management in the United States, and, indeed, in other parts of the world where the use of pesticides is increasing. The research program is aimed toward securing the answers needed by management personnel in the control of fish populations endangered by pesticides. Research of this type will equip the fishery manager with the means for accurately predicting the effects on fish of specific pesticide treatments. We look toward the day when the biologist can make a scientific appraisal of the fish population and the chemical and physical characteristics of the water before any treatment and calculate the amount of damage that will result. We are confident that fishery science is beginning the research that will bring this about, and in not too many years.

Clay-Mineral Sediments As A Reservoir For Radioactive Materials In The Sea[1]

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WE ARE ALL TOO aware that any title which has in juxtaposition the expressions "radioactive materials" and "in the sea" automatically becomes controversial in this day and age. It is not our intention here to side either with the British who pump free liquid containing upwards of 10,000 curies each month into the Irish Sea only three miles from their coastline or with public opinion in parts of America which appears apprehensive about the suggestion that some 20 curies a month might be deposited safely in selected inshore areas if contained in concrete and iron drums.

Whatever one's views may be about sea-disposal of low level wastes, the fate of radio-chemicals which may find their way into the sea is a most important problem. Nuclear powered submarines and surface ships are things of the present and nuclear powered aircraft of the near future. Nuclear weapons may well be tested further, if not used in anger. Undoubtedly from now on, every year will see a steep increase in the amount of radioactive material created by man and in the variety of his uses of nuclear power. So the chance of fission products finding their way into the sea by accident or intent will grow correspondingly and inevitably.

In the simplest—but quite unrealistic—model, one can visualize complete

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