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DDT: ITS EFFECT ON FISH AND WILDLIFE

BY

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FOREWORD

This bulletin was prepared with the hope that it would help guide entomologists and other control operators and the general public who may have need to apply DDT to control insects and other invertebrate pests. It was also written to answer the many inquiries received concerning the effects that DDT has upon the fishery and wildlife resources. The report is preliminary and far from complete although it presents a brief summary of the known effects that DDT has upon the fishery and wildlife resources of the country. Studies are still under way and a more complete and detailed account of the effects of DDT upon these resources will be made when the investigations are completed.

DDT: ITS EFFECT ON FISH AND WILDLIFE

By CLARENCE COTTAM, *Assistant Director*, and ELMER HIGGINS, *Chief, Division of Fishery Biology, Fish and Wildlife Service*

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INTRODUCTION

From the beginning of its wartime use as an insecticide the potency of DDT has been the cause of both enthusiasm and grave concern. Some have come to consider it a cure-all for insect pests; others are alarmed because of its potential harm. The experienced control worker realizes that DDT, like every other effective insecticide or rodenticide, is really a two-edged sword; the more potent the poison, the more damage it is capable of doing. Most organic and mineral poisons are specific to a degree; they do not strike the innumerable animal and plant species with equal effectiveness; if these poisons did, the advantage of control of undesirable species would be more than offset by the detriment to desirable and beneficial forms. DDT is no exception to this rule. Certainly such an effective poison will destroy some beneficial insects, fishes, and wildlife.

Many exploratory investigations were made in 1943 and 1944 by workers in the Bureau of Entomology and Plant Quarantine of the United States Department of Agriculture,¹ the United States Public Health Service,² the United States Food and Drug Administration,³

¹ Tests conducted by the Bureau of Entomology and Plant Quarantine to appraise the usefulness of DDT as an insecticide, by P. N. Annand and others. *Journal of Economic Entomology* 37: 125-159. 1944.

The effects of DDT administered orally to cows, horses, and sheep, by L. W. Orr. *Journal of Economic Entomology* 38: 428-432. 1945.

The toxicity of DDT to certain forms of aquatic life, by P. M. Eide and others. *Journal of Economic Entomology* 38: 492-493. 1945.

² Histopathological changes following administration of DDT to several species of animals, by Arthur A. Nelson and others. *Public Health Reports* 59: 1009-1020. 1944.

Toxicity and potential dangers of aerosols, mists, and dusting powders containing DDT, by P. A. Neal and others. *Public Health Reports Supplement* No. 177, pp. 1-32. 1944.

DDT water emulsion in rice fields as a method of controlling larvae of *Anopheles quadrimaculatus* and other mosquitoes, by Frederick L. Knowles and Frank W. Fisk. *Public Health Reports* 60: 1005-1019. 1945.

DDT residual house spray—a method of malaria control in rural areas, by Frederick L. Knowles and Clinton S. Smith. *Public Health Reports* 60: 1274-1279. 1945.

Toxicity and potential dangers of aerosols and residues from such aerosols containing three percent DDT, by P. A. Neal and others. *Public Health Reports Supplement* No. 183, pp. 1-32. 1945.

The use of DDT in mosquito control, by S. W. Simmons and others. *Public Health Reports Supplement* No. 186, pp. 1-96. 1945.

³ Summary of toxicological studies of the insecticide DDT, by John H. Draize and others. *Chemical and Engineering News* 22: 1503. 1944.

Acute and subacute toxicity of DDT (2,2-bis (p-Chlorophenyl) 1,1,1-Trichloroethane) to laboratory animals, by Geoffrey Woodard and others. *Journal of Pharmacology and Experimental Therapeutics* 82: 152-158. 1944.

The percutaneous absorption of DDT (2,2-bis (p-Chlorophenyl) 1,1,1-Trichloroethane) in laboratory animals, by John H. Draize and others. *Journal of Pharmacology and Experimental Therapeutics* 82: 159-166. 1944.

the Department of Agriculture of Canada and the Royal Ontario Museum of Zoology,⁴ the Illinois Natural History Survey,⁵ and the University of Missouri.⁶ Members of each of these organizations helped in laying plans for the work in 1945. During the same period many popular summaries on the efficiency of DDT have appeared in magazines and newspapers, and many articles on its production and use have been presented in trade journals.

The need for more detailed information on the effects of DDT led the Bureau of Entomology and Plant Quarantine, of the United States Department of Agriculture, to request the Fish and Wildlife Service to cooperate in studies to determine the effects of this poison on birds, mammals, fishes, and other wildlife. The Bureau of Entomology and Plant Quarantine provided funds for the initiation of the work. On areas treated with DDT, members of the Bureau of Entomology and Plant Quarantine studied the effects on insect populations, while representatives of the Fish and Wildlife Service, with the assistance of the Forest Service of the United States Department of Agriculture, the National Audubon Society, the Pennsylvania Board of Fish Commissioners, and other organizations observed the effects on birds, mammals, fishes, and other forms of wildlife. These investigations were conducted in both field and laboratory and were concerned primarily with forest insects and forest wildlife.

Most of the poison was sprayed by airplane at rates varying from $\frac{1}{8}$ to 5 pounds of DDT (in an oil solution) per acre. (Many forest insect pests can be controlled with DDT oil spray in concentrations varying from $\frac{1}{10}$ to 1 pound per acre.) A single application was the basis for most of these studies. Repeated applications, such as are required for mosquitoes and some field and orchard insects, might have shown more damaging results. Weather conditions caused considerable variation in the amounts of DDT that actually reached the vegetation; light winds or updrafts sometimes prevented the deposition of small spray particles. In addition, rough topography or paucity of landmarks apparently caused small portions of some areas to be missed or to be covered twice. The measurement of DDT deposition on glass plates, filter-paper disks, or on yellow sheets of paper, placed on the ground at frequent intervals, constituted the common means by which the actual amount and uniformity of distribution were measured; but such records were made on only a very small fraction of the total area sprayed.

The principal field investigations were made in Maryland and Pennsylvania, where the studies included insects, mammals, birds, amphibians, and fishes. Laboratory studies were made at the Fish and Wildlife Service's Patuxent Research Refuge, Bowie, Md., to determine the toxicity of DDT to mammals, birds, and amphibians, and at its Fishery Station at Leetown, W. Va., and at laboratories at the University of Missouri and at Spearfish, S. Dak., to determine its toxicity to fishes.

At the Patuxent Research Refuge, habitat and population studies in preceding years had laid a sound base for the evaluation of changes

⁴ Studies of the effects of DDT on insects and on wildlife have been reported upon but not published.

⁵ Studies of the effects of DDT on fishes and other aquatic animals have been reported upon but not published.

⁶ Toxicity of dichloro-diphenyl-trichloroethane (DDT) to goldfish and frogs, by M. M. Ellis, B. A. Westfall, and M. D. Ellis, *Science* 100: 477. 1944.

in 1945. In Lackawanna County, Pa., before the application of DDT, there was time to become familiar with the environment and to determine the current year's nesting population of birds. Elsewhere preliminary studies were brief or lacking.

The work in 1945 indicates that much remains to be done before the long-time effects of DDT on wildlife can be properly evaluated. The United States Public Health Service and the Fish and Wildlife Service have undertaken additional investigations to aid further in correcting this condition. In the southeastern coastal plain these two agencies are investigating the effect, particularly on aquatic life, of repeated small applications of DDT for the control of the larvae of malarial mosquitoes. The New Jersey Board of Fish and Game Commissioners has a similar program in relation to the control of pest mosquito larvae. Also, experiments will be undertaken in 1946 to determine the effect on wildlife when DDT is used for the control of orchard or field-crop pests, where low to high dosages may be used repeatedly. An effort will be made to determine more precisely the maximum rates of application of DDT that different forms of wildlife can tolerate.

Briefly, wildlife studies have dealt chiefly with the effect of DDT on the birds and mammals of a forest area sprayed with that compound, and some have dealt with its effects on fish. Further, studies are now under way to determine its effects on marsh and aquatic organisms, especially in connection with malarial control. Although many more investigations are needed in all these fields, it seems that the most pressing requirement is a study to determine the effects of DDT as applied to agricultural crops on the wildlife and game dependent upon an agricultural environment. About 80 percent of our game birds, as well as a very high percentage of our nongame and insectivorous birds, and mammals are largely dependent upon an agricultural environment. In such places application of DDT will probably be heavy and widespread; therefore, it is not improbable that the greatest damage to wildlife will occur there. As has been demonstrated in forest-insect control, a well-coordinated study of the application of DDT to agricultural crops will greatly minimize such damage.

This circular presents a condensed summary of reports, many of them preliminary, on studies in the field and laboratory by various members of the staff of the Fish and Wildlife Service.

FIELD STUDIES

PATUXENT RESEARCH REFUGE, MD.

On June 5, 1945, a 117-acre tract of well drained forest on the Patuxent River bottomland in the Patuxent Research Refuge, Prince Georges County, Md., was sprayed by airplane with DDT oil solution applied at the rate of 2 pounds of DDT per acre. The solution was made of 1 pound of DDT to 2 pints of xylene and 5.7 pints of No. 2 fuel oil; and 2 gallons of the solution were applied to each acre of land.

The amount of DDT reaching the ground through the forest canopy was much less than the quantity distributed. Glass plates (Petri dishes) 4 inches in diameter were placed throughout the area before the spraying operations and were collected and chemically analyzed after the treatment.

Eighteen plates were placed along the riverbanks, which are more or less overhung by the tree canopy, but which are the most exposed sites in the area, with the exception of the river itself. DDT deposition there averaged 0.6 pound per acre (ranging from 0.004 to 1.44 pounds per acre on different plates). DDT deposited on 18 plates placed on open forest floor beneath tree canopy only, showed an average of 0.05 pound per acre (range 0.002 to 0.21 pound), while the deposition on 42 plates under the tree canopy and also under ground cover of various types (weeds, grass, shrubs) averaged only 0.008 pound per acre (range 0.0008 to 0.06 pound).

The experiment was not an attempt to control any specific insect; it was conducted solely to determine the effect of DDT on the general populations of both insects and wildlife. Many insects were killed within a few days after the spray was applied; the temporary elimination of adult pest mosquitoes was outstanding. The effects of this application of DDT were not prolonged, however, for most of the species appeared to occur in normal numbers 2 or 3 weeks later.

Mammals

Two insect-eating mammals, the short-tailed shrew and the deer mouse, were censused on a 10-acre sprayed area and on a similar 10-acre control area a little more than 1 mile from the sprayed tract.⁷ From May 2 to May 7, before spraying, 50 traps for taking animals alive were distributed over these areas, and the animals were trapped, marked, and released. This procedure, with traps placed in the same localities, was repeated from June 14 to June 19, after the spraying.

On the sprayed area 40 deer mice were trapped before and 30 after the spraying; on the control area 27 were trapped before and 17 after the date of spraying. The differences on the two areas are not of statistical significance, and the consistent reductions may be due to seasonal changes in behavior. The number of short-tailed shrews trapped on the sprayed area fell from 23 before to 6 after spraying, while on the check area the number fell from 14 to 8. The larger reduction in numbers on the sprayed area is of doubtful statistical significance.

Birds

A bird census was made⁸ during May and June on a 31-acre area within the 117-acre tract of bottomland forest sprayed on June 5. Outside the sprayed tract but within the same large, continuous bottomland forest, two other areas were censused: a 32-acre area $1\frac{1}{8}$ miles from the sprayed tract and a 22-acre area immediately adjacent to the sprayed tract. The 32-acre area was used as a control; the 22-acre area was selected to determine whether the spraying caused a marked shift of birds away from the sprayed tract. Before the date of spraying an intensive search was made for nests in the three areas. During the study each nest was visited daily until the young had left or the nest had been deserted or destroyed.

The census indicated a similar population density in each of the three areas before the date of spraying; 4.1 pairs to an acre in the

⁷ These investigations were conducted by Lucille F. Stickel.

⁸ Made by Robert E. Stewart and assistants.

sprayed area, and 3.7 pairs to an acre in each of the others. The commonest species included the red-eyed vireo, redstart, parula warbler, Acadian flycatcher, Kentucky warbler, scarlet tanager, tufted titmouse, ruby-throated hummingbird, and cardinal.

During the first week after the spraying operations the bird population dropped approximately 12 percent in the sprayed area, 5 percent in the control area, and 10 percent in the area adjacent to the sprayed tract, owing, presumably, to completion of nesting or to loss by predation. These figures are too nearly alike to indicate any effects of DDT. No marked differences in the populations occurred during several weeks after the spraying, and there was no apparent movement away from the sprayed area.

At the time of spraying, nests containing eggs or young were under observation, 23 in the sprayed area and 12 in the control. No difference in hatching or survival was observed on either sprayed or unsprayed areas.

An experiment was conducted to determine whether DDT applied at the rate of 5 pounds per acre to birds' nests would have any effect on the hatching of eggs, the development of young, or the abandonment of nests.⁹ DDT was applied with a hand atomizer to an area of 1 square foot surrounding and including the nest. Of 34 nests containing eggs, 17 were sprayed and 17 were left unsprayed. Of 39 nests containing young of various ages, 20 were sprayed and 19 were left unsprayed. As far as possible, pairs of nests of the same species were compared. The treatment with DDT showed no detrimental effect on the hatching of eggs or on the development of the young; it caused no abandonment of nests even when they were located in such confined quarters as bird boxes.

Amphibians

Concurrently with the studies conducted with birds, an investigation was made to determine the effect of DDT on frogs and toads in the same wooded bottomland.¹⁰

Open-topped cages stocked with adults of green, pickerel, and bull frogs, with adult toads, and with frog and toad tadpoles were prepared and placed before the DDT was applied. These cages were inspected daily for a 9-day period after the airplane spraying. None of the animals was affected.

A second study was made in a series of artificial ponds, 20 by 50 feet, in which adults and tadpoles of several species of toads and frogs were living. Two ponds were treated with xylene and fuel oil only; 2 with an oil solution containing DDT, at the rate of 1 pound of DDT per acre; and 2 with an oil solution of DDT, at the rate of 5 pounds per acre. These applications of DDT were made early in April with a hand-operated, compressed-air sprayer. One of each pair of ponds was shallow; the other, deeper. Several untreated ponds were included in the observations. The ponds were sampled with dip nets twice before the spraying and several times thereafter.

In the deeper of the two ponds treated with 1 pound of DDT per acre, no dead or sick animals were found; but in the shallow pond (5

⁹ Conducted by R. T. Mitchell.

¹⁰ Investigation by Lucille F. Stickel.

inches deep at the center) several frogs and large frog-tadpoles and a young water snake were killed. These deaths and those of several frogs and large frog-tadpoles in both ponds treated at the rate of 5 pounds per acre obviously were caused by DDT, but some tadpoles and frogs remained alive in all the treated ponds.

Fishes

The 117-acre tract sprayed with DDT oil solution at the rate of 2 pounds of DDT per acre on June 5 included $\frac{1}{10}$ of a mile of the Patuxent River, usually a muddy stream with a flow of about 130 cubic feet a second.

Nine and one-half hours after the spraying 95 dead fishes were removed from a net stretched across the stream at the lower end of the sprayed section.¹¹ Of 20 species seined or observed in the river, those killed in largest numbers were fallfish, common shiner, bluegill sunfish, eastern madtom, and silverling minnow. Fishes drifted into the stop net for 4 days after the spraying of the river, but the greatest losses occurred within the first 48 hours. Johnny darters and rosy-sided dace were abundant in the seine hauls, but no dead ones were found.

Bluegill sunfish, yellow perch, and red-bellied sunfish were placed in six live-boxes in the river: one above, four within, and one $1\frac{1}{2}$ miles below, the sprayed tract. Losses among the bluegills within the sprayed tract were heavy; the survival in each box was less than a third. Losses among the red-bellied sunfish were low, and the yellow perch were unaffected.

It is believed that spray drifting about 150 feet from the sprayed area to a small gravel-pit pond killed all the golden shiners and pumpkin-seed sunfish in it. Red-bellied sunfish, yellow perch, and about one-third of the bluegills confined in a live-box in the same pond, survived. Mortality began later and lasted longer in the pond than in the river.

On May 8, each of eight shallow, 20-by-50-foot, soft-water ponds at the Patuxent Research Refuge was stocked with 30 large fingerling bluegill sunfish, 15 red-bellied sunfish, 14 yellow perch, and 3 adult white crappies. On May 9, three of the ponds were sprayed with 0.1 pound, two ponds with 0.5 pound, and two ponds with 1.0 pound of DDT in oil to the acre. An eighth pond was left unsprayed as a control. The ponds were inspected at frequent intervals after the application. The control pond, one pond treated with 0.1 pound of DDT per acre, and one pond treated with 1 pound of DDT per acre were drained for an accurate determination of the mortality.

The pond that had been treated with DDT at the rate of 1 pound to the acre showed an 80 percent loss in bluegill sunfish, 93 percent loss in red-bellied sunfish, and 78 percent loss in yellow perch. In ponds sprayed with 0.5 pound per acre there was also serious mortality. In one drained pond that had been sprayed with 0.1 pound to the acre, there was a loss of 43 percent among all species.

¹¹ Investigation made by Eugene W. Surber.

LACKAWANNA COUNTY, PA.**Birds**

Breeding-bird censuses similar to that at the Patuxent Research Refuge were taken on two tracts of forest land in Lackawanna County, Pa., between May 1 and June 27, 1945, both before and after the areas were sprayed with a DDT oil spray.¹²

Between May 24 and June 1 an oil spray of DDT was applied by airplane to a 600-acre tract enclosing a 40-acre census area. The tract was sprayed primarily to determine the effect of a 5-pound to the acre dosage on general insect populations and birds. This amount is considerably in excess of that necessary for the control of most forest insects. The amounts of DDT actually deposited probably ranged from much less to more than 5 pounds per acre, because of the physical conditions under which the spraying was done. Many insects were affected, while some species apparently were unaffected. The gypsy moth and other tree-feeding caterpillars were eliminated. A hive of bees placed in the tract before it was sprayed came through in good condition. Several groups of insects that were reduced by DDT had again attained their normal numbers within 3 months.

Within 48 hours after the DDT was applied, five birds showing symptoms of DDT poisoning were found within the census area; all died. In addition, two other dead birds were found, and two nests were abandoned. The species represented by the dead birds were the red-eyed vireo, black and white warbler, ovenbird, redstart, and scarlet tanager. Within 48 hours after the application of DDT to the final portion of the area on June 1, the bird population (which had been 1.6 pairs to the acre before spraying) was much reduced. On June 13 the area contained only 0.5 birds to the acre. The most commonly noted species were the ovenbird and the red-eyed vireo.

On June 9 a DDT oil spray at the rate of 1 pound of DDT to the acre was applied by airplane to a 350-acre tract enclosing a 40-acre census area. A nearly complete kill of gypsy moth larvae and a conspicuous reduction in the general insect population were effected, but at no time were insects scarce. Most groups apparently recovered within a month. Another 40-acre census area remained untreated as a control.

Before spraying, the bird population in these two areas was 2.7 pairs to the acre. The commonest species were the ovenbird, red-eyed vireo, Canada warbler, magnolia warbler, northern water-thrush, and redstart. After spraying, the population was reduced to 2.6 pairs to the acre in the sprayed area and 2.4 in the control area, owing, presumably, to completion of nesting or to loss by predation.

Fishes

On August 9 a 3-mile section of Ash Creek, in Lackawanna County, Pa., was sprayed by airplane with an oil solution of DDT, applied at the rate of 1 pound per acre as the plane followed the course of the stream. Analyses of filter papers placed at scattered points showed that an average of only 0.25 pound per acre of DDT actually reached the stream. Measurement of the drift of insects 2 hours after the

¹² Censuses taken by Neil Hotchkiss and Richard H. Pough.

DDT was applied showed them passing downstream at the rate of approximately 60,000 per hour at the surface and 15,000 per hour at the bottom.¹³ Nine and one-half hours after the spraying the rate at the surface had dropped to 30,000, that at the bottom to 11,000. At the same time the natural drift of insects in Silver Creek, the control stream, was 704 per hour at the surface and 469 at the bottom.

A census taken before spraying indicated a total brook trout population of 2,100 in the sprayed section. There were also many common suckers, common shiners, black-nosed dace, fallfish, and golden shiners, particularly in the lower mile.

Weirs were located at four places in the stream to intercept dead or dying fish, and two live-boxes were placed above each weir. In one of each pair of live-boxes were placed 30 brook trout, and in the other a miscellaneous assortment of cold-water species. Control live-boxes were placed in nearby Silver Creek, where conditions were nearly identical with those in Ash Creek.

Poisoned fish began drifting into the weirs 12 hours after spraying. Sixty-nine percent of all observed fish losses occurred within 34 hours after spraying. The warmer-water fishes—common shiners, common suckers, and golden shiners—were affected first, most of their mortality occurring within 2 days after spraying. It was estimated that less than half of the total population was killed. Brook and brown trout were more slowly affected; losses among these, as well as among the common suckers, continued for a week. Sampling of the native brook trout population before and after spraying indicated that only about 1.3 percent of the brook trout population (27 fish) were killed.

In the live-boxes stocked with brook trout, the greatest loss was 4 fish, at the weir farthest downstream. In live-boxes stocked with miscellaneous cold-water fishes, including sculpins, black-nosed dace, creek chubs, pearl minnows, top minnows, and common suckers, only 4 fish were killed out of a total of 203.

BLACK STURGEON LAKE AREA, ONTARIO

During May and June 1945, the Department of Lands and Forests of Ontario, Canada, had 100 square miles of spruce-fir forest in the Black Sturgeon Lake area sprayed supposedly with 1 pound of DDT per acre to control spruce budworm. Observations by Dr. S. C. Kendeigh indicated that 50 to 60 percent of the budworm larvae were killed.

Intensive bird studies were made on four plots of 25 acres each.¹⁴ Three of these four plots were sprayed. Populations ranged from 2.0 to 3.6 pairs of birds to the acre in the sprayed areas, and 4.4 pairs in the check area. Four birds with symptoms of DDT poisoning were found; two died. It was believed, however, that no measurable changes had resulted either in the adult bird populations or in the several nests under observation.

SAVANNA ORDNANCE DEPOT, CARROLL COUNTY, ILL.

At 30-day intervals between August 5 and October 6, 1945, the Sixth Service Command sprayed 4,000 acres of flood plain covered with mixed old-age hardwood, together with a large island, and a typical open-water area, at the Savanna Ordnance Depot, in Carroll County, Ill., to control mosquitoes. Applications of DDT, a 5-percent solution in No.

¹³ Investigations made by Eugene W. Surber.

¹⁴ Studies made by S. Charles Kendeigh.

2 fuel oil, ranged from 0.5 pound to 0.2 pound per acre on different areas. Observations on populations of birds, mammals, reptiles, amphibians, fishes, and crustaceans were made both before and after each spraying.¹⁵

Mosquitoes were readily controlled with this solution of DDT when applied at 0.2 to 0.5 pound to the acre.

Bird nesting populations were little affected, as few nests in this Upper Mississippi area are occupied after August 1. No direct effects on birds were noted, but swallows left the area to feed on land adjacent to the sprayed area.

Toothed herring and several species of shiners and dace were killed by the application of 0.5 pound of the DDT solution to the acre in agitated waters.

Most of the crayfish on the area were readily killed by the DDT solution applied at 0.5 pound to the acre.

Raccoons that fed upon the crayfish showed no evidence of being affected. Other vertebrates apparently were unharmed.

ISLAND BEACH, N. J.

The southern 5 miles of Island Beach, in Ocean County, N. J., including the shallow water just off shore in Barnegat Bay, were sprayed by airplane on July 11 with an estimated one-half pound of DDT to the acre for the purpose of eliminating mosquitoes. Three days after the spraying mosquitoes and greenhead flies were scarce, and black flies and sand fleas were gone.

Birds were observed on July 8,¹⁶ when large numbers of gulls, terns, herons, shorebirds, barn swallows, purple martins, redwings, and other songbirds were observed.

On July 14, 3 days after the application of DDT, no dead birds of any kind were found, and frogs apparently were unharmed. Crabs, which had been plentiful along the bay shore before the spraying, had moved out of the sprayed shore waters and were more abundant than ever in unsprayed areas. No dead crabs were found. Along 5 miles of the bay shore there were an estimated 100,000 small dead fishes (menhaden, mullet, and killies), upon which terns and gulls were busily feeding.

On July 18 reports were received of the dying of many edible crabs, which had reappeared in the sprayed area; and on July 21, 150 dead or dying crabs were found over a 200-yard stretch, while those in adjacent unsprayed waters were healthy. Fiddler crabs and ground-inhabiting insects, on the latter date, were abundant and apparently healthy.

OTHER FIELD OBSERVATIONS

DDT was used on an experimental basis for insect control in several other localities, but in these members of the Fish and Wildlife Service could not make detailed wildlife population studies. Careful qualitative observations were made, however, and in some of the localities damage by DDT was noted.

In Clatsop County, Oreg., spraying for the control of the hemlock looper was begun early in June and continued for several weeks.

¹⁵ Observations made by Leo K. Couch.

¹⁶ Census taken by Robert J. Hawley.

About 3,000 acres were treated, mostly with less than 1 pound of DDT per acre. Partial control of the looper was effected. A large percentage of the crayfish in the Necanicum River, which crosses the tract, were killed, but those in a nearby unsprayed stream remained healthy. Vertebrates apparently were unaffected.

At Fort Knox, Ky., more than 2,500 acres were sprayed early in September with 0.4 pound of DDT to the acre for the control of malarial mosquitoes. Most of the mosquitoes and many other insects were killed. In one bottomland pond that probably received a dosage larger than that applied generally, a large proportion of the fishes were killed (more than 100 dead and dying shiners and sunfish were found). Other vertebrates apparently were unharmed.

Part of Wallops Island, Va., was sprayed with 0.8 pound of DDT to the acre late in August. Mosquitoes and greenhead flies were temporarily eliminated. Initial mortality was very high among blue and fiddler crabs in ponds and small streams and among fishes in the ponds, but on the third day no further effect was observed.

At Blowing Rock, N. C., a 217-acre tract comprising homesites, fields, and a golf course was treated late in May and in June to eradicate the Japanese beetle. DDT was applied in dry form to the soil at the rate of 25 pounds to the acre. In addition, from June 15 to 21, all deciduous trees and shrubs in the treated tract that are food plants of the beetle were sprayed with DDT. Beetles were reduced to one-third of their 1944 population, although the treatment was applied too late to prevent beetles from emerging in fairly large numbers in 1945. Entomologists and townspeople made observations on wildlife, reporting 30 sick or dead birds and 11 abandoned nests on 5 homesites and 12 sick or dead birds and 3 abandoned nests on two properties in woods adjacent to the treated tract. Typical DDT symptoms were observed in the affected birds, all of which were noted within 3 days after the application. Apparently healthy birds were present in the area in some numbers throughout the experiment.

At localities in Maryland, Nebraska, Colorado, and Wisconsin, DDT in an oil solution was applied at rates reported to range from 0.2 pound to 5 pounds per acre. Wildlife was affected only slightly, even at the highest rate. In Utah a field of alfalfa was treated with 1½ pounds of DDT to an acre in the form of a dust, with no apparent effect on birds.

LABORATORY STUDIES

MAMMALS

During the spring of 1945 tests of DDT toxicity were made on wild-trapped field mice.¹⁷ With a basal diet of corn, wheat, and oatmeal, finely powdered DDT was intimately combined in the following proportions, by weight: 0.40, 0.20, 0.10, 0.04, 0.02, and 0.01 percent. One diet lacked DDT altogether. The mixtures were fed to groups of 5 animals each for a period of 30 days. Weight changes in the animals and quantities of food consumed were recorded in the middle and at the end of the feeding period.

In the control group and in each of the groups receiving 0.01 to 0.10 percent of DDT there was no apparent toxic effect. In the group receiving 0.20 percent of DDT in the diet one mouse died soon after the initial exposure and a second mouse died 2 days before the termi-

¹⁷ Experiments conducted by Ray Treichler and C. H. Hoffmann.

nation of the experiment. The presence of the drug in the diet apparently did not influence the quantity of food consumed.

In all five of the mice that received 0.40 percent of DDT, violent tremors were observed at the beginning of the third day after the first exposure. Before the end of the third day two of these mice had died. Another mouse died on the seventh day, and a fourth on the ninth. The last mouse lived until the twenty-first day, although decided tremors were evident throughout the period.

A similar series of tests made on wild-trapped white-footed mice showed them to be much less susceptible to DDT poisoning.

In the late winter of 1945, 10 field mice were placed in each of two cages and provided with food, water, and grass shelter to last a 30-day period. On the fourth day the entire habitat in one cage was sprayed by hand with a solution of DDT in oil at the rate of 5 pounds to the acre; the same oil mixture without DDT was sprayed over the entire habitat in the other cage. Fresh water was placed in each cage after the spraying. Seventeen days later DDT-sprayed oats were placed in the first cage and oil-sprayed oats in the second. By the end of 30 days there had been no evidence of toxicity from the use of either DDT or the oil alone.

Four cottontail rabbits were used in each of two tests of DDT toxicity, made in the spring of 1945.¹⁸ Crystalline DDT in the diet at the rate of 0.20 percent produced tremors in one rabbit on the eleventh day but it recovered. All four rabbits fed with DDT at the rate of 0.40 percent showed tremors, three of them showing tremors on the third day. Two rabbits died, one on the fifteenth day and one on the twentieth.

In another series of toxicity tests with cottontails,¹⁹ crystalline DDT was administered by means of a stomach tube in 6 dose levels ranging from 500 milligrams to 2,500 milligrams per kilogram of body weight. No symptoms of poisoning were produced at levels below 1,500 milligrams. One of three rabbits at the 1,500-milligram level showed marked tremors on the second day, but completely recovered. The others and all at the lower dosages remained normal. Two of the four animals on the 2,000-milligram dosage died on the third and thirteenth days, respectively. Two of the three animals on the 2,500-milligram dosage died on the seventh and twelfth days, respectively.

BIRDS

DDT toxicity in bobwhite quail was tested in the spring of 1944 through the use of series of 10 each of 5-week-old birds fed a mash diet containing DDT at percentages ranging from 0.40 to 0.005 during a 63-day period.²⁰ Of the quail fed mash containing 0.05 percent or more of DDT, all died. A 50-percent loss occurred when DDT was fed at a level of 0.025 percent of the diet, and there were some losses at the lowest level used. Daily food consumption for the entire period averaged 12 grams to the bird.

Toxicity was determined in adult bobwhite quail through the administration of single oral doses of DDT, either in crystalline form in gelatin capsules or in a vegetable-oil solution. Dosages of the crystalline drug ranged from 50 milligrams per kilogram of body weight to

¹⁸ Tests made by Ray Treichler and C. H. Hoffmann.

¹⁹ Made by Ray Treichler and C. H. Hoffmann.

²⁰ Experiments conducted by Don R. Coburn and Ray Treichler.

1,000 milligrams per kilogram of body weight. Six birds were used for each test. Dosages of the oil solution ranged from 40 to 1,000 milligrams per kilogram of body weight. The birds were starved for 24 hours and their weights taken for computation of the dose; they were then dosed and returned to regular feed.

Dosages of 200 milligrams per kilogram of body weight of crystalline DDT in gelatin were required to cause a significant percentage of deaths. Mortality increased with larger doses, but there were survivals even at 1,000 milligrams.

Owing to its higher rate of absorption, DDT was much more toxic in vegetable-oil solution than in crystalline form. Symptoms characteristic of DDT poisoning in other species—excessive nervousness, loss of appetite, tremors, muscular twitching, and persistent rigidity of the leg muscles, the last continuing through death—were observed in many of the birds. At the 75-milligram level, five of the six birds died; at 60 milligrams per kilogram of body weight, the DDT was fatal to four of the six birds dosed; at 50 milligrams only one of six died. Survivors in each of these groups returned to normal.

AMPHIBIANS

In mid-March 1945, a number of wood frog egg masses were collected from bottomland ponds along the Patuxent River.²¹ The eggs began hatching at once, and the tadpoles in groups of 100 (more than 2,000 altogether) were placed in aquarium jars. Some of the jars were kept as controls and were not disturbed in any way; some jars were treated with oil only; and some were treated with DDT at the rate of 5 pounds per acre. The experiment resulted in the killing within 3 to 5 days of all tadpoles treated with DDT. Those kept as controls or treated with oil only remained alive and healthy.

FISHES

At the Leetown Fishery Station, W. Va., four connected raceways, each being 125 by 8 by 2 feet, and supplied with 109 gallons of hard spring water per minute, were each stocked in mid-August with 100 brook trout, 100 rainbow trout, and 100 bluegill sunfish.²² These raceways were sprayed with an oil solution of DDT at the rate of 1 pound per acre. The spray was noticeable on their surfaces for 4 hours. Brook trout and rainbow trout, 5 to 7 inches in length, were unaffected, but 4 to 12 percent of the 3½-inch bluegill sunfish were killed. All losses of fish occurred within 5 days after the DDT was applied.

An experiment conducted late in October involved the stocking of each of 12 small, hard-water ponds with 50 bluegills (averaging about 3½ inches in length) and 50 largemouth bass (averaging about 5 inches).²³ DDT was applied in 3 different forms in 3 ponds each; 3 ponds were maintained as controls. On the 9 ponds treated, DDT was applied as an oil solution, as an emulsion, and as a suspension—each at the rate of 1 pound of DDT to the acre.

A week after these applications the ponds were drained and the surviving fish counted. The DDT in suspension killed very few fish;

²¹ Experiment conducted by Lucille F. Stickel.

²² Investigations made by Eugene W. Surber.

²³ Conducted by Eugene W. Surber, W. R. Walton, and C. H. Hoffmann.

in the solution it killed 50 to 60 percent of the bluegills but very few bass; in the emulsion it killed all of both species.

Another experiment was conducted to determine whether fish could be killed by feeding on DDT-treated insects with no other DDT present.²⁴ Each of 3 ponds was stocked with 25 adult and 25 fingerling bluegill sunfish. The fish in all 3 ponds were permitted to gorge for 2 days on flies; the flies used in two ponds had been sprayed with a 12-percent oil solution of DDT at the rate of 1 pound to the acre, whereas the flies supplied to the fish in the third pond were untreated. No fish died.

At the Columbia, Mo., and Spearfish, S. Dak., laboratories of the Fish and Wildlife Service, DDT toxicity was tested on goldfish, top minnows, small channel catfish, brook trout, brown trout, and Pacific salmon.²⁵ The fish were held in the same water for several weeks prior to the tests, under controlled temperatures, with the oxygen at or near saturation.

The DDT was used as a powder dusted on the water surface, as an emulsion sprayed on the water, and incorporated in food. The use of the dry powder gave variable results. Results were more consistent when DDT was applied in an emulsion of olive oil and soap, or kerosene and soap, to the surface of the water. The use of kerosene or of dimethyl phthalate as vehicles slightly increased the toxicity owing to toxic components carried by these vehicles.

The most toxic effects were produced when DDT was fed on or incorporated with food. The DDT was definitely more toxic when dissolved in oil than when given in fat-free carbohydrates or proteins. Its toxicity in oil was enhanced when it was dissolved in low-melting-point animal oils, such as butter, hog-fat, and fat extracted from grasshoppers, and less toxic in cocoa butter, tallow, or even in olive oil. In grasshopper oil or unsalted butter fat, as little as 5 milligrams of DDT per kilogram of fish was usually lethal to fish starved for 4 days. When given in very small doses, symptoms were usually delayed 3 days or more, and death was often delayed 6 to 10 days.

It was discovered that toxicity was increased by higher water temperatures, by softer water, and by low dissolved oxygen. Younger fishes were more affected than the older ones. Goldfish were the least sensitive of the species tested. The salmonids were more affected than were the top minnows or catfish.

SUMMARY

Field observations on the damage to fish and wildlife caused by DDT used in insect control were made in 12 States and the Province of Ontario. Fair to successful insect control was effected.

The principal investigations were made on forest lands in Maryland treated experimentally to determine the effects of DDT on vertebrates and invertebrates, and in Pennsylvania where gypsy moth larvae were the objects of control.

Application of DDT was made chiefly as an oil spray by airplane. Spray concentrations ranged from one-fifth pound to 5 pounds per acre. The greatest quantity used anywhere was an application to the ground of dry DDT at the rate of 25 pounds per acre.

²⁴ Conducted by Eugene W. Surber, W. R. Walton, and C. H. Hoffmann.

²⁵ Investigations made by M. M. Ellis, B. A. Westfall, R. O. Jones, and M. D. Ellis.

The amount of DDT that actually reached the vegetation showed considerable local variation from the specified rate of application, owing to bad weather, lack of landmarks, defective spray apparatus, and difference in density of vegetation.

Pronounced mortality in wildlife resulted from the use of most of the higher concentrations of DDT. Mortality was slight or not apparent in most of the lower dosages, those sufficient effectively to control the insect pest concerned. Invertebrates, fishes, and other cold-blooded vertebrates were more readily affected than were birds and mammals.

In the single trial made, DDT was much more toxic to fish when applied in emulsion than when applied in oil or in suspension.

In laboratory experiments, cottontail rabbits were not affected by single doses of crystalline DDT at levels less than 1,500 milligrams per kilogram of body weight. For quail, no effect was produced below the 200 milligram level. The DDT was more toxic when dissolved in oil.

Fish were usually killed by single doses of DDT as low as 5 milligrams per kilogram of body weight, especially if dissolved in oil. In oils of low-melting point the toxicity was increased.

No effect was obtained by feeding to bluegill sunfish flies sprayed with DDT in oil at the rate of 1 pound per acre.

Controlled spraying of an entire habitat, including food, at the rate of 5 pounds of DDT per acre had no effect on field mice.

RECOMMENDATIONS FOR MINIMIZING DANGER TO WILDLIFE

Use DDT for the control of an insect pest only after weighing the value of such control against the harm that will be done to beneficial forms of life. Wherever more than a small area is involved, consult county agricultural agents, State or Federal entomologists, wildlife and fishery biologists, and United States Public Health Service officials.

Use one-fifth pound or less of DDT per acre in an oil solution to avoid damage to fishes, crabs, or crayfishes; use less than 2 pounds per acre to avoid damage to birds, amphibians, and mammals in forest areas. Because of its greater effectiveness, use smaller quantities of DDT in emulsions.

Use DDT only where it is needed. Wherever it is applied by airplane, provide careful plane-to-ground control to insure even coverage and to prevent local overdosage.

In forest-pest control, wherever feasible, leave strips untreated at the first application to serve as undisturbed sanctuaries for wildlife, treating these strips at a later time or in succeeding seasons if necessary.

In the control of early appearing insect pests, apply DDT, if possible, just before the emergence of leaves and the main spring migration of birds; for late appearing pests, delay applications, whenever practicable, past the nesting period of birds. Adjust crop applications and mosquito-control applications so far as possible to avoid the nesting period.

Because of the sensitivity of fishes and crabs to DDT, avoid as far as possible direct application to streams, lakes, and coastal bays.

Wherever DDT is used, make careful before and after observations of mammals, birds, fishes, and other wildlife.