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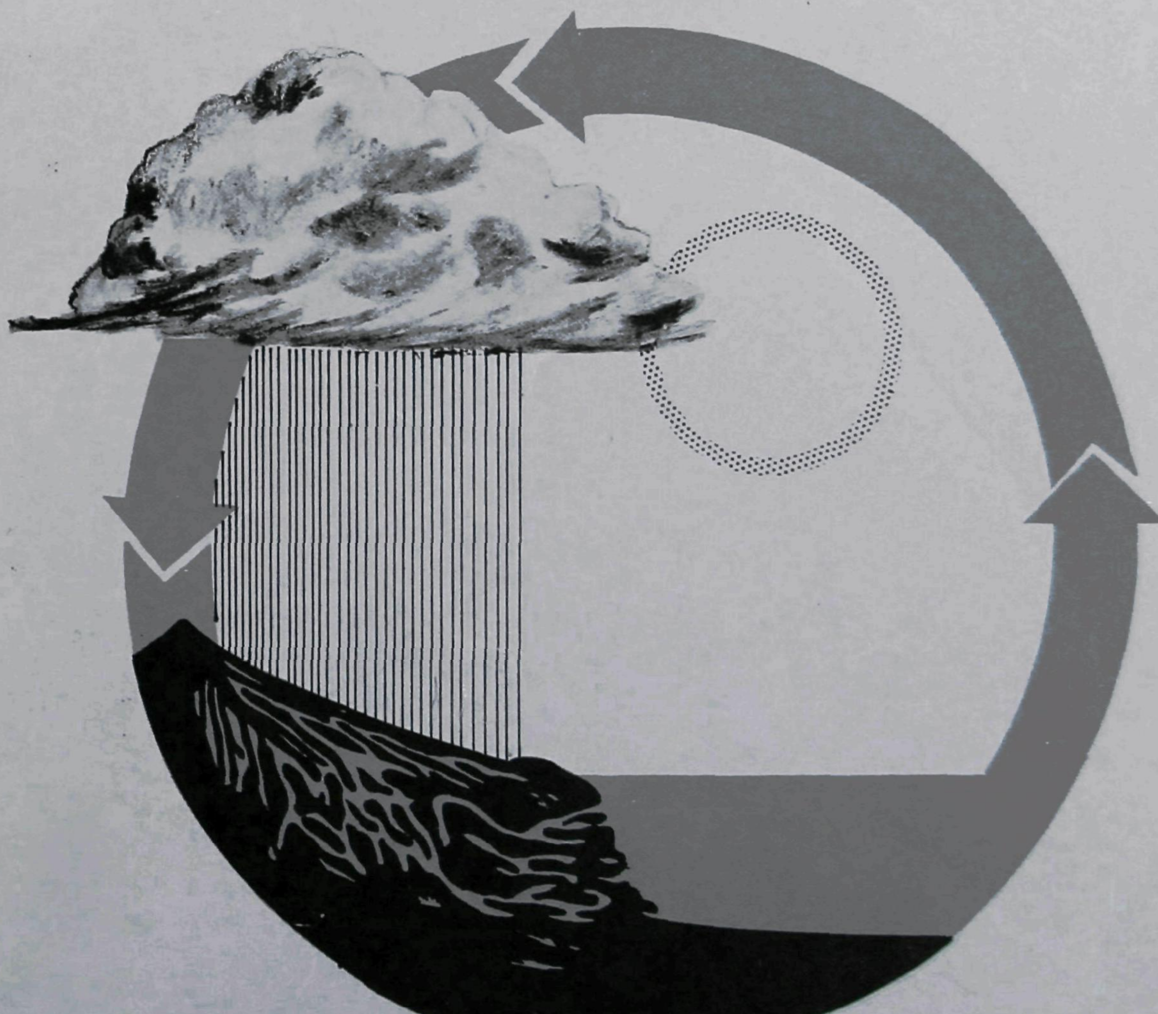

THE MOVEMENT AND IMPACT OF PESTICIDES USED IN FOREST MANAGEMENT ON THE AQUATIC ENVIRONMENT IN THE NORTHEAST

PESTICIDE STUDY SERIES - 7

THE MOVEMENT AND IMPACT OF PESTICIDES USED IN FOREST MANAGEMENT ON THE AQUATIC ENVIRONMENT AND ECOSYSTEM

This study is the result of Contract No. 68-01-0125 awarded by the OWP, as part of the Pesticides Study (Section 5 (ℓ)(2) P.L. 91-224) to Cornell Aeronautica Laboratory, Inc.

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PREFACE

The first volume of this report summarizes the findings, conclusions, and recommendations of a research study conducted during the period of 19 July 1971 to 15 January 1972. This study was conducted for the Environmental Protection Agency (EPA) by the Cornell Aeronautical Laboratory, Inc. (CAL) under contract No. 68-01-0125.

Volume II, the Appendix to the final report, contains definitive, complete and detailed treatises of the topics summarized in this volume. Each treatise represents the findings of the individuals that have contributed to this study.

ACKNOWLEDGMENTS

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New Jersey Department of Agriculture

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Health

State University of New York:

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College of Forestry at Syracuse University

United States Forest Service

Particular appreciation is expressed to personnel of the Bureau of Forest Insect and Disease Control of the New York State Department of Environmental Conservation for excellent cooperation in providing all types of useful data and information.

Significant contribution and authorship to this report have been provided by J.L. Brezner, E.A. Gasiecki, R.M. Klingaman, R.L. Lapp, R.P. Leonard, T.R. Magorian, A. Muka, R.E. Reinnagel, C.W. Rogers, R.A. Sweeney, R.L. Talley and J.T. Wozer. Drs. Brezner, Muka and Sweeney are from the State University College of Forestry, College of Agriculture, and Great Lakes Laboratory at Buffalo, respectively. All others are members of the CAL Staff.

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INTRODUCTION

New York State covers an area of about 30.7 million acres. Of this total, about 14.5 million acres are forested.

This report summarizes the findings, conclusions and recommendations relative to the use of pesticides in the forested regions of New York State, and the resultant impact on the aquatic environment.

This report is organized on a chronological basis. The scope of this study starts with an historical sketch on the use-development of pesticides in New York State forest management and concludes with indications as to the potential role of pesticides in the future. The fate of pesticides and their impact on the aquatic environment is chronologically summarized by consecutive presentation of what is applied, how is it applied, how it moves from the forest to the aquatic environment and finally, the manifestations of the pesticide within the aquatic environment.

Accordingly, this report is presented in the following principal sections:

I. Inventory of Uses
II. Application Techniques
III. Route of Pesticides into the Water Environment
IV. Impact of Pesticides Including Metabolites on the Aquatic Environment
V. Applicable Laws and Regulation Governing Pesticide Use
VI. Alternatives Used and Degree of Control

Section VII presents broad interim conclusions and Section VIII presents preliminary recommendations based on this effort.

Since the topics covered in these sections are not mutually exclusive, some overlap necessarily exists between sections in this presentation.

I.

INVENTORY OF USES

This section presents a summary of the information obtained relative to both the historical development of forest pesticide use within New York State and description and analysis of current pesticide use, including the quantities and types of chemicals used, the pests toward which they were directed, and comments on the efficacy of these treatments.

A. Historical

Serious outbreaks of destructive native forest pests were not new phenomena in New York State forests even at the turn of this century. For example, areas of both eastern New York and the Adirondacks were ravaged in the late 1800's by the forest tent caterpillar and the spruce bark beetle. As long as pests remained in forested regions little overt control was exercised by man. Rather, reliance was placed in natural control processes such as unfavorable climate, pest starvation, parasites and predators.

Early chemical control, at the start of this century, was directed toward the protection of ornamental shade trees and a few selected stands of forests that received high-use, such as resort areas. Principal chemical control materials were arsenical compounds which were used as foliar protectants. For sucking insects, contact insecticides as whale oil soap solution and kerosene emulsions were employed.

In 1869 a non-native pest, the Gypsy Moth (Porthetria dispar L.) was introduced from Europe into this country in the Commonwealth of Massachusetts. This pest attacks a variety of trees and shrubs, although members of the oak family are preferred. Early control of a non-native pest as the Gypsy Moth is generally not effective by natural processes due to decreased availability and efficacy of indigenous enemies.

In 1912, the Gypsy Moth was first found in New York State. The initial infestation, located in eastern New York State, was treated, as were several other small outbreaks. In 1923, a barrier zone was established within the State to preclude the westward spread of this non-native pest. Isolated infestations within this zone were also treated, using chemical control materials and techniques developed for shade tree protection.

The principal pesticide used against the gypsy moth in New York State was lead arsenate. This stomach poison had been specifically developed in 1892 for gypsy moth control, and was subsequently used in both barrier and local infestation roles.

During the late 1930's and early 1940's, an unfortunate alliance served to aggravate the gypsy moth problem of New York. This alliance included a combination of weather conditions (1938 Hurricane) and pest outbreaks in adjacent states which led to violation of the barrier zone; the depletion of inspection and control personnel, due to curtailment of relief (WPA and CCC) labor, and the outbreak of World War II. Up to the termination of World War II, somewhat less than 400,000 pounds of lead arsenate had been applied to selected acreage that was either infested with or threatened by the gypsy moth.

B. Inventory of Uses, 1945 to the Present

At the conclusion of World War II a new pesticide, DDT, was experimentally applied to 335 acres infested with Gypsy Moth in the counties of Albany, Fulton and Saratoga. The results were noted as "spectacular" and "amazing". The tempo of DDT treatment to Gypsy Moth quickened so that by 1949 about 135,000 acres of central and northern portions of the barrier zone were treated.

In the period from 1945 to 1971, about 3.5 million pounds of pesticide were used to control insect and disease pests in the forested lands of New York State. Table 1 presents compositional features of this total.

Table 1

COMPOSITIONAL FEATURES OF THE TOTAL QUANTITY OF FOREST PESTICIDES USED IN NEW YORK STATE 1945-1971, INCLUSIVE

PESTICIDE TYPE	QUANTITY		PERCENT OF TOTAL
	POUNDS	TONS	
DDT	2,411,540	1,206	68.8
CARBARYL (SEVIN)®	1,084,527	542	30.9
OTHERS	8,000	4	.3
TOTAL	3,504,067	1,752	100.0

Of this total, 98.6% (3.46 million pounds) of all forest pesticides were used to combat gypsy moth. This could lead to a logical, but erroneous, conclusion that this pest is the only significant pest problem in New York. Other pests as Forest Tent Caterpillar and the Saddled Prominent have defoliated millions of acres during the same period. However, against such native pests, chemicals are used only to protect high-use acreage with principal reliance being placed on natural control processes.

® Union Carbide Corporation Trademark for carbaryl (1-Naphthyl-N-Methylcarbamate).

C. Treatment Efficacy

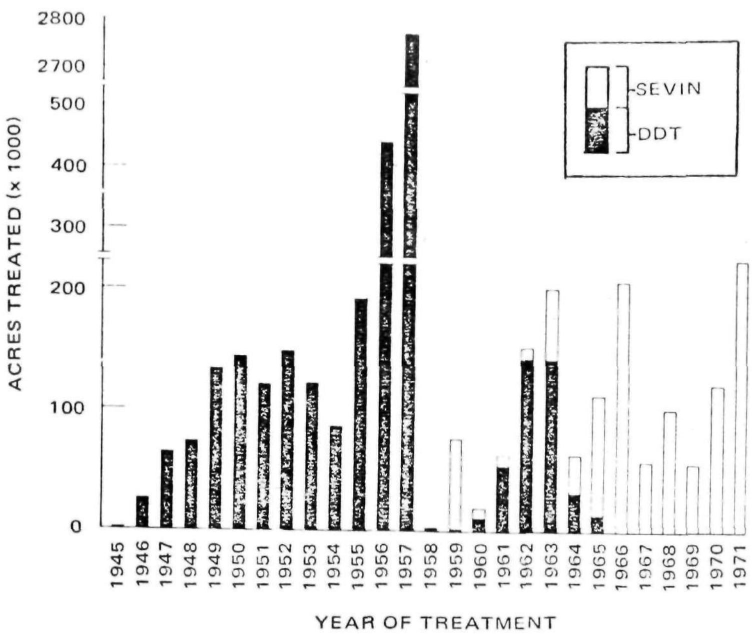
Figure 1 presents both the yearly allocation of pesticide, by type used in gypsy moth control, and the annual defoliation by this pest as measured by aerial survey.

There are several distinguishing features of this graphical presentation. The vast quantities of DDT used up until the late 1950's reflects the philosophy of control by eradication. Since that time, the concept of control and management has prevailed. Also, it should be noted that carbaryl (Sevin) was first introduced in 1959 in response to concern relative to DDT milk residue and also due to effects of DDT in trout water areas. Since 1966, no DDT has been used to control the Gypsy Moth or any other forest pest in New York State.

Exclusive use of the bio-degradable Sevin, and the general upsurge of Gypsy Moth, has led to speculation that this pesticide may not be effective. Casual observation of Figure 1, where the great increase in acres defoliated is visually "correlated" with the use of Sevin, suggests an aura of reasonableness to this concern. Detailed examination of hard data, however, demonstrates that such an assertion is not only oversimplifying but is, in large measure, incorrect.

Much of the defoliated acreage has been defoliated because it has not been treated. New York State treatment policy provides guidelines that (1) the infected acreage should be at least 50 acres in size (2) should exhibit at least 500 egg-masses per acre at the plot center, and (3) signed landowner consent must be obtained. These policy factors, coupled with manpower limitations and the abandonment of an eradication philosophy, are significant causative elements in the upward trend of woodland defoliation by Gypsy Moth.

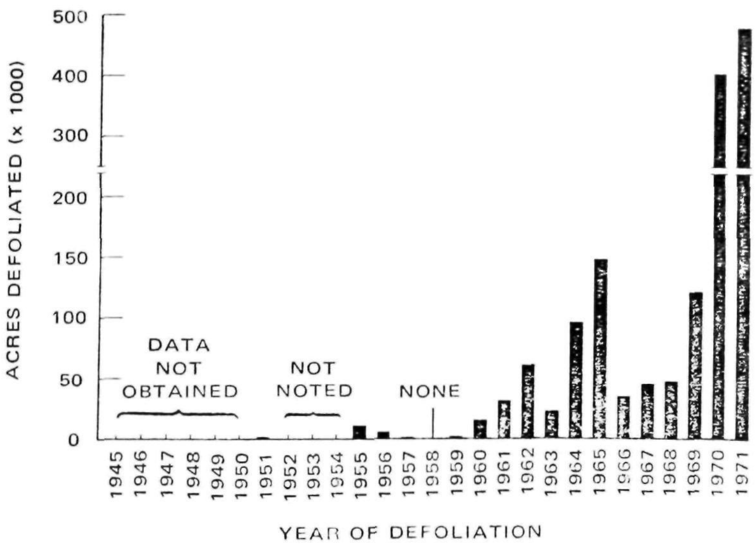
ACRES TREATED EACH YEAR WITH DDT AND/OR SEVIN



TREATED ACREAGE – GYPSY MOTH
NEW YORK STATE

YEAR	ACRES DDT	ACRES SEVIN	TOTAL
1945	335		335
1946	26,739		26,739
1947	64,944		64,944
1948	73,320		73,320
1949	134,370		134,370
1950	146,200		146,200
1951	121,648		121,648
1952	149,750		149,750
1953	122,652		122,652
1954	87,742		87,742
1955	194,376		194,376
1956	446,202		446,202
1957	2,774,417		2,774,417
1958	2,040		2,040
1959	894	76,336	77,230
1960	11,282	8,282	19,564
1961	55,112	160	55,272
1962	146,008	300	146,308
1963	144,658	59,037	203,695
1964	31,500	32,865	64,365
1965	13,486	99,969	113,455
1966		218,123	218,123
1967		41,458	41,458
1968		100,454	100,454
1969		57,652	57,652
1970		120,664	120,664
1971		250,750	250,750
TOTALS	4,747,675	1,066,050	5,813,725

ACRES DEFOLIATED EACH YEAR

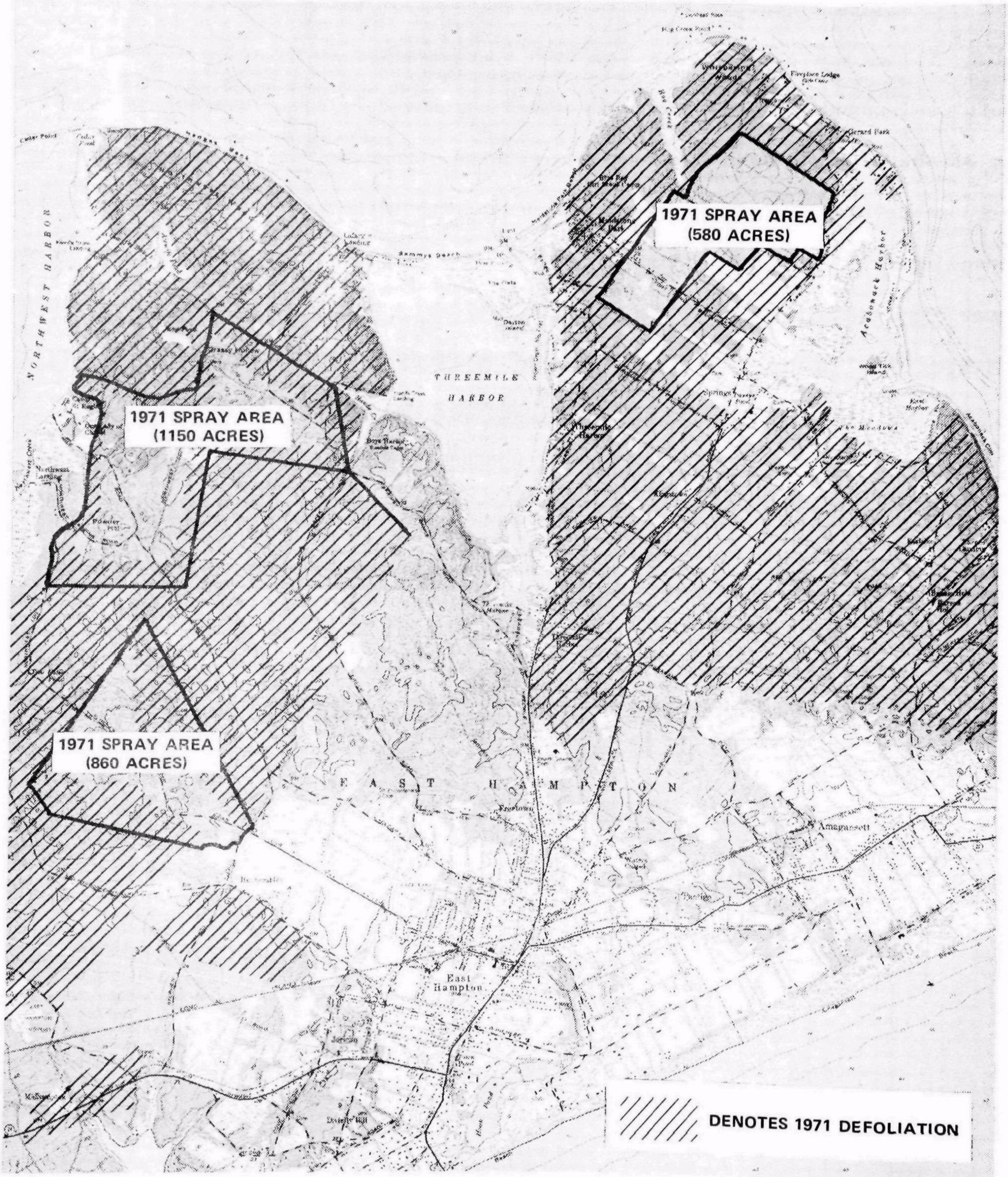


GYPSY MOTH DEFOLIATION IN NEW YORK STATE

YEAR	ACRES
1945	DATA NOT OBTAINED
1946	↓
1947	
1948	
1949	
1950	
1951	675
1952	NOT NOTED
1953	↓
1954	
1955	10,559
1956	6,649
1957	858
1958	0
1959	1,605
1960	16,490
1961	31,335
1962	61,342
1963	22,600
1964	97,237
1965	148,366
1966	34,655
1967	46,160
1968	47,525
1969	121,610
1970	416,270
1971	479,150
TOTAL	1,543,086

Figure 1 GYPSY MOTH CONTROL PROGRAM IN NEW YORK STATE, 1945-1971

Figure 2 qualitatively illustrates some of these points. This area of Long Island was aerially treated with a water-borne formulation of Sevin at a rate of 1 pound (active) per acre. Most acreage defoliated was not treated. Most of the treated acreage was not defoliated. However, it should be noted that some defoliation (not severe) did occur within the treated blocks that were adjacent to untreated woodland. This was due to reinfection due to airborne larvae dispersal from adjacent untreated regions. Experience in the past with DDT indicates that in similar circumstances, the chemical persistence of the pesticide would have controlled this reinfection, whereas the greatly decreased chemical persistence of carbaryl does not permit extended protection against the re-infection threat.



COURTESY: NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION

Figure 2 TREATED AND DEFOLIATED ACREAGE ON PART OF LONG ISLAND, NEW YORK

II.

APPLICATION TECHNIQUES

A. Inventory

In New York State pesticides for gypsy moth control are applied by spraying selected forested areas, which through annual egg-mass count surveys (conducted during the fall or winter by personnel of the state Bureau of Forest Insect and Disease Control) are known to have high levels of gypsy moth infestations. Only about one-fourth of the forested areas in New York are under state jurisdiction, and it is state policy to obtain written consent from landowners before spraying privately owned property. Most of the spraying is done by state owned or state-contracted aircraft, both to achieve timeliness of pesticide application and to permit treatment of large areas, often having limited overland accessibility. Of the total 5.8 million acres which have been treated since 1945 about 99% has been treated by airborne application, using both fixed wing and helicopter aircraft and component boom and nozzle technique. The remaining one percent has been treated using ground based equipment - vehicle-mounted or man-portable mist blowers. Ground-based spraying is carried out chiefly in suburban and recreational areas, where a greater degree of spatial control of pesticide application must be exercised.

The gypsy moth is currently attacked via droplets of pesticide spray impacted and retained on leaf surfaces. During the caterpillar or larval stage of its life cycle, which occurs in May and June, the gypsy moth is a voracious leaf-eater, and the pesticide acts as an intestinal poison, following leaf ingestion.

B. Application Rate

The pesticide used in all the early aerial spray work was DDT dissolved in oil. It was initially applied at a rate of 1 pound in 1 gallon per acre and later reduced to half this concentration. In 1959 carbaryl (Sevin), a less persistent pesticide, was found to be highly toxic to gypsy moth and its use soon became extensive; it completely replaced DDT by 1966. The first tests and early work with carbaryl used a formulation of 1 pound active carbaryl (1.2 lb. of 85% Sevin) plus 4 ounces of sticker in 1 gallon of No. 2 fuel oil. Adequate gypsy moth control was obtained where this formulation was applied in aerial sprays of 175 microns volume median diameter at a rate of 1 pound carbaryl per acre. Half this rate did not give sufficient control. Similar oil-based formulations including Sevin-4-Flowable have and are still used to some extent outside New York State. Because of objectionable slick formation with the oil-based formulas, water-based spray was tested. It was determined that water-based sprays gave adequate control when applied by air at rates of 0.5 and 1 pound active carbaryl per acre. Curiously, in New York State essentially the same formulation is now used, consisting of 1.25 pounds Sevin 80S and 4.0 ounces of Pinolene 1182 sticker in sufficient water to make 1 gallon, and it is applied at a rate of 1 pound active carbaryl per acre - twice the rate shown to be required. Simple mental calculations thus reveal that at an application rate of 0.5 pound carbaryl per acre, twice the total area could be treated with the same total amount of pesticide, or alternately, the same area with half the total amount. For mist blower operations the application rate is about 10 to 15 pounds active carbaryl per acre.

In all the known work on gypsy moth toxicity, there is a notable lack of diet-based dose-response data. The effectiveness of carbaryl sprays and amounts required per acre have essentially been established in the field for particular modes of spray operation and pest attack. The shortcomings of this approach become apparent when one attempts to examine alternate spray operations and attack modes. In addition, dose-response data for topical application of carbaryl and several other pesticides against gypsy moth larvae have only recently been determined. The contact effectiveness of carbaryl was implicit, however, in the work of Connola in which carbaryl was applied on infested areas prior to egg hatch. Unfortunately, topical application and contact effectiveness are not necessarily equivalent. For example, it has been observed that for the first instar of Pieris larvae on cotton the median lethal dose due solely to pickup is particle size dependent. A similar effect has been observed in the case of bark beetles. Whether such an effect exists for gypsy moth in its first instar stage is not known, but if so, it would offer an alternate approach to the current use of deposited droplets on foliage. By utilizing a combination of diet and contact response the timing of spray application could become much less critical. In a trial conducted in early May 1962 in New York State, Sevin was applied at a rate of 0.5 pound per acre with sticker, before foliation and before hatching of the Gypsy Moth larvae. Good control was achieved, presumably through pickup of Sevin by the emerging larvae in their travel to the emerging foliage.

C. Equipment

The aircraft and dispensing equipment used in New York State are conventional. The Stearman biplane and some of the more recent fixed wing agricultural aircraft types have been employed for small plot spray work. The bulk of the spray operations, however, are now carried out using the Grumman TBM and helicopters. Typical nozzle and boom arrangements for low volume spraying are used. Spraying specifications call for use of Spraying Systems Company diaphragm type quick acting on/off valves together with D8-45 hollow cone nozzle discs and cores. Various other nozzle types have been used including the flat fan tips 8002E-8004E and the hollow cone combinations D6-46,D7-56, D8-56 and D10-25. Available information indicates that water-formulated spray drops produced at the aircraft using these nozzle types have volume mean diameters (VMD) in the range of 200 to 500 microns. Spray uniformity is checked prior to the spray season using an array of horizontal ground impaction cards covering the full width of the spray swath. Flow rate is calibrated simultaneously. Spray droplet diameters are estimated by state personnel to be in the range of 150 to 200 microns VMD upon impaction on forest foliage. Aircraft operating conditions are typically 80 to 100 mph at 75 feet above the foliar level.

D. Procedures

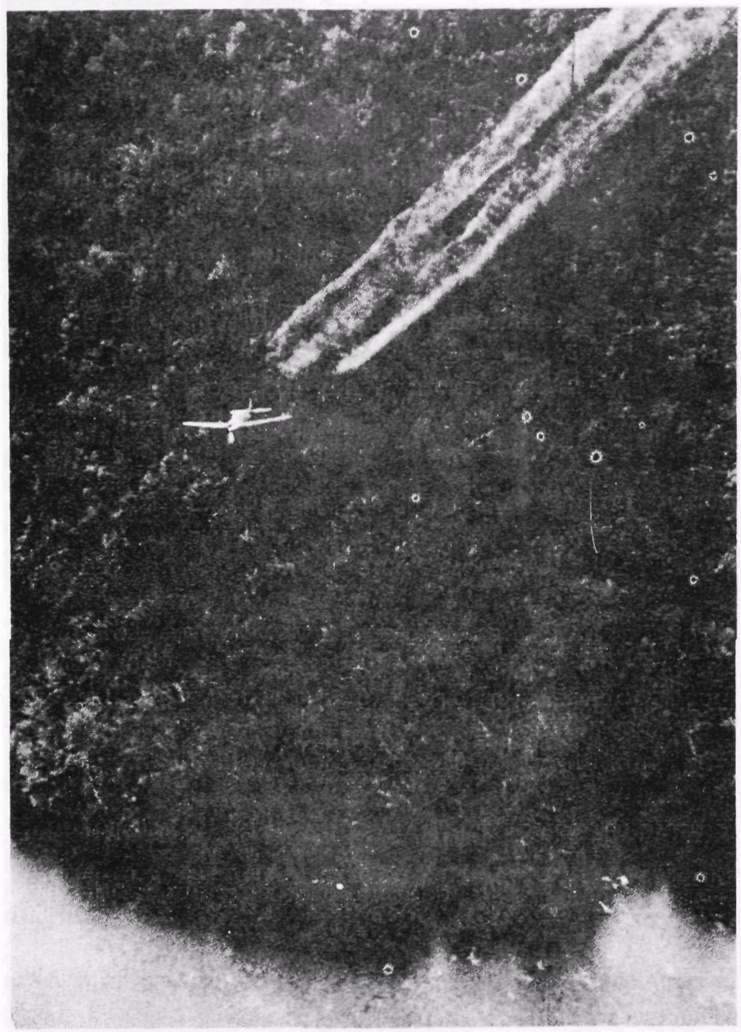
The doctrine and definitive procedures for forest spraying operations are set forth in the Gypsy Moth Control Manual distributed by the New York State Department of Environmental Conservation. This manual is closely followed in all aerial and ground spraying operations conducted by the state, and appears to give quite adequate coverage of operational matters. In particular, strict rules are enforced relating to the following:

1. No spraying is to be done over water or open land or residential areas (see Figure 3).

2. The minimum acerage to be sprayed by air is a 50 acre plot.

3. Forest areas to be sprayed only include those where ground surveys indicate a total egg-mass count of 500 or more per a acre. Records are kept of all spraying operations.

4. Notification is given to local residents regarding spray operations and what to expect.



COURTESY: NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION

Figure 3 SPRAY CUTOFF NEAR WATER

5. Proper meteorological conditions must be met or spraying operations are terminated. In order to meet near-zero-wind, high relative humidity, and temperature conditions to minimize drift, most spraying is done in early morning or late evening.

III.

ROUTE OF PESTICIDES INTO THE WATER ENVIRONMENT

The routes or pathways by which pesticides used in forest management can reach the aquatic environment include overland drainage, soil erosion and sedimentation, atmospheric transport, intentional dumping, accidental spills and disposal of "empty" pesticide containers. These general pathways have been considered according to the character of the control of prevailing processes. The first three are controlled by natural processes; the latter three are overtly controlled by man.

Pathways by which pesticides applied to forests may reach aquatic environments by natural processes are shown schematically in Figure 4. Estimates of the magnitude of movement of the two principal pesticides used in large scale aerial spraying of New York forests (i.e., DDT and carbaryl) are shown. These estimates are based on a dosage of one pound insecticide per acre as it is released from the aircraft, which is the normal application mode in New York State. There have been few studies on the fate and movement of pesticides in forested areas of New York. Consequently, inferences have been made from studies on the forested areas of the United States and Canada and from nonforested areas where applicable.

A. Introduction of the Pesticide to the Forest

Aircraft are used to apply almost all of the pesticides used in New York State forests. Generally, the aircraft fly 50 feet to 100 feet above the

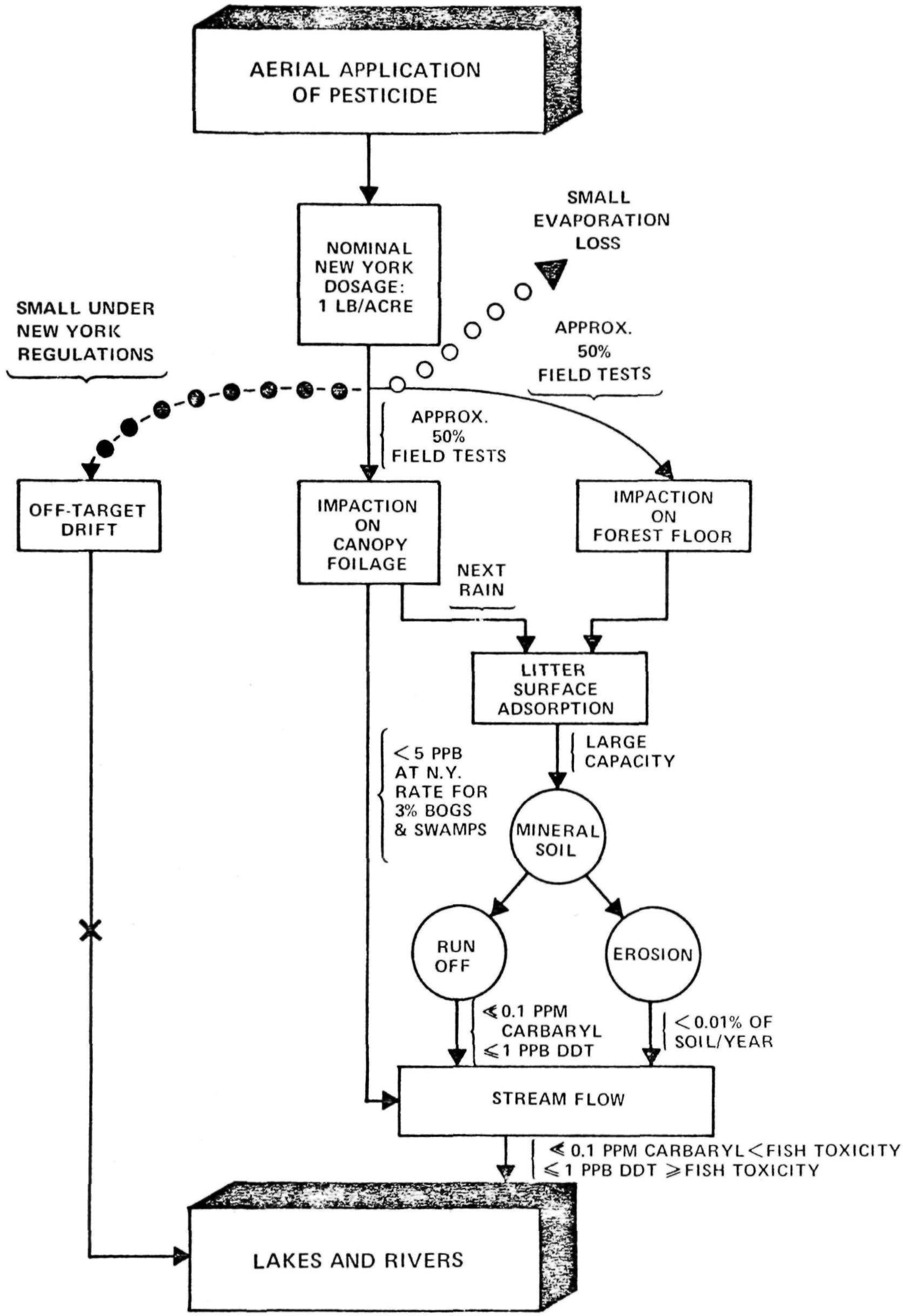


Figure 4 NATURAL PESTICIDE ROUTES IN CLOSED-CANOPY FOREST

forest canopy at speeds of 80 mph to 100 mph. The formulated insecticide is distributed from the aircraft from boom and nozzle systems operating at a pumping pressure of about 60 psi. Particle size at the aircraft varies between, typically, 200 to 500 microns VMD, although the particle size distribution is unknown. Carbaryl is presently used in this State as a water formulation whereas DDT was applied as an oil-formulated material.

The aerial spraying operation and the atmospheric conditions under which this operation is conducted are basically characterized as a diffusing system which operates to decrease the atmospheric concentration of the pesticide. Under standard operating procedures, a helicopter system releases a 30 foot wide spray swath which spreads to a 250 foot swath at canopy level. Operationally, the aircraft paths are spaced so that overlap at the canopy is minimized. Outside of inadvertent and accidental overlap, there is no reason to believe that the pesticide dosage at the canopy will exceed the nominal application rate.

Potentially, wind in and above the forest canopy can cause the pesticide spray to drift off-target. In a given light wind small spray droplets have much greater tendency to drift than large ones. There are two ways that small droplets can be produced when spraying the carbaryl-water mixture: first by the nozzle and airstream atomization of spray initially produced at the aircraft and second, by evaporation of the volatile carrier liquid before the droplets reach the forest canopy. Results from basic atomization studies indicate that for the nozzle types and aircraft flight speeds used, the mass-fraction of spray droplets with sizes sufficiently small to permit significant drift under typical operating conditions is completely negligible. Evaporative size reduction, on the other hand, is not necessarily negligible and the potential for pesticide drift exists.

While in principle off-target drift can exist, in practice, drift is minimized by rigorous adherence to a policy of spraying only under a selected set of operational and meteorological conditions. Spraying operations are carried out in the early morning hours, starting at sunrise, when prevailing atmospheric conditions minimize evaporation. Winds must be less than 8 mph. Ambient temperatures must not be over 70°F, to avoid significant convectional air currents. Material is released only from very low altitude to enhance controllability over the impact zone. To insure that existing conditions actually result in suitable deposition on target, without drift, a single spray swath is made and observed before beginning operations. Follow-up observations are continued while spraying is underway. Any significant off-target drift is visually detectable and spray operations at the time of occurrence are adjusted accordingly to minimize this effect - including terminating operations if necessary.

B. Leaching, Overland Runoff and Sediment Transport

Once the pesticide has reached the forest floor, either at the time of application or due to subsequent wash-off from the foliage, the relative importance of the transport processes are as follows.

In New York forested areas, the thickness of organic litter and humus layers generally ranges from 2 to 4 inches. The forest floor is a living organic filter, capable of absorbing surprisingly large amounts of a variety of contaminants, including pesticides. Available evidence indicates that very little of the applied pesticides would ever pass through these organic forest layers. As a result, the possibility of ground water contamination by leaching of pesticides from the organic litter is extremely remote.

Overland water runoff is unusual under a mature, canopy forest. The runoff which appears in surface stream channels several hours after each heavy rain consists almost entirely of interflow, the excess rainwater which seeps into streams from saturated soil.

Review of the literature reveals no studies on the DDT content of overland water runoff from forested watersheds. This is probably due to the rarity of overland runoff from forested watersheds. As an extreme example, calculations show that for an area with as much as 3% of land area covered with standing water approximately 1 foot deep, direct spraying with carbaryl at 1 pound per acre will add 5 ppb to the runoff water. Even on non-forested watersheds containing the same soil type as commonly found in the Catskill forest region of New York (Muskingum or Dekalb silt loam), accumulated runoff water was normally found to contain less than 0.1% of applied chlorinated hydrocarbon pesticides 12 or more months after application. The chances of carbaryl entering streams before overland water flow are far less than for DDT because of rapid degradation before and during transport.

Slopewash or particulate erosion of soil by overland flow under temperate forests such as exist in New York State is negligible. The suspended sediment of forest floods originates in the caving and slumping of undercut stream banks as well as roads and other slope disturbances. Thus, although studies have shown that sediment transport of chlorinated hydrocarbon pesticides is much more likely than is significant leaching into overland runoff, both are usually of little import in forested areas. However, the sudden movement of pesticide-laden sediments from an eroding clear cut or burned over forest could conceivably introduce large amounts of persistent and accumulated insecticides such as DDT to drainage networks, since once the tree cover is removed by lumbering or fire, rainwash erosion of litter and topsoil is rapid. Again, the danger from the nonpersistent carbaryl would be far less. Although mountains such as the Catskills are eroding much more rapidly than sandy flats like Long Island, and although both areas have been extensively treated, sediments which reach streams from either area under forest cover are not likely to contain significant amounts of pesticide residues.

The evidence indicates that there is little threat of serious contamination to streams and lakes in forested regions from pesticide transport by leaching, overland water runoff or sediment losses, when the chemical is applied by aircraft at 1 pound per acre and under an operational policy that land adjacent to water is not treated. However, this potential risk may increase if the pesticide is applied to selective acreage by a truck-mounted mist-blower. In this case the pesticide application rate is higher due to the practice of treating both leaf surfaces "to-drip," the output particle size smaller, and area may be treated more than once to protect against reinfection from adjacent areas. Drainage ditches are likely to exist along roadsides and recreational parklands in which pest control may be desired. Such ditches lead runoff directly into permanent streams. Therefore, it is not difficult to surmise that relatively high pesticide concentrations in these ditches potentially could be flushed into streams or lakes before the pesticide has been degraded.

C. Intentional Dumping, Accidental Spills and Container Disposal

Overt introduction by man of pesticides into the aquatic environment is distinctly possible, although intentional pesticide dumping is illegal in

New York State. Cursory examination of records does not indicate any problem in either dumping or accidental spills. It should be emphasized that most forested land is under the direct control and supervision of career foresters, who strictly adhere to operational regulations. If this were not the case, the occurrence of this type of action could be much greater.

In keeping with centralization of control, pesticide containers are maintained at the mixing station and disposed of in designated and proper sanitary landfill areas. In aerial applications, should the pilot require the rapid discharge of pesticides, he is procedurally obligated to do so away from open water. Therefore, the relative importance of these factors is low due to the centralized procedures and policies of those State trained personnel conducting the forest pesticide operation.

IV.

IMPACT OF PESTICIDES INCLUDING METABOLITES ON THE AQUATIC ENVIRONMENT

By virtue of the array of biological species habitating the aquatic environment, and the broad range of effects of pesticides on those species, the comments provided in the paragraphs below are necessarily quite diverse.

There are several mechanisms through which DDT and Sevin could adversely impact aquatic life. Perhaps the most obvious is that of direct kill, such as the death of all the fish in a pond due to DDT. This ultimately depends on not only the rate of application and the impacted species, but also the DDT formulation. For example, most investigators have found DDT emulsions to be more toxic to non-target organisms than DDT applied in oil or as a suspension. More subtle disruptions result when only some of the organisms in a lake or stream are destroyed by a pesticide. If the biota that was killed was the food for other animals, the latter also may die. Since this process could occur at a slow rate, or be manifest in an obscure fashion, it could go unnoticed for some time.

If the predators and/or competitors of one or more species are eliminated or significantly reduced, the "balance of nature" may be upset. For example, if a sizable quantity of the zooplankton in a pond are poisoned by Sevin the phytoplankton, whose numbers are controlled ordinarily by the zooplankton, may increase substantially. Following such an algal population explosion or "bloom," the algae may poison themselves in their own metabolites. When the dead algae decay, the oxygen in the water may decrease and cause the death of other aerobic forms.

Even more difficult to trace and evaluate is the movement of pesticides, such as DDT, through the aquatic food-web. Unfortunately, very little information is known regarding the trophic relationships of aquatic organisms. It has been observed that these "who eats who" interactions may change significantly with seasons. Within a season, feeding habits may be affected by inumerable chemical, physical and biological factors. Other complicating factors are up-take and metabolism, each of which are influenced by a myriad of known and unknown conditions. For example, DDT may be passed within a food-web in the form of DDT, DDE, DDD and/or several other metabolites. These chemicals vary considerably in their ability to induce toxicity and other metabolic disruptions.

Still another point that cannot be overlooked is the fact that despite its widespread use since 1942, the biological liaison (location and bio-chemical mechanism of action) of DDT is not understood.

Keeping the above problems in mind, a review of the impact of DDT and Sevin on aquatic environments nevertheless is of value in the formulation of regulations regarding the employment of these insecticides in forest management.

A. DDT and the Aquatic Environment

DDT has a low volatility and is not normally decomposed by sunlight or other naturally occurring chemical and physical mechanisms.

As a result, it is one of the most persistent agricultural chemicals in the environment. Though extremely low in solubility in water (less than 1 ppb), DDT is readily adsorbed onto organic matter. Hence, this pesticide tends to remain concentrated in the upper level of forest soils, with the potential that it can be carried, at any time, to streams and lakes via soil erosion.

Detritus is believed to be a significant source of introduction of DDT into aquatic food-webs. In fact, the adsorption of DDT on suspended organic matter was sited as a means of controlling black-fly larvae.

Hence, the quantity and quality of suspended material in aquatic habitats that may be contaminated by DDT should be considered prior to the application of this pesticide.

Another relevant property of DDT is the fact that it accumulates in lipid tissues. It has been demonstrated that DDT and its metabolites were persistent in some fish up to two years following a single exposure to this insecticide. In this manner, it may be concentrated and passed-on through the food-web in ever increasing concentrations (bio-magnification).

There have been few attempts to trace the movement of DDT in natural aquatic habitats. In 1967 the level of DDT in stream ecosystems before and after the application of DDT to 104,000 acres of Pennsylvania forest (oak-maple) to control fall cankerworm was investigated. A quantity of 0.5 lbs. technical grade DDT per acre formulated in a mixture of naphtha and fuel oil was applied from a plane traveling at 165 mph, 100 feet above the treetops. While after a month the DDT content of stream sediment increased by a few parts per billion, residues in brook trout were 20 to 100 times higher. White suckers also exhibited substantial increases in insecticide content. Concentrations in crayfish also increased but to a lesser extent. Between 30 and 122 days following application of the insecticide, residues decreased to near pre-application levels.

Algae and other water plants can concentrate DDT and thereby pass this insecticide up the aquatic food-web. For example, several varieties of freshwater algae concentrated DDT between 99 and 964-fold following a 7 day exposure to water initially containing 1.0 ppm DDT. Bacteria and fungi can accumulate 40 to 100 percent of the DDT from the media in which they are cultured. Similar observations have been made with marine species. Non-living algae and other plants also will concentrate DDT.

There have been innumerable studies regarding the impact of DDT on stream insects. While the above studies differ considerably with respect to rates, method, formula and time of application of the insecticide, some general conclusions can be drawn. DDT produced marked reductions in the quality and quantity of stream insects. In streams, some species were destroyed more than others. However, in other areas the reverse may have been true. If no DDT was applied, normally present taxa repopulated the stream in two to three years. This is believed due to the fact that insect eggs, which frequently have a thick "shell," are less adversely affected by DDT than are larvae or the adults. Very slight return of the "natural" stream fauna was observed where spraying took place on an annual basis. Recovery of individual species was proportional to "normal" reproductive capacities. Contaminated and drifting insects represent a significant potential source of DDT uptake by fish, many of which feed on those paralyzed invertebrates. Insects sprayed with oil-formulated DDT were more susceptible than those insects that had come into contact with DDT in suspension. Likewise, some insect mortality, particularly downstream, was related to their eating of attached plants that had accumulated DDT.

Numerous instances of fish kills following the application of DDT to control insects have been reported. There have been many more cases where more than one pesticide was applied to an area prior to a fish kill. In such an instance, it is virtually impossible to determine if DDT was the most significant factor which induced death of the fish.

Temperature appears to be an important factor which influences DDT toxicity. For example, DDT toxicity to rainbow trout and bluegills increased below 13°C and above 18.5° to 23°C.

Turbidity may also influence the toxicity of DDT. Organic particles in suspension may remove DDT from water. However, the DDT may re-enter an aquatic food-web if the organic matter is eaten by bottom organisms. Hence, suspended material could decrease acute toxicity and simultaneously increase chronic toxicity of this insecticide.

Generally speaking, within a given species, younger and smaller specimens are more susceptible to DDT poisoning than are older and larger fish. This may be related to the fact that the latter have more lipid tissue in which the DDT can be dispersed.

The negative impact of DDT on fish eggs and fly eggs can be significant. After a fish initially hatches, it is almost entirely dependent on the yolk sac for its initial source of food. As the contents of the yolk sac are consumed, the DDT in the remaining lipid in the sac becomes more concentrated. During the last stage of yolk sac absorption, mortality among the fry of numerous species has been observed. The eggs may be a vehicle through which DDT is passed to offspring. This may result in significant decline in the population of some species, such as trout. In fact, this was believed to be the prime factor in the destruction of the lake trout fishery in Lake George, New York.

One recent, and perhaps biologically significant finding, was the discovery of DDT-resistant fish and frogs. These organisms can accumulate sufficient DDT to pose a threat to higher organism, including man, if consumed.

The literature on the degradation of DDT is vast. Several excellent reviews are available to delineate pathways and products. In general, the pathways seem to be species-specific precluding the assumptions of general biological degradation. Very little work has been done on other than laboratory reared animals, plants and bacteria. With species-dependent reactions it is difficult to apply findings from domestic and laboratory cultures to the environment. This can be illustrated by pointing out that one of the principal metabolites in man is DDE, whereas in monkeys this metabolite has not yet been demonstrated. Biological degradation of DDT yields five principal products. These include DDA, DDD, DDE, Diochlorobenzophenone and kelthane. Ring cleavage has been demonstrated by a variety of microorganisms inhabiting the soil. In DDT-resistant insects the principal product appears to be a DDE resulting from an enzyme which has received a great deal of attention, DDT dehydrochlorinase. Although selected insects have demonstrated DDA and kelthane, these have not been reported with great frequency or for many species.

Many of these degradation products do possess insecticidal activity, as for example, DDD and kelthane. Others, while showing little acute toxicity, have been implicated in vertebrate steriod metabolic upset. DDE has been implicated in calcium upset for several species of birds and has been identified as the agent responsible for the "thin eggshell syndrome". It is interesting to note that even this effect is not uniform among avian populations. Whereas some birds do show reduced eggshell thickness in the presence of DDE, other birds show an increase in shell thickness with the same compound. These factors demonstrate once again that generalizations and attempts at deriving information from other species is a dangerous exercise.

Because of the long term persistence of DDT or its breakdown products in forest soils (amounting to greater than 10 years), long term effects on soil dwelling organisms and food chains must be considered. Studies have shown that DDT does accumulate in skiders, earthworms and other forest soil organisms to the extent or greater than residual soil concentrations. It has further been shown that robins and other birds feeding on forest soil organisms accumulate DDT residues to even greater concentrations than present in soil organisms.

B. Sevin and the Aquatic Environment

The impact of this pesticide was not investigated in the field to any degree until 1959, and there is considerably less information regarding its effects on non-target organisms in comparison with the voluminous literature concerning DDT. In comparison with DDT, Sevin readily dissolves in water (40mg/1 at 20°C). It is reported that Sevin, at concentrations above 0.1 ppm, is toxic to most algae. However, it has been further noted that there is only a 16.8% decrease in carbon fixation by a natural population of phytoplankton following a four (4) hour exposure to 1.0 ppm of DDT.

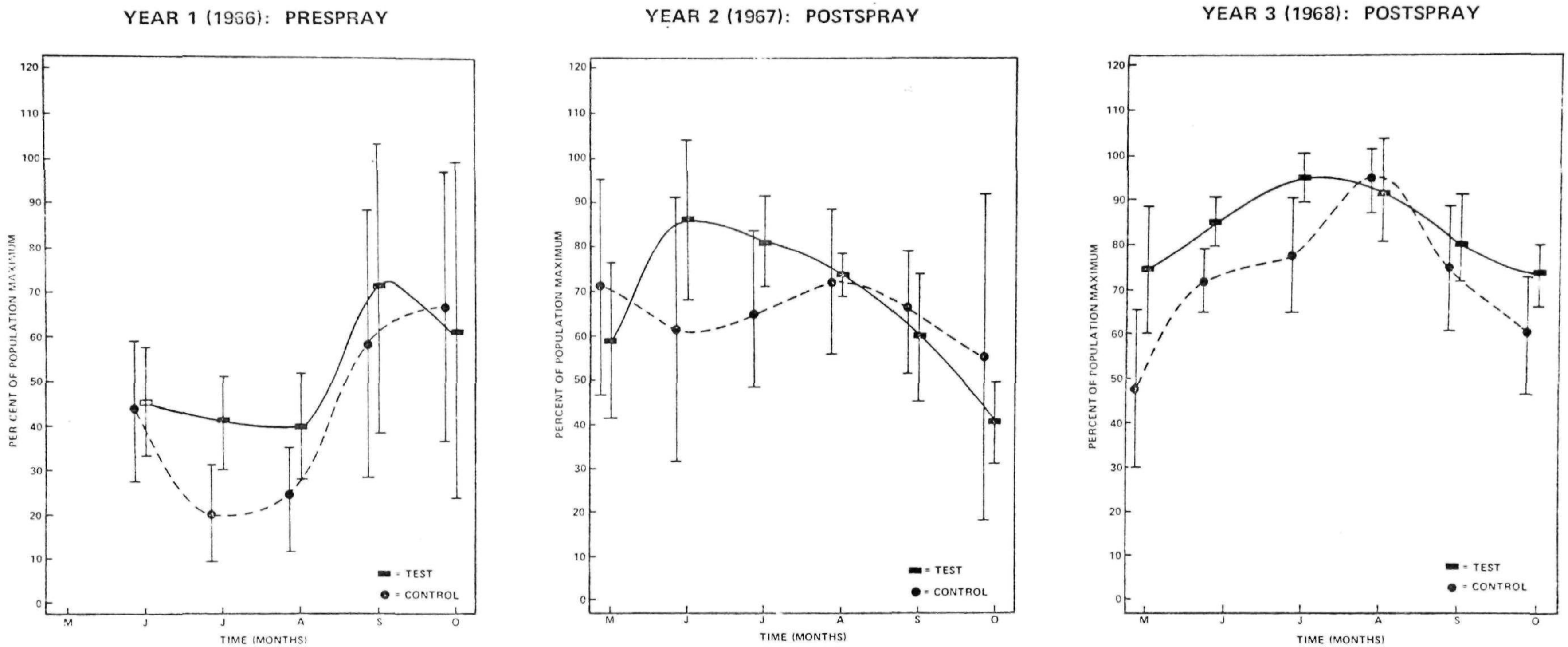
While reports prior to 1959 indicated that Sevin was highly toxic to bees, there was no information available on its effects on aquatic insects, until Burdick and co-workers demonstrated a detrimental impact on stream insects. They applied an unspecified quantity of Sevin (95T) in fuel oil to a 75,000 acre area near Oneonta, New York. The study area included two streams. The spraying did not result in any direct toxic impact on fish, which will be discussed later, but did reduce the stream insects by 50.7 to 97.2 percent. Mayflies, stoneflies, and caddisflies particularly were killed. He states: "Sevin should not be used where spray can fall on flowing streams....".

This study, however, was the result of direct application to the experimental stream, and used a hydrocarbon carrier.

Coutant made similar observations of insect kill in Pennsylvania streams "in spite of precautions against direct spraying of open water, washing spray equipment in the stream, and other 'misuses' often blamed for kills."

It must be clear, however, that it is standard procedure for New York State operations for spray aircraft to shut down when crossing or adjacent to aquatic sites. In two comprehensive studies dealing with impact on the aquatic biome, spray operation was routine, i.e., standard State procedures were followed for insecticide application. No pesticide was applied directly to any water. In each study, Sevin was aerially applied at one pound per acre as a water suspension. One study at the College of Forestry at Syracuse University, completed in 1969, was of three years duration. One year was devoted to prespray evaluation of chemical levels and stream invertebrate populations, followed by similar evaluation in two post-spray years, including analysis of a control stream. As can be seen from graphic presentations, (Figure 5), no population changes due to spray operations can be detected; the control and prespray population fluctuations within limits defined by environmental conditions (summer drought in 1966, etc.). In addition, no changes in species composition were noted. The conclusions from this study were that carbaryl is of an innocuous nature to the aquatic habitat, so long as standard State operational procedures were used.

A study of similar scope in Massachusetts, completed in 1966, followed routine spray operations of the previous year. Tompkins, in that report, indicated that: "Drift collections on the water surfaces of a pond whose



COURTESY: D.R. FELLEY, UNPUBLISHED PH.D. THESIS, THE EFFECT OF SEVIN (1-NAPHTHYL N-METHYL CARBAMATE) AS A WATERSHED POLLUTANT, 1970, STATE UNIVERSITY COLLEGE OF FORESTRY AT SYRACUSE UNIVERSITY, SYRACUSE, NEW YORK.

Figure 5 INSECTS COLLECTED AS A PERCENT OF POPULATION, MAXIMUM, IN THE TEST AND CONTROL BRANCH OF SHACKAM BROOK IN 1966, 1967 AND 1968. RANGE MARKINGS REPRESENT 95 PERCENT CONFIDENCE INTERVALS.

entire periphery was sprayed indicated that such drift, under conditions prevailing at the time of application, were negligible."

Reduction of the insect crop could have a negative effect on the fish which feed upon these invertebrates. However, no information has been generated to support this premise. Likewise, no data were found regarding recovery of the insect population with time.

Sevin has been found to be extremely toxic to crayfish, crabs and shrimps, and Daphnia, a waterflea.

Concerning fish, it is reported that 28 ppm technical Sevin in oil resulted in a 48 hour LD_{50} for goldfish. A 50 percent wettable powder formulation had an LD_{50} of 14 ppm. Values from other laboratory studies ranged from 1.75 to 13.0 ppm. Sevin has been found to be less toxic to fingerling brown trout in soft, acidic water rather than in hard, alkaline water, this was attributed to an interaction between Sevin and the components of water rather than a physiological reaction of the fish to a water condition.

Further, Sevin toxicity to fish increases with increasing temperature. However, its rate of decay to 1-naphthol via hydrolysis also increases with temperature and sunlight. While Sevin is more toxic to crustaceans than to fish and mollusks, the reverse is true for its metabolite.

The metabolite picture of Sevin has also been examined intensively. At least eleven metabolites have been identified and many other hypothesized from a variety of organisms. Many mammals demonstrate hydrolytic reactions with naphthol as a principal product. The original insecticide or its metabolic products may then be conjugated to form glucuronides or sulfates for subsequent kidney excretions. Unpublished work at the College of Forestry has demonstrated Sevin may also be used as a carbon source by many sludge bacterial.

In general, major routes of metabolic degradation of Sevin include decarbamylation, ring hydroxylation, and cleavage of the C-O-N bonds. This pesticide may be degraded by plants almost as rapidly as by animals with a host of additional products.

While the metabolism of Sevin has been extensively studied with respect to terrestrial plants and animals, no literature was found regarding the breakdown of this insecticide by aquatic forms. However, it has been observed that Sevin persists longer in soil water than in lake water.

In the Massachusetts study, residues of the pesticide Sevin in fresh water and estuarine organisms were negligible, with residues literally nonexistent one month post spray. No further tests were run. Population estimates demonstrated that "...Sevin has no immediate effect on the fish and shellfish populations therein.", and further, "no fish mortality could possibly occur under normal operation conditions,...". Another contributor to this study, Boschetti, examined the effect of spraying operations on a small isolated pond. Insignificant residues of Sevin were found. No effect was noted on the pond algae and the author concluded that proper delivery of Sevin poses no hazard to the environment.

In summary, while DDT and its metabolites tend to accumulate in lipid tissues, Sevin and its more polar soluble metabolic products tend to be more rapidly excreted. Therefore, bioconcentration of carbaryl through food chains probably does not occur.

In view of the evidence showing bioconcentration of the persistent DDT residues through forest soil to birds and other feeders, it appears that continued use could result in serious long term ecological consequences.

Carbaryl can cause ecological disturbances, but nonpersistent and rapid detoxification in biological systems would probably not produce long term ecological disturbances in forest environments if used judiciously.

C. Synergism in the Aquatic Ecosystem

The action of a combination of materials upon a system is termed synergistic if the resultant effect is greater than that expected from the individual effects. One compound may synergize another, therefore, while either compound by itself may represent little or no threat to the system.

Syngergism in the aquatic biosphere may arise from any one of four types of material combinations. The first of these is the effect of a pesticide and a naturally occurring material. It has been shown that DDT in solution with sodium humate is approximately twenty times as bioactive as an equivalent solution of DDT alone. The second case is synergism by some relatively innocuous pollutant. For example, certain fish show an increased susceptibility to DDT when detergents are present in the water. This phenomenon is similar to the uptake of nutrients by cells when surfactants are present.

The third case is that of the increased effectiveness of a pesticide, carbaryl for instance, in the presence of another chemical (e.g. derivatives of propynyl naphthyl ethers, aliphatic thiocyanates) added for the sake of its synergistic action. Since the last case is known for terrestial insects, it is presumed that a similar mechanism could be operative for aquatic insects. The fourth combination type involves the bioaccumulation of persistent pesticides as a function of the presence or absence of a congener. For example, it has been shown that DDT accumulation in rainbow trout is enhanced by the presence of dieldrin, while DDT markedly decreases the rate of accumulation of dieldrin. Similarly, DDT elimination was decreased by the presence of dieldrin, but dieldrin elimination was not enhanced by the presence of DDT.

Synergistic effects in the aquatic ecosystem have not been established as a serious threat. However, this potential problem should not be dismissed. Consideration should be given to synergism prior to application of any insecticide.

D. Impact on Humans

The impact on humans of DDT and carbaryl is a topic covered in varying depth depending on the nature of the exposure, the effect of the exposure, and the control achieved in countering the exposure.

The literature concerned with the impact of DDT on humans has been broader than that of the impact of carbaryl, probably due to the fact that DDT has been used for a much greater period of time. Investigators have surveyed human populations working with DDT in manufacturing and application, people not occupationally exposed to DDT, and persons on specially restrictive diets. By and large much of the data has verified that fact that DDT has a large potential for accumulation in biological systems, particularly in fatty tissue. Additionally, high chronic occupational exposure has been linked to various disorders of the detoxifying body systems, due to overloads and other stresses introduced as a function of detoxification and elimination of the pesticide. Certain antagonistic effects have also been found, the best example of which is the lack of DDT accumulation in persons, even those with high occupational exposure, who are taking anticonvulsant drugs.

The effect of carbaryl on the human body is much less than that of DDT except when carbaryl is taken as massive oral doses (as in suicide). In this case, the cholinesterase inhibiting action of the agent is overwhelming. For low level exposure, however, the material is rapidly degraded by the human body. Therefore, no long-term effects of carbaryl exposure are anticipated, contrary to the situation with DDT. The most important current threat concerning carbaryl is its possible teratogenecity (tendency to produce birth defects) which has been demonstrated in certain test animals.

While the application to humans of results from experiments with laboratory animals suggest that carbaryl could be injurious to man, it is noted that humans employed in the manufacture of this insecticide, who were exposed to concentrations that far exceed levels that would be encountered in spraying areas, did not exhibit any adverse symptoms.

V.

LAWS AND REGULATIONS GOVERNING THE SALE AND USE OF PESTICIDES

The laws and regulations of the State of New York and of the Federal Government, which relate to the sale and use of pesticides have been reviewed as to specific content and the apparent underlying philosophy of the law as enacted and practiced. The applicable laws and regulations on this subject cover a wide spectrum and exhibit very complex interrelationships, such that specific comments on a specific regulation would generally require legal opinion and argument. We feel that such argument is not appropriate here in view of the broader philosophical questions involved.

In an overview of the total body of law considered in this study, it appears that primary control is sought through placing restrictions on product availability, and through record keeping, with only limited attention given to the competence and the knowledge of the user.

Serious consideration should be given to expanding the laws and regulations of the State of New York and of the Federal Government to include the licensing of applicators. Through the examination and licensing of the applicator, and the control of the availability of pesticides classed for restricted use, the use of dangerous pesticides would be in the hands of responsible and qualified personnel who would be expected to operate in a professional manner to insure the maximum benefits with the minimum of hazard.

It is undoubtedly unrealistic to assume that good and meaningful, timely pesticide control can be achieved without the full qualification of the personnel engaged in the application of hazardous pesticide due to the extremely large number of combinations of use situation, the constantly changing pesticide market, and the unmanageable task of governmental monitoring or surveillance of the activities of the applicators.

In matters where the public safety or the public good is involved, state or federal licensing, is a time honored control mechanism. In an over simplification of the question of state or federal licensing, it may be generalized that the state issues licenses on a more or less personal services basis, whereas federally granted licenses tend to relate to services or functions in the public domain. The ICC licenses radio station operators, the FAA licenses aircraft pilots; whereas the states license medical doctors and engineers. It would appear that the applicators of hazardous pesticides should be federally licensed for the following reasons:

(1) The effects of pesticides do not stop at state lines, hence, interstate control is necessary.

(2) The pest does not inhabit on the basis of state lines, hence interstate uniformity in control systems is highly desirable.

(3) Examination and licensing on a national basis can lead to a higher and more uniform level of professionalism.

The social and economic importance of pest control and the absolute magnitude and characteristics of the problem are highly variable from state to state and from time to time. Approaches or techniques adopted by one state can lead to direct conflict with approaches adopted by a neighboring state. Pest control can be best studied and implemented on the basis of geographical areas determined by the pest itself, rather than by state boundaries. Such pest management procedures as quarantines, buffer zones, criteria for treatment and materials to be used may be applied in a much more effective manner when specific problems are treated on an area of involvement basis and in consideration of the national import.

Since a very large percentage of the pesticides in use today are applied by units of government, laws and licensing should be equally applicable to government and non-government uses. This has not always been the case in laws and licenses. It bears special attention in this instance, and points to the advisability of federal laws and licenses.

VI.

ALTERNATIVES TO CHEMICAL CONTROL

The availability and use of non-chemical alternatives are different for native and non-native pest infestations. The most important difference is the ease with which biological control can be invoked.

A. Native Pest Infestations

In spite of the fact that there is extensive use of pesticides, evidence demonstrates that New York State relies on natural processes to combat and control native forest pest infestations. Pesticides are used minimally and generally only in high-use areas. Table 2 presents, as an example of this reliance on natural control mechanisms, a tabulation of acreage defoliated by the Forest Tent Caterpillar along with concomitant chemical treatment for that pest.

Table 2

FOREST TEST CATERPILLAR DEFOLIATION AND CONCOMITANT PESTICIDE TREATMENT

YEAR	ACRES DEFOLIATED		ACRES TREATED WITH PESTICIDE
	TOTAL	HEAVY	
1952	3,500,000	500,000	1,000
1953	7,489,049	919.834	1,800
1954	15,321,047	2,007,447	3,200
1955-59	NOT MENTIONED		SOME IN 1955 ONLY
1960	24,425	5,000	0

The demise of this infestation resulted from a combination of factors as adverse climate, starvation and the action of predators, parasites and pest disease. The important point is that chemicals were not extensively used but were, rather, integrated to protect high-use acreage. Similar integrated chemical control was used again in 1967 through 1969 to control the Saddled Prominant, a native, northern hardwood defoliator.

B. Non-native Pest Infestations: Integrated Gypsy Moth Control

In the 1890's, the Commonwealth of Massachusetts conducted a vigorous campaign of integrated techniques to "eradicate" the Gypsy Moth. When the pest intruded into other states, New York and Pennsylvania, for example, similar efforts were pursued. These included the use of pesticides, the use of sex lures, the introduction of parasites and predators and the use of manpower to scrape and kill egg masses, band trees, prune trees, and destroy protected egg-laying habitat. While these measures proved to be useful, little effort has been made in New York State since 1945 to resort to these practices. While several attempts have been made to use a bacterium, Bacillus thuringiensis, and other pathogens and parasites, there is no evidence of a concerted effort to use these agents.

New York State is not alone and, while there is interest in the potentiality of biological control agents in all infected states, New Jersey is the only state that has manifested a commitment.

1. New Jersey Program

By 1963 the intrusion of Gypsy Moth in northern New Jersey was so great that the philosophy of eradication was abandoned in favor of integrated control. Since New Jersey had long been active in the collection and rearing of parasites to control introduced agricultural pests, it was a logical step to adopt biological control measures as an important element of this program. Accordingly in 1963, six (6) parasites of gypsy moth that were already established in New England were collected and released in New Jersey. In addition, three (3) others were reared in New Jersey and field released.

The main objective of the New Jersey program is to establish populations of various insect parasitoids throughout the distribution of the gypsy moth in that State. It is anticipated that these efforts, part of an integrated approach to managing this pest, will assist in maintaining gypsy moth populations at a level where their impact on the forest and urban ecosystems can be tolerated, both economically and ecologically.

Biological controls are utilized in the remote forested areas and chemical control (Sevin: 1 pound/acre) in the high-use urban areas. Decision to spray is voluntary and is vested solely in the municipalities, although the State does use funding mechanisms to exercise professional control.

The biological program is divided into two parts: insect rearing and field evaluation. The insect rearing facilities and techniques used are well organized, staffed and maintained. The rearing and releasing techniques developed by New Jersey should serve as excellent models for the establishment of similar facilities in other states.

The most critical part of the program, however, is the field evaluation undertaken to determine the success or failure of the biological control effort. It is too early at this time to critically review this part of the project, although it is evident that the main interest is in determining whether or not populations of various parasitoids had become "established" at the various release sites. Establishment is considered successful if a particular species is recovered from field collections three years after releasing an individual parasitoid.

However, mere "establishment" of populations of various parasitoids in the gypsy moth life system is not sufficient evidence for determining the success or failure of the program. Unfortunately, basic research is lacking on both the individual parasitoids that are being used, and the sampling techniques employed for field evaluations. This is unfortunate and is a manifestion of contraints of time and additional scientific manpower. The importance or potential of a particular parasitoid can only be determined, in most cases, by a detailed examination of the biology, behavior, ecological adaptability, and responses (functional and numerical) of individual species to changes in host density.

It has been intimated that biological control efforts in New Jersey have successfully reduced the duration of heavy defoliation from 3 to 2 years in some areas. Also, field observations to date suggest that certain parasitoid applications are playing a significant role in stabilizing gypsy moth populations at tolerable levels, although, as noted above, sufficient information is not available at this time.

However, it must be noted that biological controls require time to become established. The results are not instantaneous as with chemical sprays and losses must be both expected and accepted. The following table shows mortality sustained in a 17,855 acre forest on the Newark watershed subjected to heavy defoliation for 3 years before the gypsy moth infestation collapsed from disease and parasitism.

Table 3

YEAR	CUMULATIVE % OAK MORTALITY	TOTAL # DEAD OAKS IN AFFECTED FOREST
1968	6.5	116,693
1969	14.3	257,112
1970	38.0	686,881
1971	57.7	1,033,269

2. Another Alternative

In the example cited above, the loss of over 1,000,000 oak trees may be too high a price to pay for non-chemical control. The value of the woodlands in one state is not necessarily the same in another state. This is, in fact, the reason for different treatment philosophies within the northeastern states.

Examination and study of historical and technical literature, coupled with discussions with several individuals, have revealed that modern integrated control procedures basically ignore the use of manpower as a central ingredient.

In the past personnel have, with minimal training, served as effective gypsy moth control agents. Efforts have included scraping and creosoting of egg masses, trapping and disposal of larvae, banding of trees, and the destruction of protected egg-laying habitat. These measures have, in the past, been effective in minimizing the ravages of this pest.

In the past, hundreds of personnel have been involved in this work. Year around efforts are possible in not only overt control but also in the inspection and evaluation of woodlands for evidence of the pest. There is no reason why this technique should not or could not be resurrected and relied upon in integrated control efforts. It is evident that total reliance on chemicals is not necessary, that biological control will have minimal short-run impact on epidemic populations and that, perhaps, the intelligent use of relatively large numbers of people will not only serve to bridge the gap, but could also provide a healthful and useful employment opportunity.

VII.

CONCLUSIONS

This section presents preliminary conclusions based upon the results of this study to date. It is emphasized that these conclusions have been drawn from a case study of the use of pesticides in forest management in New York State. Within New York State almost all of the forest pesticide currently used is carbaryl (Sevin), and it is used almost exclusively to control the ravages of the non-native pest, Gypsy Moth (Porthetria dispar L.). Pesticide application operations are either conducted by career foresters of the New York State Environmental Conservation Department or under their direct supervision. Natural processes are relied upon to control native pest infestations.

Since the policy and operations with regard to the use of pesticides vary within the several northeastern states, the conclusions presented herein are not necessarily applicable to regions outside New York State.

The case study, itself, is further restrictive in the sense that it addresses only past and current experience. In turn, the impact of pesticides on the aquatic enviornment and ecosystem applies principally to the present state of affairs. Responsible prediction of the future impact of pesticides requires considerations far more extensive than mere extrapolation of current trends. A few such considerations have been explored and their implications are cast in the form of recommendations in the following section. The conclusions which follow should not provide a harbor for comfort; rather, they should be viewed as elements in a larger and longer-range assessment.

We conclude:

1. The application of carbaryl (Sevin) as a water suspension from aircraft at a rate of one pound per acre to control pests as the Gypsy Moth, and in consort with current equipment and techniques, policy, regulations and management does not have significant adverse impact on the aquatic environment.

2. Changes in treatment practice, pesticide formulation, dispersal equipment, policy, regulations and management should not be undertaken without a sound basis, because changes, themselves, can alter many of the interrelations between pesticides and the environment and can easily have a negative rather than positive impact not only on forest pest control but also the aquatic environment and forest ecosystem.

3. The current application rate of carbaryl formulated in water is excessive for Gypsy Moth control, based on reported post-spray observation of egg-mass reduction within treated average.

4. DDT should not be (and is not in New York State) used in the forest due to bioconcentration effects.

5. The short-term hazard to humans of carbaryl and DDT in dosages and conditions associated with forest pest control operations appears minimal, although not unequivocal.

6. The long-term effects of carbaryl and DDT on humans are unknown.

7. The laws governing the use of forest pesticides are insufficient to prevent environmental damage.

8. The long-term efficacy of biological control of the (non-native) Gypsy Moth is presently unknown, although short-term evidence indicates that these techniques show promise.

9. It is technically feasible to employ manpower as a control agent in integrated Gypsy Moth control programs.

VIII.

RECOMMENDATIONS

Based on the results of this study, the following preliminary recommendations are presented:

1. The aerial application rate of water-formulated Sevin should be reduced from 1 pound per acre to 0.5 pound/acre for Gypsy Moth control and possibly further, pending outcome of 2 below.

2. Field tests should be conducted to determine the minimum application rate of Sevin, formulated in either water or oil, necessary to achieve adequate control of the Gypsy Moth and other important forest pests.

3. The economic feasibility of large-scale use of manpower as a part of integrated Gypsy Moth control should be evaluated and, if appropriate, the EPA should fund a field demonstration program.

4. Federal laws should be developed which control the application of pesticides through national examination and licensing of applicators; which together with control of the availability of pesticides classed for restricted use, would insure that employment of dangerous pesticides be limited to responsible and qualified personnel.

5. The possible adverse impact on the aquatic environment and ecosystem due to long-term effects of large scale forest pest infestations (extensive defoliation, tree mortality and subsequent erosion) should be determined.

6. Additional research should be conducted on the fundamental aspects of chemical control of forest pests, with emphasis on an integrated approach considering biological aspects and behavior of the pests, environmental influences and hazards, pesticides and formulations, application techniques and attack modes, and the type and amount of control deemed necessary.

7. Additional research should be conducted to quantify the long-term impact of pesticides on the aquatic environment and ecosystem.

8. Additional research should be conducted on the fundamental aspects of biological control necessary to determine the efficacy of these forest pest management techniques.

A-1

INVENTORY OF USES

A-1.1 Introduction

This section presents information relative to both historical pesticide uses within New York State, and descriptions and analysis of current pesticide use, including the quantities and types of chemicals used, the pests toward which they were directed, and comments on the efficiency of these treatments.

Before discussing these factors, an overview of New York forests is presented. This information has been largely abstracted from the Atlas of Forestry in New York[1.1].

New York State encompasses an area of about 30.7 million acres, of which about 14.5 million acres are forested. There are three principal forested regions. The Adirondack - North Country Regions contains about 5.4 million acres of predominantly spruce, fir and northern hardwoods; the Catskill-Hudson Region is comprised of 2.6 million acres predominated by oak and mixed northern hardwoods; and the western New York Region contains 4 million acres of oak and mixed northern hardwoods. The remaining 2.7 million acres is scattered in central portions of the State.

About 17% of the forested land in New York is categorically noncommercial. Most of this land is part of the State Forest Preserve which, by mandate of the New York State Constitution, must remain "forever wild".

The remaining 83% has commercial potential. Of this total 6% is owned by the State; 8% is owned by forest industries, 24% is in farm woodlot operation; and 45% is under "other" private ownership. In short, nearly half of the forested lands in New York are not owned by farmers or forest industry but, rather, by rural nonfarmers and/or city dwellers (absentee ownership). The land parcels under private ownership tend to be small; about 55% of the private forests are in parcels of less than 100 acres. However, many of these parcels merge to form large forested land blocks.

Further, it is emphasized that commercial exploitation (timber and maple sugar) is not the only important use value ascribed to forested land. These other values include recreation (camping, hunting, fishing); soil stabilization; and watershed development and maintenance. These several values engender the concept of multiple use, a concept which prevails in current forest management practices. Under this practice, New York forests are selectively treated with pesticides to protect those high-use (tangible) and/or high-value (perhaps subjective) areas threatened by pest infestation.

A-1.2 Historical Development of Pesticide Use

The following statement by Ephraim Porter Felt, New York State Entomologist, appears on pages 253-254 in his monumental two-volume work entitled, "Insects Affecting Park and Woodland Trees".[1.2]

> "It must not be forgotten that most of the species listed as important enemies of shade trees, also feed, as previously pointed out, on forest trees, and that sometimes these earlier noticed forms may be exceedingly destructive in the forest land. Our fall webworm, Hyphantria textor Harr., for example, is occasionally very abundant on forest trees and causes a considerable amount of injury. The spiny elm caterpillar, Euvanessa antiopa Linn., lives by preference on willows and poplars, occasionally defoliating extensive areas, and the depredations of the forest tent caterpillar,

Malacosoma disstria Hubn., are too well known to require more than mention in this connection.

"Conditions are such in this country that we must rely very largely on natural agents of one kind or another to prevent serious injury to forest trees. This will ordinarily be accomplished through the activities of various predaceous and parasitic forms, which rarely attract attention because of their abundance. Fungous diseases and unfavorable climatic conditions also play an important part in checking insect ravages. Some of our native species, in spite of these checks, are occasionally very injurious over large areas. One of the most striking cases is that of the forest tent caterpillar, a species which feeds very largely on hard maples, and at irregular and rather widely separated intervals becomes so enormously abundant as to defoliate extensive areas year after year, spreading therefrom to our shade trees.

"The dangerous nature of introduced species has been generally recognized and it is well known that a considerable percentage of the more serious enemies of general agricultural crops have come to us from abroad. It is fortunate that comparatively few destructive forest pests have been brought into the country. The two most important at the present time are the gipsy moth, Porthetria dispar Linn, and the brown tail moth, Euproctis chrysorrhoea Linn. Inability to fly on the part of the first named makes it a local species, dangerous only because of its voracious appetite and the large number of food plants subject to attack. The latter species flies readily and within recent years has shown a marked tendency in America to spread into woodlands, particularly white oaks, large areas of which have been defoliated. It is nearly as destructive to hard maples and as a consequence both species are serious menaces to our woodlands. It is obviously impractical to advise extensive spraying of forests with poison, the general collection or destruction of egg masses in woodlands or similar measures, because of the enormous expense involved. It is most sincerely to be hoped that either the native parasites or introduced forms, some of which have already been imported, will prove adequate checks on both of these dangerous species and obviate the necessity of employing more expensive methods for checking these pests. Experience with the larch sawfly, Lygaeonematus erichsonii Hartg., is not encouraging, since this species has for a number of years defoliated larches over wide areas in the Adirondacks and is still a serious pest."

The importance of Felt's statement cannot be overemphasized. Its importance is vested in the combination of what was said and when it was said.

For example, while more overt attention was directed toward shade tree and agricultural diseases in 1905, Felt pointed out that the pests of shade trees can spread into the forested lands and vice versa. He cites the ravages of the forest tent caterpillar in spreading from the forest to the shade tree.

Secondly, Felt cites a reliance on biological control in the management of forest pest populations. While Felt implies that these techniques are successful, they do not always work as in the case of the larch sawfly.

Finally, both the introduction and danger of non-native pests as the gipsy (gypsy) moth are clearly discussed. Felt indicates that biological control measures were being evaluated including introduction of foreign predators. Also, the impracticality of both wholesale forest spraying with chemical control materials and the mechanical collection of egg masses to check the development and spread of such pests was asserted.

Thus far, two erroneous impressions could be drawn from the discussion. The first is that little attention had been directed to forest pest problems in New York State. This is not true for, while the literature prior to 1900 did not abound in forest entomology, Felt listed the following publications of relevance to New York.

1857 Fitch, Asa. Insects Infesting Evergreen Forest Trees. Ins. N. Y. 4th Rep't, p. 5-67.

1858 __________ Insects Infesting Deciduous Forest Trees. Ins. N. Y. 5th Rep't, p. 1-74.

1881 Packard, A. S. Insects Injurious to Forest and Shade Trees. U. S. Ent. Com. Bul. 7, p. 1-275.

1890 __________ Insects Injurious to Forest and Shade Trees. U. S. Ent. Com. 5th Rep't, p. 1-945.

1893 Hopkins, A. D. Catalogue of West Virginia Scolytidae and their Enemies. W. Va. Agric. Exp. Sta. Bul. 31, p. 121-68.

1893 __________ Catalogue of West Virginia Forest and Shade Tree Insects. W. Va. Agric. Exp. Sta. Bul. 32, p. 171-251.

1895 Packard, A. S. First Memoir on the Bombycine Moths. Nat. Acad. Sci. 7:291.

1896 Marlatt, C. L. Revision of the Nematinae of North America. U. S. Dep't Agric. Div. Ent. Tech. ser. 3, p. 1-135.

1898 Felt, E. P. Insects Injurious to Maple Trees. Forest, Fish and Game Com. 4th Rep't, p. 367-95.

1899 ________ Insects Injurious to Elm Trees. Forest, Fish and Game Com. 5th Rep't, p. 351-79.

1901 Beutenmuller, William. Monograph of the Sesiidae of American North of Mexico. Am. Mus. Nat. Hist. Mem. 6, p. 217-352.

1901 Hopkins, A. D. Insect Enemies of the Spruce in the Northeast. U. S. Dep't Agric. Div. Ent. Bul. 28, n. s., p. 1-48.

1903 Felt, E. P. Insects Affecting Forest Trees. Forest, Fish and Game Com. 7th Rep't, p. 479-534.

Concern in forest pest control was certainly more than of passing interest as Felt notes serious injury to the Adirondack spruce forests in the years 1874 to 1876.

In addition to the loss of forest trees, of great concern was the damage of ornamental shade trees. For example, the elm leaf beetle destroyed several thousand trees in the cities of Albany and Troy in 1898[1.2]. The importance of shade trees was well recognized. Again, a direct quotation of Felt[1.2] on page 5 states:

> "The welfare of the human race is closely connected with that of our trees, and any work looking to their better protection makes for the advancement of mankind. The value of our street and park trees is much greater than the cost of their production, and a city or village blessed with such has treasure which should be jealously guarded, since these magnificent growths have an important influence in modifying climatic conditions, besides adding materially to the beauty of the surroundings. This is not only true in cities and villages but also in the country at large, particularly in such resorts as the Adirondacks, where thousands go for recreation and

health. The trees in such places not only afford most agreeable shelter from wind and sun, but the evaporation from the immense leaf areas modifies the temperature and the exhalations from the coniferous needles undoubtedly aid very much healing diseased lung tissues.

"The protection of shade trees is a serious problem, largely due to the introduction into this country of certain very destructive species, such as the gipsy moth, the elm leaf beetle, the elm bark louse, the leopard moth and the San Jose scale, all exceedingly injurious and all, except the gipsy moth, well established in New York State. It is only a question of time before the latter crosses our borders. The above are a few of the important exotic species which aid such destructive native forms as the white marked tussock moth, the bagworm, the fall webworm, the scurfy and oyster scales and the cottony maple scale in their nefarious work."

Recognition of the great differences in both growing habit and intrinsic value between ornamental shade trees in cities and parks as compared to those in forested lands led to the use and development of remedial measures for the "more highly prized" trees of roadsides, parks and lawns. Felt, in discussing these recommendations, was specific in stating that, at that time, remedial measures involving pesticides were not directed at forestry application.

Biting insects were treated with a class of arsenical poisons: lead arsenate, paris green, and london purple. The role of these poisons was to protect the foliar surface by the poison deposits. Thus, when the insect ate the leaf, sufficient poison was ingested to cause death.

The sucking insects, that extract fluids from the leaf through a slender beak, were not affected by the surface protective treatment of the arsenical. Contact insecticides were used in this case. Formulations in this category included kerosense emulsion, whale oil soap solution, and lime-sulfur washes. In addition, fumigation techniques were used on relatively small trees during the period of dormancy. Hydrogen cyanide was the agent of choice for fumigation.

The costs attributable to spray programs for ornamental shade trees varied considerably, depending on the price of labor.

In Albany, New York, the average cost of a spray program was 22¢ per tree in 1900. However, Felt implied that this cost could be reduced if the program was not conducted under civil service regulations. These regulations required that men had to work only 8 hours per day and further, that both a motorman and driver were required.

The spray apparatus of note in the early 1900's was a horse-drawn spring wagon which contained a 100-gallon tank of pesticide. This mixture was pumped through hose lines, each line being handled by a man on a ladder. A Gould force pump was powered by a Daimler gasoline motor. Felt noted that this motor was advantageous because it was essentially "noiseless in operation and is scarcely noticed by passing horses".

The premonition by Felt in the early 1900's relative to the intrusion of the gypsy moth into New York came true when the insect was discovered near Wampus Pond in the eastern part of the State in 1912.[1.3]

In 1921, a Barrier Zone was proposed along the lands east of the Hudson River that border the New England States. This zone, located east of

Hudson River, extended from Long Island to the Canadian Border. It was about 250 miles long and about 30 miles wide. By 1924, more than 100 men were working under the auspices of New York State to keep the gypsy moth from entering her forests. While the results were encouraging, the state inspectors discovered 12 colonies comprised of 896 egg masses of gypsy moth scattered in eastern New York counties and Long Island. In addition to inspection, remedial measures were instituted to control the scattered colonies. In 1929, it was noted that this included the application of creosote on egg masses and spray application of lead arsenate on larvae. In 1929 the following statement was reported in the annual report of the New York State Conservation Department to the Legislature:

> "When any program is so planned that a test of several years demonstrate it a practical and successful one, changes therein would, to say the least, be unwise. That, briefly, is the situation in the gypsy moth control project."

Principal effort continued to be centered around surveys and inspection for this introduced pest. In 1930, for example, 109,347 acres were examined. While this pest was still basically excluded from New York State, a few colonies were found on Long Island. These were treated with an aqueous formulation of lead arsenate. It is interesting to note that elements of the state inspection were costly because in regions with many nurseries, like Long Island, the inspectors had to search for evidence of this pest "on their hands and knees".

In 1931, pockets of the gypsy moth were treated within the barrier zone. Wherever an infection pocket was located, an area of 600 feet around the pocket was treated with lead arsenate. This chemical was specifically developed in 1892 to control the gypsy moth[1.4]. This control chemical, the efficacy of which had been evaluated in Massachusetts in the mid 1890's, was applied as 0.8 weight percent water suspension. Seventeen tons of lead arsenate were applied in this manner[1.5].

A similar formulation of lead arsenate had been evaluated in Massachusetts in 1893 and 1894[1.6] and found to be quite effective, although its use and effectiveness was qualified accordingly on pages 473-474 as follows:

> "A careful study of the comparative effect of equal weights of the three substances used in the preceding experiments shows that there is practically no choice between Paris green and Paris green and lime, so far as the destruction of the caterpillars is concerned. The largest amount of these poisons which can be used without injuring the foliage is about 1 lb. to 150 gal. of water, and at this, or even a much larger rate, the percentage of caterpillars destroyed is not satisfactory. Since arsenate of lead in almost any strength is not injurious to foliage, a much larger amount can be used than of any of the more soluble arsenical compounds; thus the superiority of this poison as an insecticide is at once evident. While arsenate of lead may be considered the best insecticide for destroying the gypsy moth in the caterpillar stage, even this poison is of small value in exterminating this insect, since many of the caterpillars survive after feeding upon leaves sprayed with large proportions of this poison.
>
> "The experiments previously recorded show that a considerable amount of time is required for the poison used to affect the caterpillars. Those in the earlier molts were killed in a short time,

but in the later molts a much smaller per cent was destroyed, many of the caterpillars transforming and producing imagoes.

"In considering these experiments, it should be remembered that the insects were in confinement, and obliged to eat the poisoned leaves, while in field work they may sometimes find leaves that have not been sprayed, or that have received but little of the poison, and, therefore, the results in some cases might be somewhat different from those obtained in these experiments.

"The remarkable ability of the gypsy moth to resist the action of arsenical poisons is shown in the case of other poisons. Mr. Moulton covered a piece of lettuce leaf with strychnine, and fed it to a caterpillar. In about an hour the caterpillar appeared to be dead, but soon revived and fed again for a short time upon the poisoned leaf, when it rolled over on its back and for several hours remained apparently dead, but afterwards revived again and appeared as well as ever."

Non-chemical control techniques were also being used to control the gypsy moth. In the 1932 annual report, the New York State Conservation Department noted that oil burning was "very effective" against this pest in the Milan, New York area during 1931. Mr. W. E. Masterson, who has since retired from State service, was contacted relative to this notation. According to Mr. Masterson, a large weed burner that used kerosene as a fuel was used to burn or cook egg masses that were laid on or within stone walls[1.7].

While control of the gypsy moth received much attention, other forest pest problems were not neglected. In the same year, 1931, various poison sprays and dusts were evaluated against both the European Pine Shoot Moth and The Scotch

Pine Weevil. None gave much encouragement, although 12 to 16 ounces of a 50-75% solution paradichlorabenzene was effective against the Scotch Pine Weevil when spread around the soil of each tree.

In 1932, unemployment relief funds were used to support efforts in the inspection of about 300,000 acres of lands for gypsy moth. A few local infestations were found and, as before, the foliage was treated with lead arsenate in circular area (600 feet diameter) around the outbreak. About 12 tons of lead arsenate in a fish oil carrier were used in this manner over 554 acres. Figure 1.1 shows the early methods of applying forest pesticides in New York. Again, the apparent success of the gypsy moth control program is manifest in the following statement[1.5].

> "[The Gypsy Moth is] one of the few serious forest pest enemies that can be controlled and its spread prevented."

Although a severe outbreak of gypsy moth was discovered in the Bronx in 1934, few colonies of this pest were found during a vast inspection program throughout eastern New York State. This program was conducted from 1934 to 1936, and encompassed survey and inspection of about 1.5 million acres. Personnel from the Civilian Conservation Corps (CCC) carried out this work until the 11 camps were abandoned in late 1936. In 1937, 82 tons of lead arsenate were used to treat local infestations. Again in 1939, 37 tons of lead arsenate were used against the gypsy moth on 3,089 acres. It is interesting to note that in 1938, 1.75 million "microplectron" were introduced to control the European spruce sawfly, although the efficacy was not noted.

After 1939, the gypsy moth was discovered to have violated the Barrier Zone[1.3]. The reason for this intrusion has not been identified, although it has been surmised that the violent winds of the 1938 hurricane spread the pest

COURTESY: NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION

Figure 1.1 EARLY APPLICATION METHODS OF FOREST PESTICIDES IN NEW YORK STATE beyond the zone. Additionally, wind-borne larvae could have been blown beyond the Barrier Zone from the Connecticut Valley, where a major infestation had built up during the years of 1937 - 1939.

Coupled with the spread of gypsy moth, the additional factors of curtailed relief labor, and the involvement of the United States in World War II undoubtedly lead to the spread of this pest.

Even so, control was attempted during the 1940s. Lead arsenate in fish oil was applied to limited acreage during 1940, 1942, 1943 and 1944. For example, in 1940, about 29 tons were used to treat 1200 acres and 17 tons on 1105 1/4 acres in 1942. In 1943, cryolite (sodium aluminum fluoride) was used to treat gypsy moth on about 750 acres in the greater Albany area. While it was noted that this chemical was not satisfactory, an additional 5 tons was used the succeeding year on 360 acres in scattered portions of eastern New York.

A-1.3 Historical Summary of Pesticide Use

The preceding discussion, while no means exhaustive, provides sufficient detail to develop a credible historical perspective on the use development of pesticides in the control of forest insect pests and diseases in New York State.

Serious forest pest outbreaks were not a new phenomenon in the forests of New York even at the turn of the century. Citation has been made of the ravages of the forest tent caterpillar and the spruce back beetle. While in forested regions, control of these ravages was exercised through a reliance on natural control mechanisms; unfavorable climate, pest starvation, parasites and predators.

Early chemical control was directed toward the protection of ornamental shade trees and selected stands of forested regions in high-use areas such as resorts. Principal chemical control materials were the arsenical compounds which were used as foliar protectants against biting and chewing insects. However with the sucking insects contact insecticides were used. Two such materials are predominant: whale oil soap solution and kerosense emulsions.

The gypsy moth was first located in New York in 1912. This and several other small infestations were located and treated. In 1923, a barrier zone was established to preclude the westward spread of this introduced pest. This zone proved to be effective, and, although areas within this zone were infected with the gypsy moth, the chemical control methods and materials used for shade trees in the cities were used to hold the pest in check. The methods were principally hydraulic spray apparatus dispensing foliar protectants - principally lead arsenate. This chemical, although shown to be somewhat effective against gypsy moth outbreaks in Massachusetts some 40 years earlier, did not enjoy unqualified endorsement by the economic entomologists of even that time. In Massachusetts and New York, the use of manpower to kill egg masses and collect larvae strongly complemented the use of broadcast pesticides.

During the late 1930's and the early 1940's an unfortunate alliance served to aggrevate the pest control problems of New York State. This alliance was

(1) reliance on one type of pesticidal treatment with a chemical control material that was not an unqualified success,

(2) a combination of weather conditions and pest outbreaks within regions bordering the State which led to the violation of the barrier zone by a non-native pest, the gypsy moth,

(3) a depletion of inspection personnel due to curtailment of relief labor, and

(4) the outbreak of World War II.

A-1.4. Pesticide Inventory - 1945 to the Present

At the conclusion of World War II in 1945, trapping surveys were conducted on about 3,000,000 acres of forested land. In addition to this, DDT as an oil solution, was applied for the first time to 335 acres in the counties of Albany, Fulton and Saratoga. This experimental effort was undoubtedly prompted by the successful use of DDT in the Southern Pacific campaigns. This newly available control chemical was evaluated against both gypsy moth and the Spruce Budworm. The results were "spectacular".[1.5] Applied by aircraft, the cost was noted as $2.00/acre for the DDT treatment as compared to $15-$20/acre with ground blowers dispensing lead arsenate formulations.

The next year "amazing results" were obtained with DDT dispensed both by aircraft and turbine blowers over an area of about 27,000 acres. While most of this treatment was directed at the gypsy moth, efficacy against the larch case bearer and the white pine weevil was also evaluated.

The tempo of DDT treatment quickened so that in 1949, 3 years after the experimental evaluation of DDT on some 300 acres, about 135,000 acres of the central and northern portions of the barrier zone were treated. It is also noteworthy that the amount of DDT applied to an acre was reduced, by experimentation, from 1 lb in 1945 to 0.5 lb in 1949. This dosage continued to be used until the end of 1965, at which time the use of DDT was halted.

Having presented a brief narrative on the transition to the use of DDT, it is interesting to view the total amount of pesticides used in forest pest control in New York from 1945 until the present. These data were extracted for compilation and analysis from the annual reports of the New York State Conservation Department to the New York State Legislature.

In the period from 1945 until 1971, about 3,504,067 lb of insecticide have been used to control insect and disease pests in the forested lands of New York. Table 1.I presents compositional feature of this total.

The precision cannoted in Table 1.I reflects the detail to which the inventory records were examined. While this compilation was carefully developed, it is not reasonable to ascribe concomitant accuracy. For example, estimates were used in the development of the quantity of pesticides other than DDT and Sevin for, in many instances, at least one element of information required for accurate compilation, e.g., solution concentration, was not available. In such cases, judgements based on prior years where all data were noted, was applied.

The following pesticides are included in the "Other" category:

endrin	cygon
heptachlor	lead arsenate
lindane	trichlorfon
malathion	dylox

Dylox and cygon were experimentally evaluated for gypsy moth control whereas the other control chemicals were applied to selected acreage to control a variety of pests including white pine weevil, birch leaf miner, sawflys, biting flies and mosquitos.

Table 1.I

COMPOSITIONAL FEATURES OF THE TOTAL QUANTITY OF FOREST PESTICIDES USED IN NEW YORK STATE 1945-1971, INCLUSIVE

PESTICIDE TYPE	QUANTITY		PERCENT OF TOTAL
	POUNDS	TONS	
DDT	2,411,540	1,206	68.8
CARBARYL (SEVIN)	1,084, 527	542	30.9
OTHERS	8,000	4	.3
TOTAL	3,504,067	1,752	100.0

Therefore, it is reasonable to conclude that, of the total weight of pesticide used in the forested land of New York State in the inclusive years between 1945 and 1971,

(a) over 99 % of all pesticides used in forest pest control was either DDT or Sevin, and

(b) the DDT use-budget was about double that for Sevin.

The pesticide inventory information thus far discussed is presented in tabular form later in this section.

Of the total amount of DDT used in this period in forest management operations, about 99 % has been employed in gypsy moth control programs. Of equal significance, about 98 % of all Sevin used has been directed against the same introduced pest.

Put into perspective in yet another way, of the approximate total of 3.5 million lb of all types of pesticide used in forest operations in New York from 1945 to 1971, about 3.46 million lb have been used against a single pest, the gypsy moth.

Based upon the preponderant use of DDT and Sevin to control the gypsy moth and coupled with minimal quantities of all types of chemical control agents against other forest pests in New York, it could be concluded that the gypsy moth is the only significant pest to intrude forested lands.

Such a conclusion, while logical, is simply not true. This can be demonstrated by consideration of forest acreage defoliated. Over the past 20-year period (1951-1971), 30,481,132 acres of forested land have been defoliated. This figure includes all acreage where measurable defoliation has occurred, and is not meant to imply that all leaves are stripped from the trees on any given acre. The interesting fact is that, of this total acreage figure, only 1,543,086 acres were defoliated by the gypsy moth. While this figure represents a relatively small percentage (5.06 %) of the total, it would have undoubtedly been a much greater percentage without chemical treatment. A great deal of the acreage defoliated was caused by the Forest Tent Caterpillar and Saddler Prominent. Chemicals were not used to control these native pests. Rather, reliance was placed on natural control mechanisms. This is more fully discussed in Section A-6.

Is emphasized that defoliation is a manifestation of but one class of forest pest. Other classes such as borers, fungal diseases, and the like are also important. However, defoliation is not only an important type of damage but it is also amenable to aerial surveys and thus, these types of data are readily and reliably obtained.

In summary, it is demonstrable that significant quantities of pesticides have been used in the control and management of forest pests in New York. Two principal types of chemicals have been used: DDT, a persistent chlorinated hydrocarbon, and Sevin, a less persistent carbamate.

Importantly, chemicals are not relied upon to control all forest pest problems. Rather, reliance is placed upon natural control of native pests. Chemical treatment is restricted to situations where (1) a pest threatens a high-use area and/or (2) the pest is not adequately controlled by predators, parasites, and disease. Such is the case in New York with gypsy moth, an introduced pest.

As a result, the overwhelming use of pesticides is directed against this specific pest. The next paragraph deals with the efficacy of the pesticide treatment in gypsy moth control programs conducted within New York.

A-1.4.1 Pesticide Treatment Efficacy

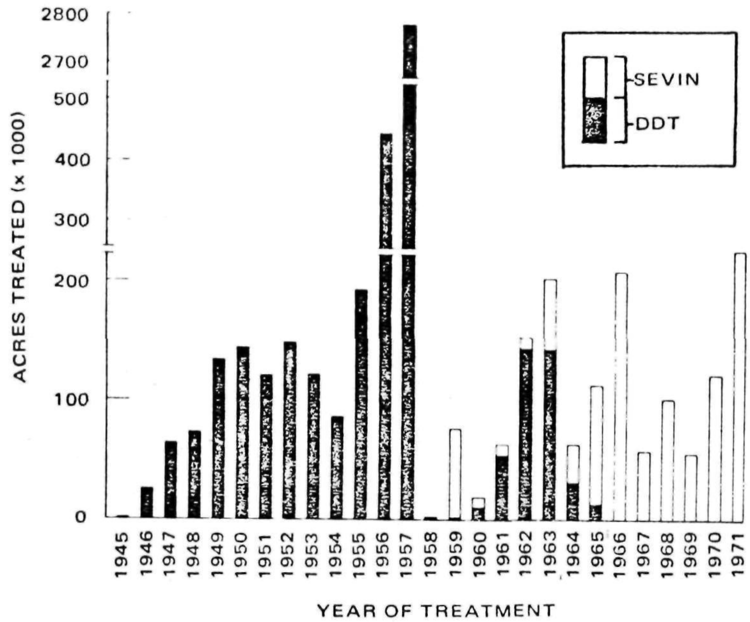
Figure 1.2 presents both the yearly allocation of pesticide, by type used in gypsy moth control, and the annual defoliation by this pest as measured by aerial survey. These data can also be used to provide the information on the quantity of pesticides used as previously presented in Table 1.I, when used in conjunction with application rate. Basically, DDT was applied at a rate of 1 lb/acre until 1949, and at a rate of 0.5 lb/acre from 1949 until 1965 inclusive. Sevin has been applied at a rate of 1 lb/acre.

Referring to Figure 1.2, several distinguishing features are apparent in this graphical presentation. The vast quantities of DDT used until the late 1950's reflects the philosophy of control by eradication. Since that time, the concept of control and management has prevailed. Also, it should be noted that Sevin was first introduced in 1959 in response to concern relative to DDT milk residue and also due to effects of DDT in trout-water areas. Since 1966, no DDT has been used to control the gypsy moth or any other forest pest in New York.

Exclusive use of the bio-degradable Sevin, and the general upsurge of gypsy moth, has led to speculation that this pesticide may not be effective. Casual observation of Figure 1.2 where the great increase in acres defoliated is visually "correlated" with the use of Sevin, suggests an aura of reasonableness to this concern. Detailed examination of hard data, however, demonstrates that such an assertion is not only oversimplifying but is, in large measure, incorrect.

The first concern in exploring the question of treatment efficacy is that of the pesticide itself: Does Sevin, applied at a rate of 1 lb/acre provide effective initial treatment? The data demonstrate that Sevin is effective. This is discussed in greater detail in Section A-2.

ACRES TREATED EACH YEAR WITH DDT AND/OR SEVIN

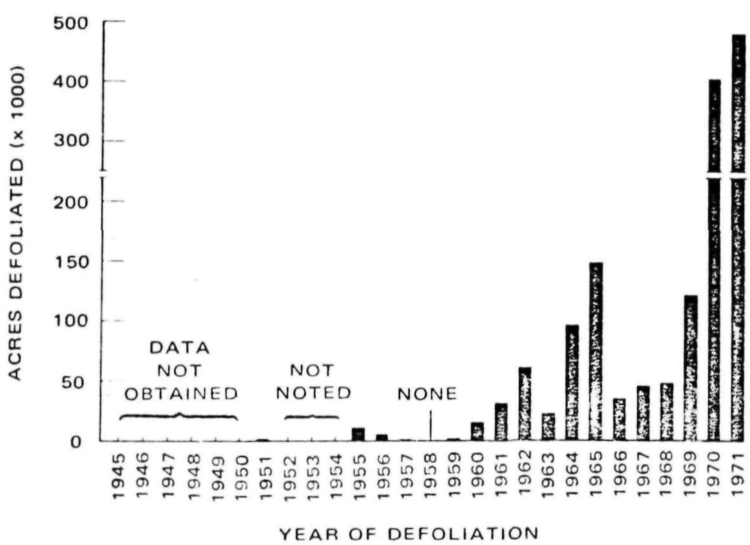


TREATED ACREAGE – GYPSY MOTH NEW YORK STATE

YEAR	ACRES – DDT	ACRES – SEVIN	TOTAL
1945	335		335
1946	26,739		26,739
1947	64,944		64,944
1948	73,320		73,320
1949	134,370		134,370
1950	146,200		146,200
1951	121,648		121,648
1952	149,750		149,750
1953	122,652		122,652
1954	87,742		87,742
1955	194,376		194,376
1956	446,202		446,202
1957	2,774,417		2,774,417
1958	2,040		2,040
1959	894	76,336	77,230
1960	11,282	8,282	19,564
1961	55,112	160	55,272
1962	146,008	300	146,308
1963	144,658	59,037	203,695
1964	31,500	32,865	64,365
1965	13,486	99,969	113,455
1966		218,123	218,123
1967		41,458	41,458
1968		100,454	100,454
1969		57,652	57,652
1970		120,664	120,664
1971		250,750	250,750
TOTALS	4,747,675	1,066,050	5,813,725

GYPSY MOTH DEFOLIATION IN NEW YORK STATE

ACRES DEFOLIATED EACH YEAR



YEAR	ACRES
1945	DATA NOT OBTAINED
1946	↓
1947	↓
1948	↓
1949	↓
1950	↓
1951	675
1952	NOT NOTED
1953	↓
1954	↓
1955	10,559
1956	6,649
1957	858
1958	0
1959	1,605
1960	16,490
1961	31,335
1962	61,342
1963	22,600
1964	97,237
1965	148,366
1966	34,655
1967	46,160
1968	47,525
1969	121,610
1970	416,270
1971	479,150
TOTAL	1,543,086

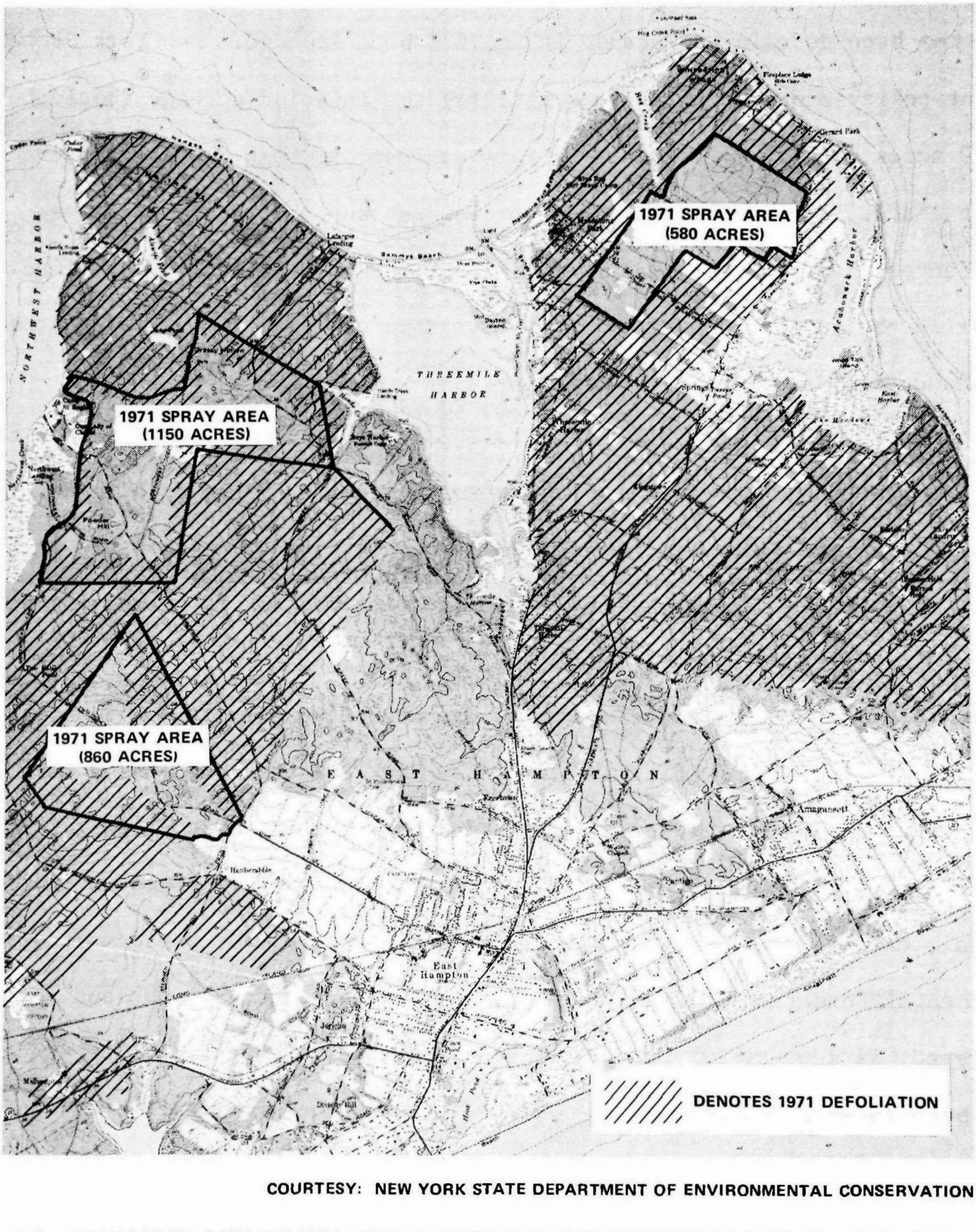
Figure 1.2 GYPSY MOTH CONTROL PROGRAM IN NEW YORK STATE, 1945-1971

The upsurge in defoliation noted in Figure 1.2 is because much of this acreage has been defoliated because it has not been treated. New York State treatment policy provides guidelines that (1) the infected acreage should be at least 50 acres in size, (2) should exhibit at least 500 egg-masses per acre at the plot center, and (3) signed landowner consent must be obtained. These policy factors, coupled with manpower limitations and the abandonment of an eradication philosophy, are significant causative elements in the upward trend of woodland defoliation by gypsy moth.

Several examples illustrate these points. In the season just past (1971), about 480,000 acres in New York were defoliated by the gypsy moth. Of this total, 150,400 acres were defoliated in Putnam County. One of the principal reasons was that the seriousness of the infestation was not fully known since there was insufficient manpower to survey the area.[1.8]

Coupled to the insufficiency of manpower, there existed a problem in timely legislative action in terms of the New York State budget. As a result, the landowner consent forms were mailed later than normal to those individuals who owned infested and treatable woodlands. Many were not returned in time for the final, carefully developed spray treatment program by the Department of Environmental Conservation. The lack of the returned landowner consent form was interpreted, as a matter of policy, as being a lack of consent. In other years, it has been interpreted as a lack of interest and hence, tacit acceptance of pest control treatment.

Finally, Figure 1.3 schematically delimits differences between treated and untreated acreage, as well as serving to illustrate an effect associated with less persistent pesticides. This area of Long Island was aerially treated



COURTESY: NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION

Figure 1.3 TREATED AND DEFOLIATED ACREAGE ON PART OF LONG ISLAND, NEW YORK with a water-borne formulation of Sevin at a rate of 1 lb(active)/acre. Most acreage defoliated was not treated. Most of the treated acreage was not defoliated. However, it should be noted that some defoliation (not severe) did occur within the treated blocks that were adjacent to untreated woodland. This was due to reinfection due to airborne larvae dispersal from adjacent untreated regions. Experience in the past with DDT indicates that in similar circumstances, the chemical persistence of the pesticide would have controlled this reinfection, whereas the greatly decreased chemical persistence of Sevin does not permit extended protection against the reinfection threat.

A-1.5 References

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A-2

APPLICATION TECHNIQUES

To alert the reader to the scope and content of this section, several points are prefatorily emphasized. The discussions and analyses presented in this section respond to two stated program goals, namely,:

(1) a discussion of the techniques of forest pesticide application and,

(2) examination of these techniques to learn how they tend to maximize or minimize pollution problems.

Since 1945, about 99 % of all forest pesticide treatment in New York has been accomplished by aerial application. This technique is successful and presents a minimum of problems due to rigorous adherence of adequate operational guidelines that have been carefully evolved over the years.

Technically, however, the "heart" of aerial application is the atomization process for which scientific information is somewhat diffuse and widely scattered in the literature. This section presents a compilation and analysis of these data which, hopefully, will be used as foundation material in evaluating future procedural changes in forest pesticide treatment.

While this information is highly technical, it has been related to other aspects of forest pesticide use, e.g., pesticide deposition effects on foliar surfaces.

The main point is that there may be increasing scientific and emotional pressure to make changes in a single element of the atomization equipment without appreciating the impact of that change on the environment. We believe that the following discussion on atomization will serve to further that understanding.

A-2.1 Introduction

The application of pesticides by spraying is the predominant method currently used in forestry and agriculture for directly controlling the size of pest populations. Much of this spraying is done with aircraft, both to achieve timeliness of application and to permit treatment of large areas, often having limited overland accessibility. Ground-based spraying accounts for the remainder.

The very introduction of pesticides into the environment implies environmental contamination; the important ecological questions, therefore, are concerned with "how much", "how important is it", "what are the alternatives", and "how can it be minimized to a tolerable level". It is now recognized that through the use of chemicals, agriculture and forestry have been brought into a highly productive but unstable state. Chemical pest control has been used extensively in maintaining this unstable state. The avoidance of further environmental contamination is not a matter of simply prohibiting the further use of pesticides; the consequences of such an action must also be taken into consideration.

Ultimately, the advantage of pesticide spraying must be weighed against the disadvantages of its cessation, as well as its hazard to the ecosystem. With this in mind, the pesticide spraying operations as currently conducted in New York for gypsy moth control are reviewed. Inasmuch as these operations tend to stress a special case, the discussion in this section also includes some relevant information from other areas. In the weighing process, the most important aspects of application techniques center on understanding the characteristics of sprays which are responsible for spray effectiveness and ascertaining the degree of effectiveness and environmental contamination which has been and might be realized. This point of view has generally been appreciated for some time, but some of the characteristics required to quantify spray efficacy and hazards are difficult to measure, particularly in the field. As a result, empirical approaches, often with incomplete parameter determination, have dominated the investigative efforts to such an extent that many of the features which are necessary for determining what is responsible for what, aside from what might be done, frequently remain unknown. Further, the molding of common features in to a consistent and unified scheme is often not pursued under this approach. The situation as it relates to insect control is adroitly noted in the following statement by Himel.[2.1]

> "In spite of a vast array of experimental difficulties, the spray application of insecticides has been an unqualified success in the control of insect populations. This success is amply documented in the scientific and ancillary literature, but should not be allowed to obscure the stark fact that very little is known, unequivocally, concerning the mechanism and mode of transport of spray droplets to the target. Furthermore, in the present era, success is not enough. Increasingly complex problems of insect control in a co-existing ecosystem have to be faced. Ecological problems are building up and cannot be ignored. It is probable that ecological factors may become the overriding consideration in the future allowable use of insecticides. There exists a critical need for more fundamental knowledge of the mechanisms of the insecticide spray process, and a critical need for a direct analytical methodology by which these mechanisms can be determined."

Something can be said for the empirical approach, however, because it produces results of direct utility and permits investigations to be carried out in cases where mechanistic characterization is not presently known to be tractable. Essentially this approach has been followed in New York; the present spraying techniques and procedures used in the case of gypsy moth have been developed operationally. As such, they appear to be capable of achieving success in gypsy moth control without gross environmental contamination, yet appear to be weak in providing understanding which can be utilized in defending current practices or in deriving improved alternate spraying procedures.

A-2.2 The Distribution Process

The application of pesticides via spraying techniques involves the following four key processes.

1. Atomization.
2. Droplet transport from disseminator to target.
3. Droplet deposition or impaction on the target or other surfaces.
4. Mode of pesticide action against the pest to be controlled.

In relation to these processes other factors are involved, including the pest, its origin and habits, the nature of the environment in which it is found, the pesticide used, the physical properties of the spray liquid, meteorological conditions, and the type, relative location and motion of the system carrying the atomizer(s).

The atomization process is fundamental to both pesticide spraying operations and research, as it is the means by which sprays are generated. In a more tangible sense, the aspects of principal importance are concerned with the characteristics of sprays that can be produced with given devices or techniques, the nature of control which can be exercised in spray production, and prospects of generating or tailoring sprays to conform to a prescribed set of characteristics.

Droplet sizes and emission rates are essentially the only features of a spray that can be controlled during spray generation with any given atomizer of known design. The extent of the control is, at best, not very great. In attempts to gain such control, a wide variety of atomizers have been designed, and many are now commercially available.

The practical realization of what can be achieved in the atomization process has been far in advance of theory. The fundamental aspects of atomization are inherently complex because of the many dimensional variables needed to characterize an atomizer, the wide range in properties of liquids or suspensions which can be used, the wide variation in dynamics of liquid flow involved, and the dependence of ejected liquid instability on liquid interactions with the surrounding medium. These complexities have thwarted essentially all known attempts to describe the detailed performance of any atomizer solely in terms of basic physical parameters. Correspondingly, the literature concerned with atomization is very extensive; it has been comprehensively surveyed by DeJuhasz[2.2] and Lapple, et. al[2.3]. The main progress in atomization characterization has come via a less detailed and sophisticated but more practical semi-empirical approach using dimensional analysis. This scheme has benefited, on the one hand, from guidance obtained through basic studies, and on the other hand, from performance characteristics experimentally determined for atomizers of specific designs. This approach has permitted the correlation of several parameters which are important in atomizer performance over a rather wide range of operating conditions. Such unification is significant in simplifying the engineering aspects of atomizer performance for spray operators and research workers alike, and should facilitate the conduct of more detailed mechanistic investigations of the process of spray transport, deposition, and mode of action.

The disintegration of a bulk liquid into droplets can be brought about in several ways which frequently can be distinquished according to the manner of supplying energy to the liquid to effect breakup. Atomizers of greatest interest in pesticide spraying include those which utilize energy arising from rotary motion, pressure, and the interaction of liquid with high-speed air. Other known types employ thermal, explosive shock, acoustic and electrical energy. It is not unusual to find atomizers which employ a combination of energy sources. In rotary devices, such as the spinning disk or cup atomizers, energy is obtained kinetically from centrifugal action as the liquid is spun off the periphery of a rotor. In hydraulic nozzles, including the plain orifice, and fan and cone spray types, the energy available at the moment of breakup is obtained from pressure built up in the liquid and released in dynamic expulsion. Two-fluid nozzles utilize, in addition to pressure expulsion of liquid, high-speed air to achieve further liquid disruption. Additional effects of high-speed air on atomization occur for each of these types when the atomizers are mounted on a moving aircraft or in a blower duct.

Rotary atomizers are the only known mechanical devices for generating nearly monodisperse droplets in sufficient quantities to be practical for use in the field spraying of pesticides. Their use is presently limited to ultra-low-volume (ULV) spraying, where application rates of only a few fluid ounces per acre are employed. The corresponding low liquid flow rates are the key to rotary atomizer utility in this case, since the requirement of a very low liquid feed rate per rotor that Walton and Prewett[2.4] found for the production of droplets in a narrow size spectrum can be satisfied, yet by using multiple rotors in parallel, practical emission rates can be achieved. An additional operational advantage for rotary atomizers is the facility to change droplet size with rotor speed, without the requirement to change liquid feed rate at the same time.

Walton and Prewett advanced the following expression to relate the various parameters governing droplet size in rotary atomization:

$$D = \frac{C}{V_d}\sqrt{\frac{\gamma d}{\rho_L}}$$

where D is a median drop diameter, γ is the surface tension of the liquid, ρ_L is the liquid density, V_d is the peripheral speed of the spinning disk, d is the disk diameter and C is a constant. Other detailed investigations of rotary atomization have been conducted, including those of Friedman, et. al.,[2.5] and Fraser, et. al.[2.6].

For many years there was concern over the unwanted production of small satellite droplets, in addition to the main droplet output of rotary atomizers. Customarily, the number of satellite drops increased with increasing feed rate. Further, at high liquid feed rates the main droplets, themselves, were smaller than predicted by the drop size expression by Walton and Prewett; often up to 90 % of the total liquid atomized was found in abnormally small droplets. Bals reported that both these effects can be accounted for in terms of liquid surface tension and the nature of the issuing point on the rotor periphery from which the liquid is released.

During the normal build up of liquid to form the primary drop, the liquid is attracted by its surface tension to the blunt edge of the rotor. When sufficient buildup has occurred, a filament is formed on which the main drop hangs prior to its release. Subsequently, this filament shatters into small droplets of uncontrolled size, forming the satellite droplets. With high feed rates, the liquid is ejected directly from the rotor as filaments and the nature of liquid build up at the rotor edge is different. These filaments subsequently break up in a manner similar to that of a single jet [2.8,2.9]. The drops so formed are smaller than predicted by the formula because the dependence of jet breakup on surface tension is different from that at the rotor edge.

Bals has shown that by using a rotor with fine teeth at the edge, the liquid buildup phenomenon encountered in normal rotary atomization is substantially reduced. The net effect is to produce considerably smaller droplets at the same flow rate, without the presence of satellite drops. The degree of monodispersity of drops so formed is slightly poorer than that obtained for normal rotary atomization.

Yeo[2.10] studied the drop size distributions from rotary atomizers spraying from aircraft and obtained the following relation for the volume median droplet diameter:

$$D_V = \frac{B}{V}\sqrt{\frac{\gamma d}{\rho L}}$$

where V is now the resultant velocity of the escaping droplet relative to stationary air, and B is a constant. Presumably this relation accounts for secondary atomization due to the shattering effect of the passing airstream through the relative velocity V. Sayer[2.11] notes that viscosity of the liquid to be atomized can be an important parameter affecting rotary atomizer performance, especially if significant changes in viscosity result from variation in spray liquid temperature. More commonly, viscosity influences the drop size results indirectly by virtue of changes in rotor loading. This can be overcome using variable flow control in the system to maintain constant rotor loading regardless of viscosity changes. Specific performance data for particular rotary device types has been given, for example, by Sayer[2.11] and Mount, et. al.,[2.12,2.13].

In spite of the complexity of rotary atomizers, as compared to other mechanical atomizers, they exhibit considerable potential for droplet size control in ULV spraying operations. Further investigation of the output of these nozzles in high velocity airstreams -- particularly when suspensions are disseminated -- appears desirable.

Hydraulic nozzles have been the most widely used types in pesticide spraying largely because of their simplicity and low cost. The plain orifice types have not been viewed with much favor in the past, because small orifices, which are highly subject to plugging, must be used to obtain reasonably small output droplets. Recent work noted by Johnstone[2.14] indicates that for herbicide application, the plain orifice type nozzle has the advantage of producing a narrower range of droplet sizes than nozzles of the fan or cone spray types. This is reported tc hold for both viscous Newtonian and pseudoplastic non-Newtonian liquids. Unfortunately this effect is known to occur only for sprays with large volume median drop sizes of the order of 1,000 microns. Hence, the result may not be of widespread utility.

Both fan and cone spray nozzles have been used and studied rather extensively for a period of several years. The atomization process in these two types is closely related, since at low pressures the nozzle transforms the liquid into an unstable sheet, either flat or conical in form, which subsequently disintegrates into droplets of various sizes.

Dorman[2.15] and Yeo[2.16] have both made a dimensional analysis of fan nozzle performance, and by using experimental data have obtained a complete solution of the equations, yielding a similar relation between the Sauter mean diameter (D_s) of the spray and the physical properties of the spray liquid. For typical size distributions produced by these nozzles, D_s is related to the volume median diameter (D_v) by a constant. Thus both expressions can alternately be written for D_v instead of D_s. Dorman examined the static case, whereas Yeo examined results for nozzles fitted to aircraft. Yeo's relation, therefore, which includes the effect of airflow past the nozzle is more general. It is:

$$\frac{D_V V_E}{\left(\frac{Q\gamma}{P_L}\right)^{\frac{1}{3}}} = \chi\left(\frac{V_E}{V}\right)$$

where Q is the liquid volume flow rate, V_E is the liquid ejection velocity at the orifice (which has been found by Dombrowski, et. al.,[2.17] to be essentially constant over the extent of the liquid fan), V is the resultant liquid velocity relative to stationary air, and χ is an experimentally determined function. The above relation was established for oil formulations over the viscosity range 3 - 12 cp and the surface tension range of 27-37 dynes/cm.

Fraser, et. al.,[2.18] on the basis of combined theoretical-experimental treatment that considers the breakup of a spray sheet to be due to wave formation, arrived at a similar functional dependence of D_v on the other parameters.

The practical utility of Yeo's expression in applications requiring more than a rough estimate of the spray volume median droplet diameter rests squarely on the accuracy and generality of the χ function. The particular form of the χ function determined by Yeo was based mainly on the droplet sizes obtained from ground deposits of aircraft spray produced with small ceramic flat fan nozzles with rectangular orifices. Aircraft altitude was about 30 feet for all tests. To our knowledge no serious attempts have been made to check Yeo's form of χ with other nozzle types, liquid properties, or droplet sizes representative of the total nozzle output.

Before pursuing this question further, it is significant to note the recent work of Ford and Furmidge[2.19-2.22] dealing with effects of viscosity on droplet sizes produced by flat fan nozzles. They found that the volume median droplet diameters produced were a function of the flow parameters given in Yeo's expression and, in addition, depended on the region of the liquid fan from which the droplets originated. There are basically two regions of concern; the thin liquid sheet which forms the central part of the liquid fan and the edges of the fan, which because of liquid surface tension tend to become curved cylindrical ligaments. The droplet sizes originating from the sheet and the ligaments are different; typically those arising from the ligaments are larger. In turn, the volume median droplet diameter of the spray output, as well as the complete size distribution, depends on how the total liquid output is divided between the two regions. Ford and Furmidge characterize this division, and hence the flow properties of liquid through a fan nozzle, in terms of four ranges of Reynolds number. These four ranges correspond to fully turbulent flow, transition flow, laminar flow with sheet formation, and laminar flow with only ligaments present. Two expressions are then required for expressing median droplet sizes for static or slowly moving nozzles. For sheet breakup:

$$\frac{D_V V_E}{(Q_S \gamma/\rho_L)^{1/3}} \cdot \left(\frac{r \vartheta \rho_L V_E^2}{\gamma}\right)^{1/3} = \text{constant},$$

and for ligament breakup:

$$\frac{D}{\Delta}\left(\frac{\sqrt{\gamma \rho_L \Delta}}{\eta}\right)^{1/6} = \text{constant}$$

where $\Delta = \left(\frac{2 Q_L}{\pi V_E}\right)^{1/2}$ is the diameter of the ligaments.

Further, Q_S is the volume flow rate of liquid into the sheet, r is the length of the sheet from the nozzle to the point of breakup, ϑ is the actual spray fan angle, η is the liquid viscosity, and Q_L is the volume rate of flow into the ligaments. In the case of rapidly moving nozzles one might expect the constant on the right hand side of each expression to be replaced by functions $\chi \frac{V_E}{V}$, similar to that used by Yeo, to account for airstream interactions. The form of these functions are unknown.

The factor $\left(\frac{r \vartheta \rho_L V_E^2}{\gamma}\right)^{1/3}$ represents a sheet instability term which is directly related to Reynolds number, and hence viscosity. The requirement to know both this factor and the relative proportion of liquid which enters the central sheet and ligaments presents practical difficulties. These quantities for various nozzles or series of nozzles commonly used are not known to have been measured in the laboratory. Further, the nozzle design, manufacturing imperfections and operating pressure can in principle have a significant effect on the spray characteristics.

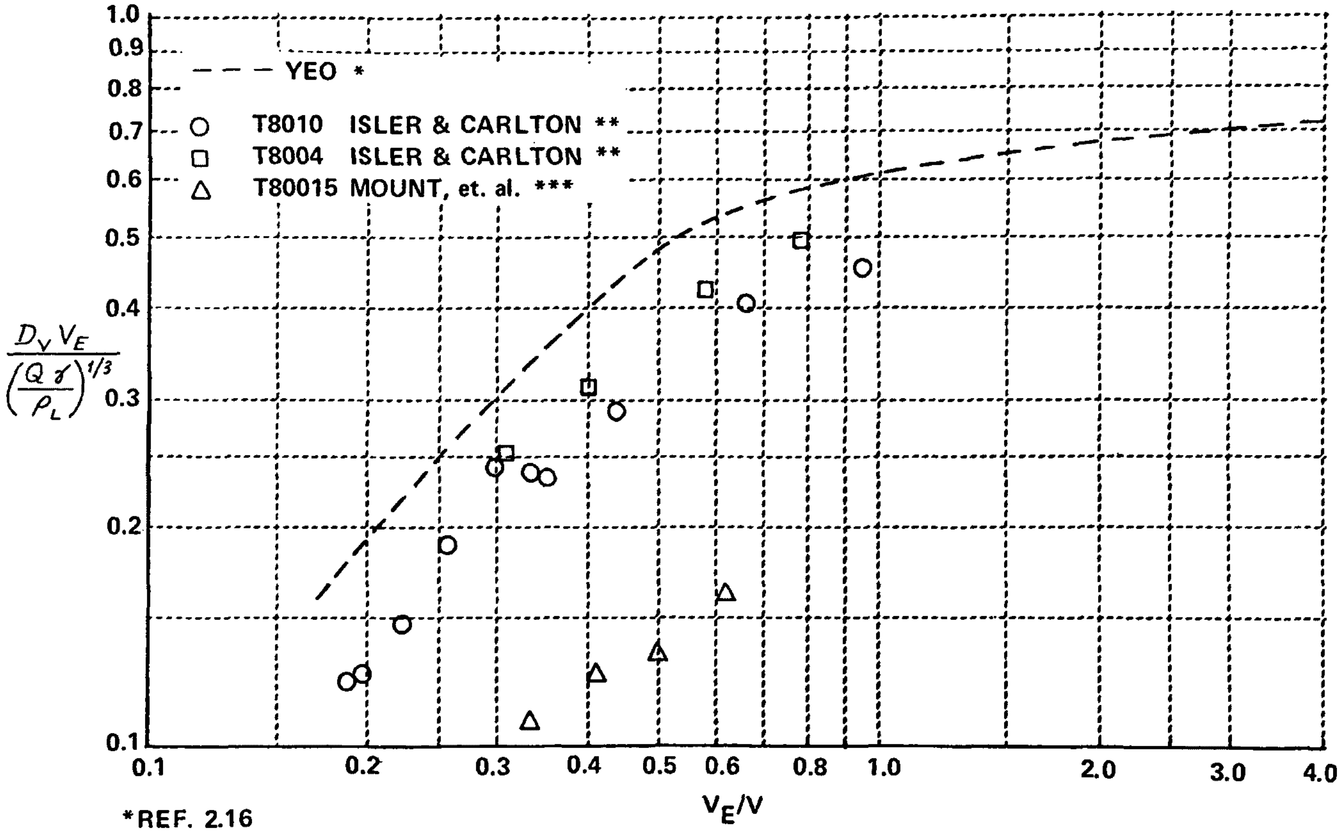
The opinion expressed by Thompson[2.23] that "the number of variables in jet-type spray nozzles seems to indicate that this nozzle is poorly suited to applying insecticides at LV (low-volume) and ULV rates" is not without some foundation: yet there are mediating aspects. For Reynolds numbers above a certain value (Re greater than 500 in the cases examined by Ford and Furmidge) the instability factor appears to be nearly constant and Yeo's expression allegedly applies. This case is of primary interest for low viscosity liquids and high liquid ejection velocities. Secondly, the working tolerances and degree of quality control exercised by reputable nozzle manufacturers are quite good. Manufacturing imperfections are kept to a minimum. Operator-induced imperfections resulting from cleaning a nozzle orifice with a sharp instrument are likely to be more of a problem; such procedures are simply not tolerable. Thirdly, it is seldom, in practical pesticide spraying operations, that a single nozzle is employed. Routinely, a bank of 10 or more nozzles are used in aircraft spraying and imperfections will tend to influence the breadth of the size distribution rather than an average spray parameter such as the volume median diameter. If a single nozzle is used it may be necessary to calibrate it separately. Nozzle wear, unfortunately, is a factor which cannot be completely overcome. Its effects can be minimized by employing nozzles with orifices made from very durable materials such as tungsten carbide -- but the cost is rather high. Another alternate is planned replacement after a given amount of nozzle operating time. There appears to be little one can do to salvage a worn out nozzle.

Reverting to the consideration of Yeo's χ function, it now becomes more apparent why it generality is of interest. A preliminary comparison of Yeo's function (converted to D_v) with data of Isler and Carlton[2.24] and Mount, et. al.,[2.25] for Spraying Systems Co. Tee Jet fan nozzles with elliptical orifices in the 80° series is shown in Figure 2.1. It is immediately apparent that something is different.

In the case of Isler and Carlton's data, the ranges of variation of parameters is nearly the same as Yeo's except for slightly higher airspeeds and aircraft altitudes of 50 - 100 ft instead of 30 ft. There are some differences in droplet sizing techniques, but both involved sizing from spray deposits on the ground, and this would not be expected to significantly alter the results. The most likely sources for the variation are differences in nozzle types or spray altitude. Since the general nature of the functional dependence of the factor involving size with V_E/V is the same, the difference is tentatively attributed to spray altitude. Spray release altitude can alter the sizes of droplets deposited on the ground through the cumulative effects of both spray drift and evaporation.

In the case of Mount's data, the difference is almost certainly due to the way the spray droplets were sized, and the difference in viscosity of the spray liquid. Mount and his co-workers collected droplets of 95 % technical malathion by impaction directly in the spray output of a nozzle mounted at various angles in a blower airstream. This simulated scheme gave results which compared well with the corresponding ones obtained from aircraft dispersal.

As it stands, therefore, it appears that Yeo's χ function is of direct utility only when the original conditions for which it was derived are closely

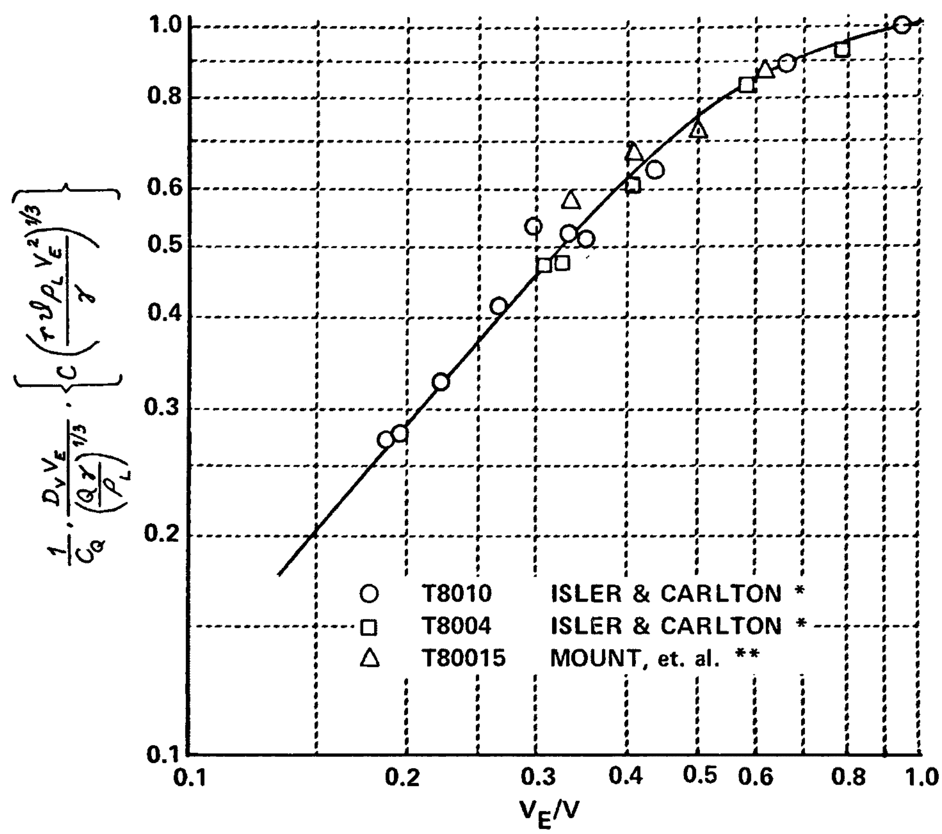


*REF. 2.16
**REF. 2.24
***REF. 2.25

Figure 2.1 PERFORMANCE CORRELATION OF FLAT FAN NOZZLES MOUNTED ON MOVING AIRCRAFT BY YEO'S METHOD duplicated. In addition, it seems that the prospect of obtaining such a function with greater generality depends on basing it on the total size spectrum from a nozzle or series of nozzles, rather than on the spray which deposits on the ground after experiencing a variable amount of evaporation and drift. Such a treatment should also incorporate considerations of viscosity affects, probably along lines similar to those employed by Ford and Furmidge.

A preliminary indication of the type of conformity that can be achieved solely by using the Ford and Furmidge type of expression for sheet breakup is shown in Figure 2.2. The ordinate parameter group in Figure 2.2 includes the nozzle discharge coefficient C_Q. These results were obtained by "back solving" for the instability factor using the measured (or extrapolated) volume mean diameter at $V_E/V = 1$ and normalizing the χ function to unity at this point. Available data are not sufficient to allow the complete dependence of the instability factor with Reynolds number to be estabished this way. However, for each nozzle type examined, the results -- combined with available drop size data for water -- appear to qualitatively follow the type of variation found by Ford and Furmidge.

It will be noted that the preceding discussion is limited almost solely to the volume median droplet size rather than the complete size distribution. Data on complete size distributions for various fan nozzles types are relatively scarce. Hedden[2.26], Tate and Jansen[2.27] and Mount, et. al.,[2.25] give some representative data. In addition, the Spraying Systems Co. and the Delevan Manufacturing Co., for example, have generated some of these data for certain types of fan (and cone) nozzles under static conditions using water. To date there are no known investigations which have been successful in relating the complete size distribution to operational parameters of fan nozzles, even under static conditions.



*REF. 2.24
**REF. 2.25

Figure 2.2 PERFORMANCE CORRELATION OF FLAT FAN NOZZLES MOUNTED ON MOVING AIRCRAFT BY MODIFIED FORD AND FURMIDGE METHOD

Such a result would be of some significance in atomization theory, but its practical utility is not clear at the moment because typically, fan nozzles produce a rather broad-size spectrum and the current trend (or desire) in pesticide spraying is toward the use of sprays in a narrow size range. The answer to the question of which is better does not lie within the realm of the atomization process; it must come from other sources.

Hollow cone spray nozzle performance has also been examined by various workers, including Knight[2.28] Radcliff[2.29,2.30], Nelson and Stevens[2.31], and Ford and Furmidge[2.22]. Several practical aspects of atomizer design and performance are discussed by Joyce[2.32], Giffen and Muraszew[2.33], and Fraser, et. al.[2.34]. In principle, the atomization of a conical sheet of liquid produced by a cone nozzle is somewhat easier to treat than the flat sheet because edge ligaments do not exist. The production of the sheet itself, however, appears to be related in more complex way to the atomizer details (e.g., see Nelson and Stevens, and Radcliff).

Ford and Furmidge[2.22] found the variation spray droplet size with viscosity to be similar to that noted previously for fan nozzles. The results can be considered in terms of three ranges of Reynolds number which correspond to turbulent flow in the conical liquid sheet, transition flow in the sheet, and laminar flow. As the Reynolds numbers become small, which corresponds to viscosity becoming large, the angle of the cone becomes smaller and the droplet sizes increase. When the viscosity becomes quite large a conical sheet is no longer formed, and the droplets become quite large.

The expression obtained by Ford and Furmidge relating the various parameters to volume median droplet D_v size for a static or slowly moving cone nozzle is:

$$\frac{D_V V_E}{\left(\frac{Q\,\gamma}{\rho_L}\right)^{1/3}} \cdot \left(\frac{\gamma}{\ell \sin\frac{\alpha}{2}\cdot \rho_L V_E^2}\right)^{1/3} = \text{constant},$$

where Q is the total volume emission rate of liquid, V_E is the velocity with which the liquid is ejected from the nozzle, ℓ is the length of the sheet from the orifice to the point of breakup, α is the cone angle of the sheet, and other quantities are the same as in the fan nozzle case.

For a nozzle moving at a relatively high speed in air, or spraying into a high speed air stream, it is expected that the constant on the right hand side of the above expression should be replaced by a function $\chi\left(\frac{V_E}{V}\right)$ similar to that introduced by Yeo[2.16]. For cone nozzles the form of the χ function is unknown.

Practical application of the preceding droplet size expressions requires information on the sheet dimensions ℓ and α, or alternately "back solution" for the initiability term from measured volume median diameters. Sufficient data are not known to be available to permit this to be carried out at present.

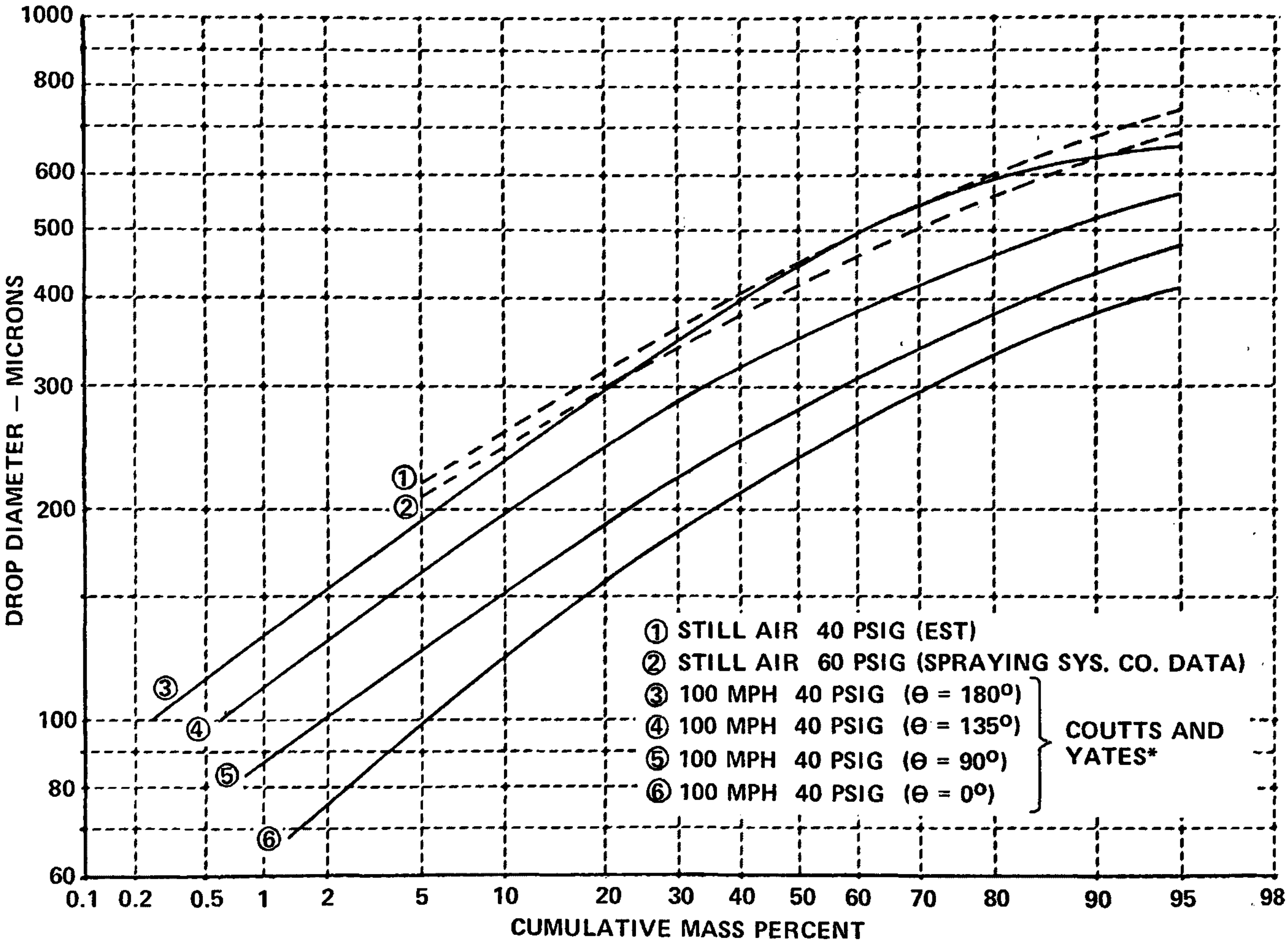
Also, the published information does not seem to be sufficient to characterize the χ function for cone nozzles, but preliminary examination of this matter using the data of Isler and Carlton[2.24] and the expressions of Ford and Furmidge[2.22] suggest that the nature of this χ function may be somewhat different from that indicated for fan nozzles.

For cone nozzles the available data on droplet sizes are rather meager. In addition to manufacturers data noted earlier, some information is available from the actual and simulated field tests conducted by Coutts and Yates[2.35], Butler, et. al.,[2.36] and Mount, et. al.,[2.25]. Typical droplet size distributions expected using a D6-46 hollow cone nozzle spraying water into still air and into moving air are shown in Figure 2.3. In this figure, θ is the angle which the nozzle makes with the thrust line of a fixed wing aircraft. For $\theta = 0°$ the nozzle axis is directed into the airstream; for $\theta = 90°$ it is directed vertically downward.

Hollow cone nozzles have been used rather widely in aerial spraying operations, in part because of the convenience in using various combinations of disks and cores to achieve desired application rates and, hopefully, the correct droplet size suited to the application. Sayer[2.11] has compared the spread of droplet sizes obtained on ground deposits from sprays of fan, hollow cone and spinning disk atomizers and finds the spread generally to decrease in the same sequence as this order of nozzle type.

The last type atomizer which has been considered for pesticide spraying is the two-fluid system. Each of the preceding types have been viewed in the two-fluid sense also because of their interaction with high speed air when mounted on aircraft or in a blower duct. Mounting any one of the previously noted hydraulic nozzles in a blower duct essentially constitutes what is involved in configuring a mist blower, although other design considerations are usually involved as well. The high speed air employed in mist blowers can often be channelled for greater interaction with the ejected liquid than is customarily obtained in the aircraft case, so smaller droplet sizes can be achieved. One additional control aspect of spray ejected from mist blowers not readily obtained in aerial spraying, is the ability to direct the spray (a small amount of spray directively is realized, of course, when spraying from slowly moving helicopters near the ground).

The classical form of two-fluid nozzle system, known as a pneumatic atomizer, in which air and liquid are closely coupled for maximum interaction has



*REF. 2.35

Figure 2.3 TYPICAL DROPLET MASS-SIZE DISTRIBUTIONS EXPECTED FOR D6-46 HOLLOW CONE NOZZLE SPRAYING WATER only received exploratory attention in pesticide spraying to the present time. This type system has the potential for producing spray droplets down to a few microns in diameter when properly driven, and may be of interest if future investigations should indicate that very small droplets are required.

Until the very recent work of Kim and Marshall[2.37], the quantitative expressions developed to characterize pneumatic nozzle output were far from satisfactory. These investigators appear to have accomplished a "first" in atomization investigations by successfully describing the atomizing characteristics -- including both the median diameters as well as the complete mass size distribution -- for a class of convergent - type nozzles in terms of operating conditions and relatively simple dimensions of the atomizer. Their results are not quoted here, but reference to their original paper should be made if this area becomes of interest in pesticide spraying.

A final remark in connection with the atomization process seems in order. Considerable effort over the past few years has been expended in attempts to use spray adjuvants, such as spray thickness, invert emulsions, etc. to give the liquids to be atomized a non-Newtonian character. Typically pseudoplastic behavior is sought in which viscosity decreases with increasing shear. The immediate goal of these efforts is to achieve larger droplets than are obtainable with Newtonian liquids of the same surface tension when sprayed through the same nozzle. The alleged benefit of this approach, through the elimination of small droplets, is to acquire droplet size control, and in the case of aerial spraying to reduce drift. Indications are that while small droplet production is reduced, small droplets are not eliminated. Bouse[2.38] further notes that "narrower swaths, less uniform distribution patterns and fewer droplets per unit area for a given application rate are undesirable consequences of the use of large drops. Higher rates of application are sometimes required to compensate for the reduction in droplet numbers in order to obtain adequate spray coverage on the foliage".

There is little question that drift, coverage, and droplet sizes produced are interrelated, but there is no clear cut evidence to indicate that going to larger droplet sizes to reduce drift will at the same time either increase pesticide efficacy or reduce environmental contamination in the area where the spraying is done. The critical feature involved is one of efficiency of the pesticide itself; the physical form - once reasonable coverage is achieved - is important primarily to the extent that it effects pesticide efficacy. The optimum droplet size for pesticide spray droplets, therefore, is the size that gives maximum pest control with minimum amount of pesticide and minimum environmental contamination.

The determination of such an optimum size - if indeed one exists for each pest or certain classes of pests - is not an atomization problem, but does involve the process of droplet interaction with the target or pest as well as the mode of pesticide action. Answers to the question of what is an optimum droplet size have stimulated much controversy. Such answers are not easily obtained, but the techniques employed for this type investigation received a significant boost through the introduction of the FP tracer method by Himel[2.39].

The controversy centers around the utility of small droplets in roughly the 5 to 100 micron size range. If it should be resolved that such small droplets are highly effective in pest control, which is indicated for certain pests in the work reported by MacCuaig[2.40], Himel and Moore[2.41,2.42], Himel[2.43], and Mount[2.44], then conventional spraying techniques and equipment would be completely mismatched in terms of producing droplet sizes of interest. Most of the sprays produced with current equipment emphasizes the large droplet spectrum. It may well be that the bulk of the spray so produced do little but contaminate the environment. Obviously, if this should prove to be the case, then conventional aircraft spraying likely could not cope with the drift problem and the introduction of new delivery techniques - perhaps still using aircraft as the delivery system - would need to be developed.

The question of what droplet sizes of pesticide give the greatest pest mortality, and the way the pest should be attacked to achieve such results are probably the most needed information in this area. Application techniques should then be considered accordingly.

The process of transporting spray droplets from an atomizer to the target is largely a problem involving meteorology, especially for aerial spraying, but one which has not yet been solved to most workers satisfaction. It is a very complex problem in general because of the difficulties in characterizing the atmospheric microstructure in the vicinity of small plants, brush and trees. Droplet transport as it applies to aerial spraying operations in New York is discussed in a later section of this report.

The terminal nature of this transport process, in which droplets interact with or penetrate trees and forest foliage has been considered, for example, by Davis, et. al.,[2.45], Maksymiuk[2.46,2.47], Johnson[2.48], Frear and Asquith[2.49], Bouse[2.38] and Himel[2.43]. Some of the fundamental aspects of droplet impaction on foliage have been summarized by David[2.50].

Bouse examined the penetration of large droplet aerial sprays of water through the canopy of 40-ft tall oaks and an underlying layer of 15-ft tall yaupon foliage. The effect of mass (or volume) median diameter on penetration is shown in Figure 2.4. The spray application rate in this work was typically

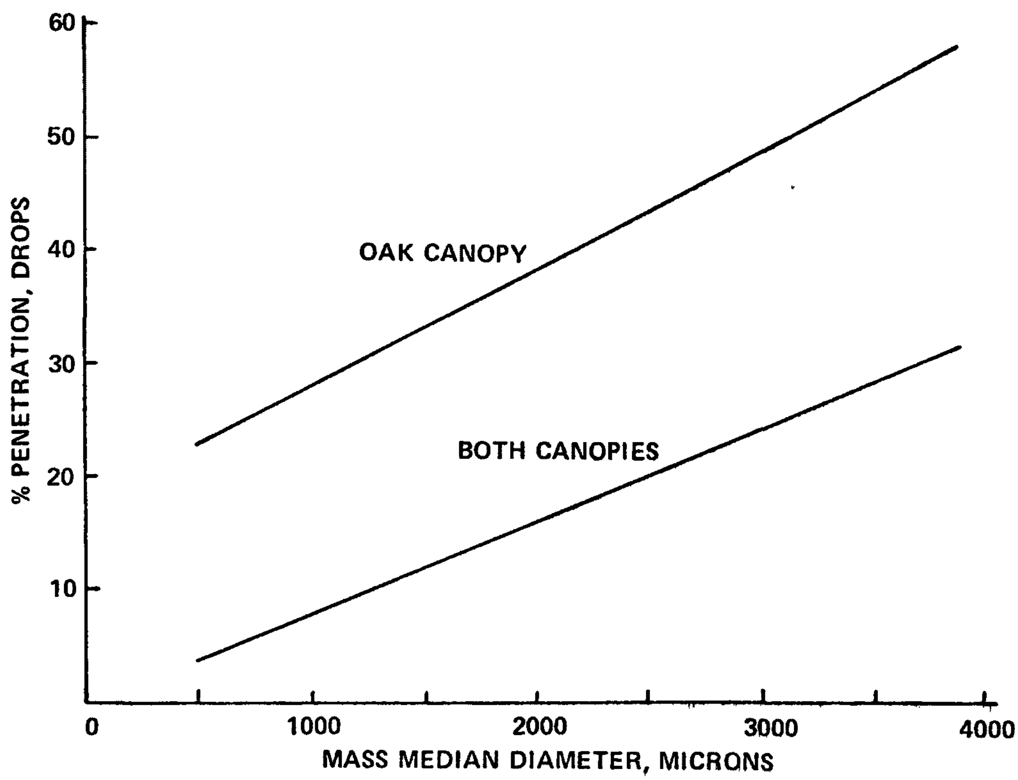


Figure 2.4 EFFECT OF MASS MEDIAN DIAMETER ON PERCENT OF DROPS PENETRATING THE FOLIAGE CANOPIES (FROM BOUSE 2.38)

about 4 gallons per acre, which when coupled with the large droplet sizes employed suggests that increasing penetration with droplet size may be due primarily to liquid run-off from upper foliage. This appears relevant, because impaction and retention of droplets with sizes in the range of about 150 to 500 microns (smaller than the sizes used by Bouse) may be limited primarily to the outer layers foliage layers, as indicated by Himel[2.1]. For deciduous tree species, droplets larger than about 150 microns would also be expected to deposit on ground level foliage in the open, or directly on the ground. This part of the spray would be expected to contribute mainly to environmental contamination.

Aerial spray droplet impaction data taken from foliage samples on a coniferous type tree using the FP tracer method has been given by Himel[2.43] and is noted in Table 2.I. No droplets smaller than 39 microns were included in the count, but Himel notes that a very large number of droplets in the 21 to 30 micron size range was present on all collected specimens of foliage and bark. The spray employed had a D_{max} of 350 microns and an D_v of 144 microns.

TABLE 2.I SPRAY-DROPLET DISTRIBUTION ON A 22-FT DOUGLAS FIR TREE

Sample location	Part Sampled	D_{max}	D_{avg}	No. droplets counted
Crown apex	needles	155	97	431
	bark	115	64	
Lateral branches at 15-ft height				
Terminal	needles	150	97	56
Center	needles	107	76	57
Base	needles	92	67	33
Lateral branches at 10-ft height				
Terminal	needles	120	93	41
Center	needles	95	64	28
Base	needles	105	73	35
Lateral branches at ground level				
Terminal	needles	102	64	40
Center	needles	97	64	45
Base	needles	94	64	85

Again droplets larger than about 150 microns will be significant in environmental contamination.

It appears that the foliage in a forest acts as a size selection mechanism for pesticide spray droplets that are applied from above the canopy. Evidently there has been some degree of protection afforded the forest pests from aerial pesticide sprays applied in the past, because complete pest eradication has never been achieved. Just how significant this protection is, is not known, but it undoubtedly varies somewhat with forest type and pest species. The prospects for altering this screening effect are not good as long as sprays must penetrate the canopy from above. If spray were released in or below the canopy the effect may largely disappear. Droplet fallout on the ground would be enhanced, however, unless small droplet sizes were employed. If droplet impaction on the foliage is important in the mode of pesticide action against the pest it is possible that electrostatic charging of the spray could be beneficial. The use of charged sprays has been explored in agriculture and, while the results are not always consistent, charging does not degrade impaction on foliage and usually enhances it. Investigations in this area include the work of Bowan, et. al.[2.51,2.52] Law and Bowen[2.53], Roth and Porterfield,[2.52] Sasser[2.55] and Splinter.[2.56]

What is required for efficient attack of a particular pest is quite important in view of the preceding mechanistic factors which influence the ability of sprays to penetrate the environment where the pest exists. In rather general terms Johnstone [2.14] has outlined certain modes of pesticide action in the following statement.

> "The liquid toxicant may, for instance, act directly by penetration into and thereby poisoning or disrupting the metabolism of the organism, i.e. direct contact action. This is the normal mode for much herbicidal activity, some fungicides and a few insecticides. Alternatively, the toxicant may act indirectly through residual activity. For example, in the case of many insecticides, the action

may either be by pick-up of the toxic deposit as the pest concerned traverses a contaminated surface, or by stomach action following consumption of contaminated foliage. The toxicant may also act in less obvious ways; for example, by fumigant effects from materials with relatively high vapour pressures."

At this point it is useful to restrict further discussion specifically to the gypsy moth, a pest of principal concern in northeastern forests, and to pesticide spraying conducted in New York for its control.

A-2.3 Pesticide Application Techniques Used in New York State

In New York, pesticides for gypsy moth control are applied by spraying selected forested areas, which through annual egg-mass count surveys (conducted during the fall or winter by personnel of the state Bureau of Forest Insect and Disease Control) are known to have high levels of gypsy moth infestations. Only about 25 % the forested areas in New York are under state jurisdiction and it is state policy to obtain written consent from landowners before spraying privately owned property. Most of the spraying is done by state-owned or state-contracted aircraft. Of the total 5.8 million acres which have been treated since 1945, about 99 % has been treated by airborne application using both fixed-wing and helicopter aircraft and component boom and nozzle technique. The remaining 1 % has been treated using ground-based equipment -- vehicle-mounted or man-portable mist blowers. Ground-based spraying is carried out chiefly in suburban and recreational areas, where a greater degree of spatial control of pesticide application must be exercised.

The gypsy moth is currently attacked via droplets of pesticide spray impacted and retained on leaf surfaces. During the caterpillar or larval stage of its life cycle, which occurs in May and June, the gypsy moth is a voracious leaf-eater, and the pesticide acts as an intestinal poison, following leaf ingestion.

The pesticide used in all the early aerial spray work was DDT dissolved in oil. It was initially applied at a rate of 1 lb in 1 gal/acre and later reduced to half this concentration. In 1959 Sevin, a less persistent pesticide, was found to be highly toxic to gypsy moth[2.57-2.59] and its use soon became extensive; it completely replaced DDT by 1966. The first aerial spraying lasts and early work with Sevin used a formulation of 1 lb active Sevin (1.2 lb of 85 % Sevin) plus 4 4 oz of sticker in 1 gal of no. 2 fuel oil. Adequate gypsy moth control was obtained where this formulation was applied in aerial sprays of 175 microns volume median diameter at a rate of 1 lb/acre. Half of this rate did not give sufficient control. Similar oil-based formulations including Sevin-4-Flowable have been and are still used to some extent outside New York[2.60,2.61].

Because of the objectionable slick formation with the oil-based formulas, water-based spray was tested. It was determined that water-based sprays gave adequate control when applied by air at rates of 0.5 and 1 lb/acre[2.62,2.63]. Results of these tests are given in Tables 2.II and 2.III.

Curiously, in New York essentially the same formulation is now used, consisting of 1.25 lb Sevin 80S and 4.0 oz of Pinolene 1882 sticker in sufficient water to make 1 gal, and it is applied at a rate of 1 lb/acre twice the rate shown to be required. Simple mental calculations thus reveal that at an application rate of 0.5 lb/acre, twice the total area could be treated with the same total amount of pesticide, or alternately, the same area with half the total amount. For mist blower operations the application rate is about 10 to 15 lb/acre.

How low the application rate of active carbaryl can be and still achieve gypsy moth control is apparently not well known. Connola[2.64] has stressed the importance of conducting tests at rates of 0.25 lb/acre (and smaller rates if warranted) for this purpose.

Table 2.II

POST-HATCH TREATMENT, 1963 AIRPLANE SPRAY TESTS WITH SEVIN AND STICKERS AGAINST GYPSY MOTH IN NEW YORK

Plot No.	Acres	Date Sprayed	Amount Sevin Per Acre	Spray Deposit	Estimated Egg Masses Per Acre		Counted Egg Masses Per Acre
					Pre-spray	Post-Spray	Post-Spray
4	100	5/31	1/2 lb. + 3 ozs. "Lovo" 192	satisfactory	2128	0	0
5	55	5/31	1/2 lb. + 3 ozs. Fish oil	satisfactory	2088	0	0
6	80	5/31	1/2 lb. + 3 ozs. "Ortho" sticker	satisfactory	5384	24	6
7	705	5/31	1 lb. + 1 oz. Tung oil	satisfactory	2904	0	0
8	190	5/28	4/5 lb. + 1 oz.	unsatisfactory	984	Unsatisfactory Test	
9	365	5/31	1 lb. no sticker	satisfactory	2118	18	6[1]

[1]Possibility of protected unhatched old egg masses.

TABLE 2.III

POST-HATCH TREATMENT, 1965 AIRPLANE SPRAY TESTS WITH SEVIN AND STICKERS AGAINST GYPSY MOTH IN NEW YORK

Plot no.	Acres	Date Treated	Additives to formulations of 1/2 lb. carbaryl in 1 gal. spray[a,b]	Post spray rainfall on plot to 6/25 (in.)	Avg. estimated no. of egg masses/1/10 acre	
					Pre-Spray	Post-Spray
1	160	6/7	4 oz. Pinolene no. 1882	1.07	184.6	0.0
2	1150	6/11-6/12	4 oz. Pinolene no. 1909	0.62	245.8	0.0
3	110	6/12	4 oz. Ucar Latex no. 40	1.14	336.8	0.8
4	150	6/7	No sticker	1.34	553.6	4.8
5	150	6/12	7 oz. Ucar Latex no. 680	1.90	773.6	0.0

[a] Spray dosage was 1 gal of spray/acre.

[b] All formulations were active Sevin in 1 gal. of aqueous spray.

In all known work on gypsy moth toxicity, there is a notable lack of diet-based dose-response data. The effectiveness of Sevin sprays and amounts required per acre have essentially been established in the field for particular modes of spray operation and pest attack. The shortcomings of this approach become apparent when one attempts to examine alternate spray operations and attack modes. In addition, dose-response data for topical application of Sevin and several other pesticides against gypsy moth larvae have only recently been determined[2.65]. The contact effectiveness of Sevin was implicit, however, in the work of Connola[2.62] in which Sevin was applied on infested areas prior to egg hatch. Unfortunately, topical application and contact effectiveness are not necessarily equivalent. For example, it has been observed that for the first instar of Pieris larvae on cotton the median lethal dose due solely to pickup is particle-size dependent[2.14]. A similar effect has been observed by Lyon[2.66] in the case of bark beetles. Whether such an effect exists for the gypsy moth in its first instar is not known, but if so, it would offer an alternate approach to the current use of deposited droplets on foliage. By utilizing a combination of diet and contact response, the timing of spray application could become much less critical. In a trial conducted in early May, 1962, in New York Sevin was applied at a rate of 0.5 lb/acre with sticker, before foliation and before hatching of the gypsy moth larvae. Good control was achieved; presumably through pickup of Sevin by the emerging larvae in their travel to the emerging foliage.

The aircraft and aerial dispensing equipment used in New York are conventional. The Stearman biplane and some of the more recent fixed-wing agricultural aircraft types have been employed for small plot spray work. The bulk of the spray operations, however, are now carried out using the Grumman TBM and helicopters. Typical nozzle and boom arrangements for low volume spraying are used. Spraying specifications call for use of Spraying Systems Company diaphragm type quick-acting on/off valves together with D8-45 hollow cone nozzle discs and cores. Various other nozzle types have been used including the flat fan tips 8002E-8004E and the hollow cone combinations D6-46, D7-56, D8-56 and D10-25. Available information indicates that water-formulated spray drops produced at the aircraft using these nozzle types have volume mean diameters in the range of 200 to 500 microns. The mass size distribution of carbaryl typically used in the water formulation is shown in Figure 2.5. Spray uniformity is checked prior to the spray season using an array of horizontal ground impaction cards covering the full width of the spray swath. Flow rate is calibrated simultaneously. Spray droplet diameters are established by state personnel to be in the range of 150 to 200 microns volume mean diameter upon impaction on forest foliage. Aircraft operating conditions are typically 80 to 100 mph at 75 ft above the foliar level.

Mist blowers employed in gypsy moth control are usually contracted machines which are also employed at other times for other pests. Typically these machines employ either an axial-flow or squirrel cage fan to produce an air stream with exit speed of 110-160 mph. For specificity, the characteristics of one rather widely used machine, the John Bean Rotomist 100 (Manufactured by John Bean Div. FMC Corporation, Jamesboro, Ark.) is shown below.

Air discharge rate	28,000 ft^3/min
Air speed at exit orifice	100 mph
Engine 172 cu in	67 hp
Fan Size	29 in dia

Frequently there is some difficulty in obtaining even spray coverage on trees with any of these machines, but especially if blowers of inadequate

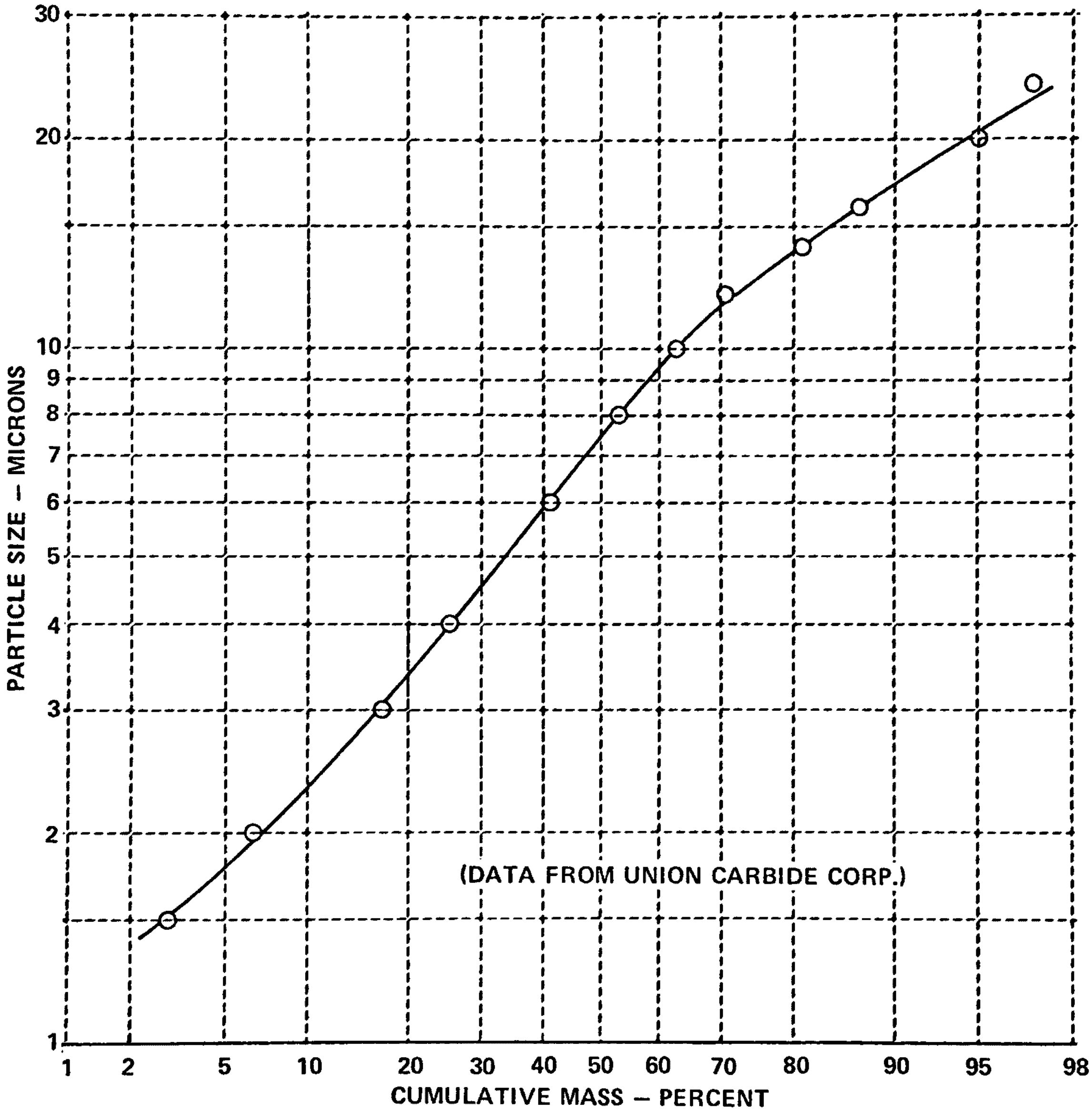


Figure 2.5 TYPICAL PARTICLE MASS-SIZE DISTRIBUTION OF SEVIN 80S

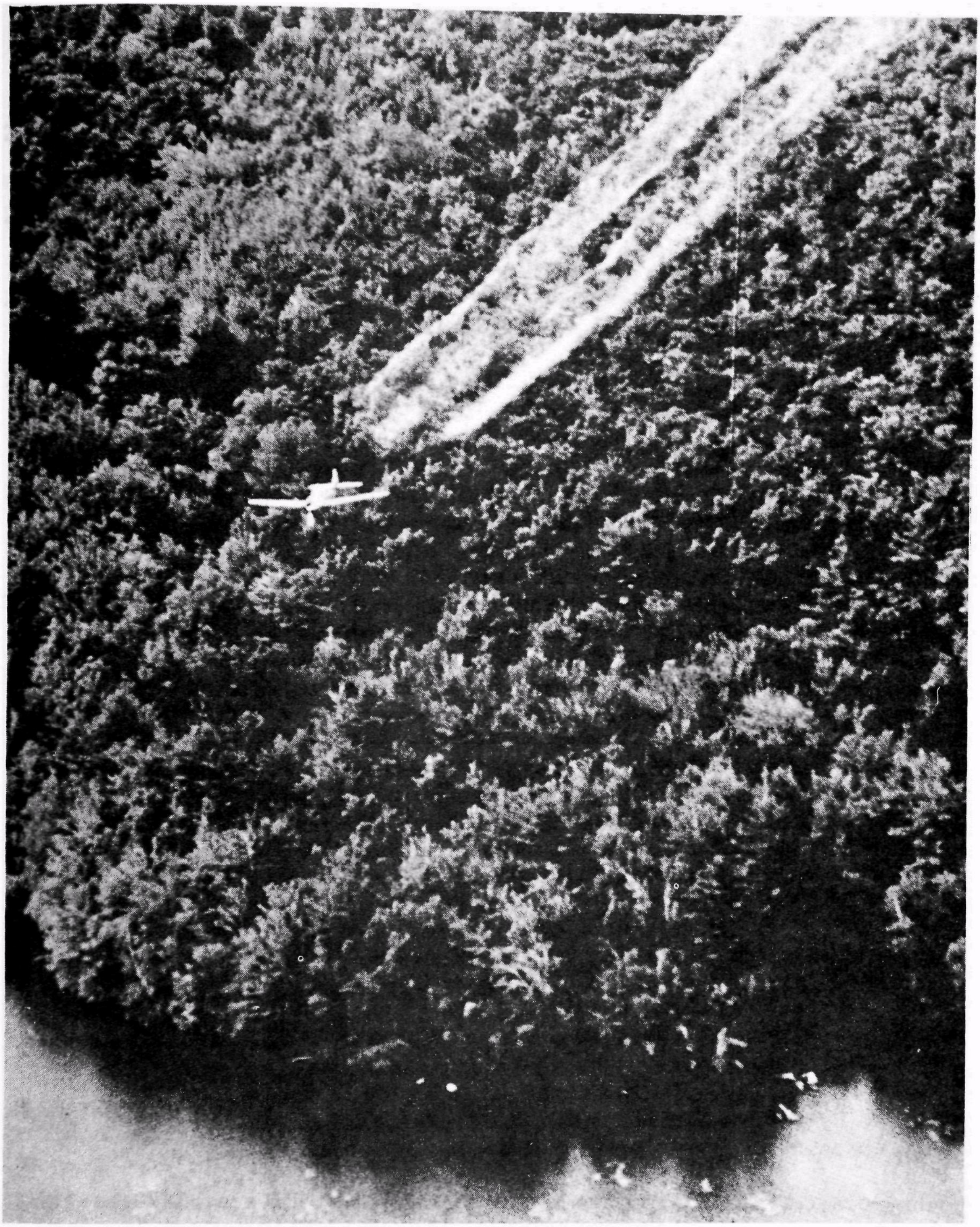
size are used[2.67]. The usual problem is that 2-5 times as much material may be deposited on lower branches as in the tops of the trees. The proper combination of air blast and droplet sizes ejected are important in obtaining good coverage. For the noted system, typically about 80 % of the spray output (water) consists of droplets in the 50 - 100 micron size range. Tests made at the Cornell University indicated that about 70 % of the spray, applied at a rate of 60 gal/acre was accounted for on above-ground tree surfaces. This figure dropped to 75 % when the application rate was increased to 400 gal/acre.

Hydraulic sprayers have been used in the past in New York but currently their use is very minimal. Typically these units were carried on large trucks together with a spray tank containing 300 - 600 gal. The pump units were connected to hand-operated spray guns by up to 200 ft of high-pressure hose. In practice, the spray gun operator walked around the tree outside the drip line shooting short bursts of spray into the foliage and over the tree to cover both the top and bottom of the leaves, branches and tree trunks. Spray pressures of 650 lb/in^2 were used and 30 - 40 gal of finished spray/acre were required to obtain coverage to the point of runoff.

The doctrine and definitive procedures for forest spraying operations are set forth in the Gypsy Moth Control Manual distributed by the New York State Department of environmental conservation. This manual is currently being revised to include current standard practices. The manual is closely followed in all aerial and ground spraying operations conducted by the State, and this procedure appears to give adequate coverage of operational matters. Inasmuch as this control manual is detailed and extensive in its coverage of topics, ranging from public relations to technical calibration topics, and from detailed job descriptions to individual forms which are submitted for each operation, no attempt is made here to reproduce it in its entirety or in sections.

The adherence to regulations during spray operations is facilitated in that such operations are under the direct control and supervision of career foresters. Except for State-contracted pilots, who also come under the same supervision, the spray operations are also staffed by career personnel. In particular, strict rules are enforced relating to the following:

1. No spraying is to be done over water or open land or residential areas (see Figure 2.6).
2. The minimum acreage to be sprayed by air is a 50-acre plot.
3. Forest areas to be sprayed only include those where ground surveys indicate a total egg-mass count of 500 or more per acre. Records are kept of all spraying operations.
4. Notification is given to local residents regarding spray operations and what to expect.
5. Proper meteorological conditions must be met or spraying operations are terminated. In order to meet near-zero-wind, high relative humidity, and temperature conditions to minimize drift, most spraying is done in early morning or late evening.



COURTESY: NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION

Figure 2.6 SPRAY CUTOFF NEAR WATER

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A-3

ROUTES OF PESTICIDES INTO THE WATER ENVIRONMENT

A-3.1 Introduction

The routes or pathways by which pesticides used in forest management can reach the aquatic environment include overland drainage, soil erosion and sedimentation, atmospheric transport, intentional dumping, accidental spills and disposal of "empty" pesticide containers. These general pathways have been considered according to the character of the control of prevailing processes. The first three are controlled by natural processes; the latter three are overtly controlled by man.

Pathways by which pesticides applied to forests may reach aquatic environments by natural processes are shown schematically in Figure 3.1. Estimates of the magnitude of movement of the two principal pesticides that have been, or currently are in large-scale aerial spraying of New York forests (i.e., DDT and Sevin) are shown. DDT is no longer used in New York. These estimates are based on a dosage of 1 lb/acre as it is released from the aircraft which is, at present, the normal application rate in New York. There have been few studies on the fate and movement of pesticides in forested areas of New York. Consequently, inferences have been made from studies on forested areas of the United States and Canada from nonforested areas where applicable.

Biological transport, the spread of pesticide from the treated forest by animals including birds and insects, is readily shown to be minute compared with atmospheric or aquatic transport mechanisms.

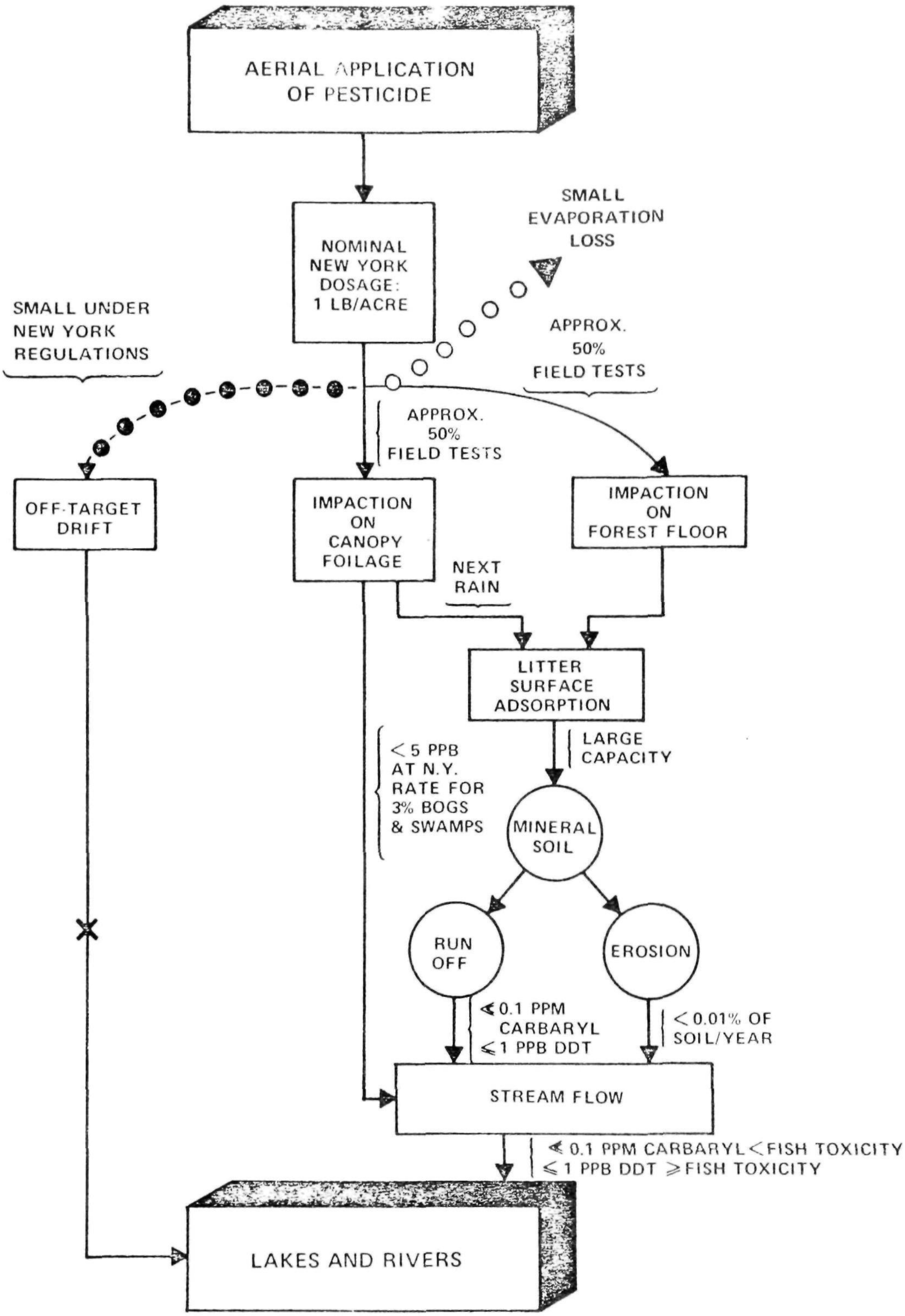


Figure 3.1 NATURAL PESTICIDE ROUTES IN CLOSED-CANOPY FOREST

Overt introduction of pesticides by man into the aquatic environment is distinctly possible, although intentional pesticide dumping is illegal in New York. Further, it is emphasized that the large-scale use of pesticides in forest pest control operations is under the direct control and supervision of career foresters who strictly adhere to operational regulations. If this were not the case, the direct importance of this type of environmental insult could be significant. Fortunately, it is not.

A-3.2 Atmospheric Routes and Rates of Pesticide Travel

This portion of the study is concerned with behavior of the pesticide-bearing spray from its dissemination at the aircraft to its arrival at the forest canopy or the surface. Spray behavior along this pathway depends on many variables including underlying terrain, wind, air temperature and humidity, atmospheric turbulence, and aircraft operational procedure. These variables range over wide intervals and a study of the entire problem was not the goal of this project. Rather, the problem was limited to practical proportions by consideration of only the current operational procedure of the New York State Department of Environmental Conservation (NYSDEC) with respect to control of gypsy moth by Sevin. Spraying of DDT was not considered as it is no longer used in New York.

In the present investigation, the information on spray formulation, types of nozzles, aircraft operations and weather constraints was obtained from the NYSDEC. Next, extreme conditions contained within the limits of the operational procedures were chosen to maximize the effect of a particular atmospheric process on routes and rates of pesticide travel. Under this scheme, if a process proved to have a negligible effect under these most severe conditions, it was considered obviously negligible under less severe conditions. Where a process was non-negligible, potential contaminating effects were estimated and the pertinent data presented.

Operational procedures in New York have been outlined elsewhere in this report, but they are repeated here as a background for the present discussion.

(1) Over reliatvely flat terrain, the aircraft flies at right angles to the prevailing wind direction. In mountainous terrain, the aircraft flies parallel to height contours.

(2) Spraying swaths are spaced approximately 250 ft apart and are flown 75 ft above canopy top.

(3) Flights are carried out primarily in early morning hours, with some late evening flights.

(4) Operations are not carried out when the wind speed at flight altitude exceeds 8 mph.

(5) Operations are not carried out when the relative humidity is low. In practice, these criteria are specified in terms of temperature; operations do not proceed when the temperature exceeds 70°F.

Over relatively flat terrain, the aircraft tracks are flown parallel and spaced so that continuous coverage will result at the canopy top. The NYSDEC performed tests in which their helicopter was flown over a test area under appropriate atmospheric conditions. From a 75-ft altitude, the swath width at the ground, as determined from deposition of spray on ground-based samplers, was 250 ft.

A-3.2.1 Evaporation of the Liquid Carrier

Evaporation of spray drops affects the rates and routes of travel of pesticide to the aquatic environment by reducing the terminal fall velocity of the pesticide between the aircraft and the canopy. Therefore, evaporation causes the residence time of the pesticide in the atmosphere and the effects of wind drift and turbulence to increase. Upon complete evaporation of a given droplet, the pesticide residue is so small that it may be suspended and contaminate the atmosphere.

To investigate the effects of evaporation quantitatively, computations were made to determine the change in drop diameter during the 75-ft vertical fall between the aircraft and canopy. The equation[3.1] used for droplet evaporation was

$$\frac{dr}{dt} = \frac{G}{r}\left(\frac{e}{e_s} - 1\right)$$

where r = droplet radius in cm

t = time in seconds

e = vapor pressure of water

e_s = saturation vapor pressure of water

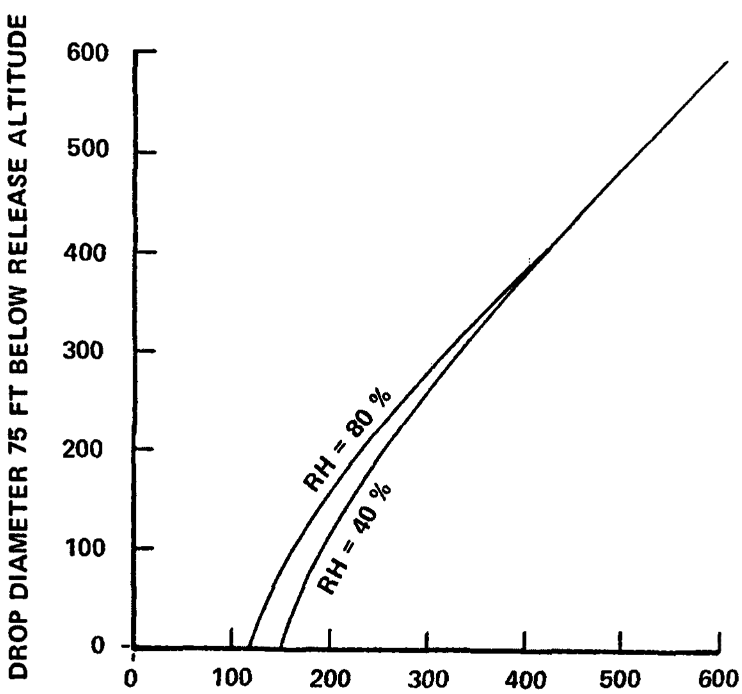
G = 0.9×10^{-6} cm^2 sec^{-1}

Even though this is an equation for mass change only, it is derived from simultaneous solution of the mass transfer and heat transfer equations governing droplet growth. The effect of heat transfer is contained in the G factor.

This equation was solved in stepwise fashion for each of two constant values of e/e_s which correspond to 40 and 80 % relative humidity. The 80 % value is likely to be the minimum encountered during the early morning operation, and the 40 % value was assumed as the minimum during any operation. To obtain numerical values of evaporation, $\frac{dr}{dt}$ was computed for each initial value of r and then used to reduce the radius for a 10-second interval. Simultaneously, the drop was allowed to fall for 10 seconds with the fall velocity corresponding to the initial radius. The radius and fall velocity were then reduced and the computation repeated until the drop either evaporated or fell the 75 ft to the canopy. This computation does not take account of turbulence whose effect would be to keep the drops aloft longer and thus increase their evaporation. In practice, natural atmospheric turbulence is very small under the restricted operating conditions, but wake turbulence may be significant. Wake turbulence is not well enough understood to permit meaningful estimates to be made of the increased residence time of a particle in the atmosphere.

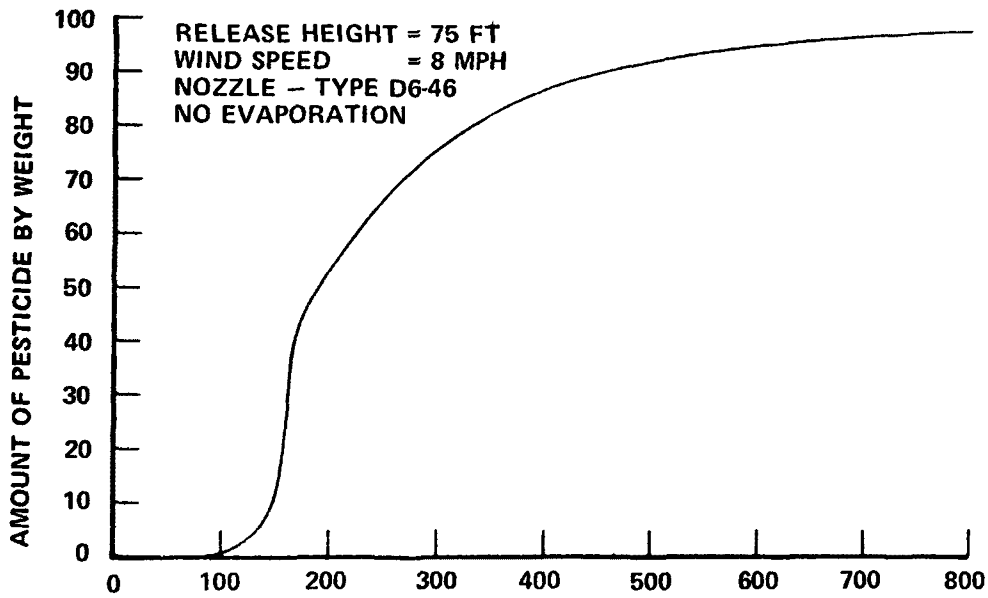
The results of these calculations are shown in Figure 3.2. The diameter below which all drops evaporate completely is 120μm for 80 % and 150μm for 40 %. The residual pesticide is likely to remain airborne as atmospheric pollution. Because of the quadratic form of the curves, virtually all droplets larger than these critical sizes retain diameters exceeding 20μm through the 75-ft fall and truly reach the canopy. The small differential in mass due to pesticide in droplets with final diameters smaller than 20μm which may or may not fall to the canopy is well within the accuracy of the calculation considering the precision with which the operation can be flown and variation in initial drop-size distributions. It is reasonable, therefore, to use these results to estimate the minimum fraction of pesticide that actually reaches the canopy level.

The drop-size distribution of the spray generated by the nozzle system at the aircraft is not, in general, known. The drop-size distributions generated by the nozzles are known for laboratory conditions of spraying into still air.[3.2]



INITIAL DROP DIAMETER

DROP EVAPORATION DURING FIRST 75 FT OF FALL



DOWNWIND DISTANCE FROM RELEASE POINT IN FEET

TOTAL AMOUNT OF PESTICIDE REACHING THE CANOPY OVER A GIVEN DOWNWIND LINE SEGMENT

Figure 3.2 PESTICIDE DROPLET EVAPORATION AND DRIFT CHARACTERISTICS, AIRBORNE APPLICATION

These distributions are presented in the form of accumulated volume percentage vs drop diameter, i.e., the percentage of spray volume in drops of diameter smaller than a given value. Effects of atomization on the distribution when water is sprayed into moving air have been studied only for one specific nozzle.[3.3] These results were extended to other nozzles and estimates made of the percentage of spray in drops which completely evaporate before reaching the canopy. This information was then used to estimate the fraction of released pesticide that reaches the canopy level and presumably is trapped on vegetation or the surface.

In the Coutts and Yates[3.3] atomization experiment, spray from a Spraying Systems Corporation D6-46 nozzle was injected at various angles into air flowing at 100 mph. One of the configurations was with the nozzle directed at right angles to the air flow (ϕ = 90°), which is the typical orientation of the nozzles in field spraying operations. The Coutts and Yates data of concern were those for 150μm and 120μm, the drop diameters below which the computations showed complete evaporation occurring for relative humidity of 40 and 80 % respectively. For still air conditions in the laboratory, the accumulated volume percentage at 150um or less was 0.75 %, while for the atomization experiment using moving air it was 10 %, a 10-fold increase. Using this factor, the accumulated volume percentage at 150um diameter for similar conditions of atomization was estimated for other nozzles used in field operations. A similar analysis was conducted for the 120um drop diameter, and results from both analyses are listed in Table 3.I. For 40 % relative humidity (RH) the maximum percentage is 12 % but can go as low as 1 %, while at the higher 80 % RH, the general level of percentages is around 5 %.

The Coutts and Yates experiment on atomization was based on an airspeed of 100 mph and nozzle pressure of 40 psi. Operationally, these factors are 80 mph and 60 psi, respectively. The changes of both these factors from experiment to

Table 3.I

ESTIMATES OF INCREASED ACCUMULATED VOLUME PERCENTAGE DUE TO ATOMIZATION BY AIR STREAM AS COMPARED TO STILL AIR

	STILL AIR		MOVING AIR, V = 100 mph; Ø = 90°	
	ACCUMULATED VOLUME PERCENTAGE AT		ACCUMULATED VOLUME PERCENTAGE AT	
NOZZLE	150 um OR LESS	120 um OR LESS	150 um OR LESS	120 um OR LESS
D6-46	0.75	0.1	10	4
D8-56	0.1	< 0.1	1	< 1
D7-56	0.1	< 0.1	1	< 1
D10-25	1	0.3	12	< 12
8002E	0.3	< 0.1	3	< 1
8003E	0.5	0.1	5	4
8004E	1	0.2	10	8

operations act to reduce the accumulated volume percentage at the diameters in Table 3.I. However, in view of the crudeness of the present analysis, it appears that a reasonable estimate of maximum volume loss from evaporation during field operations is around 10 %. Thus, for the Sevin 80S slurry with a density of essentially one, it may be concluded that at least 90 % of the pesticide in the spray reaches the canopy under the New York spray operation.

At this point it is imperative that the preceding discussion is brought into both philosophical and technical focus. In the preceding discussion, an analysis was presented which examined the importance of particle size distribution of the pesticide formulation as it is released from the aircraft. While this analysis is by no means exhaustive, it does demonstrate the criticality for in-depth knowledge of both the spray equipment and the conditions under which this equipment is operated. Unfortunately, there is insufficient knowledge available to thoroughly elucidate these interactions.

Rather than dismiss the problem altogether, it was decided to invoke a philosophy of the "extreme condition." Therefore, laboratory data were coupled with theoretical computations to explore a "worst case". Realistic, but extreme, atmospheric conditions were used to calculate the fate of small spray droplets. We concluded then that under an extreme or a worst case condition, a reasonable estimate of the maximum spray volume lost is about 10 %. This is not an insignificant quantity, if it were to occur. However, under the procedural operating conditions which are used, where there is both high RH and weak natural turbulence, the maximum volume loss will be much less.

A-3.2.2 Overdosage Within Treated Area

Turbulence acts to spread the plume from its width at the aircraft to the swath observed at the ground. The complete spreading process is complex and depends on, among other processes, downwash, wing tip vortex motion, and atmospheric diffusion. Because of the complexity of the spreading process, it cannot be treated completely from a theoretical standpoint. Empirically, New York field tests show that the plume spreads to 250 ft at the ground from a 75-ft release altitude. However, there is no information about variability of swath width with wind speed or the variation of the drop-size distribution and pesticide concentration across the plume at the ground. Such information is required if the question of overdosage at the canopy top is to be examined. For example, under calm conditions the pesticide concentration is probably peaked at the center of the swath, while with a wind this distribution would be skewed downwind. A definitive and quantitative treatment of this problem must await either sophisticated computer modeling or more extensive field observations. However, for purposes of examining contamination of aquatic environment, it seems likely that any concentration peaks above the application rate will be smoothed out by subsequent processes acting between the canopy top and entry of the pesticide into water bodies.

A-3.2.3 Off-target Drift

In the previous section, the effect of atmospheric motions on the pesticide concentration within the target area was noted. Perhaps a more important effect on atmospheric motion is the movement of pesticide away from the downwind edge of the target block. Our conversations with the NYSDEC personnel indicate an acute awareness on their part of the drift problem and a strict *adherence to the operational guidelines provided for eliminating* off-target drift. In view of the care taken in these operations and the calculations presented here, it appears that for pesticide spraying performed statewide over a number of years, contamination of water bodies by off-target drift is negligible.

Consider, again, an extreme case in which a pesticide is applied directly to a body of water 10-ft deep, at the nominal application rate of 1 lb/acre. The pesticide concentration in this instance would be 36 ppb. Thus, even for the case of direct application of the pesticide, its resultant concentration in the water is small. This case is extreme in that it assumes the released pesticide directly enters the water at the application rate. A more realistic picture would be that some portion of the spray released over the target area drifts onto a non-target water body.

By considering the drift problem in terms of the spray released along the most downwind track in a block, a more quantitative treatment is possible than with the overdosage problem discussed previously. Because of the variation of fall velocity with drop size, a spray released into a uniform horizontal wind field reaches the canopy at various downwind distances. This information, combined with the distribution of pesticide spray mass with drop diameter, can provide estimates of the off-target drift. In turn, these estimates can be used to specify the flight track offset needed in order to ensure minimizing off-target drift.

The particle travel distances computed represent the worst case, which occurs with a wind speed of 8 mph, the upper limit for which operations are carried out. Using these distances, the drop distributions generated in the field by a D6-46 nozzle and assuming no evaporation of drops, a computation was made of the total amount of pesticide reaching the canopy over a given distance measured downwind from the release point (Figure 3.2). For example, 25 % reaches the canopy within 160 ft of release while 50 % falls within 200 ft. At a distance of 800 ft, 98 % has fallen out. From such a chart, a proper location of aircraft tracks upwind of water bodies can be determined in order to minimize the amount of direct contamination by pesticide drift.

The curve in Figure 3.2 was arbitrarily ended at 800 ft, the downwind distance at which a 100um diameter droplet reaches the surface at an 8-mph uniform wind. (If evaporation is considered, droplets of initial diameter equal to approximately 130 and 170um will reach the canopy 800 ft downwind in atmospheres 80 and 40 % RH, respectively. The percentage of pesticide that does not reach the surface within 800 ft of the release point increases to 5 and 14 %, respectively.) In Table 3.I, it is shown that under the same respective conditions, 4 and 10 % of the released material is contained in drops which can evaporate completely and consequently remain airborne. Considering evaporation, therefore, approximately 3 and 4 % of the released pesticide reaches the surface at distances exceeding 800 ft in atmospheres of 80 and 40 % RH.

Even without further dispersion, it is apparent that the pesticide contamination of a 1-ft deep pond will be of the order of 1 ppb whenever the downwind leg of the spray pattern is more than 800 ft away.

In the field, the initial spraying swath is laid down within the center of a target area in order to estimate the existing drift. Then, based on the drift of the trial swath, the outermost downwind track is flown at a distance upwind from the target area boundary such that off-target drift is minimized. Subsequent tracks are then located successively upwind. In summary, with strict adherence to the operational guidelines provided for elimination of off target drift, contamination of non-target areas, while possible, appears to be small.

A-3.2.4 Atmospheric Contamination by Complete Evaporation

As a starting point for consideration of atmospheric contamination, the maximum volume loss by evaporation of 10 % is used. From prior discussion, this calculated value is an extreme case and, although this value appears at first glance, to be potentially alarming, it again is pointed out above that 10 % represents a maximum value possible and not the lower average value which is likely to occur. This latter value though not presently determinable, is undoubtedly less than 10 %, and, from this fact alone, actual contamination is less than that computed. More importantly, even though 10 % represents a significant threat, the actual threat is reduced considerably when considered in connection with the vast dispersive characteristics of the atmosphere.

In order to assess atmospheric contamination from the previously-derived amounts of pesticide injected into the atmosphere, an estimate must be obtained of the dispersion capability of the atmosphere. The approach taken was that of computing contamination for an extreme condition of minimum dispersion. If the pesticide concentrations are low under this condition, the contamination levels will be even lower under conditions of higher dispersion.

The following computations are based on the 10 % by volume complete evaporation computed above and the assumption that the slurry (pesticide and water) is homogeneous. Under these assumptions and a concentration of 1 lb of pesticide per gallon of water, 46 grams of pesticide enter the air for each acre sprayed. For a 1-cm thick layer of air covering an acre, 46 gm provide a concentration of 1150 ppm.

To account for the dispersive properties of the atmosphere, the material must be distributed in the vertical. Turner[3.4] provides data from Slade[3.5] which indicates for very stable atmospheric conditions a plume spread of 15 m in the vertical after 4 km travel of a quasi-instantaneous source. The source is composed of gas or particles with diameters less than 20 um. For Sevin 80S, only about 6 % of the dry material has diameters greater than 20 um[3.6]. Furthermore, computations based on a homogeneous slurry and an initial diameter of 150 um for the completely evaporating drop, show that the residual pesticide particles must be less than 4 um in diameter. Thus, this dispersion parameter is applicable to the problem.

Under conditions of even less dispersion where the plume depth is 10 m, for example, after a plume travel of less than 4 km, the pesticide concentration would be reduced from 1150 to 1.15 ppm. The facts are, however, that wake turbulence will cause the initial plume to increase to several meters thickness immediately. Small drops evaporate after only a very short fall while large drops do not evaporate until just above the canopy; initial thickness of the particulate plume from the evaporated drops is therefore of the order of 25 m. Even for the very stable situation, this concentration will decrease as the dispersion operates over a longer time period. Finally, after an early-morning operation, the stability will decrease as time elapses, leading to increased dispersion and reduction of the concentration. For initial conditions of smaller stability, the dispersion will lead to smaller values of concentration.

The pesticide residue from evaporated drops is not permanently suspended in the atmosphere. Current thinking indicates a mean residence time of 2-3 days, with the material returning to the earth's surface at a location determined by synoptic scale atmospheric motions and precipitation patterns.

In the context of this discussion, the value of 1.15 ppm represents the absolute maximum concentration that can occur in the atmosphere. Pesticide contamination of the atmosphere by New York forest spray operations is certainly negligible.

A-3.2.5 Washoff of Pesticide by Rain

An important interaction between atmospheric processes and pesticide behavior after it reaches the canopy is washoff of pesticide by rain. The potential for washoff and the rate at which it operates depend on the frequency of occurrence of rainfall intensities. The only data of this type which are available for New York are those published by Dethier[3.7], wherein the probability of weekly precipitation in amounts of 0.2, 1.0 and 2.0" is given. In order to examine the rate of washoff of pesticide that is initially impacted on the canopy, one needs the probability that specific precipitation amounts will occur after 1, 2, . . ., 10 days during the treatment period. These statistics do not currently exist, and it is recommended that they be prepared, at least for selected rainfall recording stations located in the New York treatment areas. In view of the chemical decay rate of pesticide currently in use in New York (i.e., Sevin), the data would probably be more meaningful for determining effectiveness of the spray than for determining the rate of transport to the aquatic environment.

A-3.2.6 Summary Statement Concerning Atmospheric Pathways

The aerial spraying operation and the atmospheric conditions under which this operation is conducted are basically characterized as a diffusing system which operates to decrease the atmospheric concentration of the pesticide. Under standard operating procedures, for example, a helicopter system releases a 30-ft wide spray swath which spreads to a 250-ft swath at canopy level. Operationally, the aircraft paths are spaced so that overlap at the canopy is minimized. Outside of inadvertent and accidental overlap, there is no reason to believe that the pesticide dosage at the canopy will exceed the nominal application rate.

Potentially, wind in and above the forest canopy can cause the pesticide spray to drift off target. In a given light wind, small spray droplets have much greater tendency to drift than large ones. There are two ways that small droplets can be produced when spraying the Sevin-water mixture: first by the nozzle and airstream atomization of spray initially produced at the aircraft and, second, by evaporation of the volatile carrier liquid before the droplets reach the forest canopy. Results from basic atomization studies indicate that for the nozzle types and aircraft flight speeds used, the mass-fraction of spray droplets with sizes sufficiently small to permit significant drift under typical operating conditions is completely negligible. Evaporative size reduction, on the other hand, is not necessarily negligible and the potential for pesticide drift exists.

While in principle off-target drift can exist, in practice, drift is minimized by rigorous adherence to a policy of spraying only under a selected set of operational and meteorological conditions. Spraying operations are carried out in the early morning hours, starting at sunrise, when prevailing atmospheric conditions minimize evaporation. Winds must be less than 8 mph. Ambient temperatures must not be over 70°F, to avoid significant convectional air currents. Material is released only from very low altitude to enhance controllability over the impact zone. To ensure that existing conditions actually result in suitable deposition on target, without drift, a single spray swath is made and observed before beginning operations. Follow-up observations are continued while spraying is underway. Any significant off-target drift is visually detectable and spray operations at the time of occurrence are adjusted accordingly to minimize this effect, including terminating operations if necessary.

The discussion which follows describes and analyzes the pathways by which pesticides, once on the forest floor, can move from the original point of application.

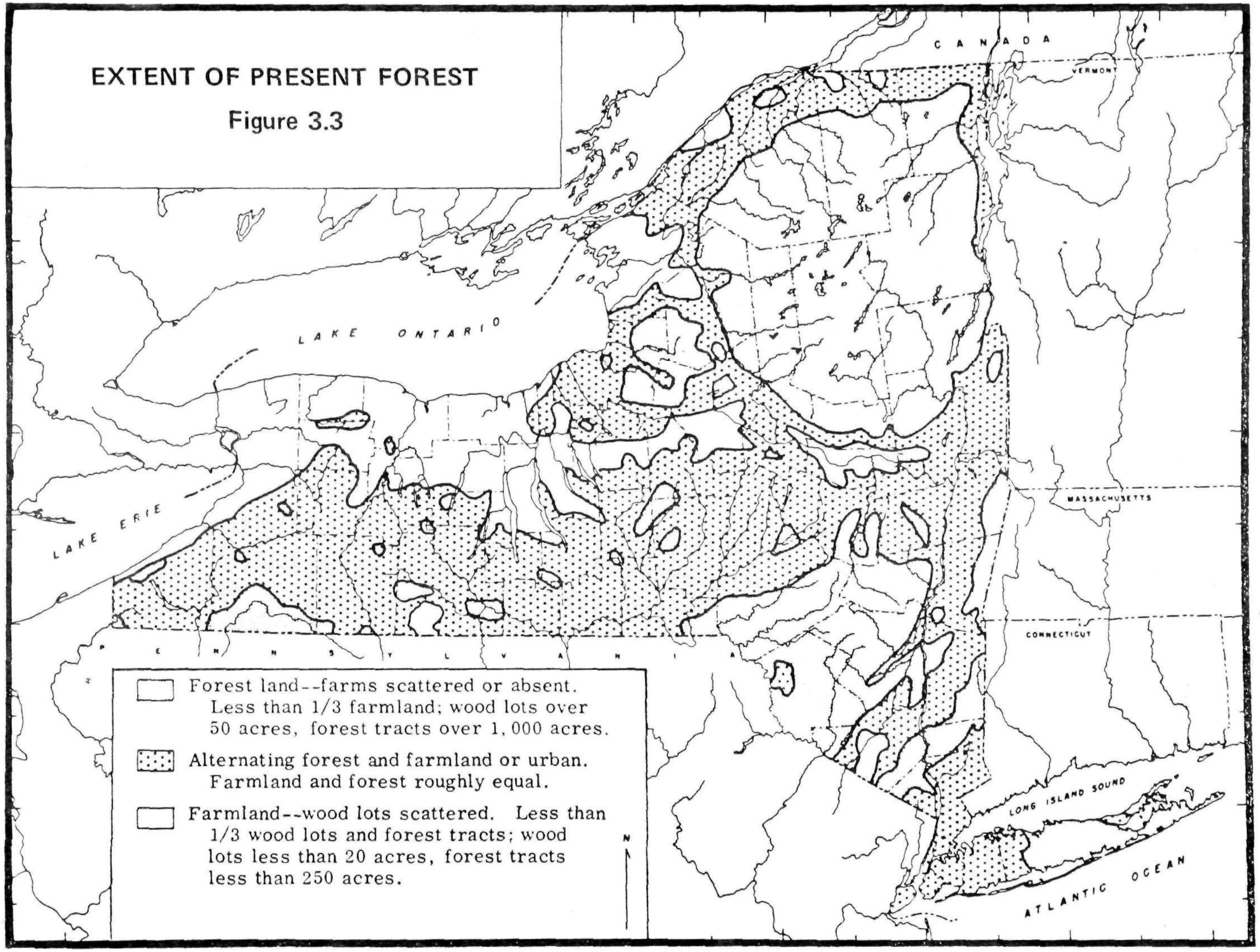
A-3.3 Relevant Descriptions of New York Forest Regions

The sections which follow present analyses and discussions of the pathways by which pesticides are transported within the forest once they reach the forest floor. In considering these movement and interactions, factors such as topography, soil type and forest type are relevant. This section provides, therefore, a descriptive overview of these factors for New York forest regions.

A-3.3.1 Topography and Soils of Forest Regions

The principal forested lands of New York are shown in Figure 3.3. The occurrence of forested lands in the State is related to topographic, geologic, edaphic and climatic factors. In general, either virgin forest land was too steep or rocky for cultivation, infertile, or subject to harsh climate or a combination thereof. Figure 3.4, depicting land form categories of the State, when compared to Figure 3.3, shows that the heavily forested Adirondack and Catskill regions coincide with mountainous land form regions of the State. Figure 3.5 shows that areas of the State containing slopes greater than 10 % coincide quite well with the forested lands of the State. The forest regions to be discussed appropos to soil and topographic characteristics are numbered in Figure 3.3 and will be discussed in that order.

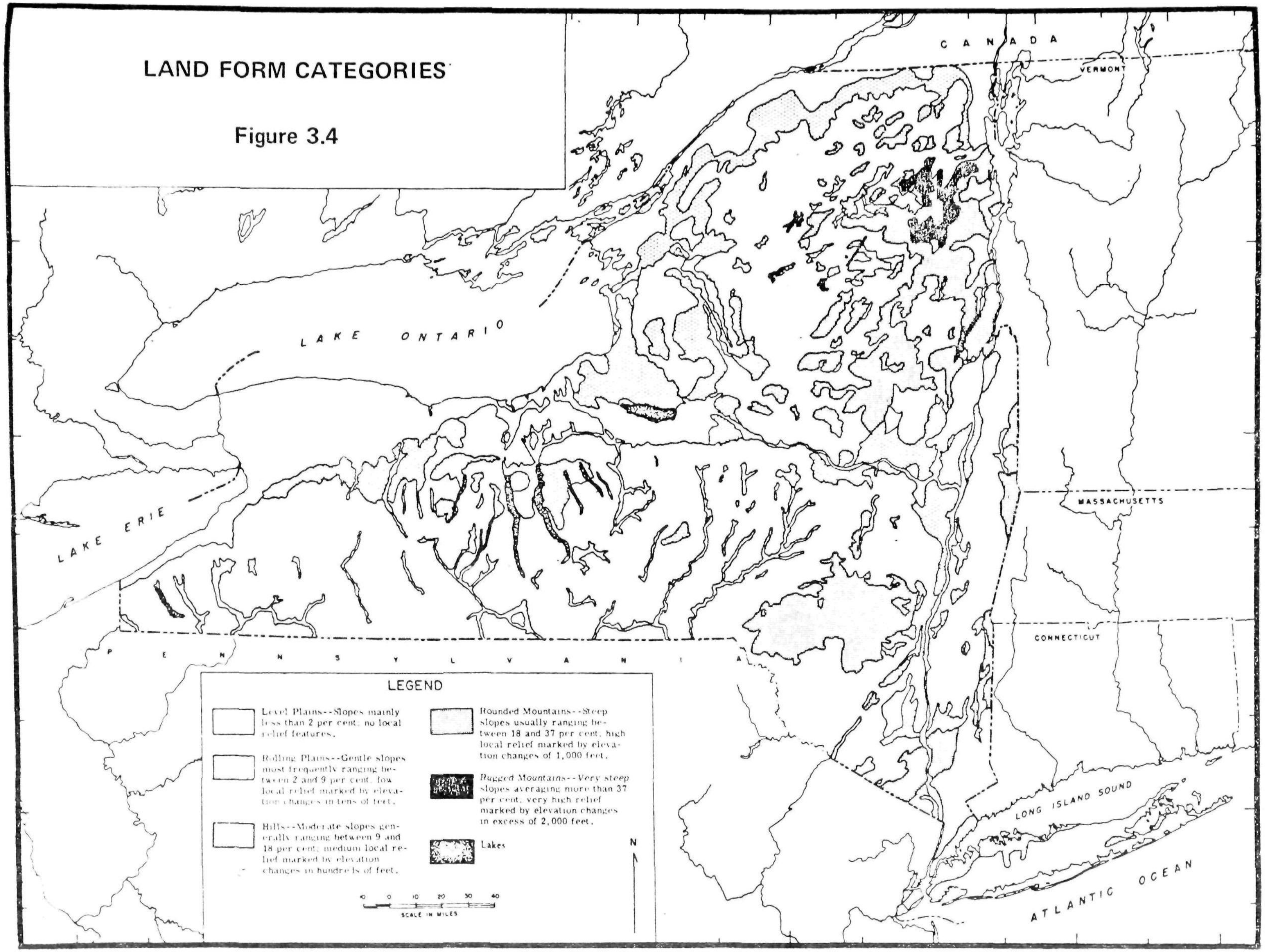
All of the forests and their soils in the area of this study have developed since the melting of the last continental glacier. The center ridge of Long Island marks the southern-most end moraine during the ice age, the first to be abandoned by melting, some 15,000 years ago. The edge of the ice then retreated in approximately a few centuries up the Hudson to the Mohawk Valley, leaving a large ice cap in the Adirondacks and smaller glaciers in the Catskills



EXTENT OF PRESENT FOREST

Figure 3.3

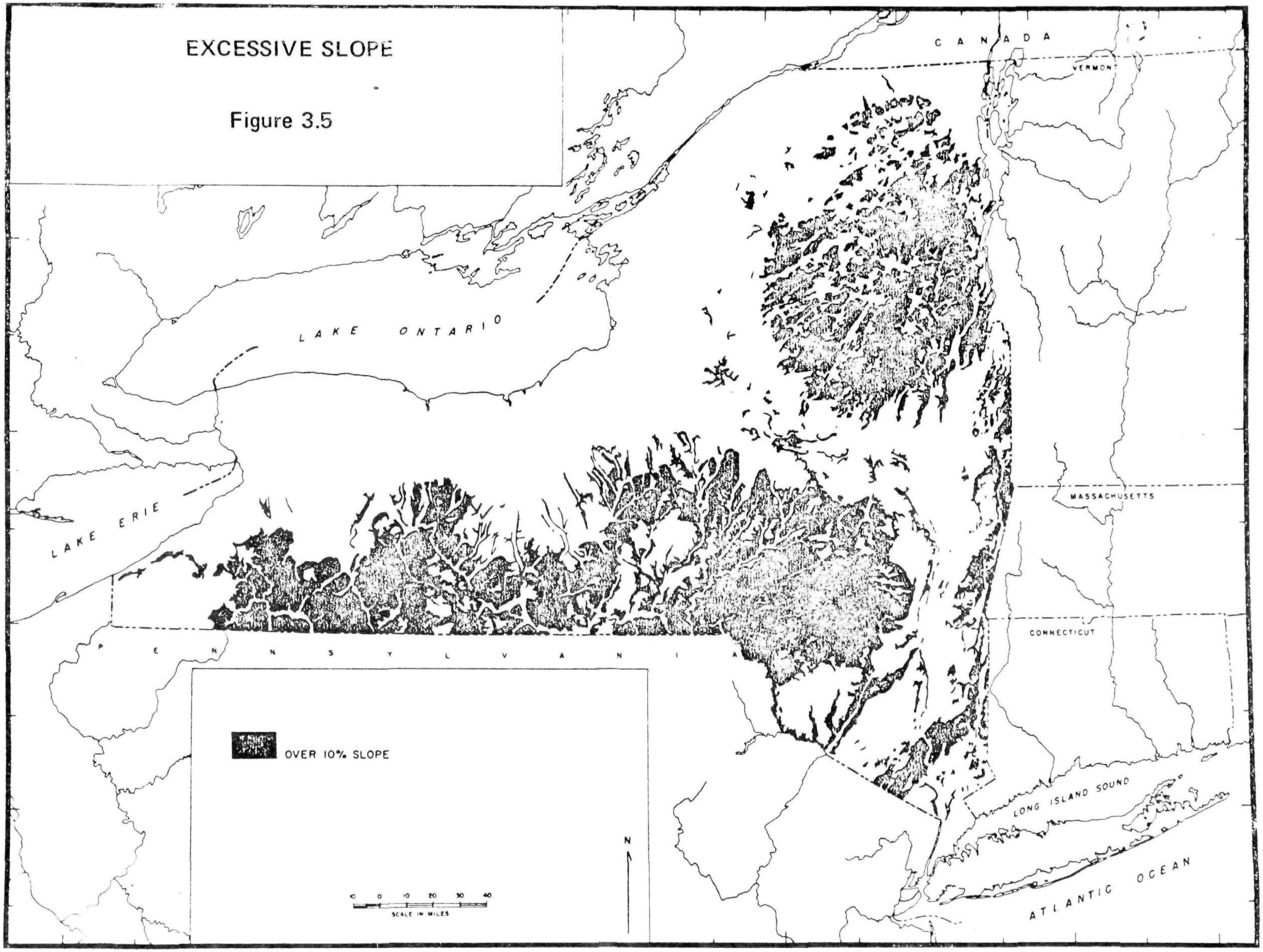
SOURCE: GEOGRAPHY OF NEW YORK STATE, JOHN H. THOMPSON, EDITOR, SYRACUSE UNIVERSITY PRESS (WRITTEN PERMISSION FOR ILLUSTRATION REPRODUCTION PENDING.)



LAND FORM CATEGORIES

Figure 3.4

SOURCE: GEOGRAPHY OF NEW YORK STATE, JOHN H. THOMPSON, EIDTOR, SYRACUSE UNIVERSITY PRESS (WRITTEN PERMISSION FOR ILLUSTRATION REPORDUCTION PENDING.)



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until 5,000 years ago. The diversity of the lowland oak forest in the Hudson Valley developed during this period. In the shorter subsequent 5 millenia, the birch-beech-maple forest of the upland has developed, although its diversity is still increasing rapidly under such evolutionary pressures as the gypsy moth.

Region I - Catskills

In a Land Form Region map of New York given in Figure 3.6, it is seen that the forested Catskill region contains three distinct subregions: the Catskill Mountains (F-1) containing steep slopes usually ranging between 18-37 %; the Delaware Hills (F-2) with moderate slopes ranging between 9-18 %; and the Helderberg Hills (F-3) having a similar slope range.

Soils in the Catskills regions were developed from glaciated red shales and sandstones. Examination of the Soil Association map of New York prepared by Cline[3.8] shows that the principal Soil Series in the region are shallow (15-30" depth) Oquaga and Lackawanna soils on the mountainous terrain and deeper Lackawanna and Wellsboro soils on the high hills bordering the Catskill Mountains (i.e., Delaware Hills and Helderberg Hills). Many of the soils, especially on steeper slopes, contain large amounts of stones and gravels. Bedrock exposure is common on steep slopes.

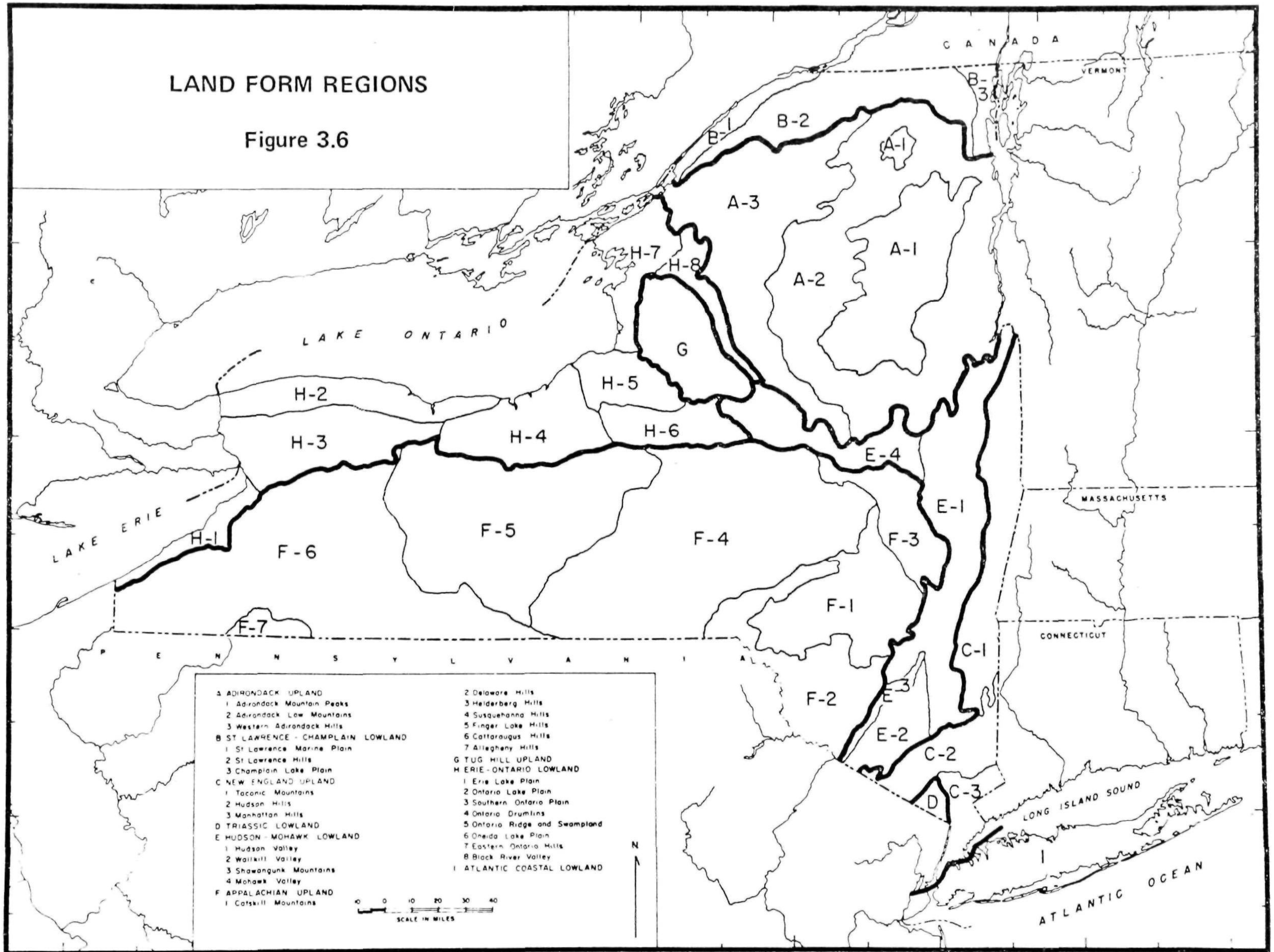
Textures of A and B horizons range from silt loam to loams and thus contain about 8 to 25 % clay. (Insecticide adsorption will be primarily on clay minerals and organic matter. Content of these constituents, therefore, must be stressed.) Hydrogen ion activity of surface soils will be pH 4.5 to 5.5. Subsoil pH's will range from 5.0 to 6.0.

Region 2 - Adirondacks

Figure 3.6 shows that subregions of the Adirondacks include the Adirondack Mountain Peaks (A-1), Adirondack Low Mountains (A-2) and Western

LAND FORM REGIONS

Figure 3.6



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Adirondack Hills (A-3). Soils in the Adirondacks have developed on glacial till from coarse textured granitic rocks. Consequently, soils of the Adirondacks are coarser textured than those of the Catskills. Substantial portions of the landscape, especially on the mountain peaks, contain little or no soil cover.

Soils of the Adirondacks are classical examples of Podzols. The northern 66 % of the region contains predominantly Herman and Beckett soils, whereas the southern 33% contains predominantly Gloucester and Essex soils. The ground surface in forested areas of the Adirondacks as diagrammed in Figure 3.7 is covered with a 2-4" layer of leaf litter and humus. Cline and Lathwell[3.9] reported the average organic matter content of representative Adirondack soils to a 3" depth as 53 %. This 3" layer, as will be shown in a later section, can adsorb all or most of applied insecticides which penetrate through or are washed off overlying forest canopies.

Below the surface layers of representative Adirondack podozol (A_0 horizons) soils, there are gray layers about 2-4" thick (A_2 horizons) which are leached of clay, organic matter, and iron minerals. These constituents are deposited in the upper part of B horizons giving reddish yellow iron-rich subsoils.

<u>Region 3 - Tughill</u>

This region is dominated by very stony soils of the Worth Series. They developed in glacial till from sandstone. Typical profiles and textures of upland soils in this region are similar to those of the Adirondacks as presented in Figure 3.7 Reactions of organic humus (A_0 horizons and A_2 horizons) in both the Adirondacks and the Tughill Plateau range from about pH 3.5 to 4.5. B horizons are slightly less acid and range from about pH 4.0 to 5.0.

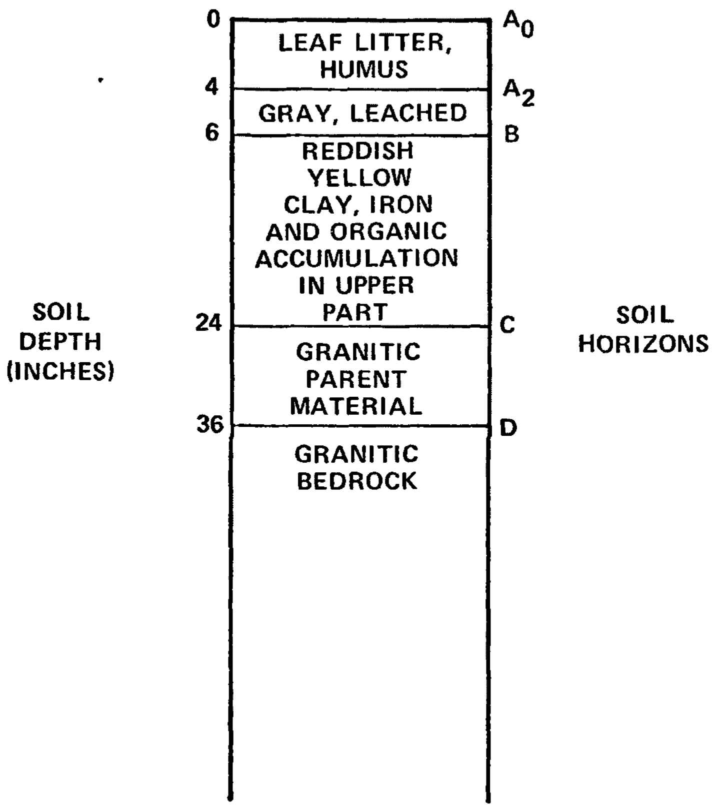


Figure 3.7 CHARACTERISTIC PODZOL SOIL IN ADIRONDACKS*

*PODZOLS IN CATSKILLS ARE SIMILAR EXCEPT FOR SHALE AND SANDSTONE PARENT MATERIALS

Region 4 - Allegheny Hills

Topography of the Allegheny Hills is characterized by moderate slopes generally ranging between 9 and 18 %. The soils in this region have developed in till from sandstones and shales. The principal upland soils Lordstown, Oquaga, and Lackawanna series.

Oquaga and Lackawanna soils occur in the Catskills region and were described previously. Lordstown soils in forested areas will have thin layers of leaf litter and humus over loam to silt loam A and B horizons. Clay content comprise 20 to 35 % of soil profiles and bedrock generally occurs at depths of 20-30".

Region 5 - Bear Mountain

Over 75 % of this region is occupied by rock outcrops or very shallow soils on steep slopes. Forest vegetation occupies local pockets of deep soil. It would seem that any pesticide spraying in this region could result in appreciable runoff to tributaries of the Hudson River because of steep, rocky slopes. Unfortunately there are no known studies of pesticides in runoff water from such terrain.

Region 6 - Berkshires

This region contains some shallow or very shallow soils on steep to hilly terrain. These soils are medium textured (8-25 % clay) and stony. Appreciable portions of this forested area contain soils developed from limestone rather than granite, shale or sandstone which are parent materials of soils discussed previously. These soils contain appreciable quantities of clay with surface soils containing 10 to 25 % clay and subsoils containing 10 to 35 % clay. Reaction of these high lime soils will be considerably higher than soils discussed previously with pH's of 6.0 to 6.5 in A horizons and 6.5 to 7.0 in B horizons.

Region 7 - Long Island

In contrast to other forested regions of the state, forested areas of Long Island contain principally level plains with slopes mainly less than 2 %. Since much of the soil on Long Island has developed on loose, coarse textured (sands and gravels) glacial outwash, they are extremely permeable and droughty.

Two principal soils of the forested areas are the loamy sand to sand Adams Series and gravelly sandy Colton Series. Both of these soils are strong Podzols and contain about 5 to 15 % clay.

Other extensive soils on forested areas of Long Island are Plymouth, Haven and Bridgehampton Series. Plymouth and Haven soils contain somewhat more clay (approximately 10 to 25 % clay) while Bridgehampton soils consist of fine sandy loams deposited over gravels. Many soils on Long Island are extremely permeable to ground percolation but studies on similar soils indicate little danger of groundwater contamination by normal usage of pesticides in forested areas.

A-3.3.2 Forest Types of New York

The State displays the entire range of forests found in the Northeastern United States.[3.9A] Although there are local variations in stands due to selective cutting as well as location of the soil caterra, the potential zonal or climax vegetation as described by Kuchler[3.10] is related to regional climate.

Long Island (Region 7 of Figure 3.3), as part of the Atlantic Coastal Plain, has a variety of southern oak-pine woodland on the sandy, seaward side. Pitch pine, scarlet and black oak are dominant on the dry, sandy flats frequently devastated by hurricans and fires. These oaks have been seriously attacked by gypsy moths.

The lower Hudson, Susquehanna, Allegheny and Finger Lakes Valleys were originally covered with Appalachian oak-chestnut forest. Only in Region 5 do extensive stands of this valley forest remain. White oak is the indicator tree for the Appalachian forest. Where this tree occurs, other southern hardwoods, including red oaks and formerly chestnut, now regrowing from sprouts, are also found. Red maple and an undergrowth of mountain laurel, blueberry and wintergreen, give the forest floor a shrubby appearance. Gypsy moth attack is widespread along the Hudson. Northern white pine grow on sandy valley flats and some hemlock occur in deep, shady valleys.

Isolated stands of elm-ash swamp are found on Bear Mountain (Region 5). The undrained shallow depressions on this pre-Cambrian ridge are covered with white ash and formerly American elm, now killed by Dutch elm disease. In this and the following forest types, gypsy moth defoliation is not so severe.

North of the Appalachian forest type and at higher elevations is found the characteristic northern hardwood or birch-beech-maple-hemlock forest. This forest originally covered the remaining lowlands of the state and the foothills of the Catskills, Berkshires and Adirondacks. It is now found extensively in Region 4. Sunny, dry south-facing slopes are mostly beech. Maple is most abundant except where cut over, where yellow birch persists. Steep, shady north-facing slopes and poorly-drained spots are solidly hemlock in old stands. Basswood, hop-hornbeam and ash are found on richer, more calcareous soils. The undergrowth is restricted to ferns and low herbs. Litter is normally thick.

Relatively pure stands of sugar maple and beech were found on the glacial lake beds of Lakes Erie, Ontario, Champlain and the St. Lawrence River. Some horsechestnut, hickory, ash, black walnut, yellowpoplar (tulip), black cherry, red oak, basswood and rock elm were found in these lowland forests, now primarily restricted to farm woodlots.

Above the pure hardwood forest is found a broad zone of yellow birch mixed with red spruce as well as beech, maple and hemlock (Regions 1,2,3, and 6). The yellow birch are often very large and of low timber value. At the highest elevations in the Adirondacks and Catskills (Regions 1 and 2), above the range of hardwoods, is found the spruce-fir forest or taiga. These dense conifer stands vary from low matted krummholz at timberline to medium-tall mountain forests of balsam fir and red spruce with mountain ash and poplars or aspen.

A-3.4 Persistence of Pesticides in Forest Soils

One of the most important properties of a pesticide determining its degree of threat to terrestrial or aquatic ecosystems is the length of time which it will persist in components of the environment to which it is applied or transported. It can reasonably be assumed that the longer a pesticide or a toxic metabolite thereof persists in a component of the environment the greater the threat to life forms within that component. This section presents data on the persistence in soils of the two principal insecticides (i.e., DDT and Sevin) which have been used in New York forest spray programs. Biological consequences of persistence are discussed in Section A-4.

DDT

Although there have been numerous studies on the persistence of DDT in agricultural soils, relatively few studies have been conducted on DDT persistence in forest soils. None of these studies were in forested areas of New York.

Woodwell[3.11] and Yule[3.12] measured DDT residues in forest soils of New Brunswick. At one site, containing second growth spruce-fir forest and a loam soil, a total of 4 lb of DDT per acre had been applied over a 6-year period from 1952-1958. In 1967, 9 years after final application, residual DDT levels of 0.84 lb/acre were measured, or 20 % of the total aircraft application. At a second site which received a total DDT application of 4.4 lb/acre, 16 % of the total application was present in 1967-68. It is claimed[3.12] that the former site may have received higher applications than originally thought. Since adequate data on release conditions were not recorded, there is no way of knowing what percent of the applied DDT actually reached the ground.

In a Mississippi study conducted on sandy loam plots containing scattered small trees and shrubs, a known quantity of DDT was distributed on top of the soil.[3.13] After 20 years, between 34 and 50 % of the applied DDT was recovered.

There have been a large number of studies of the persistence of chlorinated hydrocarbon insecticides in agricultural soils. Edwards[3.14] extensively reviewed and analyzed all available studies on DDT persistence in soils up to 1966. Data from 29 studies on DDT persistence in field soils showed that the time required for 95 % disappearance of DDT from soil ranged from 4 to 30 years with average persistence of 10 years. It was further calculated that, on the average, 80 % of applied DDT persists for more than 1 year; 50 % persists for more than 3 years; after 3 years, the amount persisting ranges from 26 to 70 %, depending on soil type, pH, organic matter and other parameters. Persistence is greatest in the more acid and highly organic soils. The data also showed that persistence correlates with solubility of the chlorinated hydrocarbon pesticide, as shown in Table 3.II.

Table 3.II

CORRELATION OF INSECTICIDE SOIL PERSISTENCE
WITH WATER SOLUBILITY

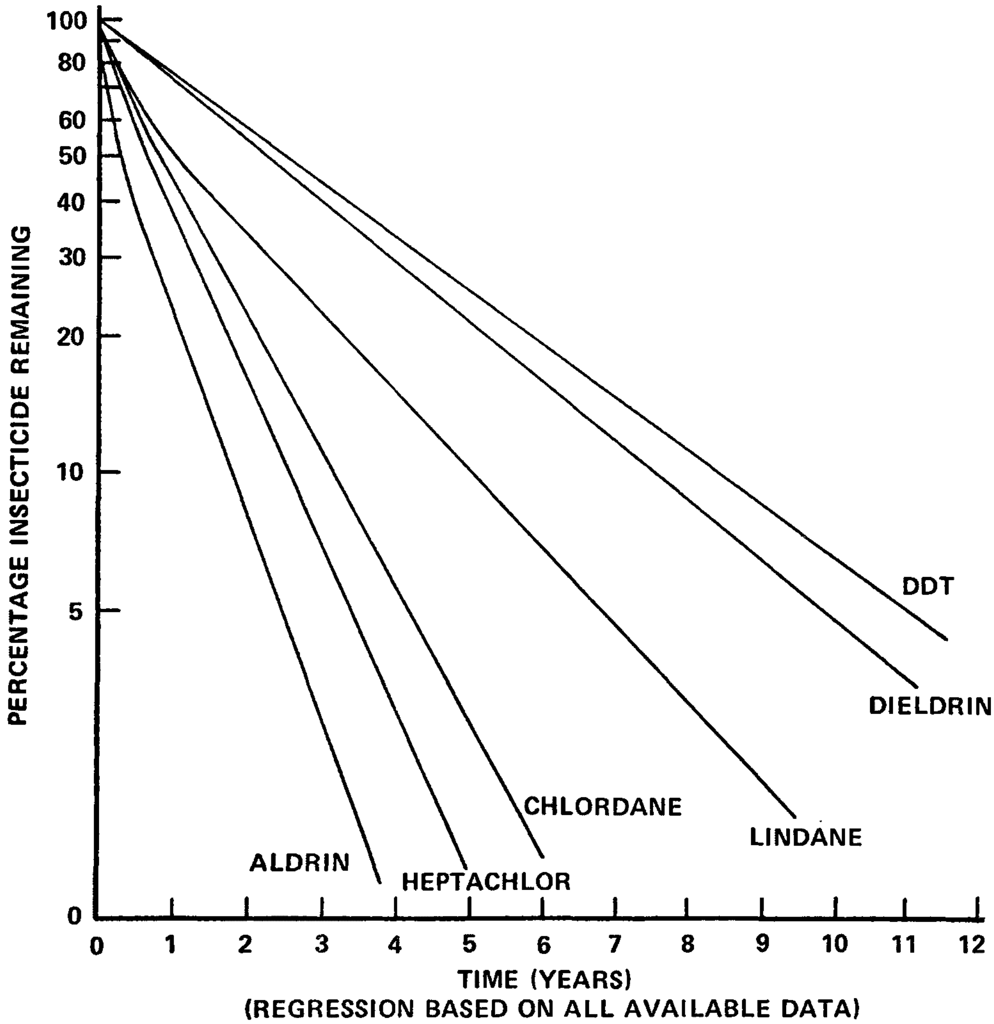
	Pesticide	Solubility in Water (ppm)
Most Persistent	DDT	0.0002
↓	Dieldrin	0.10
	Aldrin	0.05
Least Persistent	Lindane	10.0

Regression analysis of all available data up to 1966 showing the breakdown of chlorinated hydrocarbon insecticides in soils was performed by Edwards.[3.14] The results of this analysis are shown in Figure 3.6.

It is likely that the persistence of DDT in forest soils is substantially longer than the decay curve shown in Figure 3.8. This is because of the demonstrated greater persistence of DDT and other chlorinated hydrocarbons in acid soils high in organic content.[3.14-3.19] Edwards' data for regression analysis included many soils having higher pH's and far less organic matter than normally found in forest surface soils. The Mississippi study referenced earlier in which up to 50 % of applied DDT was present in a forest soil after 20 years, lends support to this belief. Dimond, et. al., found no apparent decline in DDT residues in forest soils 9 years after DDT application of 1 lb/acre, and suggested that persistence follows more closely than 35-year half-life determined as the upper limit of DDT retention in some agricultural soils.[3.19] The 35 year-half-life is probably reasonable to use under the conditions of the present study.

Sevin

In contrast to DDT, Sevin is relatively, non-persistent in soil with the reported half-life of 8 days.[3.20] Sevin is easily hydrolyzed[3.21] and thus



COURTESY: C.A. EDWARDS, "INSECTICIDE RESIDUES IN SOILS," RESIDUE REVIEWS, V. 13, 1966.

Figure 3.8 BREAKDOWN OF CHLORINATED HYDROCARBON INSECTICIDES IN SOIL will be detoxified before it can be moved any appreciable distance by percolating waters in forest soils.

The persistence of Sevin has been studied in field studies conducted on the Shackam Brook Watershed, located in Tompkins County, New York. The surface soils on this watershed are silt loams and loams derived from shaly glacial till, and are representative of soils which predominate in forested terrain of South Central and Southwest New York State (i.e., Appalachian Upland, exclusive of Delaware Hills and Catskill Mountains). This mixed hardwood-conifer watershed was aerially sprayed with Sevin at a rate of 1 lb/acre.

Soil samples were collected over a 2-year period following application. At a detection limit of 0.1 ppm, no Sevin was detected in any of the samples taken to depths up to 6". No other studies of Sevin in forest soils are known.

It is apparent from available data that DDT or its toxic metabolites will be available for movement through the forest to the aquatic environment for decades after application; Sevin on the other hand can be subject to transport through the forests for only a few weeks.

A-3.5 Transport Processes in Forests

The possible mechanisms by which pesticides could be transported from soil to the aquatic sector of the forest environment include leaching, runoff and sediment transport. These mechanisms are discussed in the following sections.

A-3.5.1 Leaching

In New York forested areas, the thickness of organic litter and humus layers will generally range from 2-4". This layer acts as an organic filter and has a large capacity for adsorbing and retaining applied pesticides, thereby preventing downward percolation through mineral soil horizons. Careful review of the extensive literature revealed no studies on DDT or Sevin content of leachates from New York forest soils.

Both Woodwell[3.11] and Yule[3.12] found DDT residues only in the top few inches of forest soil. Smith also found very limited movement of DDT through the soil, with no detection of DDT or its analogues greater than 12" below the soil surface after 20 years, with an instrument sensitivity of 0.01 ppm DDT[3.13]. Thus, although DDT does persist for a long period of time in forest soil, its movement through soil profiles is extremely limited.

Riekerk, et.al.,[3.23] found DDT concentrations of forest floor, A_1 horizons and A_2 horizons to be an order of magnitude apart with the lowest DDT concentrations of soil materials a thousand times more concentrated than percolating leachates. This indicates the large retention action of forest soils, especially the organic litter and humus.

The extent of pesticide leaching from New York soils may be estimated from the limited studies in other forested areas and other laboratory and field studies. Field studies of DDT leaching from a fir plantation near Seattle, Washington, were conducted by Reikerk, Cole and Gessel[3.23]. Soils on the study site were permeable sandy loams, underlain by gravels Organic humus layers overlying mineral soil horizons were less than 1". The Washington study site thus represented types of soils found on Long Island and parts of the Adirondacks, except for generally deeper organic layers in New York soils, and less permeable subsoil in the Adirondacks.

DDT was applied at rates of 0.5 and 5.0 kg/hectare (approximately 0.4 and 4.4 lb/acre). Leachate was collected beneath the organic surface layers and to 15-cm depths. During a 1.5-year period covering two wet seasons, only a small fraction (less than 2%) of applied DDT was observed to move by leaching greater than to the 2-cm depth. Less than 1 % of applied DDT was collected in leachate water at the 15-cm depth.

Although Sevin was not included in the Washington study, another carbamate insecticide, Zectran, was. Analyses of leachates in plots treated with Zectran indicated that less than 1 % passed through the surface soil. The soils in the Washington study were ones which represent the most extreme vulnerability to pesticide leaching because of thin organic horizons, coarse texture, high rainfall and high permeability. It is, therefore, very doubtful if pesticide leaching in any forested area of New York would exceed that observed in the Washington study.

Extensive studies on agricultural soils generally not having a highly organic surface layer also show minor leaching of pesticides[3.24-3.26, 3.14]. Lichenstein[3.24] has conducted numerous studies on agricultural soils and concluded that it is unlikely that water in deeper soil layers can be contaminated with insecticidal residues from upper agricultural layers.

We may conclude from these studies that the organic litter mat is sufficient in all New York forests to prevent measurable leaching of any applied insoluble pesticide.

A-3.5.2 Runoff

A short, light rain falling into a forest evaporates from the leaf, bark and litter surfaces and consequently does not contribute to the transport of pesticide. Heavier, longer rains, however, pick up most of the pesticide present on leaves, bark and litter surfaces by solution and localized scouring, and can therefore set the pesticide in motion.

Overland water runoff is exceptional under a mature canopy forest[3.20, 3.27]. The runoff which appears in surface stream channel several hours after each heavy rain consists almost entirely of interflow, the excess rainwater which seeps into stream banks from saturated soil. The available data show that there is essentially no pesticide in runoff from treated forests.

Northeastern forest soils soak up rainfall at almost any rate. The soil is fully capable of adsorbing all precipitation. The measured infiltration capacity in these forests is 50"/hour or more[3.28]. Runoff, therefore, occurs by percolation through the soil. Betson and his TVA colleagues[3.27] have shown that forest runoff orginates in only small portions of the watershed area near the stream channel. Water infiltrating the upland soil adds to the groundwater or piezeometric head causing surface seepage from the soil at the foot of the slope. This observation has been confirmed for complex glacial landforms in Vermont by Dunne and Black[3.29].

Water appears on the surface in hollows and flows slowly along well-established but rarely used drainageways or swales. Frost creep tends to level these swales so that in New York, even swales will show only 10 to 30 ft of overland flow.

Seepage from forest soils into ephemeral stream channels can be predicted from the Laplace equation which applies to groundwater flow in layered media:

$$\nabla^2 Z = o$$

where Z is the piezometric head or elevation of the free groundwater surface.

For example, planar solution of the Laplace equation shows that a small hillslope, while saturated to the surface during a prolonged rainstorm, will drain toward a surface stream at a rate proportional to its gradient. The resulting maximum runoff rate to be expected from New York forests varies from 1"/hour on steep Dekalb soils found in the Catskills (measured at Coshocton, Ohio) to 0.5"/hour (measured at Emery Park, Erie County, September, 1967). Basic runoff data have been published by the U.S. Forest Service and Agricultural Research Service[3.30, 3.31]. All show that overland flow is negligible for a wide variety of forests and terrain.

The rain falling directly into the channel, overhung with branches, runs off immediately. Pesticides originally residing on such locations are immediately transported to permanent water bodies. However, this small area runoff cannot contribute significant amounts of pesticide to drainage systems. As an extreme example, calculations show that for an area with as much as 3 % of land area covered with standing water approximately 1-ft deep (found primarily in the Bear Mountain range, Region 5), direct spraying with Sevin at

1 lb/acre will add 5 ppb to the runoff water. Even on nonforested watersheds containing the same soil type as commonly found in the Catskill forest region of New York (Muskingum or Dekalb silt loam) accumulated runoff water was normally found to contain less than 0.1 % applied chlorinated hydrocarbon pesticides 12 or more months after applications.

In hardwood forests, the wet, matted, broad leaves lie on the surface like shingles on a roof. Such litter is impermeable in spots even where the underlying soil is unsaturated. Where the surface is permeable, water will fall into the soil as infiltration. The net effect is that overall surface flow is minor and usually limited in length to less than 30 ft.

The rainwater, with its suspended and dissolved pesticide load, soaks into the litter and from there, infiltrates into the mineral soil. As the water percolates into the litter and soil, it is adsorbed in the thin liquid film which clings to each particle. A large part of the pesticide is transferred by diffusion to the adsorptive particle. As infiltration continues, each film thickens to the drip point so that the water is slowly falling through the soil. As discussed in A-3.5.1, the highly organic litter and humus layers, as well as clay minerals, effectively retain pesticides against the gravitational and drag forces of percolating water.

The soil water is absorbed by tree root hairs and returned to the atmosphere by transpiration from the leaves. The infiltration capacity for a given water temperature and vicinity is a function of soil capillarity and the distribution of soil voids by size in each soil horizon[3.32]. The high water capacity of forest soils is due to the large root mass of the trees. The roots, which normally extend into bedrock, grow and move so as to open continuous voids for infiltration. These voids are largest near the trunk of each tree where the stemflow is absorbed. These effects, designed by arboreal evolution to hoard water for transpiration, also minimize overland flow. The actual infiltration rate, up to capacity, is dependent on the antecedent moisture present in the soil. If the water depth is sufficient, gravity will cause the water to move laterally over the surface as overland flow. Surface rocks, logs and deadwood imbibe any local overland flow, damming and diverting it into the soil.

Literature review uncovered no studies on the DDT content of overland runoff from forested watersheds. This is due perhaps to the rarity of sustained overland runoff from forested watersheds. Review of literature shows few studies on pesticide levels in runoff, even from agricultural watersheds. Studies were conducted on the content of the chlorinated hydrocarbons, dieldrin and methoxychlor, from cultivated plots located at the Appalachian Experimental Watershed, Coshocton, Ohio[3.26, 3.33]. They are discussed here only to set some tentative estimates on the magnitude of the problem. Field and laboratory studies are, of course, needed to obtain more accurate assessment of DDT in forest runoff.

Both of the aforementioned studies were conducted on Muskingum silt loam soils. This soil type occurs over a large portion of the Catskill Mountains and Delaware Hills of New York. The total amount of applied methoxychlor recovered in runoff for a period of 14 months after application amounted to only 0.004 % of that applied[3.26]. Over 25 % of the loss was associated with one storm which occurred when the topsoil was frozen.

The second study at the Appalachian Watershed[3.33] involved water runoff of dieldrin from silt loam soils on 13-14 % slopes. Data were collected on two different watersheds for two different years (1966,1968). In 26 months after the 1966 application, 0.007 % of applied dieldrin had been lost in solution to runoff water. In 12 months after the 1968 application (5 lbs/acre) 0.07 % of applied dieldrin was collected in runoff water. It was pointed out that the 1968 treatment was performed on soils which had been prepared so as to maximize runoff. It was further found in the above studies that largest losses in runoff occurred when soil was bare or had only thin cover.

It can be reasonably concluded that in forest environments, chlorinated hydrocarbon residues, including DDT, in runoff waters would be far less than those observed above, as long as forest cover remained intact.

In a study previously alluded to, runoff of Sevin from a forested watershed in New York was monitored.[3.22] At a detection limit of 0.01 ppm, no Sevin was detected in drainage waters from a watershed treated at 1 lb/acre. Samples were analyzed for a period of 2 years after application. The chances of Sevin entering streams with overland water flow are even far less than for DDT because of rapid degradation before and after transport.

The most serious contamination hazards involving runoff of applied insecticides from forest soils may be associated with truck-mounted mist-blower application to selective acreages. In this case, the pesticide application rate is higher due to the practice of treating both leaf surfaces "to-drip." The output particle size is smaller, and area may be treated more than once to protect against reinfection from adjacent areas. Drainage ditches are likely to exist along roadsides and recreational parklands in which pest control may be desired.

Such ditches lead runoff directly into permanent streams. Therefore, it is not difficult to surmise that relatively high pesticide concentrations in these ditches could potentially be flushed into streams or lakes before even the least-persistent pesticide has been degraded.

A-3.5.3 Sediment Transport

Slopewash or particulate erosion of soil by overland flow under mature temperate forests such as occur in New York is negligible.[3.27] The suspended sediment of forest floods originate in the caving and slumping of undercut stream banks as well as roads and other slope disturbances.[3.32] Thus, although studies have shown that sediment transport of chlorinated hydrocarbon pesticides is much more effective than overland runoff,[3.8,3.23] we will show in the following paragraphs that it is usually of little import in intact forested areas. Serious problems may occur in regions where the natural forest conditions have been altered by man.

The basic situation at a point on a forested hillslope is illustrated in Figure 3.9. It must be recalled that, in the discussion of leaching, we concluded that the pesticide remains in the top 10 cm of soil and/or virtually its entire lifetime in the soil.

The erosion of hills and valleys by precipitation-induced processes include:

(1) weathering of rock to debris by infiltrating precipitation and creep of wet debris and bedrock,

(2) wash entrainment or lift of loose debris by surface runoff of excess precipitation and,

(3) landslides or slope failure.

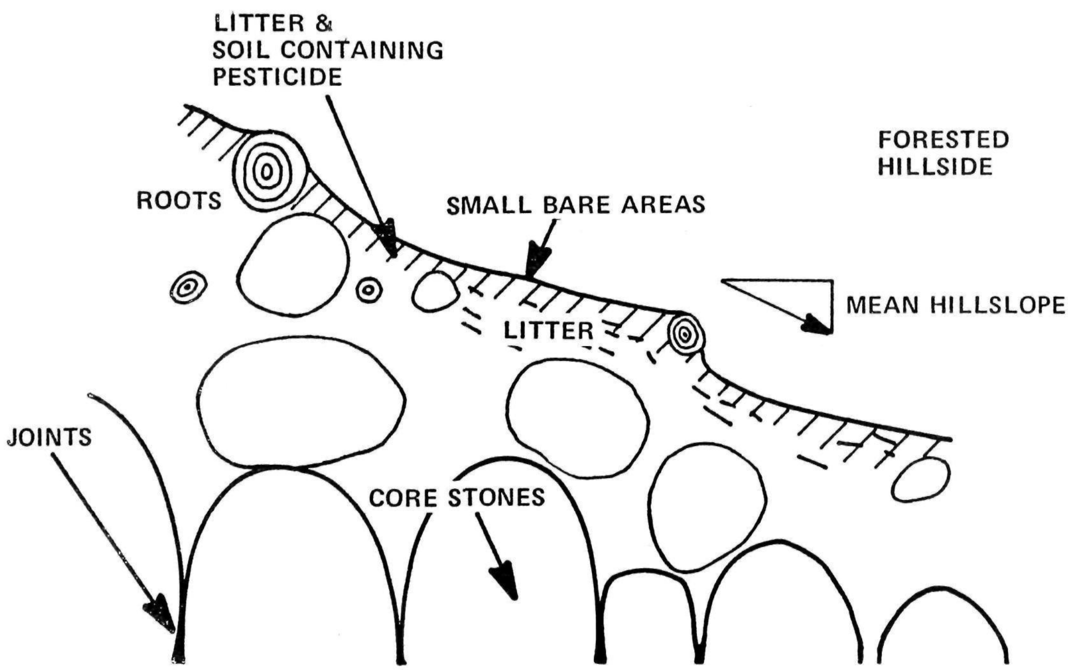


Figure 3.9 TYPICAL FOREST STREAM BANK CROSS SECTION

The erosional processes of importance are, therefore, limited to those which cause transport of the uppermost layer of soil. While vegetation promotes the disintegration of rocks and chemical weathering, it retards the transport of the weathered material. Where vegetation is profuse there is always an excess of material awaiting transportation and the limit to the rate of erosion comes to be merely the limit to the rate of transportation. Under closed-canopy forest, it is the thick layer of litter and dead wood that prevents overland rainwash erosion of soil. Saturation of this thick root mat leads to creep. Creep processes, however, are relatively minor in temperate forests due to the anchorage of tree roots in bedrock. Leopold, et. al.,[3.34] in a summary article shows for example, that the mean surface creep rate in temperate forest is of the order of 0.6 mm/year. Obviously, therefore, creep is unimportant in releasing pesticide-laden sediment to the aquatic environment.

Surface wash erosion of soil requires a relatively high velocity of overland flow. It was shown in the previous section that under temperate forest cover surface flow rates are extremely slow and total overland transport is limited to distances of the order of 30 ft. Erosion due to overland flow is, therefore, negligible in a standing temperate forest.

Catastrophic landslides are occasionally produced by torrential rains, associated with very severe weather such as hurricanes, in mountains of the eastern United States. In a study performed in Northern Virginia, Hack and Goodlett[3.35] found that a maximum of 1 % of the land area in high mountain forest was removed by slides during the "100 year" storm of 1949. A very simple calculation based on these data shows that such land slides cannot produce serious pesticide contamination in regions treated with Sevin. If the entire area had been recently treated with 1 lb/acre and the slides produced by 4" of rain (lower than the actual case), the concentration of pesticide in the rain water alone would be approximately 1 ppm. For Sevin, which does not persist from year-to-year and for which toxicity levels exceed this value significantly, such landslides are not important. For DDT on the other hand, a single application could produce pesticide concentrations that are toxic to many species.

In smaller rainstorms, very minor landslides and stream bank caving produce silt in the stream water. The percentage of the total land area affected is, of course, extremely small and the contamination problem is reduced by many orders of magnitude or more. Data from the U.S. Department of Agriculture[3.35A] show that the total erosion rate into stream channels in mountainous regions of New York averages approximately 0.01 acre-ft/sq mi/year. If this mass of material was eroded entirely from the top 10 cm of surface which contains virtually all pesticide, the total pesticide load introduced into streams by bank erosion would be 12g/year/sq mi of mountainous area. Considering average annual rainfall in the same region, it is obvious that introduction of pesticide into water by stream bank erosion is completely negligible.

The preceding discussion pertains only to intact forest areas. The problem of erosion is substantially more serious in the forest when cover is disturbed. When a steep mountain forest is clearcut, disasterous soil erosion usually follows. It is not the act of clearcutting alone but the roads, log skidding, slash burning and subsequent land-use practices which lead to catastrophic soil erosion. Sediment is produced from road and other soil disturbances including bank erosion by permanent stream channels.

The sudden movement of pesticide-laden sediments from an eroding clear-cut or burned-over forest introduce catastrophic amounts of persistent accumulated insecticides such as DDT to local drainage networks. The magnitude of the problem may be estimated from the Coshocton study previously discussed[3.33]. Dieldrin residues found in sediments eroded from a bare or sparsely vegetated watershed contained 2.2 % of the applied dosage (5 lb/acre). This represented about 30 times as much insecticide as found in runoff water from an adjacent watershed for the same 12-month period.

The possible release of DDT or other persistent chlorinated hydrocarbon insecticides in sediment losses from denuded forest watershed is of concern. Because of the short term persistence of Sevin in soil, the chances of forest denudation and resultant sediment runoff occuring coincident with Sevin presence in soils are very small.

Concentration of persistent pesticides that could occur in runoff if a forest area were clear-cut or burned-out can be estimated. The accumulation of DDT residues in organic forest soil horizons typically reaches 0.5 lb/acre or 40 ppm in 3" of humus, where spraying continues for many years, although values as high as 2.2 lb/acre have been found[3.14]. The sediment concentration, although known only approximately, is typically of the order of 10-15 % for serious erosional events on disturbed terrains. Using the nominal concentration of pesticide in the surface soil of 40 ppm, the concentration of pesticide C in the stream discharge is as high as:

$$C = 15\ \% \times 40\ \text{ppm} = 6\ \text{ppm, in the runoff.}$$

For drainage basins exceeding 100 acres, depending on soil type, sediment will be deposited in the stream bed for removal at a later time, and thus cause continued pesticide contamination. Even with very small cut-over watersheds, however, toxic local DDT concentrations can be produced in waters adjacent to the cut-over area. The toxic organic sediment settling in water bodies from such erosion provides a long-lived source of DDT contamination due to the low solubility characteristic of persistent pesticides. The DDT concentration in sediment will be essentially the same as in the soil removal since DDT is essentially insoluble in water. From the lake sediment, the pesticide is further concentrated in the aquatic food chain.

In summary, the available evidence indicates that there is little threat of serious contamination to streams and lakes in forested regions from pesticide transport by leaching, overland runoff or sediment losses, when the chemical is applied by aircraft at 1 lb/acre and forest denudation does not occur. If forest cover is removed from DDT-treated acreages, serious stream and lake contamination can occur as a result of pesticide-laden sediment runoff. Even though DDT is no longer used in New York, this threat still exists because of the long-term persistence of the chemical. Therefore, it is essential to prevent the denudation of forest acreage that has been treated with DDT in past years. This threat is negligible, however, on that acreage that has been treated only with Sevin due to the rapid degradability of this chemical.

Saturation spraying of selected acreages of forested lands with truck-mounted mist blowers could result in serious runoff of pesticides along roadside drainage ditches.

A-3.6 Intentional Dumping, Accidential Spills and Container Disposal

Overt introduction by man of pesticides into the aquatic environment is distinctly possible, although intentional pesticide dumping is illegal in New York. Cursory examination of records does not indicate any problem in either dumping or accidential spills in forest pest control operations. It is emphasized that most forested land is under the direct control and supervision of career foresters, who strictly adhere to operational regulations. If this were not the case, the occurrence of this type of actions could be much greater. Control by foresters is exercised not only during treatment operations conducted by State personnel using State equipment, but also when the State contracts to commercial applicators for forest treatment.

For example, during the 1971 spray season, almost 70 % of the approximate 250,000 acres treated for gypsy moth were conducted by aerial applicator firms under State contracts. In addition to following operational procedures discussed in Section A-2, these firms must be registered as required by Article II of The Agriculture and Markets Law, and are subject to Rules and Regulations set forth in Part 154[3.36]. Those subsections dealing with disposal of unused pesticides and pesticide containers are quoted herein.

"154.5 Disposal of Pesticide Containers and Unused Pesticides

(a) No pesticide containers shall be disposed of in any place other than at a refuse disposal site, a sanitary land fill, or in an incinerator, all of which shall have been approved for the purpose. Reusable containers may be disposed of for uses not prohibited in 154.6 below, providing such containers are treated as outlined.

(b) Containers of pesticides shall be treated in the following manner before disposal:

(1) Disposal of Non-combustible Containers

(1) Rinse at least twice with water or the pesticide carrier being used. Return rinses to the spray tank.

(ii) Transport the cleaned containers to the approved disposal site - see Section 154.5-a.

(iii) Returnable containers shall be rinsed as in b-1-i above, tightly closed to prevent leakage, the exterior cleaned, and the containers returned to the supplier.

(2) Combustible Containers of Pesticides shall be disposed of as follows:

(i) At the same sites as approved for noncombustible containers - see Section 154.5-a.

(ii) Small quantities of combustible containers may be burned with permission under the applicable provisions of the Public Health Laws and the rules and regulations existing thereunder, except containers of volatile hormone type herbicides.

(c) Surplus or unused pesticides shall be disposed of by burial with at least 18 inches of compacted cover in such a manner and at such a location within the disposal area that ground or surface water is not contaminated.

154.6 Re-use of Pesticide Containers

(a) No pesticide containers shall be sold or used for the storage of human or animal food or water, nor shall such containers be used for the storage of cooking utensils, dishes or clothing.

(b) No pesticide containers shall be sold or used for any other purpose unless such purpose has been approved by the Commissioner and the containers have been properly cleaned."

In keeping with centralization of control during forest pest control operations, pesticide containers are maintained at the mixing station and disposed of in designated and proper sanitary landfill areas. Further, in aerial applications, should the pilot require the rapid discharge of pesticides, he is procedurally obligated to do so away from open water. Therefore, the relative importance of these factors is low due to the centralized procedures and policies of those State trained personnel conducting the forest pesticide operation.

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A-4.

IMPACT OF PESTICIDES, INCLUDING METABOLITES, ON THE AQUATIC ENVIRONMENT AND FOREST ECOSYSTEM

A-4.1 Introduction

The impact of pesticides, including metabolites, on the aquatic environment and the forest ecosystem is discussed in this section beginning with an examination of how pesticides affect the aquatic environment. Next, the fate of pesticides in the forest ecosystem is studied with consideration given to non-biological and biological degradation and to the bioconcentration and toxicity of pesticides in the forest environment. This is followed by a discussion of the antagonistic and synergistic effects of DDT and Sevin. The impact of pesticides on humans is studied in the next and final paragraphs of this section.

There are several mechanisms through which DDT and Sevin insecticides could have an adverse impact on aquatic life; the most obvious is that of direct kill, such as the death of all the fish in a pond due to DDT. This varies not only with the rate of application and the impacted species but also with the DDT formulation. For example, most investigators have found DDT emulsions to be more toxic to non-target organisms than when DDT was applied in oil or as a suspension.[4.1] More subtle disruptions result when only a segment of the organisms in a lake or stream are destroyed by a pesticide. If the biota that was killed was the food for other animals, the latter also may die. Since this process probably would occur slowly, it may go unnoticed.

If the predators and/or competitors of one or more species are eliminated or significantly reduced, the "balance of nature" may be upset. For example, if a sizable quantity of the zooplankton in a pond are poisoned by Sevin, the phytoplankton (whose numbers are controlled ordinarily by the zooplankton) may increase substantially. Following such an algal population explosion or "bloom," the algae may poison themselves in their own metabolites. When the dead algae decay, the oxygen in the water may decrease and cause the death of other aerobic forms.

Even more difficult to trace and evaluate is the movement of pesticides, such as DDT, through the aquatic food web. Unfortunately, very little is known regarding the trophic relationships of aquatic organisms. It has been observed that these who-eats-who interactions may change significantly with the seasons. Within a season, feeding habits may be affected by innumerable chemical, physical and biological factors. Another complicating factor is uptake and metabolism, each of which are influenced by a myriad of known and unknown conditions. For example, DDT may be passed within a food web in the form of DDT, DDE, DDD and/or several other metabolites. These chemicals vary considerably in their ability to induce toxicity and other metabolic disruptions.

Still another point that cannot be overlooked is the fact that despite its widespread use since 1942, the biological liaison (location and biochemical mechanism of action) of DDT is not understood.

Keeping these problems in mind, a review of the impact of DDT and Sevin on aquatic environments nevertheless is of value in the formulation of regulations regarding the employment of these insecticides in forest management.

A-4.2 DDT and the Aquatic Environment

The impact of DDT on total aquatic ecosystems has been reviewed by several authors[4.2-4.18] whose works provide a general overview.

DDT has a low volatility and is not normally decomposed by sunlight or other naturally occurring chemical and physical factors.[4.11] The degradation rate in soil and water, in the absence of organisms, generally does not exceed 5%/year.[4.3] As a result, it is one of the most persistent agricultural chemicals in the environment. Though it is extremely low in solubility in water (less than 1 ppb),[4.20] DDT is readily adsorbed onto organic matter.[4.21] Hence, this insecticide tends to remain concentrated in the upper level of forest soils, with which it can be carried to streams and lakes via soil erosion.[4.22] Detritus is believed to be a significant source of introduction of DDT into aquatic food webs. The adsorption of DDT on suspended organic matter was sited as a means of controlling black-fly (Simulium articum) larvae.[4.23] Hence, the quantity and quality of suspended material in aquatic habitats that may be contaminated by DDT should be considered prior to the application of this pesticide.

Another relevant property of DDT is the fact that is accumulates in lipid tissues. Cope[4.24] demonstrated that DDT and its metabolites were persistent in some fish for up to 2 years following a single exposure to this insecticide. In this manner it may be concentrated and passed on through the food web in ever increasing concentrations (biomagnification).[4.18] (Movement of DDT through aquatic food webs will be discussed in a later section.)

There have been few attempts to trace the movement of DDT in natural aquatic habitats. The cost of such studies, as well as the availability of an uncontaminated and monitorable area, probably have been the major factors in detering such investigations. One of the earliest experiments to ascertain the impact of DDT on an ecosystem was done in 1945 by Dr. Cottam and his associates.[4.1] Using an airplane, they sprayed a 117-acre tract of Patuxent River bottomland in Maryland with 2 lb/acre of DDT in oil. Examinations for kill were conducted up to 300 days following application. (No attempt was made to investigate the possible cumulative effects of DDT since this problem was generally not recognized at the time.) Within 12 hours, dead shiners and bluegill were observed. Representatives of these species also had been placed in boxes in the Patuxent River above and below the sprayed areas. Less than a third of the bluegills survived while the other fish were unaffected. However, in later experiments nearly all species exhibited 75 % or greater mortality when tested in an area in which 1 lb/acre of DDT was applied to a pond. Hence, factors other than taxonomy appear to be more important with respect to the impact of DDT on fish. (This observation will be discussed at length in a later section.)

From the Patuxent study, as well as others conducted in Fort Knox (Kentucky), Island Beach (New Jersey), Clifton (Pennsylvania) and Black Sturgeon Lake (Ontario, Canada) Cottam[4.1] concluded that mortality among non-target organisms increased when applications exceeded 1 lb/acre, particularly when oil formulations were employed. Invertebrates and cold-blooded vertebrates were more subject to mortality than were birds and mammals. The variations in the application procedure, insecticide formulation, season and area sprayed plus a number of other factors makes it exceedingly difficult to deduce further conclusions from this series of investigations.

One experiment having much better controls was carried out by the Ohio Cooperative Wildlife Research Unit[4.10,4.25] during which 3.9 millicuries of chlorine-36 ring-labeled DDT was applied at a rate of 0.2 lbs technical DDT per acre to a 4-acre marsh in Northern Ohio. Initially (4 hours after application) concentrations of the insecticide were detected in the emergent and floating vegetation (i.e., Potamogeton pectinatus, Lemna minor, Utricularia vulgaris). Traces were also found in crayfish (Orconectes immunis), tadpoles (Rana pipiens) and carp (Cyprinus carpio). It was believed that these amounts were the result of direct spray. The first instance of bioaccumulation was noted in Cladophora, an attached alga, 3 days after application. This plant had a DDT content of 96 ppm which was 3,125 times higher than the background. A northern water snake (Natrix sipedon) had 36 ppm after 13 months; carp (Cyprinus carpio) also had their higher concentration of 19 ppm after 13 months. Generally speaking, plants and invertebrates accumulated their highest residues within the first week, while vertebrates took considerably longer.

Cole, et. al.,[4.26] investigated the levels of DDT in stream ecosystems before and after the application of DDT to 104,000 acres of Pennsylvania forest (oak maple) to control fall cankerworm (Alsophilia pometaria). A formula of 0.5 lbs technical DDT in naphtha and fuel oil per acre was applied using an airplane traveling at 165 mph at 100 ft above the treetops. Although the DDT content of stream sediment increased by a few parts per billion after 1 month, the residues in brook trout (Salvelinus fortinalis) were 20-100 times higher. White suckers (Catostomus commersoni) also exhibited substantial increases in insecticide content. Concentrations in crayfish also increased but to a lesser extent. Changes in concentrations of DDT and its metabolites with time are given in Table 4.I. (Site 1 was 1 mile above the splash dam sampling location.) Between 30 and 122 days after application, the insecticide residue decreased to near pre-application levels.

In a Long Island marsh that was sprayed annually with DDT for more than 20 years to control mosquitos, Woodwell[4.18] discovered more than 32 lb/acre

Table 4.I

RESIDUE IN FISH AND CRAYFISH BEFORE AND AFTER THE APPLICATION OF 0.5 LB TECHNICAL DDT/ACRE

(VALUES IN PARTS PER MILLION)

SITE	BROOK TROUT			
	DDE	TDE	o,p'-DDT	p,p'-DDT
LYMAN RUN SITE 1				
PRE-TREATMENT	0.34	NR	NR	0.54
TREATMENT +30 DAYS	4.8	6.1	NR	9.5
TREATMENT +122 DAYS	0.29	0.16	0.12	0.20
TREATMENT +380 DAYS	0.33	0.10	NR	0.23
SPLASH DAM				
PRE-TREATMENT	0.42	0.10	NR	0.37
TREATMENT +30 DAYS	1.5	6.1	NR	10.6
TREATMENT +122 DAYS	0.31	0.11	0.04	0.07
TREATMENT +380 DAYS	0.36	0.10	NR	0.09
SITE	WHITE SUCKERS			
	DDE	TDE	o,p'-DDT	p,p'-DDT
LYMAN RUN SITE 1				
PRE-TREATMENT	2.4	NR	NR	1.8
TREATMENT +30 DAYS	4.7	5.7	NR	NR
TREATMENT +122 DAYS	0.27	0.13	NR	NR
TREATMENT +380 DAYS	0.18	0.24	NR	NR
SPLASH DAM				
PRE-TREATMENT	0.72	NR	NR	0.9
TREATMENT +30 DAYS	5.0	7.8	NR	NR
TREATMENT +122 DAYS	0.83	0.54	0.04	NR
TREATMENT +380 DAYS	0.25	0.32	NR	NR
SITE	CRAYFISH			
	DDE	TDE	o,p'-DDT	p,p'-DDT
LYMAN RUN SITE 1				
PRE-TREATMENT	NR	NR	NR	0.47
TREATMENT +30 DAYS	0.89	0.71	NR	0.88
TREATMENT +122 DAYS	0.09	0.09	NR	0.10
TREATMENT +380 DAYS	0.02	NR	NR	0.06
SPLASH DAM				
PRE-TREATMENT	1.1	NR	NR	1.9
TREATMENT +30 DAYS	1.4	1.6	NR	1.1
TREATMENT +122 DAYS	0.02	0.01	NR	0.01
TREATMENT +380 DAYS	0.06	NR	NR	0.07

NR = BELOW LIMIT OF DETECTABILITY (0.002 ppm)

DATA FROM COLE et. al., 4.26

in the sediment just below the mud-water interface. The water contained 0.00005 ppm. Plankton had 0.4 ppm DDT; bay shrimp, 0.16; snails (Nassarius sp.), 0.26; eels (Anguilla rostrata), 0.28; minnows (Cyprinodan sp.), 0.94; and flounders (Paralichthys sp.), 1.28. Shore-birds, which fed on the fish, had up to 75.5 ppm.[4.18,4.19]

Fredeen and Duffy[4.8] examined the St. Lawrence River Ecosystem after 36,831 lb of technical DDT were added in six doses of approximately 6,000 lb each in the spring and summer of 1966 through 1967. The insecticide was added directly to the river in slugs of 0.17 to 0.38 ppm emulsified DDT for 16-39 minutes to control undesirable insects in the "Expo" exposition site. Fish were collected downstream of the treatment area from 3-70 days after the insecticide was discharged in 1967. The highest average concentrations of 0.74 ppm were detected in carp (Cyprinus carpio) and catfish (Ameiurus nebulosus); in bottom-feeding species, snails (Campeloma) and clams (Pisidium), the average was approximately half as much.

Attempting to avoid the problem of uncontrollable variables, Metcalf, Sangha and Kapoor[4.27] constructed a model ecosystem with a 7-element food web. They added Carbon 14-labeled DDT to approximate an application rate in nature of 1 lb/acre. The insecticide accumulated in mosquito larvae, snails and fish as DDE, DDD and DDT. A biomagnification of 10,000-100,000 was observed after 30 days.

Eberhardt, et. al.,[4.4] attempted to mathematically model the kinetics of DDT in a freshwater habitat, although additional model verification is necessary.

Macek and Korn[4.28] demonstrated in the laboratory that brook trout (Salvelinus fontinalis) accumulated approximately 10 times more of available DDT from food than directly from water. This reinforces the work of Woodwell, et. al., regarding biomagnification.

Some uptake of DDT across the gills by fish directly from the water does occur.[4.29] A noteworthy point is the fact that uptake is stimulated by increasing salinity. Hence, the detrimental effect of DDT on fish could be greater if the pesticide were applied to brackish rather than to fresh water.

Stickel[4.30] provides further information on the impact of DDT on total ecosystems.

There have been more DDT studies with individual species or groups of organisms, particularly fish, than have been done with entire ecosystems. The following discussion of the effects of DDT on specific organisms and taxonomic groups begins with the lower trophic levels.

The impact of DDT and its metabolites on algae was reviewed by Christie[4.31] and Sweeney,[4.32] as well as included in a literature survey by Ware and Roan.[4.33] Christie observed that DDT in concentrations up to 100.0 ppm was neither toxic to, nor significantly degraded by, Chlorella pyrenoidosa, a common green alga. Similar observations have been made by others.[4.34] Ukeles[4.35] reported that concentrations exceeding 60.0 ppm were necessary to inhibit the growth of five species of marine phytoplankton over a 10-day period. The concentrations necessary to kill most algae exceed the DDT concentrations found in nature by more than 10,000-fold.[4.36,4.37] However, low concentrations of DDT can adversely affect phytoplankton. For instance, an exposure for 4 hours to 1.0 ppm DDT resulted in a 77 % decrease in carbon fixation, a technique for evaluating photosynthesis-respiration ratios.[4.38] Wurster[4.19] reported reductions in carbon fixation by four species of marine algae of up to 45 and 75 % following a 24-hour exposure to 1.0 and 100.0 ppb DDT, respectively. Using natural phytoplankton populations from Lake Ontario, Glooschenko[4.39] measured up to a 29.1 % decrease in Carbon-14 uptake following an exposure to 1.0 ppb DDT. Further reductions were noted at 10.0, 100.0 and 1000.0 ppb.

Perhaps of greater importance is the fact that algae and other water plants can concentrate DDT and thereby pass this insecticide up the aquatic food web. For example, several varieties of freshwater algae concentrated DDT between 99- and 964-fold following a 7-day exposure to water initially containing 1.0 ppm.[4.40] Bacteria and fungi can accumulate 40-100 % of the DDT from the media in which they are cultured.[4.41] Similar observations have been made with marine species.[4.33] Non-living algae and other plants also will concentrate DDT.

The mechanism of DDT accumulation by living cells, which may occur by adsorption and/or active uptake, is not fully understood.[4.32] There is evidence to support both postulations.

Zooplankton and benthic animals also can concentrate DDT. Pontoporeia affinis, a bottom-dwelling amphipod (crustacean) which is an important component in many freshwater food webs, was found to amass 50 times the concentration of DDT, DDE and DDD that was found in surrounding lake sediments.[4.42]

Most of the studies regarding the interactions of DDT and mollusks have been done with marine species, such as the easter oyster (Crassostrea virginica) and common mussel (Brachidontes recurvus).[4.43] These filter feeders are among the most "efficient" of the aquatic forms at removing and concentrating DDT. Aside from increasing the likelihood of the insecticide being passed on within the food web, a concentration of 7 to 10 ppb DDT in water will inhibit shell deposition by 50 %. While freshwater mussels are less common and correspondingly of lower importance as a food than their saltwater counterparts, freshwater species most likely are as adversly affected by this insecticide.

There have been innumerable studies regarding the impact of DDT on stream insects.[4.44-4.51] While the studies differed considerably with respect to rates, method, formula and time of application of the insecticide, some general conclusions can be drawn. DDT produced marked reductions in the quality and quantity of stream insects. In streams, some species were destroyed more than others. However, in other areas the reverse may have been true. If no DDT was applied, normally present taxa repopulated the stream in 2-3 years probably because the insect eggs, which frequently have a thick shell, are less adversly affected by DDT than are larvae or the adults.[4.52] A very slight return of the natural stream fauna was observed where spraying took place on an annual basis. Recovery of individual species was proportional to normal reproductive capacities, i.e., mayflies (Ephemeroptera) and midges (Chironomidae) recovered more quickly; stoneflies (Plecoptera) and caddisflies (Trichoptera) more slowly. Contaminated and drifting insects represent a significant potential source of DDT uptake by fish, many of which feed on those paralyzed invertebrates. Insects sprayed with DDT-oil were more toxic than those insects that had come into contact with DDT in suspension.[4.53] Likewise, some insect mortality, particularly downstream, was related to their eating of attached plants that had accumulated DDT.

More literature concerning DDT and fish has been published than on any other form of aquatic life. This topic was included in a comprehensive literature review by Johnson.[4.54] Henderson, et. al.,[4.55] and Reinert,[4.56] among others, published compilations regarding the accumulation of DDT and its metabolites in fish.

It is virtually impossible to compare laboratory studies concerning the determination of lethal dosage or concentration due to the vast differences in environments (water temperature, pH, etc.), age and the physiological condition of fish, etc. However, generally speaking, the "sport" fish species are more sensitive than the trash-species.[4.54] The 72-hour LD_{50}s ranged from 0.1 ppm for goldfish (Carassius auratus) to 0.001 ppm for brown trout (Salmo trutta).[4.11] The toxicity of DDE to fish appears to be 10-fold less than DDT. In other words, it takes 10 times the concentration of DDE to kill the same fish under the same environmental conditions than is necessary with DDT.[4.54]

Holden[4.57] determined that in a 1-ft deep stream, the ratio of the recommended quantity of DDT to control blackflies (Simulium sp.) to the amount which destroyed half the trout (Salvelinus sp.) in 24 hours was 1:17. The shortcomings of the utilization of such acute toxicity data was discussed at length by Rudd and Genelly.[4.58]

Numerous instances of fish kills following the application of DDT to control insects have been reported.[4.59-4.61] There have been many more cases where more than one pesticide was applied to an area prior to a fish kill.[4.62] In such an instance, it is very difficult to determine if DDT was the most significant factor which induced death of the fish.

Temperature apparently is an important factor which influences DDT toxicity. Cope[4.63] reported that with respect to rainbow trout (Salmo gairdneri) and bluegills (Lepomis macrochirus), DDT toxicity increased below 13°C and above 18.5 - 23°C. Bridges, et. al.,[4.64] observed similar results.

Turbidity may influence the toxicity of DDT. Organic particles in suspension may remove DDT from water.[4.65] However, the DDT may reenter an aquatic food web if the organic matter was eaten by bottom organisms. Hence, suspended material could decrease the acute toxicity and increase the chronic toxicity of this insecticide.

Johnson[4.66] reported a decrease in the toxicity of DDT with increasing alkalinity. However, since the waters he was observing also were turbid, his conclusion may be invalid.

Within a given species, the younger and smaller generally are more susceptable to DDT poisoning than the older and larger fish.[4.67] This may be related to the fact that the latter have more lipid tissue in which the DDT can be dispersed.

The negative impact of DDT on fish eggs and fly eggs can be significant. After a fish initially hatches, it is almost entirely dependent on the yolk sac for its initial source of food. As the contents of the yolk sac are consumed, the DDT in the remaining lipids in the sac becomes more concentrated. During the last stage of yolk sac absorption, mortality among the fry of numerous species have been observed.[4.68] The eggs may be a vehicle through which DDT is passed on to the offspring. This may result in a significant decline in the population of some species such as trout.[4.69,4.70] In fact, this was believed to be the prime factor in the destruction of the lake trout fishery in Lake George, New York. This factor led to the subsequent extensive use of non-persistent Sevin.

Environmental stress decreases the resistance of fish to DDT. Examples of the above can be starvation, low dissolved oxygen and water temperatures and physiological changes associated with spawning.[4.71,4.72] These conditions may have occurred during many of the static toxicity tests that have been reported which could invalidate the results from such studies.[4.73]

Numerous aquatic organisms can metabolize DDT.[4.31,4.74,4.33] Yeasts declorinate DDT to DDD (TDE).[4.75] Some algae can convert DDT to DDE; however, the process is fairly slow -- 9 % in 3 weeks.[4.33]

Some anaerobic aquatic bacteria, such as Klebsiella pneumonia and Aerobacter aerogenes degrade DDT to TDE. Reduced Fe (II) cytochrome oxidase appeared to be the enzyme responsible for this chemical change.[4.76] Intestinal microflora play a major role in the degradation of DDT in fish. These bacteria can metabolize DDT to DDE and DDD.[4.77,4.78]

A limited amount of research has been conducted on DDT metabolism by fish. Atlantic salmon, Salmo salar, degrade DDT to DDE and DDD.[4.79-4.81] In vitro investigation with carp blood and DDT showed some conversion to DDE, DDD and possibly DDMU.[4.77]

While much literature has been generated regarding the breakdown of DDT by terrestrial insects, virtually nothing could be found concerning aquatic anthropods. However, since the metabolic pathways of the latter do not differ appreciably from the land forms, it can be assumed with reasonable confidence that aquatic insects also metabolize DDT and related chemicals. For further informatio on this subject, the reader is directed to compilations by Dr. Calvin Menzie[4.74] and Spencer.[4.82]

One recent, and perhaps biologically significant finding, was the discovery of DDT-resistant fish and frogs.[4.83,4.84] These organisms can accumulate sufficient amounts of DDT to pose a threat to higher organism, including man, if comsumed.

A determination of the effects of any agent on the forest ecosystem, requires a comparative investigation. Regrettably, there has been no pre-application study of our northeastern forests, delineating the "normal" parameters of the woodlands, either physical or biological. Most studies have been of short duration, determining only the effectiveness of the control and the persistence of the chemical.[4.85-4.87]

In order to assess the degree of impact of chemical sprays on the aquatic biome within the forest, it is essential that prespray studies be made of the biological, chemical and physical parameters. Animal species, their composition and numbers, aquatic plant varieties, chemical levels of the area under study, and the physical attributes of the lentic or lotic environment must be evaluated. These studies should be undertaken several years prior to spray, so that population dynamics and normal variations due to climatic conditions are included. Then, and only then, can an impact statement be drawn following pesticide application, since a comparative framework has been established.

Following World War II, DDT was routinely used in forest pest management in New York and this was continued for almost 20 years, until reports of aquatic destruction and food web magnification forced a halt to the application of this material (N.Y. State Sect. S. A. F., 1964). The carbamate Sevin has been used exclusively ever since although trials of other pesticides and biological agents were made in recent years.

No systematic pre- and post-spray long term studies were undertaken with DDT. Reports of extensive fish kill and stream invertebrate destruction were reported many times for New Brunswick, Maine, Montana, New York and Ontario, following DDT sprays for control of gypsy moth and spruce bud worm.[4.88-4.91] DDT sprays demonstrate persistence for many years following application as found by a national pesticide monitoring program throughout the country presenting data on levels of DDT in fish, aquatic insects and water.

Only a few long-term studies comparing the post-spray effects of Sevin to the pre-spray environment have been conducted. Following the rapid change from DDT to Sevin, several investigators attempted to define the effects of the latter compound on aquatic ecosystems so that at least some review of environmental impact may be made. Following a spray operation for the hemlock looper in Washington State, utilizing Sevin at 1.6 lb/acre and covering 43,204 acres, a total of five streams were examined, after spraying. No adverse effects were noted except for a slight reduction in stoneflies in one of the streams.[4.92] In 1959, Burdick (unpublished report) indicated that Sevin had no effect on aquatic insects in North Carolina. In 1960, however, he did note a rather dramatic reduction (50.7 - 97.2 %) in stream insects in New York, following direct application to the stream surface.[4.93] Mayflies (Ephemeroptera), stoneflies (Plecoptera) and caddisflies (Trichoptera) particularly were killed. Following a spray application with Sevin in Pennsylvania, Coutant did note a high incidence of aquatic insect drift, although mortality per se was not examined.[4.94]

In 1965 the state of Massachusetts embarked on a comprehensive environmental impact study of aqueous Sevin formulation used in a gypsy moth control program on Cape Cod. A total of 22,400 acres were sprayed at the rate of 1 lb/ 1 gal/acre. Careful attention was paid to the mechanics of the spraying operation and spray cards corroborated the deposition. An evaluation of the effectiveness demonstrated fair to moderate larval control. However, the reduction in egg mass counts in the fall of 1965 was excellent[4.87] (see Table 4.II).

Aerial leaf residues of Sevin disappeared rapidly. In one plot by day number four post spray, residues were all but gone (Figure 4.1) and in the second plot, by the tenth day, little remained[4.95] (Figure 4.2). Little recoverable material was obtained from the leaf duff and in some cases post spray analysis yielded lower quantities than the checks.[4.96] These results are in agreement with findings at the State University College of Forestry at Syracuse University.

Table 4.II

GYPSY MOTH EGG MASS COUNTS, CAPE COD

MASSES/ACRE 1964	MASSES/ACRE 1965	PERCENT REDUCTION
100	0	100
380	0	100
150	0	100
1,000	0	100
0	0	100
1,400	0	100
500	0	100
0	0	100
1,000	0	100
500	0	100
10,000+	230	98
5,000	0	100
1,000	0	100
1,000	0	100
5,000	0	100
3,000	0	100
10,000+	0	100
250	0	100
10,000+	0	100

MASSES/ACRE 1964	MASSES/ACRE 1965	PERCENT REDUCTION
10,000+	0	100
10,000+	0	100
300	0	100
10,000+	0	100
1,000	0	100
30	0	100
5,000	0	100
10,000+	0	100
10,000+	0	100
100	0	100
130	0	100
5,000	0	100
6,000	0	100
150	10	93
130	0	100
10,000+	0	100
10,000+	0	100
10,000 +	0	100
200	0	100

MASSES/ACRE 1964	MASSES/ACRE 1965	PERCENT REDUCTION
100	0	100
100	0	100
10,000+	0	100
10,000+	0	100
10,000+	0	100
5,000	0	100
10,000+	0	100
500	0	100
1,000	0	100
1,000	0	100
1,000	0	100
1,000	0	100
1,000	0	100
10,000+	400	96
10,000+	750	92
120	0	100
60	10	83
10,000+	10	99
70	0	100
5,000	0	100
500	10	98

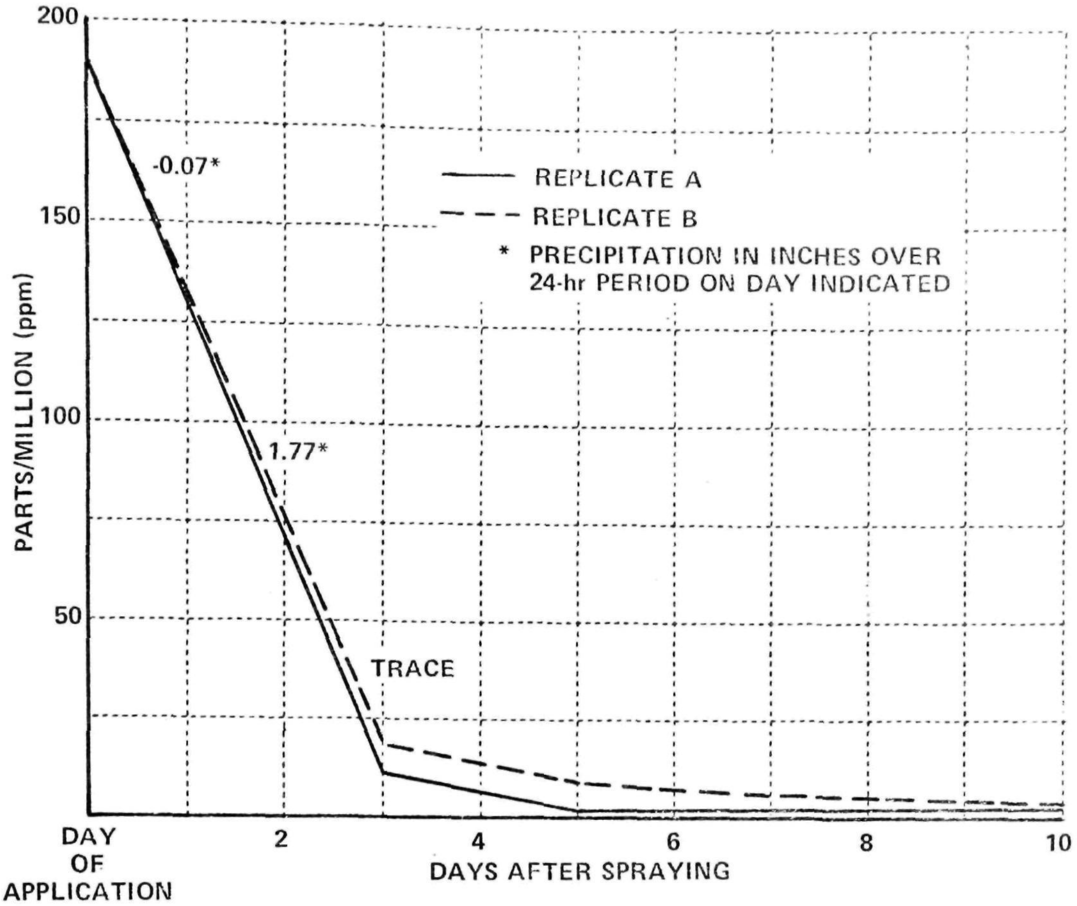


Figure 4.1 DISAPPEARANCE OF CARBARYL FROM OAK LEAVES AERIALLY SPRAYED AT THE RATE OF 1 LB/ACRE (PLOT 12)

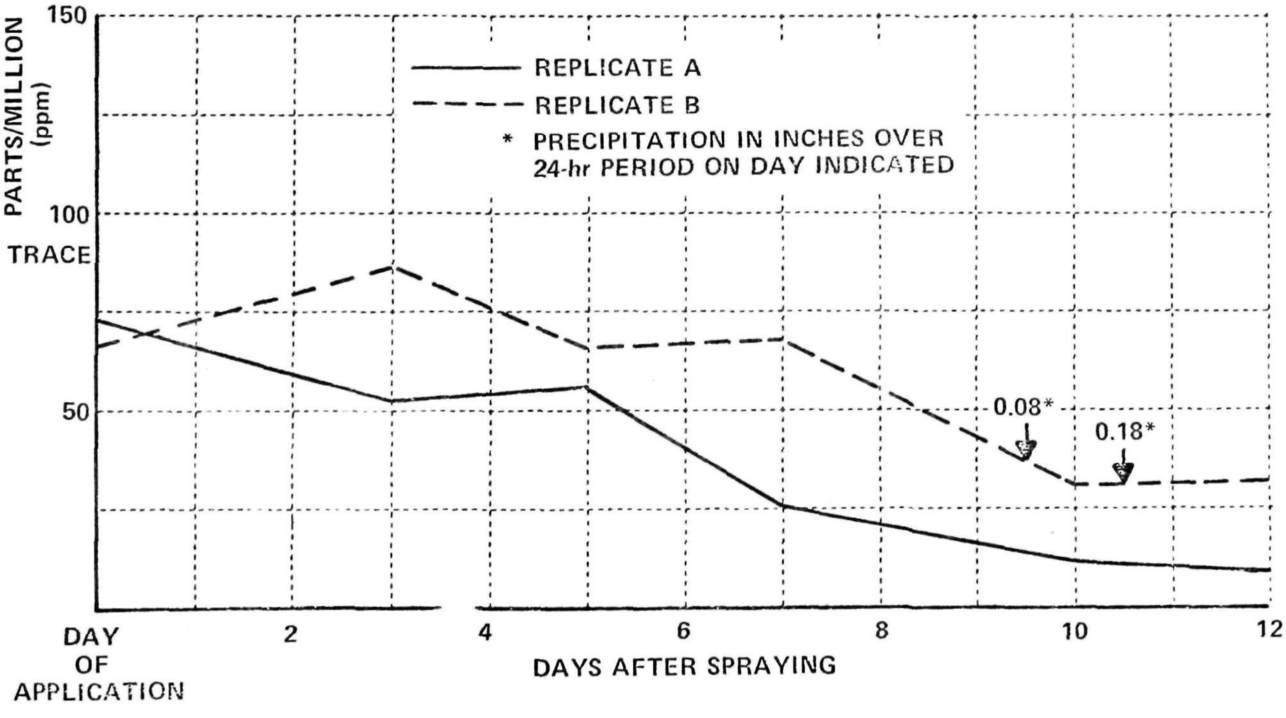


Figure 4.2 DISAPPEARANCE OF CARBARYL FROM OAK LEAVES AERIALLY SPRAYED AT THE RATE OF 1 LB/ACRE (PLOT 13)

The Cape Cod area represents both a marine and a fresh water aquatic habitat thus affording a unique opportunity to examine the impact of Sevin on both types of aqueous habitats.[4.97] The investigator analyzed a number of estuarine forms (Table 4.III) at up to 1 month post spray and found accumulation nil. Fresh-water vertebrates (Table 4.IV) demonstrated similar results. The author felt that Sevin had no effect on the organisms he tested, and further stated of this pesticide: "No fish mortalities could possibly occur under normal operating conditions...." Within the spray area lies a small landlocked pond of approximately 138 acres supporting a diverse warm-water fishery. Forested areas adjacent to the pond were sprayed by helicopter with the pilot taking standard precautions for shutdown. Table 4.V demonstrated the very low residue up to 4 months post spray in the water and soil.[4.98] In addition, algae populations showed no adverse reaction to the applications, thus justifying the author's contention that, "...the application of Sevin by helicopter for gypsy moth control at the rate of 1 lb/acre, when conducted under the proper conditions and in accordance with established spraying techniques, will not result in hazardous contamination in water and soil." Thus, at least two authors emphasize the importance of standard application procedures to assess the impact of the pesticide in the environment.

Sevin, as with most biologically toxic and active reagents does have an LD_{50} for all life systems. However, the extension of data on acute toxicity to low level chronic intake, when such levels exist, is scientifically unsound. Thus, in 1966, a 3-year study at the State University College of Forestry at Syracuse University was undertaken to evaluate the impact of Sevin on the aquatic ecosystem.[4.99] The following operating parameters were established prior to operations.

Table 4.III

APPARENT SEVIN OR METABOLITES IN THE TISSUES OF MARINE AND ESTUARINE ORGANISMS COLLECTED BOTH PRIOR TO AND AFTER THE 1965 CAPE COD GYPSY MOTH SPRAYING PROGRAM

LOCATION	SPECIES	PRESPRAY DATE	PRESPRAY NO.	PRESPRAY WGT. (gms)	PRESPRAY ppm*	POSTSPRAY DATE	POSTSPRAY NO.	POSTSPRAY WGT. (gms)	POSTSPRAY ppm*
SHOESTRING BAY	MUMMICHOG	5/5/65	4	27.2	0.15	6/3/65	2	33.0	0.19
	ALEWIFE	5/5/65	1 (p)	30.2	0.11	6/3/65	1	35.6	0.18
	WINTER FLOUNDER	5/5/65	7	25.2	0.13	6/3/65	1	6.6	0.38
	SOFT-SHELL CLAM	5/5/65	1	32.2	0.13	6/3/65	1	30.1	0.05
	QUAHOG	5/5/65	1	28.0	0.17	6/3/65	1	37.1	0.04
PRINCE COVE	WINTER FLOUNDER	5/5/65	1 (p)	25.8	0.22	6/3/65	1	25.5	0.06
	MUMMICHOG	5/5/65	3	28.5	0.20	6/3/65	2	35.8	0.19
	STICKLEBACK	5/5/65	50	26.8	0.19	6/3/65	62	25.8	0.06
	SOFT-SHELL CLAM	5/5/65	1	32.8	0.13	6/3/65	1	26.8	0.10
	QUAHOG	5/5/65	1	37.6	0.07	6/3/65	1	37.3	0.04
	AMERICAN OYSTER	5/5/65	2	26.8	0.09	6/3/65	3	25.0	0.10
CHILDS RIVER	SOFT-SHELL CLAM	5/6/65	1	33.2	0.10	....	.....	....	....
	BAY SCALLOP (SEED)	5/6/65	6	24.5	0.13	6/3/65	5	27.9	0.09
	QUAHOG	5/6/65	2	25.0	0.13	6/3/65	3	31.1	0.08
	WINTER FLOUNDER	5/6/65	2	27.6	0.18	6/3/65	2	28.7	0.06
	MUMMICHOG	5/6/65	2	25.4	0.13	6/3/65	4	30.0	0.11
	STICKLEBACK	5/6/65	27	25.9	0.19	6/7/65	20	25.3	0.20
WEST FALMOUTH HBR.	SOFT-SHELL CLAM	5/4/65	2	24.7	0.17	5/28/65	2	33.4	0.10
	AMERICAN OYSTER	5/4/65	4	37.0	0.14	5/28/65	3	31.6	0.05
	QUAHOG	....	.....	....	....	5/28/65	1	31.5	0.08
	WINTER FLOUNDER	5/4/65	1 (p)	35.1	0.12	5/28/65	1	25.2	0.13
	MUMMICHOG	5/4/65	3	25.6	0.13	5/28/65	3	30.0	0.17
MASHPEE RIVER	SOFT-SHELL CLAM	5/5/65	3	28.7	0.09	6/1/65	3	34.0	0.05
	QUAHOG	5/5/65	2	34.6	0.09	6/1/65	1	32.1	0.24
	WINTER FLOUNDER	5/5/65	6	29.3	0.11	6/1/65	1	6.8	0.74
	MUMMICHOG	5/5/65	6	25.4	0.06	6/1/65	2	33.0	0.10
	ALEWIFE	5/5/65	1 (p)	25.6	0.16	6/1/65	1 (p)	25.4	0.20
COONAMESSETT RIVER	SOFT-SHELL CLAM	5/6/65	1	28.0	0.12	6/2/65	2	31.2	0.13
	QUAHOG	5/6/65	3	26.5	0.12	6/2/65	2	48.7	0.13
	WINTER FLOUNDER	5/6/65	1 (p)	35.1	0.16	....	.....	....	....
	ALEWIFE	5/6/65	1 (p)	27.9	0.09	6/2/65	1 (p)	41.9	0.16
	MUMMICHOG	5/6/65	4	29.8	0.14	6/2/65	4	30.0	0.11
	SILVERSIDE	5/6/65	50	26.2	0.16	6/2/65	35	27.2	0.21
PAMET RIVER	QUAHOG	5/3/65	1	27.1	0.09	6/4/65	2	29.7	0.08
	SOFT-SHELL CLAM	5/3/65	1	26.1	0.12	6/4/65	2	29.1	0.08
	BLUE MUSSEL	5/3/65	3	30.0	0.17	6/4/65	2	21.9	0.23
	MUMMICHOG	5/4/65	4	28.9	0.11	6/4/65	3	27.4	0.34
	SAND LANCE	5/4/65	6	28.4	0.12	6/4/65	3	28.4	0.15
	STICKLEBACK	5/4/65	15	29.0	0.23	6/4/65	22	26.2	0.19

ppm: PARTS PER MILLION

COURTESY: REPORT OF THE SURVEILLANCE PROGRAM CONDUCTED IN CONNECTION WITH AN APPLICATION OF CARBARYL (SEVIN) FOR THE CONTROL OF GYPSY MOTH ON CAPE COD, MASSACHUSETTS. *PUBLICATION OF THE COMMONWEALTH OF* MASSACHUSETTS, PUBLICATION NO. 547, 1966.

Table 4.IV

APPARENT SEVIN OR METABOLITES IN THE TISSUE OF FRESHWATER FISH COLLECTED BOTH PRIOR TO AND AFTER THE 1965 CAPE COD GYPSY MOTH SPRAYING PROGRAM

LOCATION	SPECIES	PRESPRAY				POSTSPRAY			
		DATE	NO.	WGT. (gms)	ppm*	DATE	NO.	WGT. (gms)	ppm*
PAMET RIVER	SUNFISH	5/3/65	3	31.7	0.10	6/4/65	2	35.3	0.10
PAMET RIVER	SUNFISH	5/3/65	3	25.0	0.13	6/7/65	2	34.5	0.10
PAMET RIVER	BROOK TROUT	5/3/65	1	41.2	0.08	----	--	---	---
LAWRENCE POND	YELLOW PERCH	5/5/65	10	33.0	0.11	6/7/65	2	40.0	0.13
MASHPEE-WAKEBY	WHITE SUCKER	5/5/65	5	31.0	0.09	6/4/65	1	43.9	0.11
MASHPEE RIVER	AMERICAN EEL	5/5/65	6	32.2	0.06	5/30/65	2	34.4	0.14
LAWRENCE POND	YELLOW PERCH	5/5/65	5	37.0	0.15	6/10/65	1	39.5	0.12

*ppm; PARTS PER MILLION

Table 4.V

LAWRENCE POND, SANDWICH, CARBARYL (SEVIN) IN WATER AND TOPSOIL PRIOR TO AND FOLLOWING APPLICATION FOR GYPSY MOTH CONTROL

WATER				TOPSOIL		
DATE 1965	LOCATION	SEVIN (ppm)		DATE 1965	LOCATION	SEVIN (ppm)
		SURFACE	DEPTH**			
6/1	SOUTH END	0.000	0.000	6/1	AT SHORE	0.008
	WEST SIDE	0.000	0.000		100′ FROM SHORE	0.022
	NORTH END	0.000	0.000		200′ FROM SHORE	0.000
6/5*	SOUTH END	0.001				
		0.001				
6/9	SOUTH END	0.002	0.002	6/9	AT SHORE	0.018
	WEST SIDE	0.002	0.003		100′ FROM SHORE	0.080
	NORTH END	0.002	0.002		200′ FROM SHORE	0.300
6/24	SOUTH END	0.001	---			
	WEST SIDE	0.001	---			
	NORTH END	0.001	---			
10/7	SOUTH END	0.0007	---	10/7	AT SHORE	0.034
	NORTH SIDE	0.0000	---		100′ FROM SHORE	0.035
	NORTH END	0.0004	---		200′ FROM SHORE	0.035

*DATE OF APPLICATION

**SAMPLING DEPTHS VARIED FROM 10-25 FT.

1. The effectiveness of the spray for gypsy moth control would not be evaluated.
2. A year of prespray examinations of the chemistry and population levels of the aquatic insects would be made.
3. The State would be instructed to spray the test site as if this area were a typical spray site.
4. The pesticide concentration and stickers used would be those currently accepted by State pesticide officials for use in gypsy moth control programs.
5. The aquatic habitat would be followed for 2 years post spray.

The area selected for study is part of the Shackam Brook watershed, near Fabius, New York. It is state-owned land covered largely by second-growth hardwoods. The area is, for the most part, densely forested, with a solid canopy. It is an ideal spray site in that it (Figure 4.3) is east of and separated from the control site by a rather high north-south ridge. The topography is reasonably steep; streams course their way in both areas and converge south of the test site. Of the 1,997 acres in the test area, 365 acres were sprayed. A state-owned Bell 204-E turbojet helicopter dispensed 1 lb of Sevin, aqueous plus 4 ounces of Pinolene 1882, per acre. Standard shutoff procedures were followed when the aircraft approached the aquatic site.

Prespray water samples (1966) consisted of 15 liters monthly for analysis. In 1967, daily samples were taken in June, July and August; weekly in September and biweekly for the balance of the year. A monthly schedule was reinstituted in 1968.

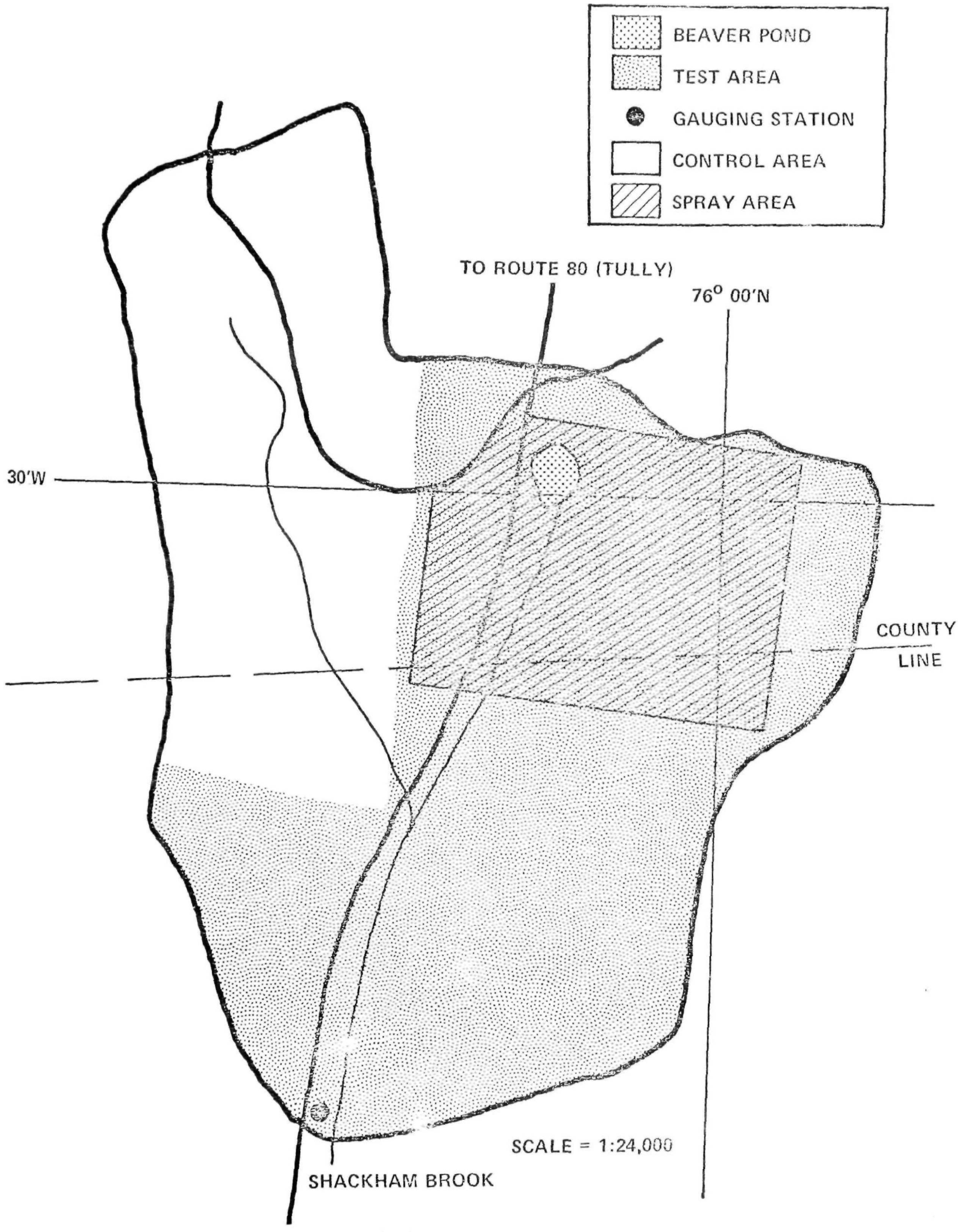


Figure 4.3 SHACKHAM BROOK STUDY AREA

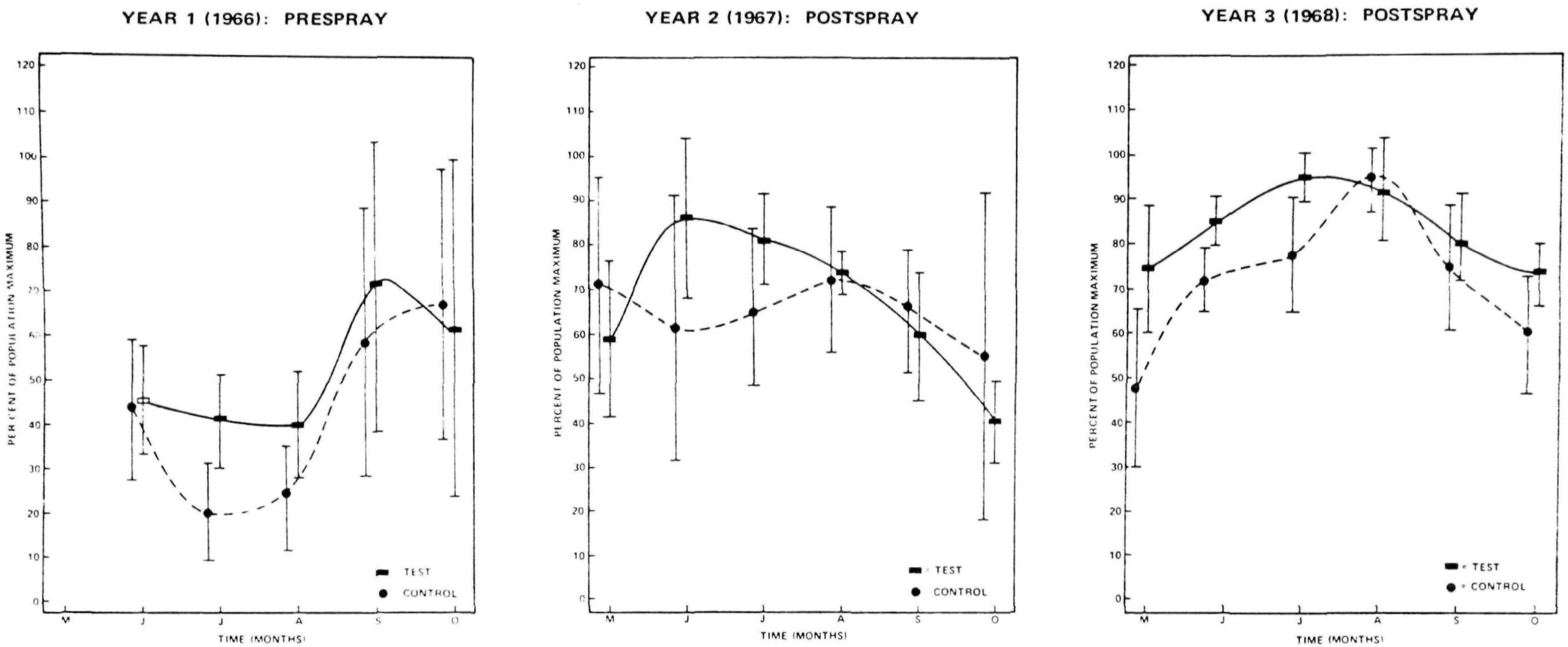
Aquatic insect populations were sampled weekly for 2 years, post spray, and when possible, weekly prespray. Insects were identified and populations estimated. The results were not surprising, based on findings of several other studies. At no time did Sevin or Naphthol show residues over 0.1 ppm (the detection limits). The effect on aquatic insect population for the full 2 year post spray were also negative, (Figure 4.4). Further, no species composition changes occurred for any of the aquatic insects under study.

An observation comparable to the Massachusetts study was made, viz, soil and duff samples taken from under the canopy were routinely negative.

Several of the stream Odonata (dragonflies) were recovered and analyzed for Sevin but all were below the limits of detectability. An LC_{50} determination set the level of Sevin at 2.0 ppm (Figure 4.5).

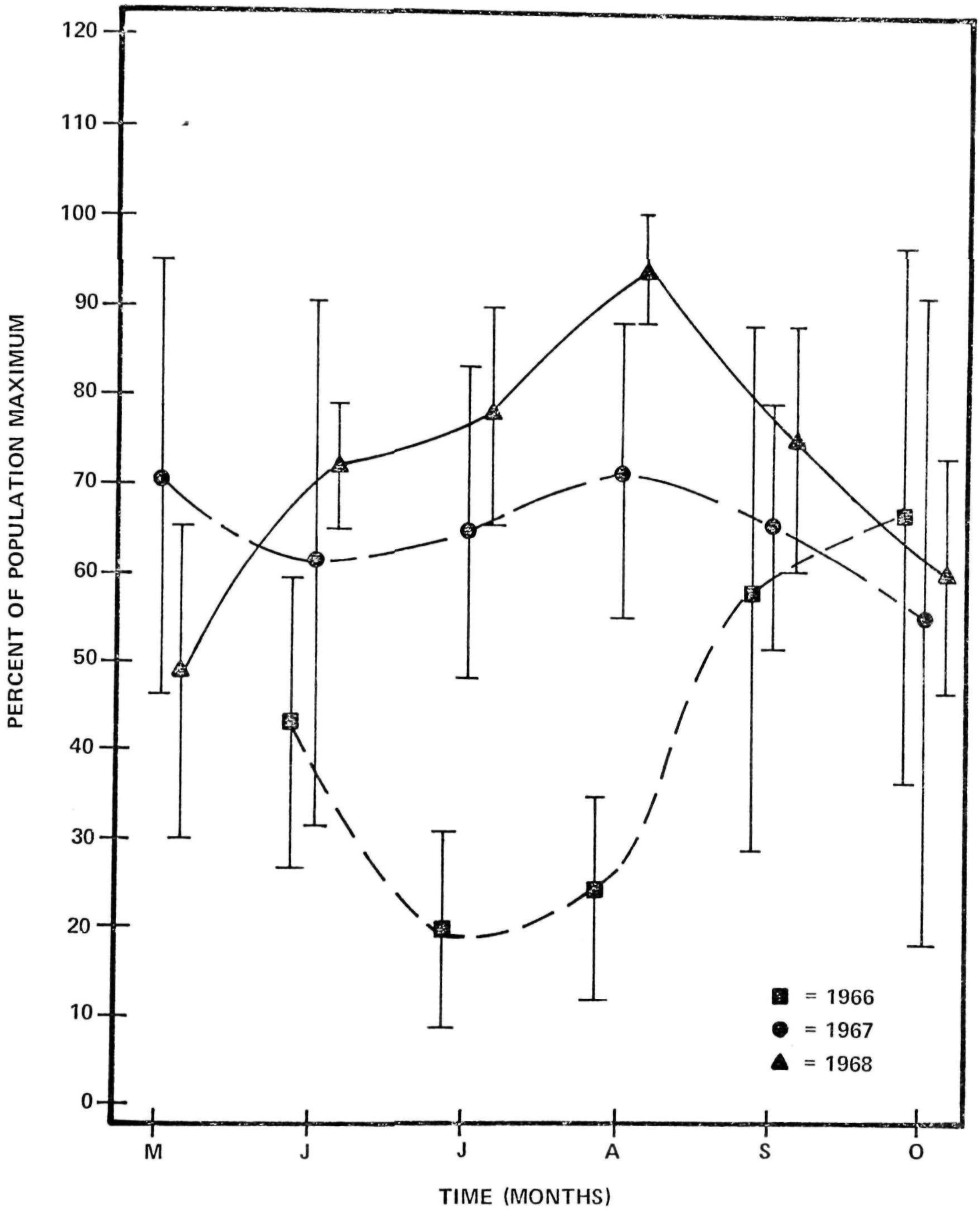
Thus, as a result of this study:

1. Laboratory analysis of water, soil and insect samples taken from the Shackam Brook near Tully, New York after application of Sevin at 1 lb/acre showed no residues of Sevin or 1-naphthol above the 0.1-ppm level at any time during the 3-year study period (June 1966 - November 1968).
2. Analysis of aquatic insect larval and naiad population levels over the 3-year period showed no fluctuations that could be associated with the spraying of Sevin and subsequent runoff.
3. Fluctuations in population levels of the aquatic insect larvae and naiads were most probably a function of climatic conditions, primarily water levels as influenced by rainfall.



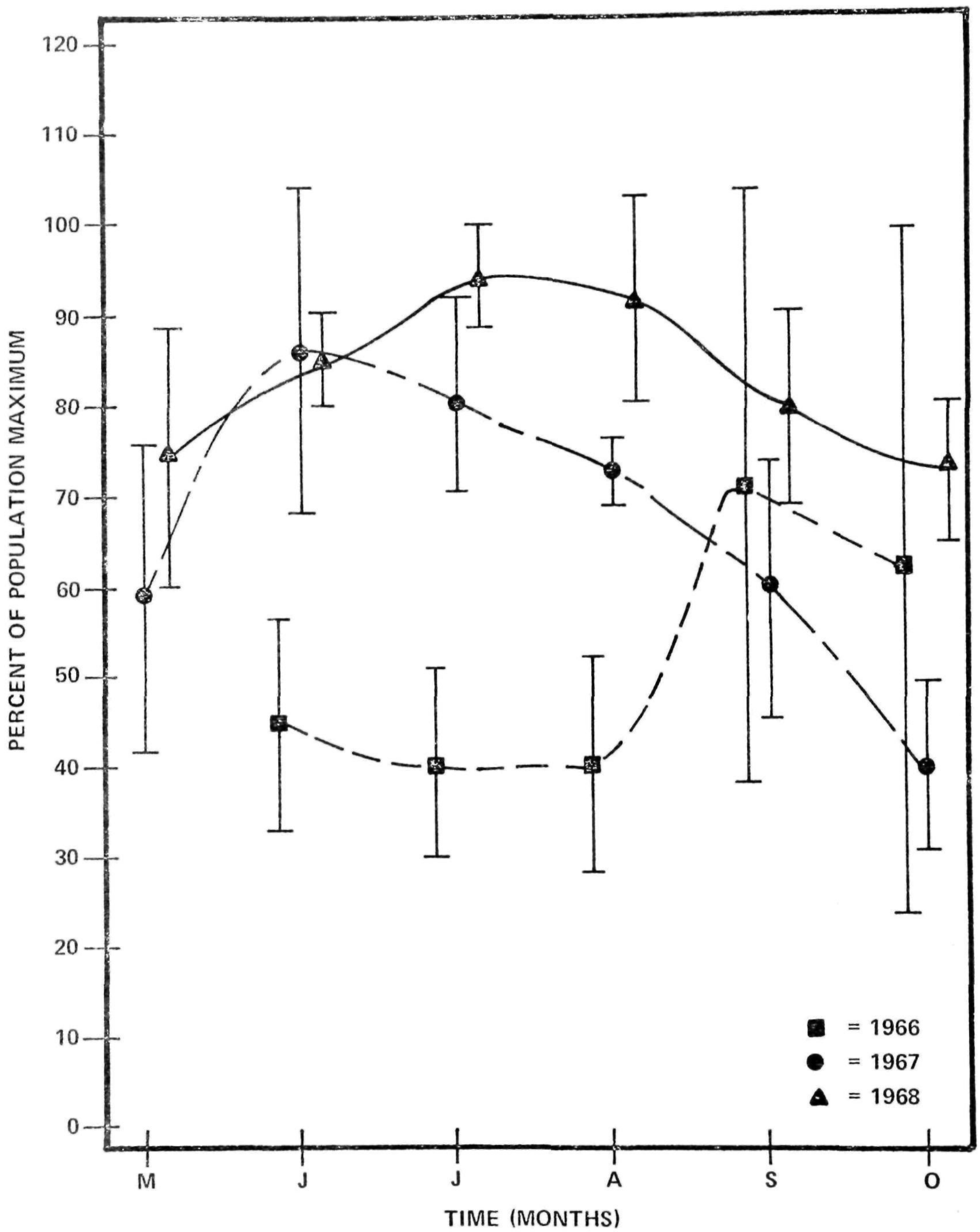
COURTESY: D.R. FELLEY, UNPUBLISHED PH.D. THESIS, THE EFFECT OF SEVIN (1-NAPHTHYL N-METHYL CARBAMATE) AS A WATERSHED POLLUTANT, 1970, STATE UNIVERSITY COLLEGE OF FORESTRY AT SYRACUSE UNIVERSITY, SYRACUSE, NEW YORK.

Figure 4.4 INSECTS COLLECTED AS A PERCENT OF POPULATION, MAXIMUM, IN THE TEST AND CONTROL BRANCH OF SHACKAM BROOK IN 1966, 1967 AND 1968. RANGE MARKINGS REPRESENT 95 PERCENT CONFIDENCE INTERVALS.



TOTAL INSECTS COLLECTED, AS PERCENT OF THE POPULATION MAXIMUM, IN THE TEST BRANCH OF SHACKHAM BROOK FOR 1966, 1967 AND 1968. RANGE MARKINGS INDICATE 95 PERCENT CONFIDENCE INTERVAL.

Figure 4.4 (Continued)



TOTAL INSECTS COLLECTED, AS PERCENT OF THE POPULATION MAXIMUM, IN THE TEST BRANCH OF SHACKHAM BROOK FOR 1966, 1967 AND 1968. RANGE MARKINGS INDICATE 95 PERCENT CONFIDENCE INTERVAL.

Figure 4.4 (Continued)

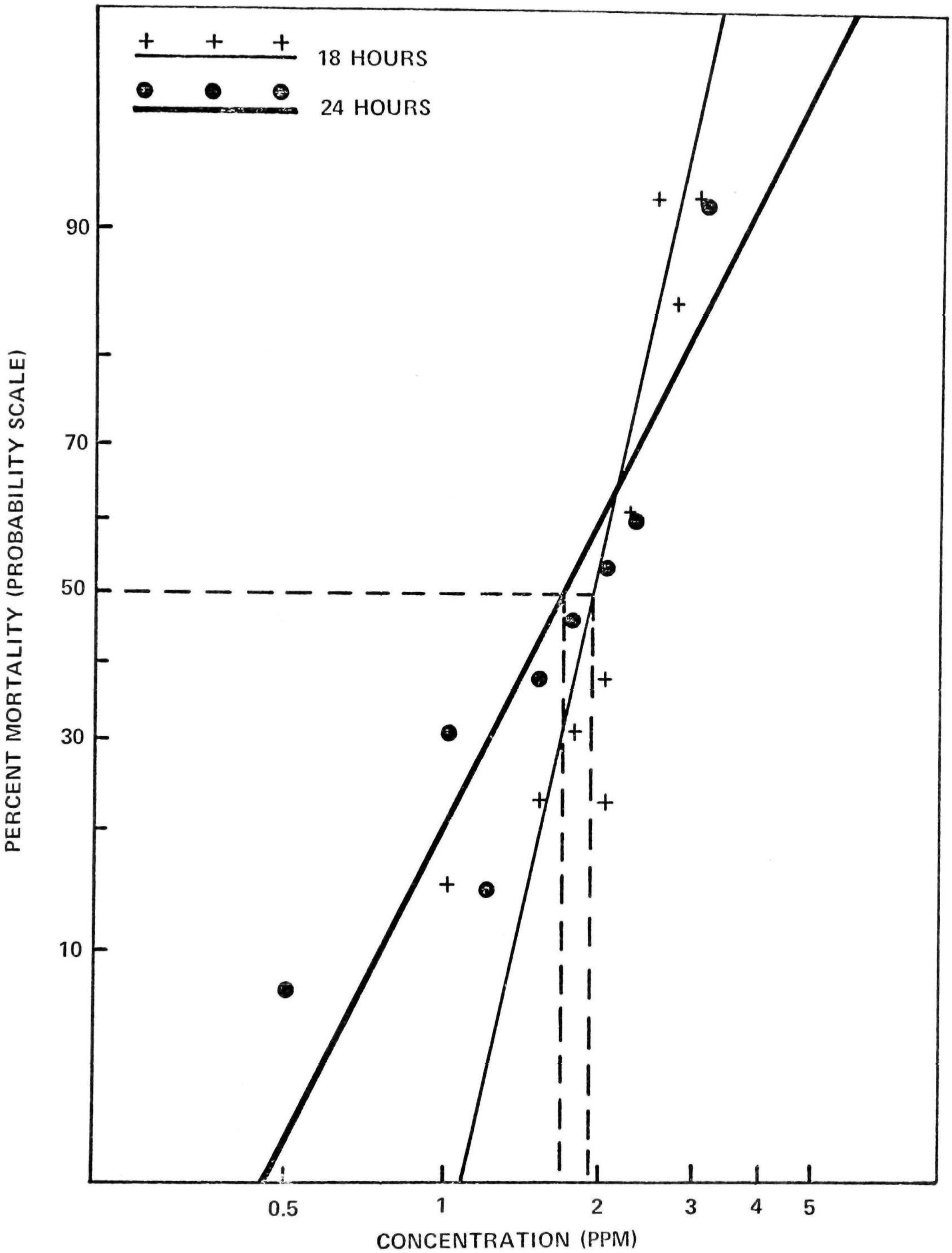


Figure 4.5 CONCENTRATION OF SEVIN IN PARTS PER MILLION VERSUS PERCENT MORTALITY TO DETERMINE LC_{50} OF ODONATA AT 18 AND 24 HOURS

4. Sevin had no polluting effect upon the test watershed and deleterious effects were not found in aquatic insects.

Relative to other aquatic environments, Sevin, having a solubility rate in water of 40 mg/l at 20°C, readily dissolves in water as compared to DDT. However, Christie[4.100] and Palmer and Maloney[4.101] have reported Sevin, at concentrations above 0.1 ppm, to be toxic to most algae. However, only a 16.8 % decrease in carbon fixation by a natural population of phytoplankton following a 4-hour exposure to 1.0 ppm of the insecticide was noted by Butler.[4.102]

Muncy and Oliver[4.103] found that Sevin was extremely toxic to crayfish, crabs and shrimp. Parker, et. al.[4.104] made similar observations with respect to Daphnia, a waterflea.

Concerning fish, Haynes, et. al.[4.105] reported that 28 ppm technical Sevin in oil resulted in a 48-hour LD_{50} for goldfish (Carassius auratus). They stated that 50 % wetable powder had an LD_{50} of 14 ppm. Values from other laboratory studies ranged from 1.75 to 13.0 ppm.[4.106,4.107] Henderson, et. al.[4.108] observed a 96-hour TL_m for fat-head minnows (Pimephales promelas) of 6.7 to 7.0 ppm and 12 to 13 ppm in hard and soft water, respectively. Burdick, et. al.,[4.109] while working with fingerling brown trout (Salmo trutta), found Sevin to be less toxic in soft, acidic water rather than in hard, alkaline water. They attributed this to an interaction between Sevin and the components of water rather than to physiological reaction of the fish to a water condition. The biochemical pathway of Sevin toxicity in fish is the same as that in insects.[4.110]

Sevin toxicity to fish increases with increasing temperature.[4.109] However, its rate of decay to 1-naphtol via hydrolysis also increases with temperature and sunlight.[4.111] While Sevin is more toxic to crustaceans than to fish and mollusks, the reverse is true for its metabolite.[4.106]

While the metabolism of Sevin has been extensively studied with respect to terrestrial plants and animals,[4.112] no literature was found regarding the breakdown of this insecticide by aquatic forms. However, it has been observed that Sevin persists longer in soil water than in lake water.[4.113]

A-4.3 Fate of Pesticides in the Forest Ecosystem

Many non-biological and biological factors cause degradation of DDT and Sevin thus inducing disappearance of the parent compound and increasing the concentration of metabolites. This section describes some of these pathways that operate in the forest ecosystem. In addition, effects due to differences in the chemical persistence of DDT and Sevin are briefly discussed in terms of bioconcentration or toxicity to forest organisms.

A-4.3.1 Non-biological Degradation

Light, particularly untraviolet, was the major cause of Sevin degradation to naphthol and methylisocyanate ($CH_3N = C = 0$).[4.114] Further, several unidentified products were formed when Sevin was irradiated at 254 mm as a solid.[4.115] As early as 1949, Chrisholm reported that DDT lost activity against the housefly following sunlight irradiation.[4.116]

Water will degrade many pesticides when in alkaline condition. DDT loses HCl to form DDE[4.114] or DDD,[4.117] of which the latter may be implicated in fish kills. Sevin readily hydrolyzed in water (at a pH of 8 or more) to a number of products, one of which was 1-naphthol.[4.118]

Degradation of DDT may be accelerated in the presence of metallic catalysts in the soil or water. Fleck and Haller described a dehydrohalogenation due to iron catalysis in soil.[4.119-4.121] Crosby[4.114] reported the same findings with a definite end product of DDD. Fe and Al accelerated DDT decomposition.[4.122] Heat may also degrade these pesticides, with Sevin forming naphthol and methyl isocyanate and dehydrohalogenation of DDT, although both picolinic acid and salicylol aminoguanidine may inhibit heat composition.[4.123] Other organic reagents may do the same, and include active groups, viz, carboxyl, thiol, amino, phenolic and aliphatic hydroxyls.

Although these pesticides will degrade, it is accepted that DDT and its metabolites, DDD and DDE, represent the most persistent compounds of those used in insect control. In Ohio river water, for example, 100 % of the parent DDT remained unchanged after 8 weeks, whereas Sevin showed only 5 % residual after 1 week and nothing by 2 weeks.[4.124]

Alexander[4.125] presents the following summary of pesticide degradation.

1. No degradation occurs (recalcitrant chemicals).
2. Degradation is too slow to prevent environmental contamination.
3. Degradation is complete, but products are harmful.

The following conditions must be met for a pesticide to be biodegradable.

1. An organism must exist or evolve which can metabolize the chemical.
2. The chemical must be metabolizible.
3. The chemical must reach the organism.
4. The chemical must induce enzymes, since few of these metabolic enzymes are constitutive.
5. The environment must be favorable for reactions.

A-4.3.2 Biological Degradation

By their very nature, living forms will tend to biotransform if enzymes for these pathways are present. This is simply a means for survival, particularly if the compound is toxic. Several of the metabolic pathways for biotransformation of both Sevin and DDT have been elucidated for laboratory animals and plants but little is known of these pathways in the wild. Thus acute poisoning by the pesticide may result in the field yet the effects of low level doses of the parent compound or its metabolites have not been resolved.

Although the results of pesticide metabolism may be clearly demonstrated in certain animals and plants, it is dangerous practice to extend these findings to include other organisms. DDE, for example, is a common DDT metabolite in man yet monkeys show no trace of this material. Further, the effects of these chemicals may vary. The thin eggshell syndrome of DDE and falcons has been verified yet domestic hens show a greater shell thickness with the same material.

Five products of DDT metabolism represent the major pathways of degradation; DDA, Kelthane, DDD, DDE and dichlorobenzophenone[4.126] (see Figure 4.6). Two of these products, DDD and Kelthane, are recognized pesticides in their own right. The most widely recognized pathway involves a dehydrochlorination of DDT to yield DDE and has been described in many mammals, fish and insects. In insects, a high titer of the enzyme dehydrochlorinease will confer immunity to the pesticide, and in the classic case of the development of the resistant housefly strains, the genome for this enzyme was selected for by environmental saturation of DDT.

At this juncture, it would be well to point out that developing pesticide resistant strains is much more likely if lower concentrations of pesticides are used. Although environmental contamination may be reduced, for example, by utilizing only one quarter to one third of a pound per acre of DDT, and arriving at only an 80 % control figure, the chances of developing a strain with a potential to detoxify these pesticides is much greater than if one uses a

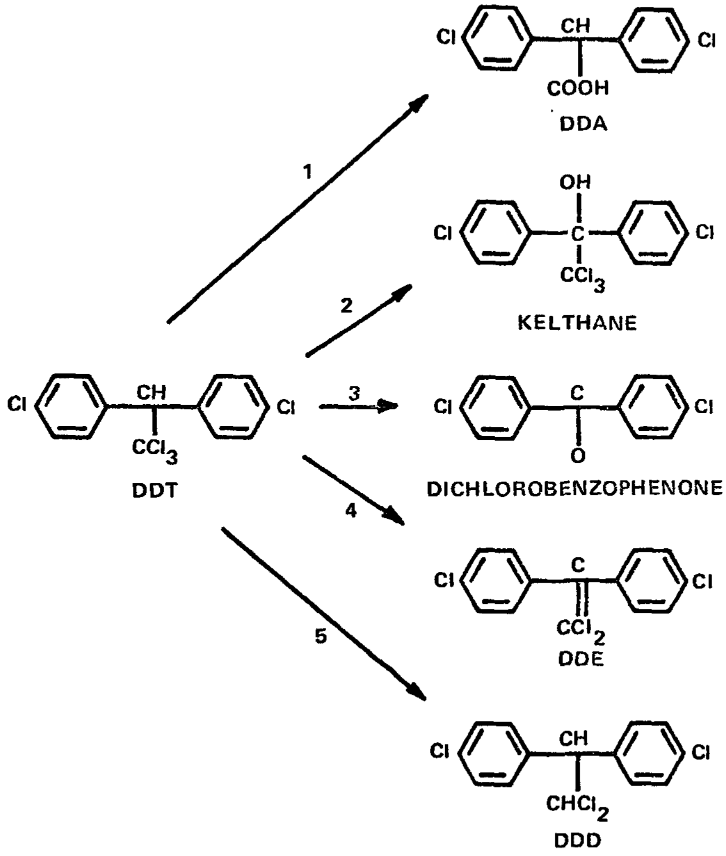


Figure 4.6 ROUTES OF DDT METABOLISM

concentration high enough to obtain a 95-99 % kill. The evaluation of alternatives (environmental contamination versus resistant strains) is, at best, a subjective choice and offers a real paradox.

One interesting study by Randall[4.127] on the spruce budworm, suggested that this insect was developing resistance to DDT in New Brunswick forests. A recent publication by Carolin and Coulter[4.128] in northwest Canadian forests discounted the former author's findings and further stated that parasites of the budworm were not affected by DDT sprays.

The principal agents for the degradation of DDT in the forest ecosystem, however, are not the macroscopic life forms but rather the microbes and in particular those in the soil. Kaufman[4.129] indicated that for halogenated acids, the rate of decomposition decreased with increasing numbers of chloride atoms. Although individual reports of pathways may vary, the overall pattern of degradation follows the patterns as outlined above, with the exception that microbes may utilize ring materials as carbon sources.

The literature on Sevin degradation is not as complete as that of DDT. A number of products may result from Sevin metabolism (Figure 4.7), and many others remain unidentified. The principal metabolite resulting from hydrolytic cleavage is 1-naphthol and in most mammals studied, this product is rapidly conjugated with glucuronides and sulfates for excretion.[4.130-4.133] Baron, et. al.[4.134] confirmed one of the metabolites in cow urine and milk as 5,6-dihydro-5,6-dihydroxynaphthol.

Insects, in addition to naphthol, will give rise to a variety of hydroxy and dihydroxy derivatives.[4.134-4.136]

Sludge bacteria utilize Sevin as a carbon and nitrogen source (Baum, unpublished report) while other soil microbes may hydrolyze phenyl carbamates.

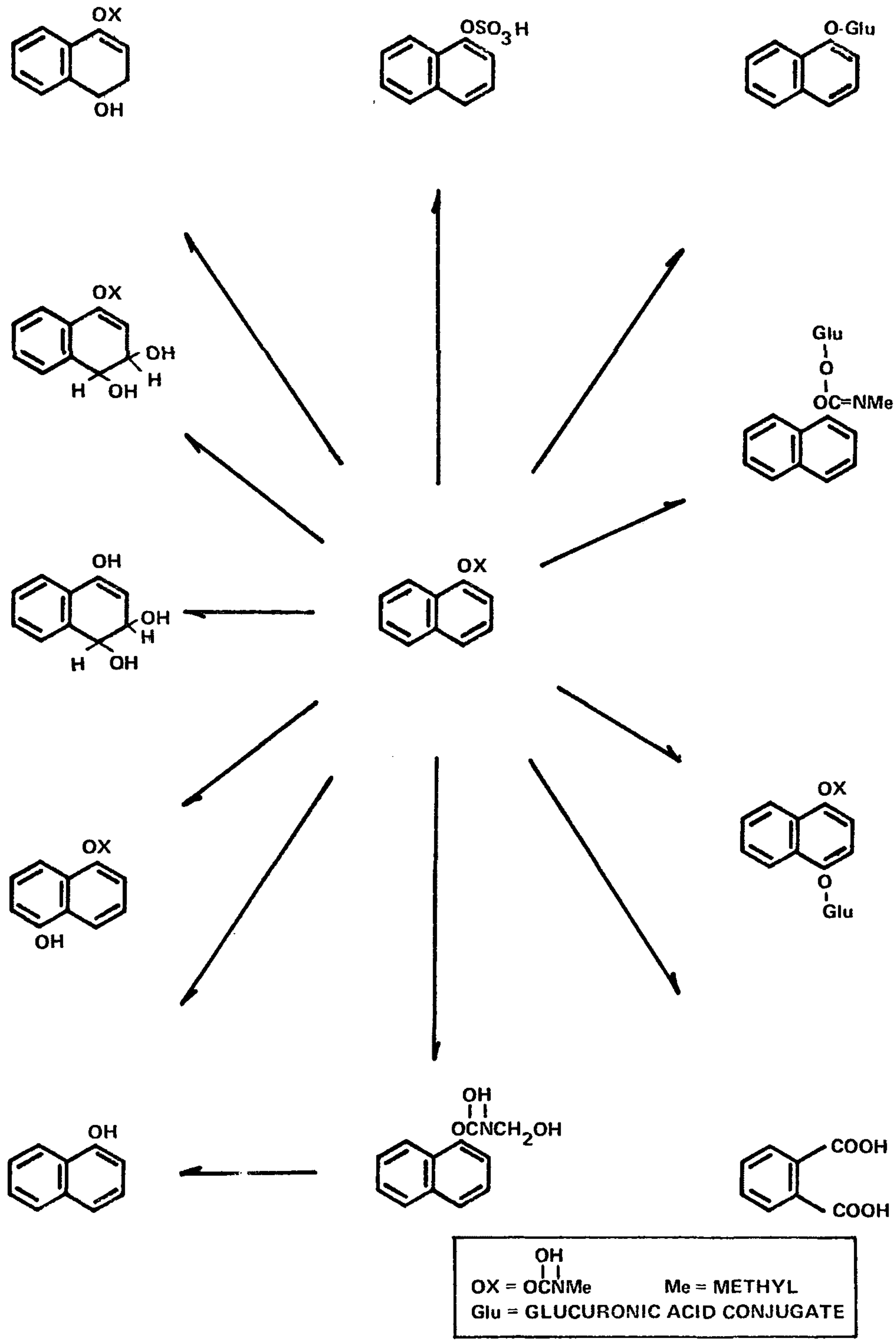


Figure 4.7 POSSIBLE METABOLIC AND CATABOLIC PRODUCTS ARISING FROM DEGRADATION OF SEVIN

Even green plants may metabolize Sevin into water soluble derivatives.[4.137] The picture is a confusing one at present, yet all agree that the parent molecule is rapidly degraded into a variety of metabolites by many different enzymatic pathways. O'Brien[4.126] refers to cockroach production of a "...galaxy of metabolites."

A-4.3.3 Bioconcentration and Toxicity of DDT and Sevin in the Forest Environment

Leaching, overland water runoff and sediment runoff of applied pesticides from forested areas are normally negligible mechanisms for the endangerment of aquatic life. A different set of problems is encountered when the interaction of pesticides with in situ forest soil environments is considered. Because of the long-term persistence of DDT in forest soils, long-term effects on soil-dwelling organisms and food chains must be considered.

Chlorinated hydrocarbon insecticides, including DDT, have been found to be relatively nontoxic to earthworms but do accumulate in fatty tissue.[4.138] Dimond, et. al.,[4.139] presented data on residual DDT and metabolite concentration in samples of earthworms collected from contaminated forest soils. He concluded that although there were too few samples to show a clear pattern of persistence, residues in worms appeared to reflect residues in soils with all samples from treated areas being higher in DDT content than those from untreated soils and with the highest residues in worms coming from soils that were treated two or three times. Yule[4.140] found that surface-dwelling insects in forest soils contained more DDT than the average (6 in) content of topsoil habitat but less than in litter only. Edwards[4.141] summarized available data on chlorinated hydrocarbon accumulation in soil organisms and calculated concentration factors. His data concerning DDT are reproduced in Table 4.VI.

Biomagnification of residues in birds resulting from DDT application in forested areas has been reported. Following DDT treatment of 0.75 lb/acre for white fir sawfly control, Herth and Flickinger[4.142] found that residues in robins were at or below pretreatment level in 3 months after treatment whereas juncos and chickadees had accumulated residues of 231 and 638 % of early post-treatment levels. Dimond, et. al.,[4.139] found that levels of DDT in robin populations from forested areas treated at 1 lb/acre appeared to reflect levels of soil contamination and were probably as persistent. His data showed no decline in residues in robins up to 9 years after treatment even though lower levels should be expected. Assuming that robins receive much of their DDT burden from feeding on earthworms, he found that magnification of DDT residues in robins amounts to one order of magnitude over earthworms. Herth and Flickinger's data thus conflict with Dimond's. The consistency of DDT persistence shown by Dimond's data for every year up to 9 years after application reinforces the belief that DDT does, in fact, persist in robins for long periods of time.

There have been studies which strongly implicate the observed mortality of birds to high accumulations of DDT in body tissue. These studies involved the ground spraying of Dutch Elms and therefore probably resulted in very high dosages over localized areas.[4.143,4.144] Dimond, et. al.,[4.139] found that DDT and metabolite residues in robins collected from DDT-treated forested areas were well below lethal dosages. He further states that higher levels of DDT may be present in other types of forest birds (i.e., fish feeders and predators) and that it is difficult to dismiss the possibility that certain birds are

Table 4-VI

RESIDUES OF PESTICIDES IN SOIL INVERTEBRATES AND THEIR ENVIRONMENT

LOCATION	REFERENCE	NO. OF SITES	SOURCE OF RESIDUE	DDT & RELATED COMPOUNDS		
				MAX.	MEAN	CON. FACTOR†
GREAT BRITAIN	STRINGER & PICKARD 1963 (247)	1	SOIL (ORCHARD) EARTHWORNS (L. TERRESTRIS) OTHER SP.	26.6 – 13.7 14.0	11.4 – 7.7 8.1	– – 0.67 0.71
GREAT BRITAIN	DAVIS 1968 (55)	10 2	SOIL (ARABLE) EARTHWORNS SOIL (ORCHARD) EARTHWORMS	0.8 0.05 17.2 40.0	0.3 9.7 19.6	– 0.06 – 2.10
GREAT BRITAIN	EDWARDS (UNPUB-LISHED)	2	SOIL (ARABLE) EARTHWORMS	– –	– –	– –
GREAT BRITAIN	WHEATLEY & HARDMAN 1968 (283)	1	SOIL (ARABLE) EARTHWORMS L. TERRESTRIS A. LONGA A. CALIGINOSA A. CHLOROTICA A. ROSEA O. CYANEUM	– – – – – – – –	0.93 – 1.1 1.34 2.5 4.6 2.6 1.24	– – 1.18 1.43 2.68 4.86 2.78 1.33
GREAT BRITAIN	DAVIS & HARRISON 1966 (57)	2	SOIL BEETLES SLUGS SOIL BEETLES SLUGS	0.8 2.3 – 17.2 5.2 40.1	0.3 – – 9.7 – –	– 2.81 – – 0.31 2.33
U.S.A.	BARKER 1958 (10)	1	SOIL EARTHWORMS L. TERRESTRIA L. RUBELLUS O. LACTEUM H. ZETEKI H. CALIGINOSIS TRAPEZOIDES	– – – – – – –	9.3 – 19.2 680.0 173.0 492.0 106.0	– – 2.06 73.10 18.6 52.8 11.3
U.S.A.	HUNT 1965 (136)	1	SOIL	–	9.9	–
U.S.A.	HUNT 1965 (136)		EARTHWORMS L. TERRESTRIS	– –	– 140.6	– 14.2
U.S.A.	IN DUSTMAN & STICKEL 1966 (71)	3	SOIL EARTHWORMS	3.0 25.0	1.8 17.0	– 9.44
U.S.A.	U.S.D.I. 1967 (266)	67	SOIL EARTHWORMS	– –	0.98 9.64	– 9.8
U.S.A.	U.S.D.I. 1966 (265)	1	SLUGS SLUGS	– –	42.7 19.7	– –
U.S.A.	U.S.D.I. 1967 (266)	2	SOIL EARTHWORMS	– –	– –	– –
U.S.A.	DOANE 1962 (65)	1	SOIL** EARTHWORMS	– –	12.5 43.0	– 3.44
GREAT BRITAIN	CRAMP & CONDER 1965 (48)	1	SOIL EARTHWORMS SLUGS	0.69 1.20 2.55	– – –	– 1.73 3.70

*mg/kg.

†CONCENTRATION FACTOR = $\frac{\text{CONCENTRATION IN ANIMAL}}{\text{CONCENTRATION IN SOIL}}$

**ppm CALCULATED FROM INITIAL DOSE RATE.

threatened for periods of many years by one or a few light applications of DDT over large areas.

In contrast to DDT, Sevin and other carbamate insecticides are highly toxic to earthworms and have resulted in appreciable decreases in earthworm populations in agricultural soils[4.145,4.146] and grasslands.[4.147] Barrett[4.148] conducted intensive studies on the effects of Sevin on a grassland ecosystem but did not include earthworms. He found that although Sevin applied at a rate of 2 lb/acre remained toxic for only a few days, the total biomass and numbers of anthropods were reduced more than 95 %. After 7 weeks, total biomass but not total numbers returned to control level.

Of perhaps greater concern with respect to the forest environment was the highly significant decrease in litter decomposition which Barrett attributed to be the result of a reduction in microanthropods and other decomposers. Edwards[4.145] also expressed concern for the effect of insecticides on populations of soil-forming organisms in forest soils (i.e., earthworms, enchytraeid worms, wood lice, millipedes, mites, springtails, termites, and beatle and fly larvae). Forest soils could conceivably become infertile without recycling of nitrogen, phosphorus potassium and other mineral constituents engendered by microbial and insect degradation of forest litter. The loss of organic and mineral soil mixing and aeration promoted by earthworms and other soil organisms could further result in massive soil structure that is not suitable for root penetration.

The literature review uncovered no studies involving the possible inhibiting effects of Sevin on soil-forming processes in in situ forest soils. However, analysis of the disposition of Sevin at the 1 lb/acre dosage normally applied in New York spraying programs indicates that the problem may not be serious. From field studies, it is estimated that only 50 % of applied pesticide (i.e., Sevin) or 0.5 lb/acre directly reaches the ground at the time of application. Later additions from leaf wash probably have negligible toxicity because of the rapid degradation on leaf surfaces. Previous studies showing toxicity of Sevin to soil organisms were at much higher dosages (2 lb/acre).[4.141,4.148] It appears probable that the insecticide reaching the forest floor would migrate very slowly through the highly organic litter and be appreciably decomposed before depths of maximum biological activity were even reached. Nevertheless, studies should be initiated to determine if soil-forming processes in the forest soils of New York can be impaired by continued usage of Sevin or other insecticides. First, it is necessary to estimate how much of the aerially applied pesticide reaches the forest floor at the time of application and how much is added by leaf wash-off up to a period of 1 week after application. It is especially important to determine how long it takes for re-establishment of normal soil biotic communities after application of Sevin. This would provide guidelines on how often the forest may be sprayed without cumulative or permanent ecologic consequences to soil biota and related food chains.

There are no studies indicating bioconcentration of Sevin or toxic metabolites in forest biota. It is doubtful if bioconcentration can occur because of the rapid Sevin breakdown in natural systems.[4.148-4.150]

A-4.4 Antagonism and Synergism

The action of one compound upon the effects of another in a single system may be termed as being either antagonistic or synergistic. These two terms, long used in describing the effect of additives on pesticides used in small quantities, will be discussed in this section to illustrate current literature trends in the field of pesticide research.

For the purposes of this brief review, the definitions of Williams[4.151] will be used for antagonism and synergism. Williams describes antagonism as the combined effect of two agents that tends to lessen the gross effect of both the agents, as in using an antidote to treat a poison case or by speeding up metabolic rates so that the primary toxicant may be more quickly reduced to less toxic metabolites. Synergism, on the other hand, is the interaction of two compounds to produce a potentiating effect greater than the sum of the separate effects of either agent alone. For example, parathion has a greater toxicity for individuals who use the tranquilizer chlorpromazine.

A-4.4.1 DDT

The first topic to be considered herein involves the synergistic effects of DDT with other materials or physical states. McLean, et.al.,[4.152] have shown that rats suffering from protein depletion suffer disproportionately greater harm from DDT exposure than do rats fed with a normal diet. This occurs because protein depletion causes activity of the microsomal hydroxylating enzyme systems and the cytochrome P-450 contents of the liver to fall to one-third or less of the normal level in only 4 days. Protein depletion may, therefore, augment liver damage caused by aflatoxin because the toxin is not metabolized to an inactive product any longer by the microsomal hydroxylating enzyme system. Induction of enzyme synthesis by DDT or phenobarbitol is also inhibited. Protein depletion may protect against liver damage or other effects when the actual damaging agent is a product of an enzyme system suppressed by protein lack (e.g., carbon tetrachloride or glycerine). This beneficial effect is reversed by administration of DDT or phenobarbitol. Protein depletion does not alter the toxicity of cloroform given as a sing'e oral dose. Enzyme induction phenytoin was more potent than phenobarbitone in reducing DDE blood levels. In another case[4.153], a 42-year old pesticide formulator was noted to contain zero or trace amounts of DDT and DDE residues in his serum. He had been employed for over 16 years in a plant that formulated DDT prior to 1964. The last formulation involving DDT took place at the plant in the spring of 1970. Over the same period that the man had been observed, 1967-1971, his fellow workers (29 individuals) with 10-25 years experience and consequent exposure had, at their last measurement in July 1970, 24 ppb p,p'-DDT and only 0.5 ppb p,p'-DDE. These figures are contrasted with the general population that had, in 1969, 4.4 ppb p,p'-DDT and 14.9 ppb p,p'-DDE. The subject in this case had been taking 30 mg phenobarbitol t.i.d. and 100 mg diphenylhydantoin t.i.d. for over 25 years to control post-traumatic epilepsy. Table 4.VII lists the effects of these anticonvulsant drugs on body DDT burden in the larger sampling described by Davies, et.al.[4.154].

The activity of synergistis in biological systems is dependent on their mode of metabolism. Fishbein, Falk, Fawkes and Jordan[4.155] investigated the action of piperonyl butoxide, Tropital and actachlorodipropyl ether. This brief discussion will focus on the activity and metabolism of methylenedioxybenzene derivatives, of which piperonyl butoxide and Tropital are examples. Falk and Kotin[4.156], likewise, treat this subject in a recent paper. They attribute the

Table 4-VII

EFFECT OF ANTICONVULSANT DRUGS
ON BODY DDT BURDEN

	DDE LEVEL (ppb)		DDT LEVEL (ppb)
	IN BLOOD	IN FAT	IN FAT
CONTROL	9.1	—	—
OUTPATIENT ON PHENOBARBITONE	3.5	—	—
OUTPATIENT ON PHENYTOIN	1.9	—	—
OUTPATIENT ON BOTH DRUGS	1.7	—	—
INPATIENT ON BOTH DRUGS	0.8	0.09	0.17
INPATIENT CONTROL	4.5	2.08	2.70
GENERAL POPULATION	—	5.5	8.4

synergistic action of these compounds with pesticides to the inhibition of enzyme systems or the prevention of enzyme induction. With chlorinated hydrocarbons such as DDT, dehydrochlorination to the less active DDE may be prevented. On the other hand, with thiophosphonate compounds, activation is prevented with DDT in protein-depleted rats makes them more sensitive to lethal and hepatotoxic actions of chloroform. Protein depletion may, therefore, protect one organ at the expense of another. For example, dimethylnitrosamine, which requires demethylation in a microsomal enzyme system before it can exert its toxic effects causes severe liver necrosis in normal rats. In protein-deficient rats, on the other hand, the severity of liver necrosis is greatly reduced but all survivors die of kidney tumors because of the decrease in liver clearance of dimethylnitrosamine which allows the toxin to contact the kidneys. In general, if the site of relevant interaction between a toxin and a cell is also the site altered by the diet, changes in the diet will probably alter the toxic effect of the toxin.

It has been shown that diet is important in maintaining metabolic potential over toxins introduced either intentionally or accidentally into a living organism. Of equal importance is the interaction of pesticides with naturally occurring materials found either at the site of pesticide application or, and perhaps more importantly, found at the site of accumulation of the pesticides following runoff or other natural processes into waterways. Wershaw, et.al[4.157] have demonstrated that DDT is a 0.5 % solution of sodium humate which is at least 20 times as bioactive as a DDT solution alone. This tends to indicate that other naturally occurring polyelectrolytes may act similarly with members of the spectrum of organochlorine compounds that may be found in the environment. Another interesting example of synergism is the interaction of two commonly used pesticides: DDT and dieldrin. Macek, Rodgers, Stallig and Korn[4.158] have shown that in rainbow trout DDT accumulation is enhanced by the presence of dieldrin, while DDT markedly decreased the rate of accumulation of dieldrin. Similarly, DDT elimination was decreased in the presence of dieldrin but dieldrin elimination was not enhanced by the presence of DDT.

Cain[4.159] stated that DDT and 2, 4-D synergise with respect to fish toxicity. The impact of DDT and parathion are more than additive[4.160].

Dugan, Pfister and Sprague[4.161] studied a New York watershed emptying into Lake Ontario and assessed its burden of several organochlorine pesticides and detergents. Following the evaluation, they generated data concerning the effect on goldfish of the susceptibility to three organochlorine pesticides as a function of exposure to alkylbenzenesulfonates. They determined that chronic exposure to 4 ppm alkylbenzene-sulfonates results in a much greater susceptibility to three types of chlorinated hydrocarbons: DDT, dieldrin and endrin. This finding is supported by the work of other investigators that found correlation between nutrient uptake by cells and presence of surfactants.

The antagonistic effect of certain anticonvulsant drugs on the action of DDT has been shown for humans. Davies, Edmundson, Carter and Barquet[4.154] followed the p,p-DDT levels in 77 outpatients and 48 chronically nonambulant mentally defective inpatients who had been taking anticonvulsant drugs (phenobarbitone and/or phenytoin or diphenyl hydantoin) for more than 3 months for convulsive disorders. The study was confined to white patients greater than 6 years old. The DDE levels (principal DDT metabolite) were strikingly lower in patients on anticonvulsant drugs than in the general population. It was determined that this lead to a net antagonistic reaction with these compounds.

A-4.4.2 Sevin

Singh[4.162] studied the effects of carbaryl and caffeine on albino rats. The interaction in this case is antagonistic since the carbaryl treated rats showed minor tremors, salivation and urination while caffeine treated animals, in addition to being alert and displaying none of the above symptoms, predictably increased their performance in activity wheel cages.

In another study, 30 derivatives of propynyl naphthyl ethers were synthesized and evaluated as synergists for carbaryl against houseflies. Sacher, et.al.,[4.163] reported that the most active in the series was 1-naphthyl-3-butynyl ether. The synergistic ratio was 176.5. They also found that the ether was not harmful to white mice, probably owing to the fact that the ether is channelled into two different metabolic pathways between the housefly and laboratory mouse. In another study involving houseflies, Bakry, Metcalf and Fukuto[4.164] investigated benzyl thiocyanates, benzyl isothiocyanates, phenyl thiocyanates and alkyl thiocyanates for mode of action as insecticides and carbaryl synergists. They found that for aliphatic thiocyanates the synergistic ratio with carbaryl increased fourfold from C_4 to C_{12}.

Falk and Kotin[4.156] in their article on pesticide synergists and their metabolism, point out two important areas involving these interactions that need attention and caution. The first concerns the buildup and storage of synergistic agents in the mammalian (human) organism, and the second relates the danger of some of these synergists when taken in combination with high doses of certain drugs as medications.

A-4.5 Impact on Humans

The evaluation of the human health threat presented by the use of pesticides has been the subject of many reviews over the past few years. The exposure of the American public to pesticides has been either very high, as in the case of pesticide workers (those involved in manufacturing, formulating and application) or very low (the average non-occupationally exposed person). The former group represents a ready source of individuals for the study of the effects of chronically high exposure to pesticides.

The use of pesticides in this country has increased greatly since the commercial introduction of DDT after World War II. Despite this fact, the death rate due to pesticides has remained stable since 1939[4.165]. In 1961 the mortality rate for pesticides (including fumigants) was 0.65 per million population although the ratio of non-fatal to fatal poisoning cases was 100 to 1. Since the death rate has remained stable over this period despite the higher use and greater availability of pesticides, indications point to the fact of greater safety being exercised with these materials. Additionally, since approximately one-half of the pesticide fatalities involve children, the current rate can be potentially halved simply by childproofing pestide containers and embarking upon a program of education wherein the safer use and handling of pesticides in and around the home is stressed.

The fate of the pesticide worker in any phase of the production, formulation or application of pesticides varies with the organization he is associated with[4.166]. For example, the pesticide worker in a modern manufacturing plant, since the corporate structure represented therein demands high working standards, is exposed to greater hazard driving to and from work than while at work manufacturing pesticides. Small formulating plants, on the other hand, may employ people under working conditions that make pesticide exposure a daily occurence. Structurally pest control operators characteristically have no fear of their "favorite" compounds and are not described as being careful. This group is sometimes heavily exposed but manages to stay on the job by avoiding excessive exposure.

A-4.5.1 DDT

The literature abounds with reports containing data on the effect of DDT on the human body in various stages of life. Westermann[4.167] states that the average American had, in 1969, 50 mg of DDT in his body. Oral doses of 10 to 20 mg have induced toxic symptoms in man and this same dose is sufficient to kill more than 1000 tons of flies. Durham[4.168] indicated that there has been no significant increase in the storage of DDT by the general population of the United States since this parameter was first measured in 1950. Many writers and scientific investigators around the world have been concentrating their efforts on delineating the problem of the growing DDT residue potential in the human sphere of influence. Kadis, et.al.[4.169] examined 217 tissue samples from autopsies performed in Alberta, Canada in 1967 and 1968. They found that the mean concentration of p,p'DDE, -DDD and -DDT in adipose was 4.34 ppm. The levels in other tissues were according to the following scale: liver, kidney, gonad, brain. No correlation was found between accumulated level and age of subject. The concentration of p,p'DDE and -DDD was higher in ovarian than in testicular tissue, but the DDT concentration in male fat was higher than in female fat. The difference in the presence of DDT metabolites in the male and female gonads is probably due to the difference in cyclic change associated with the organs.

A survey of 1500 poisoning cases lead to the publishing of a paper by V.I. Pol'chenko[4.170]. In it, the author describes the typical symptoms of DDT poisoning: ordinary widespread disorders of the gastro-intestinal, respiratory, nervous and cardiovascular systems, as well as blood, liver and skin diseases. A literature survey Durham[4.171] states that practically the entire American population has some DDT residues in its tissues. The 1969-reported mean storage level was 3 ppm as DDT and approximately 8 ppm as DDT equivalent for metabolites of DDT. It further states that no significant increase had taken place in the period 1950 to 1969.

As fish accumulate DDT primarily through their food chain[4.28], so do most other organisms. Since man is at the top of the food pyramid, he has the dubious benefit of receiving the highest intake concentrations because of the concentrating action of all his predecessors in the food chain. The significance of pesticide residues in the food of humans was stressed by Kraybill[4.172] in his article reporting the differences in pesticide levels in foods depending on preparation source. For the period 1962 to 1964, household meals contained 0.314 mg DDT and 0.173 mg DDE while restaurant meals contained 0.038 mg DDT and 0.44 mg DDE as reported by the Public Health Service. This difference is interesting in that the private shopper (housewife) purchases foodstuffs on the basis of cosmetic value more than anything else. The restauranteur on the other hand pruchases for price and value. Consequently, his purchases may not be as pleasing to the eye as those of a private purchaser, but do represent a lower level of pesticide content because of the mode of agriculture it represents.

The question of human toxicity has been investigated in people exposed to varying levels of DDT. This section will deal with the effects of DDT on various systems of the body. O'Leary, Davies and Feldman[4.173] measured blood levels of p,p'DDT and -DDE in obstetric patients in Dade County, Florida. The venous blood of 28 Caucasians and 73 Negroes was sampled following or during spontaneous abortion. In addition, samples from 45 Caucasians and 107 Negroes served as controls. The results indicated that gestational exposure to DDT is not a significant abortifacient stimulus. No relation between age or parity and DDT levels was noted but DDT levels were significantly higher among Negroes. In another study, Rappolt, et.al.,[4.174] reports that 39 stillbirths studied in Kern County, California in 1964 and 1965 had associated with them high levels of p,p'DDT and p,p-DDE, its metabolite. The organochlorine compount concentrations in tissues of 35 pregnant women, 33 non-pregnant women in the fertile portion of their lives and 23 neonates were documented in another study[4.175]. During pregnancy, the storage of p,p'-DDT, -DDD, o,p'-DDT and o,p'-DDD, o,p'-DDE and total o,p'-DDT is reduced in adipose. The same effect was observed for dieldrin and BHC isomers. All the organochlorine insecticides found in the adipose of pregnant women was also found in maternal and fetal blood samples suggesting that in pregnancy the metabolism of organochlorine insecticides is enhanced and these agents can pass through the placental barrier. The placental passage of pesticides was investigated by O'Leary, et.al.[4.173] by monitoring p,p'-DDT and -DDE levels in human blood during pregnancy. Fortyfive Caucasians and 107 Negroes in late pregnancy were sampled. Fortyseven paired samples of maternal and cord blood were analyzed as well as 70 paired samples from newborns (24 Caucasians and 46 Negroes). The amnionic fluid of 42 women at or near term was sampled, as well as 12 paired samples of vernix caseosa from back and axilla of newborns, and 12 placental samples. The DDE concentration of 152 blood samples in pregnant women ranged from 3 to 92 ppb (mean in Caucasians was 10.8 ppb; mean in Negroes was 15.2 ppb). The DDE concentration in the cord blood of 70 neonates was a mean of 4.8 ppb in Caucasians and 5.9 ppb in Negroes. These figures indicate that the DDE concentration in Caucasians does not differ markedly from that in Negroes. However, the data on DDT levels among the two racial groups is markedly different. Caucasian maternal blood has a DDT level of 17 ppb, while that of Negroes was 32 ppb; the cord blood of Caucasians contained 5 ppb DDT, while that of the Negroes contained 9 ppb and the amnionic fluid of Caucasians had a DDT level of 6 ppb, while the Negroes level was higher at 14 ppb. Despite the implication that the Negro retains higher levels of DDT, it is also apparent that DDT does indeed permeate the placental barrier. The effects of this on the fetus are not completely understood and, in the opinion of the authors of the referenced article, should be thoroughly investigated.

The personnel in the previous study probably didn't have a marked occupational exposure to DDT in the time during which they were sampled since they were pregnant. Yet, their tissues contained considerable quantities of the pesticide. A study undertaken in the Ukraine from 1964 to 1965 bears this out. Therefore, the problem is not one confined to the United States. The author of the Ukrainian study (Gracheva, 1969) concludes that the main source of non-occupationally exposed persons to DDT contamination must be through the food chain. So it is with neonates as well. In some countries the primary source of food for newborn infants is from human milk. A study conducted on residents of Kiev[4.176] and its surroundings indicates that for the urban group, a substantial proportion (74.6 %) contained detectable amounts of DDT in their milk. Also examined were women from an agricultural area with a high use rate of DDT. The group had an identical incidence of DDT in milk with the urban group, but the mean DDT concentration was higher (0.19 mg/l vs 0.10 mg/l). The investigator also generated more data supporting the passage of DDT through the placental barrier. A similar study conducted in Eastern Europe[4.177] was concerned with milk samples of both urban and rural dwelling women. The combined level of p,p'-DDT, -DDE and -DDD was 12.87 ppm.

A number of reports have been published in recent years documenting the state of various human organs after occupational and low-level exposure to DDT. This section will briefly describe a number of these. Phillips, Ritcey, Murray and Hoppner[4.178] found no obvious correlation between the level of organochlorine compound ingestion and the incidence of low Vitamin A stores in the liver.

Paramonchik[4.179] reported on the functional state of the liver in workers engaged in the manufacture of organochlorine compounds, among these was DDT. Liver function studies were performed on 360 workers with varying exposure to DDT. Most workers with DDT and hexachlorane for 11-15 years. A few had other slight contact with organochlorine compounds of hepatotropic action. Of the 208 workers synthesizing DDT and preparing DDT dust and paste, functional liver changes were found in 54 individuals. Krasniuk, et.al.,[4.180] studied 100 workers in a DDT manufacturing facility. The antitoxic function was disordered in 58 out of 80 tested. In addition, the urinary excretion was up to 75 % below normal and the carbohydrate function was disordered in 69 workers. Paramonchik and Platonova[4.181], in yet another study, discussed the functional state of the liver and stomach in persons occupationally exposed to the action of organochlorine compounds. The 70 persons were occupationally exposed to the action of organochlorine compounds. The 70 persons examined were employed in the production or use of organochlorine compounds, consisting of both men and women in the age group 21 to 50 years, most with greater than 10 years experience and consequent exposure. Thirty one members of the examined group had symptoms of a mild toxic action. In 20, initial signs of chronic organochlorine intoxification appeared (toxic diencephalitis, polyneuritis or initial symptoms of toxic hepatitis). The remaining 19 had no signs of organochlorine-induced disorders. Changes in the gastrointestinal tract appeared as chronic gastritis and peptic ulcers. Workers with less than 10 years exposure experienced intensification of the acidogenic and pepsin-secretory functions of the stomach and insignificant liver disorders. Workers with greater than 10 years exposure had definite disorders of the liver functions, as well as a depression of the two stomach functions found in workers with less than 10 years exposure.

The levels of DDE, DDD, DDT, dieldrin, β-BHC and heptachlor epoxide were determined at autopsy in the fat and liver of 271 patients who previously exhibited various pathological states of the liver, brain and other tissues. Radomski, et.al.,[4.182] in reporting these findings, compared them with the results of random autopsies and with a group designated "infectious diseases." There was a striking lack or correlation between pesticide concentration in the fat and liver of all the cases. There was, however, a significant correlation between pesticide levels in the fat and brain. In the presence of brain tumors, no increase in pesticide level in the brain was noted over that found in normal brain tissue. But a higher level of DDE was found in the brain of those afflicted with encephalomacia and cerebral hemorrhage. A highly significant elevation of pesticide levels was found in all cases of carcinoma of various tissues, particularly, the DDE concentrations in metastatic liver disease was 7 times higher than normal. Significantly elevated levels of DDE and dieldrin were found in portal cirrhosis, but not in fatty metamorphosis. Levels of DDT, DDE, DDD and dieldrin were consistently and significantly elevated in the fatty tissue of those cases that suffered hypertension. Those home pesticide users who used high levels of these products had 3-4 times the DDT and DDE level as those who used minimal quantities. This indicates that pesticides used in the home have a tendency to accumulate in the dwellers, probably because the agents find their way into the food consumed in the household in high levels.

The functional state of the stomach has been described for workers exposed to significantly high DDT levels in their ambient environment by Platonova[4.183]. A significant frequency of complaints of a dyspeptic nature were the following: loss of appetite, heartburn and nausea, pains in the epigastric region and right hypochrondium and disordered stools. More than 51 of the 102 workers surveyed and examined had disordered secretory and acidogenic functions of the stomach (either intensified or depressed). Gastric enzymatic function was altered, usually as intensification. An increase of the number of organic diseases paralleled an increase in work experience with organochlorine pesticides. This discovery led to the hypothesis that changes in the functional state of the stomach are caused by disorders of neural reflex regulation of gastric secretions. Krasniuk and Platonova[4.184] investigated 558 persons in contact with organochlorine poisons. Of this number, 234 manufactured DDT and preparations, 148 worked with DDT and hexachlorane and the balance worked with hexachlorane alone. A study of the stomach contents and X-ray examinations established that functional gastric disorders or chronic gastritis occurred in 2.2 % of the DDT owrkers, 17 % of the hexachlorane workers and 29 % of the DDT-hexachlorane group. In a control group of 216 persons, the frequency of similar gastric pathology was 6.5 %. In addition, the stomach disorder frequency increased with the length of work exposure: 14 % had up to 5 years experience; 18.9 % had from 6-10 years exposure and 31.8 % had more than 10 years exposure.

The renal system is also covered in some detail by investigators in the field. Loganovskii[4.185] studied 106 workers with a history of prolonged exposure to small amounts of DDT, hexachlorane and ether sulfonate. While the findings confirmed those of other body systems, the urinary findings were predominantly normal. Renal disorders, it is thought, may be the result of direct action of organochlorine compounds on kidneys or by way of their injurious effect(s) on other organs or systems. In another publication[4.186], Loganovskii investigated the state of glomerular filtration and tubular reabsorption in the kidneys of persons exposed to organochlorine compounds over long periods. The exposure time was greater than 10 years. Prolonged contact with small quantities of DDT, hexachlorane and ether sulfonate leads to disordered glomerular filtration and tubular reabsorption. These effects are most clearly seen in workers exposed for from 10-15 years and in those with chronic intoxification. The exposure for 3-5 years increased the rate of glomerular filtration, while exposures of from 10-15 years caused this parameter to decrease. Significantly, fewer disturbances were noted in tubular reabsorption. Krasniuk, et.al.,[4.187] noted not only functional changes of the kidneys in accordance with the findings of others but also characterized morphological alterations within the microstructure of the kidney. Morgan and Roan[4.188], on the other hand, failed to find evidence of chronic occupational differences in glomerular filtration and tubular reabsorption between a group of 65 pesticide workers and 23 controls. However, the pesticide workers in this test were occupationally exposed to organophosphates as well as organochlorine pesticides.

Edmundson, Davis and Cranmer[4.189] studied the effect of DDT aerosol exposure on the blood and urine levels of DDT and DDE and DDA. First-day blood samples showed no correlation between blood levels of DDT and DDE, the amount sprayed and the spraying time. There was, however, a slight correlation between the excretion time of DDA and the amount sprayed and the spraying time. A study was conducted to determine the epidemiological significance of serum DDT level in three groups of men exposed to decreasing levels of DDT[4.190]. Blood samples were taken bi-monthly in 1968. No clear relationship was found between the degree of occupational DDT exposure and the total serum DDT level. All groups exhibited a 6- fold increase in total serum DDT level in the period between April and August. They also exhibited a relative decrease in serum DDE level for the same period. The results indicate that local agricultural and municipal insecticide programs increase DDT exposure to all subjects, regardless of the degree of occupational exposure. Also, DDT appeared in the sera soon after absorption from the external environment.

Edmundson, et.al.[4.191], published a study of the p,p'-DDT and -DDE levels in personnel occupationally exposed to DDT. DDT was detectable in 80 % of the control group but was below the consistently measurable level (7 ppb). In the occupationally exposed group, the mean of white workers was less than 7 ppb except for white formulators (21 ppb) and aircraft sprayers (25 ppb). The non-white members of the exposed group were noted to have: 40 ppb for formulators, 10 ppb for floral sprayers and 32 ppb for agricultural sprayers. There was no evidence of clinical toxicity during the 2-year observation period. It was noted that the DDT blood level depends on the recency of exposure while the DDE blood level is a stable value. Another study [4.191] measured the serum lipoprotein value of persons long exposed to the action of organochlorine compounds. The exposure was via airborne DDT in various stages of production. In addition, the levels of hydrogen chloride, chlorobenzene, hexachlorane and chlorinated derivatives of phenols were quantified. Changes were detected in the ratio of alpha-to-beta-lipoprotein levels in both directions. A simultaneous study demonstrated frequent hypoalbuminemia and hypergammaglobulinemia. The measurement of serum lipoprotein level proved a valuable supplementary index of liver function in relation to organochlorine compound exposure.

Ballistocardiography was used to detect the presence of marked diffuse changes in the myocardium and a disorder of its contractile function in workers exposed to organochlorine compounds[4.192]. Ballistocardiography was done on 58 individuals with electrocardiographic signs of extracardiac disorders in cardiac function and on 52 workers with diffused changes of the myocardium of a dystrophic type.

The therapeutic utility of DDT and its metabolites is being investigated by workers in the field. Greim[4.193] reported on the toxicity of DDT and the therapeutic utility in a recent article. The general features of DDT metabolism are discussed, as well as the reaction of DDT which may render it useful as a therapeutic aid by increasing the metabolic rate of the agent itself and also of certain drugs.

In addition to the use of DDT as a therapeutic aid, Hayes, et.al.,[4.194] reported on the effects of long term, high oral doses on the human organism. The average doses administered were 555 times the average intake of all DDT-related compounds by 19-year olds in the general population and 1250 times the intake of DDT itself. The investigators postulate that since no definite clinical or laboratory evidence of injury by DDT was found, the degree of safety with the use of DDT is high for the general population. In a prior study by Hayes[4.195], he reports on the feeding of volunteers with DDT dissolved in oil at doses of 0, 3.5, and 35 mg. per man per day. These men were on ordinary diets and the test included, in addition to the ten subjects, four controls. No clinical effects associated with the DDT dosage were detected.

A statement, found in the report by Hayes,[4.195] states: "Some of the diseases which are claimed to have increased because of DDT, in fact, have shown no increase. Some of the other diseases are increased largely because of the changing distribution of age groups in the population of the United States. Because of improvements in the control of communicable diseases of children and adults, a greater proportion of people live to be old enough to have cancer and those forms of heart trouble which strike in middle or old age".

This statement sums up the feeling of pesticide proponents in this country and probably around the world. There is irrefutable evidence that the use of pesticides has improved the lot of millions of people around the world; the malaria campaigns during and after the World War II being the best example.

Pennsylvania has been using pesticides for the control of the gypsy moth menace much the same as have other states in the northeastern part of this country. A publication describing this program[4.196] emphatically states that DDT as used in the gypsy moth program presents no hazard to human health. The report cites further work by Wayland Hayes, M.D. that involved a study of 40 men occupationally exposed to high levels of DDT. Despite storing relatively large amounts of DDT in their fat (average over 300 ppm), no adverse effect on the health of the men was noted. In addition, in a program involving the ingestion of DDT by human volunteers, no sensitization to the material was demonstrated on the part of the volunteers.

A-4.5.2 Sevin

The toxicity of Sevin of carbaryl (1-naphthyl-N-methyl carbamate) on humans has not, to this date, been well documented due to its relatively late entrance as an economic poison. Its primary mode of action, however, is as a cholinesterase inhibitor, and consequently, must be countered accordingly (atropine treatment, for example).

The mammalian toxicity of Sevin was discussed and examined in a paper by Carpenter, Weil, Palm, Woodside, Nair III and Smyth[4.197]. The study subjects included rats, dogs, rabbits and guinea pigs. The data generated indicates that under ordinary circumstances accidental exposure to Sevin in conditions accompanying forest site spraying would not prove harmful to these animals since rats tolerate 200 ppm in their diet without significant deviation from control animals and that dogs tolerate 400 ppm on the same basis. This study included information on metabolism, cholinesterase inhibition, alleviation of symptoms with atropine sulfate and their aggravation by pyridine-2-aldoxime methiodide, and the absence of neuromuscular degenerative potential, carcinogenic activity, and sensitizing propensity. The Sevin was administered as single doses via oral, parenteral, percutaneous and respiratory routes. Some of the test series included long term administration of the material via one or more of the above routes. A comparison of effects between Sevin and another cholinesterase inhibitor, parathion, indicates that although the Sevin dose was higher than was the parathion dose (0.56 gm/kg body weight versus 0.0093 gm/kg body weight) the parathion produced a slower but more progressive depression on plasma, erythrocyte and brain cholinesterase systems as compared with the higher doses of Sevin.

Farago[4.198] reported a case of fatal, suicidal Sevin poisoning. The man in question drank 0.5 liter of Sevin 80 solution and was hospitalized immediately. He was under aocoholic intoxication at the time of ingestion. Immediately upon hospitalization, gastric lavage was initiated and circulatory stimulants administered. The development of pulmonary edema and disordered vision attested to his worsening condition. Atropine was administered every

30 minutes, but atropinization was not observed. After administering 250 mg PAM, the pulmonary edema progressed. Death occurred 6 hours after ingestion. An autopsy and chemical analysis of the subject's blood, gastric lavage fluid, stomach and contents, intestines and contents, liver, kidneys and urine revealed a Sevin distribution of from 14.8 to 244.8 mcg % in the stomach, intestines and and gastric lavage fluid and 1.4 to 3.1 mcg % in the blood, kidneys, liver and urine. The cholinesterase activity of the blood was strongly inhibited at 0.12 delta pH/hr. Sevin absorption was so rapid that excretion had already begun, as attested to by the Sevin found in the urine. Since gastric lavage was begun within 30 minutes and the quantity found in the stomach was less than that found in the intestines (14.8 vs 17.6 mcg %), it is postulated that the lethal dose was absorbed within 1.5 hours of ingestion. In addition, it is documunted that from the course the poisoning took, PAM administration was an error, although death was, in the estimation of the authors, not preventable. In general, the autopsy results confirmed, in the human system, facts known about Sevin in other biological systems, viz, Sevin is rapidly degraded in the human system--1 metabolite was found in the stomach contents, 3 in the intestine contents, 4 in the liver and kidneys and 5 in the urine. Sevin itself, as noted earlier, was still present in all these tissues and fluids in lesser quantities.

The massive self-administered dose of carbaryl described in the preceding paragraph is probably not representative of cholinesterase inhibition poisoning because other effects due to the mass involved were presumably operative. The details of cholinesterase inhibition were discussed in a paper by Main[4.199]. The kinetics of this mechanism are detailed in a step-wise fashion for organophosphates and carbamates. The first step in the process involves the formation of a binding complex between the inhibitor and cholinerterase. This step, together with the phosphorylation or carbamation reaction, determines the inhibitory and consequently the toxic power of the compound. The theoretical and experimental contexts are defined within which valid estimates of the reversible equilibrium constant may be made. This constant measures the affinity or organophosphate and carbamates in the liver appears to be an important factor in the metabolism of carbamate insecticides in several animals, including man[4.200]. Dealkylation is the mechanism by which some carbamates are degraded to less toxic metabolites in the liver. In the process of this action, however, phospholipid snythesis and metabolism in the liver, as well as in the brain and heart, is lowered in white rats[4.201]. This same action has been observed for DDT. Over a short term, DDT and Sevin are about equal in their power to depress phospholipid metabolism. Long-term administration demonstrates DDT to be a stronger depressant on phospholipid metabolism than is Sevin.

The effect of carbamic acid derivatives on nucleic acid metabolism in the rat liver and spleen is described by Anina[4.202]. In this study, rats were sacrificed after receiving maximally tolerated doses of Sevin, carbine, diptal or TMTD in either aqueous suspension or oil emulsion via stomach tube. Enzyme activity and nucleic acid quantity were determined in the liver and spleen. Carbamates were noted to increase ribo- and deoxyribonuclease (RNA and DNA) activity compared with controls. A decrease in nucleic acids was noted in the spleen. All the carbamic acid derivatives increased the quantity of RNA in the liver. This effect was significantly higher with carbine and diptal as compared with the other derivatives. The effect of DNA varied with the identity of the derivative. Sevin and TMTD significantly increased the quantity of DNA in the liver, while diptal exerted a slight depressing action. While the nature of the increase in nuclease activity remains clouded, the data testifies to the intensity of the process of nucleic acid breakdown by carbamates.

Rats and mice were used as the subjects of a study of certain pesticides on the hypophysis and its gonadotropic function[4.203]. DDT and Sevin actions were seen as an increase in the luteinizing function of the hypophysis in white rats and in mice. The effect was more pronounced with DDT than it was with Sevin. In addition, both DDT and Sevin increased the esterus cycle and the duration of its phases in both rats and mice.

Boyd and Krijnen[4.204] studied the effect of protein intake on the oral toxicity of carbaryl in the rat. They found that the interval-to-death was not related to the amount of casein in the diet but the timing was inversely proportional to the dose of carbaryl.

Many of the cited studies were performed on laboratory animals rather than being observations of carbaryl's effect on the human body because of the lack of widespread domestic use of the product and because of the rather severe restrictions with respect to licensing being placed on today's product. That is to say, before a product can be marketed as an economic poison, it must be screened using laboratory animals.

Strother[4.205] compared the metabolism of certain carbamates by human and rat liver fractions and determined that the two pathways differ for Sevin in that the human liver fraction appeared to produce 2 more metabolites than did the rat liver fraction. With this in mind, the results appearing in the literature concerning the toxicity and metabolism of Sevin in laboratory animals should be considered as approximate or "best estimates".

There has been much recent publicity concerning the teratogenic effects of Sevin in beagle dogs; certain groups have extended this information directly to human organism. Smally, et.al.,[4.206] published a report on the teratogenic action of carbaryl in beagle dogs which has since become the guideline and sourcebook for arguments against large scale use of Sevin in the northeast against the gypsy moth (Porthetria dispar). Smalley's original work did demonstrate a teratogenic effect on beagle dogs caused by Sevin but the doses reported were quite high (3.125 to 50 mg/kg body weight daily). The extension of these facts to the human situation cannot be considered as completely foolproof since humans in areas being sprayed for gypsy moth infestation are not exposed to doses nearing the levels used in the beagle dog study.

Furthermore, the metabolic pathways for Sevin in the man and dogs is not exactly identical[4.207, 4.208]. The metabolites of Sevin found in the urine of dogs receiving Sevin doses are not all the same as those found in human urine specimens of subjects taking doses of Sevin.

The report of the Secretary's Commission on Pesticides and their Relationship to Environmental Health[4.209], which is also known as the Mrak Report or the Mrak Commission Report, reviews the status of pesticide use and side effects in the United States. It states that certain of the major pesticide types have associated with them typical symptomatic responses:

organochlorine pesticides - general action is to increase excitability of the nervous system. Some compounds damage the liver as well.

organophosphate pesticides - cholinesterase inhibitors

carbamates - cholinesterase inhibitors

The report further states that the present level of exposure to DDT and aldrin-dieldrin type pesticides have not produced any observable adverse effects on controlled studies of volunteers. In organophosphates, there is no residue risk--only the risk of acute toxicity.

In pesticide toxicity studies, a number of factors have been found to be important in determining the response of the animal to the toxicant, viz, species, age, sex, disease, nutrition, environmental temperature and light.

Chapter 6 of the report[4.209] is entitled, Teratology of Pesticides. This chapter calls for immediate restriction of Captan, Carbaryl, the butyl, isopropyl, and isocotyl esters of 2, 4-D Folpet, mercurials, PCNB and 2, 4, 5-T as a result of the teratogenetic action of these in laboratory animals. For teratogeneticity screening tests, several guidelines are proposed within this chapter. An important one involves the selection of the test animals. Using materials of known purity, stability, etc., it recommends that at least 2 species be chosen on the basis of metabolic and pharmacokinetic similarity to humans.

Seven sections[4.209] dealing with literature reviews of the teratogenic effect of pesticides are presented, being highlighted by pesticide identity. Section b. - Carbaryl, states:

> "b. Carbaryl - This was tested at 66.7 and 200 ppm in the diet of pregnant mice (FAO/WHO, 1967). In 2 litters at the 200 ppm level, a total of 7 instances of skeletal malalignment, nonfusion, incomplete ossification, and 1 case of cleft palate and gross facial malformation were noted as opposed to no malformations in the lower level group and 2 cases of cleft palate in controls. Teratogenetic findings for carbaryl are also presented in the Bionetics study. In a study in which beagle dogs were fed carbaryl during gestational periods at levels of 50, 25, 12.5 and 6.25 and 3.125 mg/kg body weight daily, teratogenic effects were found at all but the lowest dose level (Smalley, 1968)."

The Bionetics Research Laboratories of Litton Industries Study for the National Cancer Institute report is included in Chapter 6[4.209]. The study tested various pesticides and related compounds for teratogenic effects. The paragraphs on carbaryl and 1-naphthol, a principal carbaryl metabolite state:

> "Other pesticides producing a statistically significant increase in the proportion of litters containing abnormal fetuses and in the increased incidence of abnormal fetuses within litters were: Captan, Folpet, 2, 4-D isooctyl ester, 2, 4-D butyl ester, 2, 4-D isopropyl ester, carbaryl (Sevin) and IPC. These pesticides produced elevated inciand in one solvent only. The results for carbaryl and for IPC were less consistent than for other compounds. (The pesticides 2, 4, 5-T, PCNB, Captan, Folpet, carbaryl, IPC and the butyl and isopropyl esters of 2, 4-D were statistically significant at the 0.01 level, for one or more tests. This criterion is similar to that adopted by the Technical Panel on Carcin0-genesis, Chapter 5, to identify "positive" compounds. The isooctyl ester of 2, 4-D was significant at the 0.05 level.) Compounds inducing only an increase in the proportion of abnormal fetuses within letters were: a-naphtol, and 2, 4-D methyl ester. The statistical significance of these results was relatively weak; further study is required before any conclusions can be reached. Similarly, 2, 4-D produced only an increase in the proportion of abnormal litters during 1965 in AKR mice. Due to the teratogenic

activity of certain of its esters, 2, 4-D should be studied further.

Carbaryl plus piperonyl butoxide did not show an overall increase in nonspecific anomalies, but resulted in significantly more cystic kidneys for doses above 10 mg/kg carbaryl plus 100 ul/kg piperonyl butoxide."

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A-5

LAWS AND REGULATIONS CONCERNING THE USE AND SALE OF PESTICIDES IN NEW YORK STATE

This section presents a description and distillation of the current laws of New York pertaining to the use and sale of pesticides. While these laws are necessary to prevent environmental damage, they are not totally adequate. Specific inadequacies are identified in the first part of this Section; the second part discusses a rationale for extending the scope of pesticide laws.

A-5.1 Current New York State Laws

The primary law in New York governing the use and sale of pesticides is found in the Environmental Conservation Law, which became effective 1 July 1970. This law created a Department of Environmental Conservation and transferred the responsibility for the control, sale and use of pesticides from several agencies within the state government to the new department of Environmental Conservation.

The Conservation Law, Public Health Law and the Agriculture and Market Law were amended to transfer the authority governing the use and sale of pesticides to the new Environmental Conservation Department.

Prior to the enactment of the Environmental Conservation Law, all of the laws, rules, and regulations of the State of New York relative to the sale and use of pesticides were directed towards safety and control, with only implicit attention given to water pollution problems other than those resulting from specific and identifiable sources. The broader question of pesticide runoff to natural streams resulting from large area treatment was, for example, not explicitly addressed until the enactment of the Environmental Conservation Law.

This new law takes full cognizance of the entire problem of enviornmental conservation and addresses solutions to the problems as well as regulations for day-to-day control.

The following is quoted from the Environmental Conservation Law to illustrate the concern of the law for the total problem.

Chapter 140, Laws of New York State, 1970, Article I, paragraph 14.

"Paragraph 14. Functions, powers and duties of department and commissioner

It shall be the responsibility of the department, in accordance with such existing provisions and limitations as may be elsewhere set forth in law, by and through the commissioner to carry out the environmental policy of the state set forth in section ten of this article. In so doing, the commissioner shall have power to:

1. Coordinate and develop policies, planning and programs related to the environment of the state and regions thereof.
2. Promote and coordinate management of water, land, and air resources to assure their protection, enhancement, provision, allocation, and balanced utilization consistent with the environmental policy of the state.
3. Provide for the propagation, protection, and management of fish and other aquatic life and wildlife and the preservation of endangered species.
4. Provide for the care, custody, and control of the forest preserve.
5. Provide for the protection and management of marine and coastal resources and of wetlands, estuaries and shorelines.
6. Foster and promote sound practices for the use of agricultural land, river valleys, open land, and other areas of unique value.

7. Encourage industrial, commercial, residential and community development which provides the best usage of land areas, maximizes environmental benefits and minimizes the effects of less desirable environmental conditions.
8. Assure the preservation and enhancement of natural beauty and man-made scenic qualities.
9. Provide for prevention and abatement of all water, land and air pollution including but not limited to that related to particulates, gases, dust, vapors, noise, radiation, odor, nutrients and heated liquids.
10. Promote control of pests and regulate the use, storage and disposal of pesticides and other chemicals which may be harmful to man, animals, plant life, or natural resources.
11. Promote control of weeds and aquatic growth, develop methods of prevention and eradication, and regulate herbicides.
12. Provide and recommend methods for disposal of solid wastes, including domestic and industrial refuse, junk cars, litter and debris consistent with sound health, scenic, environmental quality, and land use practices.
13. Prevent pollution through the regulation of the storage, handling and transport of solids, liquids and gases which may cause or contribute to pollution.
14. Promote restoration and reclamation of degraded or despoiled areas and natural resources.
15. Encourage recycling and reuse of products to conserve resources and reduce waste products.

16. Administer properties having unique natural beauty, wilderness character, or geological, ecological or historical significance dedicated by law to the state nature and historical preserve.

17. Formulate guides for measuring presently unquantified environmental values and relationships so they may be given appropriate consideration along with social, economic, and technical considerations in decision-making.

18. Encourage and undertake scientific investigation and research on the ecological process, pollution prevention and abatement, recycling and reuse of resources, and other areas essential to understanding and achievement of the environmental policy.

19. Assess new and changing technology and development patterns to identify long-range implications for the environment and encourage alternatives which minimize adverse impact.

20. Monitor the environment to afford more effective and efficient control practices, to identify changes and conditions in ecological systems and to warn of emergency conditions.

21. Encourage activities consistent with the purposes of this chapter by advising and assisting local governments, institutions, industries, and individuals.

22. Undertake an extensive public information and education program to inform and involve other public and private organizations and groups and the general public in the commitment to the principles and practices of environmental conservation and development programs for the teaching by others of such principles and practices.

23. Cooperate with the executive, legislative and planning authorities of the United States, neighboring states and their municipalities and the Dominion of Canada in furtherance of the policy of this state as set forth in section 10 of article two of this chapter.

24. Exercise and perform such other functions, powers and duties as shall have been or may be from time to time conveyed or imposed by law, including, but not limited to, all the functions, powers and duties assigned and transferred to the department, department of agriculture and markets, and office for local government in the executive department by a chapter or chapters of the laws of nineteen hundred seventy."

While the new Environmental Conservation Law places the responsibility for the sale and use of pesticides within the Department of Environmental Conservation, specific rules and regulations pertaining to pesticides are to be found in the Agriculture and Markets Law, the Public Health Law and the Conservation Law.

Portions of these relevant laws and regulations are abstracted and discussed below.

Article 11 of the Agriculture and Markets Law

All pesticides, except those Federally registered, must be registered with the State. The Commissioner of the Department of Environmental Conservation may refuse to register a pesticide. Pesticides are registered on a restricted or non-restricted use basis. The non-restricted use pesticides may be sold and used without restriction providing such use is in accordance with the registration and the label, whereas restricted use pesticides may be distributed and resold only by holders of a Commercial Permit. The primary purpose of the Commercial

Permit appears to be to maintain control of the pesticide in the distribution chain since there is no requirement for the holder of the permit to have any knowledge in the field of pesticides.

In addition, purchase permits are required for the purchase of all restricted use pesticides. The primary purpose of this permit appears to be to limit the sale of restricted use pesticide to qualified persons and to control the application or use of such pesticides.

Article 11A of the Agriculture and Markets Law

Article 11A provides for the regulation of custom applicators. Custom applicators must be registered by the Commissioner, Department of Environmental Conservation, for any application of pesticides for others. This rule applies to both non-restricted and restricted use pesticides.

The primary purpose of this regulation appears to be the registration of all applicators so as to have records of usage, to control areas of application and to set some standard of competence on the part of the applicator, although the competence aspect of the regulation appears to be weak and not well defined.

Part 154.4 of Rules and Regulations

Part 154.4 of the Rules and Regulations (Ref. Circular #865, Department of Environmental Conservation) is of particular interest to this study and is quoted below.

> "154.4 Restriction on the Application of Pesticides by Commercial Application.
>
> (a) Pesticide application to areas adjacent to crops, pasturage, lands and waters shall be such that contamination does not occur."

Official Compilation of Codes, Rules and Regulations of the State of New York

Under Part 155, "Rules and Regulations Relating to Restricted Pesticides," the restricted use pesticides are defined and listed. In addition, the conditions under which these materials may be handled and used are delineated.

Environmental Conservation Law

Under Section 77 certain functions of the health department, air pollution control board, and pesticide control board are transferred to the Department of Environmental Conservation:

> "All of the functions and powers possessed by and all the obligations and duties of the department of health, commissioner of health, and the air pollution and pesticide control boards pertaining to or connected with sewage service in realty subdivisions; drainage of sewage service into waters; water pollution control; air pollution control; planning for collection, treatment and disposal of refuse; and recommendations for controlling the use, transportation, storage and disposal of pesticides, approval of marine toilet pollution control devices and establishing effluent standards therefore, more particularly described in titles two and three of article eleven, article eleven-A, eleven B, and twelve C, sections thirteen hundred-a, and thirteen hundred-B, title nine of article thirteen and article sixteen of the public health law and section thirty-three-c of the navigation law, including the administration of state aid for local expenditures therefor, are hereby transferred and assigned to, assumed by and devolved upon the department of environmental conservation."

Another law of principal interest to this study is Article 12, "Water Pollution Control" of the Public Health Law. While Title 1 of Article 12, "General Provisions and Public Policy" address the question of pure water, it is primarily concerned with discrete inputs of waste materials to water bodies. It does not directly address the question of runoff water into natural drainage systems which have picked up pesticides or other potential pollutants which were applied to an area for control over the area. However, the Department of Environmental Conservation has taken a major step towards the effective control of pesticides or other chemicals entering the waters of New York State with the issuance of three orders as follows:

(1) Order Establishing Regulations Governing the Use of Chemicals for the Control of Elimination of Aquatic Vegetation published as Part 609 of the Official Compilation of Codes, Rules, and Regulations of the State of New York.

(2) Order Establishing Regulations Governing the Use of Chemicals for the Control or Extermination of Undesirable Fish, published as Part 610 of the Official Compilation of Codes, Rules and Regulations of the State of New York.

(3) Order Establishing Regulations Governing the Use of Chemicals for the Control or Elimination of Aquatic Insects, published as Part 613, of the Official Compilation of Codes, Rules and Regulations of the State of New York.

Each of these regulations requires permits for the treatment of water and limits the choice of chemicals to those listed in the regulations.

However, the regulations do not require the holder of a permit to have any special training or knowledge even though the permit holder is responsible for any inaccuracies in the required registration data or any damage resulting from the chemical treatment.

Therefore, while the laws and regulations of New York relative to pesticides and their use evidence design toward responsible use within the environment, we believe that the laws do not require sufficient proof of either user competence or equipment applicability.

The discussion which follows presents some considerations relative to the possible formulation of laws to amend this insufficiency.

A-5.2 Considerations in the Formulation of Laws, Rules and Regulations Pertaining to the Research, Development, Handling and Use of Pesticides

Society, in general, requires laws, rules and regulations for the people of that society to live in harmony with each other. Through law, the rights and priviledges of the individual are protected, and, of equal importance, the less fortunate members of society are assisted by the more fortunate members of society.

The great majority of our laws, rules and regulations, hereafter referred to simply as laws, are developed "after the fact". Hence, they are designed to deter, stop, or control a practice, which is considered to be in discord with the common good. Such laws are, therefore, addressed to a situation which has advanced to a point where corrective action must be taken to protect the rights and priviledges of the individual or to establish an equitable condition. In one sense then, laws may be looked upon as disabling a segment of the society from engaging in practices which are abusive to another segment of society, rather than as enabling society in general to improve its posture in a truly anticipatory fashion. Experience has shown us that our laws have considerable difficulty in dealing with future conditions, except in the most general of terms, since our technology and the environment in which we use the technology are subject to constant change. It is difficult to generalize in this area, but it is probably fair to state that most of our laws tend to relate to an existing situation and, therefore, have great difficulty in providing adequate protection to new and unforeseen situations.

The broad field of pesticides is most interesting in this regard. Laws have been enacted to control the handling and use of pesticides only after considerable use of these materials has made clear that some level of control was needed. The laws appear to have been enacted in reaction to a situation and as a result, may not serve to deter the development of new and hazardous situations related to the current use of pesticides.

Laws can never be an effective substitute for competence, good judgment, and a deep concern for the total impact of an act or procedure on the part of personnel engaged in activities which are addressed by the laws. This statement points to the need for examining and licensing personnel who wish to engage in activities which are proven to have the potential for infringement on the rights and priviledges of others. Licensing may be on the local, state and federal level depending upon the nature and scope of influence of the activity.

We can find many examples of laws and licenses at all levels of government. The laws, rules, regulations and licensing requirements of the Federal Communications Commission (FCC) may serve to illustrate this point.

Among the responsibilities of the FCC is the control of the use of the electromagnetic spectrum so as to achieve the maximum benefit to society from the finite bandwidth which is available. Since electromagnetic radiation knows no political boundaries, the FCC was structured on a national level and provided with international agreements reached at worldwide conventions. The practical uses of the electromagnetic spectrum, the equipment and techniques involved, and the actual extension of the spectrum itself into ever shorter wavelengths, has required truly visionary rules and regulations so as to protect the rights of all concerned but which at the same time, do not stifle technological development.

The problems allied to the use of the electromagnetic spectrum parallel the problems allied to the use of pesticides, namely,

(1) Electromagnetic radiation and pesticides, once released, propogate or disperse in accordance with natural law.

(2) The use of pesticides and the electromagnetic spectrum are constantly on the increase.

(3) Research is constantly developing new pesticides just as research is evolving new equipment and techniques for use in the electromagnetic spectrum

It is axiomatic that laws can be no more effective than the effectiveness of personnel involved. Herein lies the great difference between the laws relating to electromagnetic radiation and laws relating to pesticides.

The FCC has its laws as do the control agencies for pesticides, but, the FCC requires the purveyors of the art to be thoroughly examined and qualified as to fundamentals. These "user personnel" bear full and professional responsibility to conduct all of their acts and operations within the intent of the law. In addition, equipment is licensed for use only after it has been qualifed and a determination made that it functions within the law. Normally, licensed equipment must be under the direct supervision of a licensed operator.

These views on pesticide applicator licensing may be tempered to the point where the requirement for a license could be dropped if it could be demonstrated that no harm will result through irresponsible pesticide use. Again, let us look to the FCC. A nonlicensed operator may purchase and use a 100 milliwatt radio transmitter operating in the Citizen Band (CB). In this instance the band is very restricted, the power very limited and the equipment is very carefully examined and qualified for this use. Over-the-counter-pesticides which would present no hazard to the user, which are very specific and which would have a very limited area of influence can be seen to closely parallel the CB situation. The pesticide itself, as well as the packaging and dissemination mode must, of course, be thoroughly developed, tested, and qualified for this special case of use by a nonlicensed operator.

In summary, we believe that the laws and regulations governing the use and sale of pesticides, while comprehensive, are not sufficient to prevent environmental damage. This assertion is based on our belief that these laws and regulations do not require sufficient proof of competence on the part of the users of pesticides and do not require sufficient test, evaluation and licensing of the pesticide, and the equipment used to apply the pesticides.

It is emphasized that our discussion has not been designed to explicitly propose the national examination and licensing of pesticide applicators at the expense of other alternatives. Rather, it has been advanced in the recognition that the social and economic importance of pest control and the absolute magnitude and characteristics of the problem are highly variable from state to state and from time to time. As a result, approaches or techniques adopted by one state can lead to direct conflict with approaches adopted by a neighboring state. Pest control can be best studied and implemented on the basis of geographical areas determined by the pest itself, rather than by state boundaries. Such pest management procedures as quarantines, buffer zones, criteria for treatment and materials to be used may be applied in a much more effective manner when specific problems are treated on an area of involvement basis, and in consideration of the national import.

Since a large percentage of the pesticides in use today are applied by units of government, laws and licensing should be applicable to government as well as nongovernment users. This has not always been the case in laws and licenses. It bears special attention in this instance, and points to the advisability of federal laws and licenses.

A-6.

ALTERNATIVES TO CHEMICAL CONTROL

The objectives of this portion of the study were to identify and analyze:

(1) feasible methods of forest pest control as an alternative to the use of chemical pesticides and,

(2) chemical pesticide uses considered to be essential and for which no suitable alternative is available.

Before considering specific alternatives to chemical control of forest pests, it is important to recognize that different criteria are used to "define" control. These criteria reflect not only differences in training (scientist vs. layman) but also differences in expectations of profession-related gains and most importantly, the differences in impact on individuals, states or agencies, given a lack of pest control.

DeBach[6.1] defines control simply as the maintenance of a more or less fluctuating population density within certain definable upper and lower limits over a period of time by the action of abiotic and/or biotic environmental factors. The upper and lower limits, or the density, will change appreciably only if the actions of the regulatory factors are changed, or if certain ones are eliminated or if new ones are added. This control may be natural or introduced.

Natural control (or other nonchemical alternatives) may or may not regulate the population of a specific insect within a time frame consistent with man's interest and chemical pesticide measures may be invoked to counter this situation.

Consider the case of forest insect defoliators. Reliance on a particular type of control will be largely dictated by the amount of tree defoliation that can be accepted. This criterion considers not only the short-term loss (lack of leaves) but also the time over which the concomitant loss has to be accepted and, hopefully, the longer-term loss associated with tree mortality, for example.

In this illustrative case, a nominal set of three criteria are outlined. These are that the criterion of control is:

(1) little or no defoliation,

(2) defoliation occurs and concomitant short-term (e.g., 3 years) loss is accepted and,

(3) defoliation occurs and concomitant long-term (e.g., more than 3 years) loss is accepted.

Therefore, depending upon the criterion selected as being appropriate, both the type of control and the degree to which the control is invoked will be dictated by the impact that defoliation manifests. Consider the following examples:

(1) Little or no defoliation implies not only that the "trees must remain green" but also that larvae (caterpillars) will not be present. In such cases, rapid and relatively complete control is required and the use of chemicals may be the only appropriate control agent. Examples where such a control criterion could be considered as appropriate are resort areas, public camp and picnic areas and forested urban communities. Since resort areas are dependent upon vacationers for income, the lack of leaves on trees and/or presence of numbers of caterpillars will have a serious impact on summer vacation business. The same can be said for public campgrounds and picnic areas. In addition, however, it may be highly desirabl

to kill the larvae to preclude egg mass transport to uninfected regions by trailer transport.

Forest-urban communities with susceptible tree types present a particular problem in that the manicured conditions of the groundcover along with the presence of household pets effectively destroys the habitat of beneficial predators and parsites. Here, too, the high value placed on each tree and the potential financial loss in removing and replacing lost trees demands rapid protection. Further, the nuisance associated with larvae such as the gypsy moth (frass, staining of house paint, and known human dermal reactions) aggrevate the citizens to exert political pressures on those in charge of pest control operations.

(2) Defoliation and concomitant short-term loss is accepted implies that either the pest will disappear or will, as a minimum, stabilize to an acceptable level of damage. Much of the northeastern forested lands are placed within this category. Whether or not forested acreage is considered in this category will, however, vary from state to state as the dependence upon a forest economy varies.

Natural control infers that there are a series of checks and balances that regulate insect populations and explains why native insects only periodically attain pest status. Even when this occurs, however, the infestation of a native insect can be expected to collapse in a relatively short time (3 years) due to the effects of starvation, and the buildup of disease, natural parasites and predators. Within such native pest infestations, certain recognized high-use areas, such as a sugar bush, will be treated with chemicals to prevent serious economic loss.

An introduced pest such as the gypsy moth presents a different problem, since it arrives without its natural biotic control agents. Although there is considerable disagreement between authors on the subject of theory of population control concerning the role that the various environmental factors play in controlling insect populations (Milne,[6.2] Thompson,[6.3] and Andrewartha & Birch,[6.4] to name a few) it is generally accepted that the introduction and establishment of the natural enemies (parasites, predators and pathogens) of an introduced pest is a logical and beneficial control method. However, the ease with which these natural control agents can be introduced and established is much more difficult than with native pest outbreaks, and may not be consistent with the period over which losses attributable to defoliation can be tolerated.

(3) Defoliation and long-term loss is accepted could include remote, low value areas where the apparent value of the woodlands is not clear. Two basic factors must be borne in mind: first, such areas may serve as a source of infestion to land-use areas included under the preceding control criteria; secondly, the apparent low value of a particular woodland plot today will not, necessarily, have the same apparent low value at some future date. Increase in woodland value could arise, for example, by increased pressures for recreational facilities and/or watershed development.

The availability and use of nonchemical alternatives are different for native and non-native pest infestations. Of singular importance is the ease with which biological control can be invoked. Accordingly, the following discussion on pest-control alternatives is presented in two parts identified as native and non-native (i.e., introduced pest as the gypsy moth) forest pest infestations.

A-6.1 Native Pest Infestations

In spite of the fact that there has been and is extensive use of pesticides, evidence demonstrates that New York relies on natural processes to combat and control native forest pest infestations.

In 1952, the Forest Tent Caterpillar defoliated about 3.5 million acres of forested land. Of this total, 500,000 defoliated acres were noted as "complete"[6.5]. The following year about 7.5 million acres were defoliated. In 1954, about 15.3 million acres were measureably defoliated. No further defoliation is mentioned for this pest until six years later, 1960. Table 6.I lists these figures, presents numbers of acres either completely or heavily defoliated, and the number of acres that were chemically treated in response to this infestation.

Table 6.I
FOREST TENT CATERPILLAR DEFOLIATION AND
CONCOMITANT PESTICIDE TREATMENT

YEAR	ACRES DEFOLIATED TOTAL	ACRES DEFOLIATED HEAVY	ACRES TREATED WITH PESTICIDE
1952	3,500,000	500,000	1,000
1953	7,489,049	919,834	1,800
1954	15,321,047	2,007,447	3,200
1955-59	NOT MENTIONED		SOME IN 1955 ONLY
1960	24,425	5,000	0

The demise of this infestation of Forest Tent Caterpillar was a combination of factors as climate, starvation and the presence and buildup of predators, parasites and pest disease. The important point is that chemicals were not extensively used and that New York relied on biological control mechanisms to halt the ravages of the pest. This reliance on biological control is more than mere forest pest control philosophy; it is operational philosophy.

The following is quoted from "Saddled Prominent".[6.6]

> "This pest often causes about three years of heavy defoliation before such natural controls as insect parasites, predators, birds, and rodents severely reduce their numbers. Starvation and disease also bring an end to outbreaks. However, during outbreaks in valuable stands such as sugar bushes, high-value commercial woodlands, or high-use recreational areas, artificial control may be necessary to prevent serious injury to trees."

In 1967, Saddled Prominent caused light-to-moderate defoliation of 39,000 acres of hardwoods; principally beech and sugar maple. In their annual report, the Bureau of Forest Insect and Disease Control noted a "buildup coming". The next year 763,955 acres were defoliated. Of this total, 89,195 acres were classified as heavily defoliated. By 1969, 953,575 acres were defoliated. In this same year, New York treated about 12,000 acres of high-use land. In regard to this modest treatment, Risley [6.7] wrote:

> "With any heavy infestiation of this magnitude a certain amount of public pressure is expected. After a thorough analysis of the situation the Conservation Department decided to treat sugar bushes and State high-use areas. These areas were chosen because the sugar bush industry stands to lose the most from this infestation as well as State areas which received much public-use. All areas to be treated in this control program were examined in the spring of 1969 to make sure that they supported a pupal count of 0.5 per square foot. The sampling technique used in these areas was also developed by the Applied Forestry Research Institute. The Department used this best biological information available in determing whether the areas required chemical control".

In 1970, 3 years after the outbreak, the Saddled Prominent defoliated 88,850 acres, which is less than 10% of the previous year. It was noted in the annual report of the Conservation Department that 49,000 acres had been scheduled for Sevin treatment, but that the treatment was cancelled due to population collapse.

In the 1971 Spray Report issued by the Bureau of Forest Insect and Disease Control, New York Department of Environmental Conservation, the following quote is provided relative to Saddled Prominent Control:

> "This year's spraying has been cancelled, because of natural biological controls. Areas in District #12 and #1 are being watched for buildup and defoliation. No spraying."

It is also interesting to note that the 1971 Defoliation Report issued for New York State showed that the Cherry Scallop Shell Moth defoliated 166,500 acres. Of this total, all but 1,000 acres were 75 to 100 % defoliated, and no chemical control treatments were used.

A-6.2 Non-native Pests

It has been pointed out in earlier portions of this report that the forest pest in New York receiving virtually all of the chemical pesticide treatment is the gypsy moth, Porthetria dispar. Accordingly, the discussion which follows reviews the various alternatives which have been used instead of chemical pesticides. These alternatives include:

(1) silvicultural techniques,

(2) genetic controls,

(3) behavorial controls,

(4) traps control,

(5) biological controls, and

(6) direct controls.

An overview of these control techniques is presented. Following this overview, two elements are discussed in somewhat greater detail. The first of these is a discussion of the current efforts being undertaken by the New Jersey Department of Agriculture in the biological control program for gypsy moth in that state. The second control element presented in detail, examines the historical use of manpower in the direct control of this introduced pest during the late 1800's up through the start of World War II. Presentation of this detail is warranted since, during that period, there was less reliance on the use of chemical pesticides. This was partly due to the lack of economic methods of pesticide application, i.e., aerial application, that we have availed ourselves of since 1945.

Since all of the discussion focuses on gypsy moth control, a capsule of its history, life cycle and habits is initially presented to assist in understanding both the development and usefulness of the various control measures.

A-6.2.1 Gypsy Moth - Porthetria Dispar

History

The gypsy moth is a foreign insect that was accidentally released near Boston, Massachusetts in 1869. Without its natural effective enemies to contain it, and finding an abundance of favored food trees, the moth has spread rapidly and now inhabits most of New England, eastern New York and Pennsylvania, most of New Jersey and threatens the vast oak forests of the entire eastern United States.

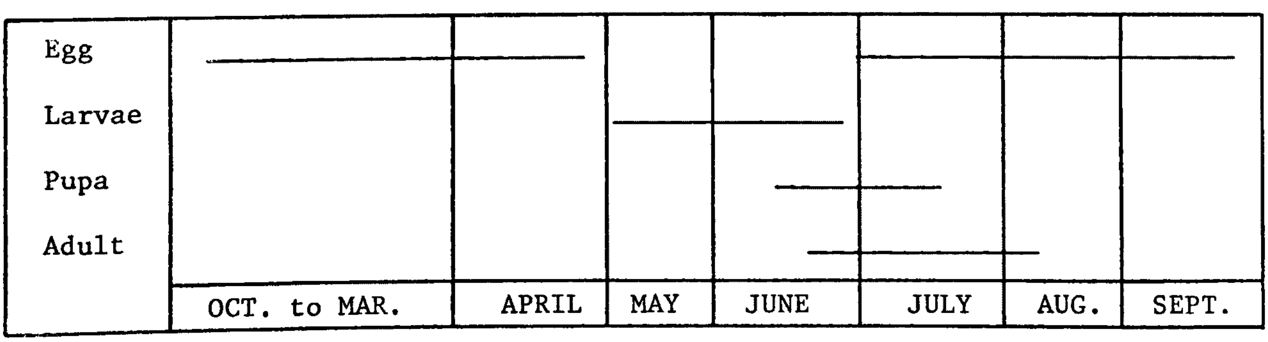
The moth was first discovered in the eastern part of New York State in 1911 and, in spite of repeated attempts at eradication, it is now found throughout the eastern half of the state. As a matter of review, during this year this pest defoliated about 480,000 acreas in New York. Further, an additional 250,000 acres that were infested were chemically treated.

Life Cycle

The gypsy moth goes through one generation a year in the four stages shown in Figure 6.1.

FIGURE 6.1

LIFE CYCLE OF GYPSY MOTH



The period of emergence and the length of time spent in each of the stages depends on the locality, weather, pest population density and amount of available food.

a. Egg Stage —— The insect overwinters in the egg stage in flattened oval clusters approximately 1" long by 0.5" wide and averaging about 400 eggs. The cluster is covered with yellowish hair from the abdomen of the female and is deposited near or on the ground on rubble, stones, walls, bark, etc. If deep, moist, ground cover is not available, eggs are usually laid in protected spots on the lower portion of tree trunks.

b. Larval Stage —— The eggs hatch with warm weather in the spring, usually in late April or early May. Hatching may continue over a period of several weeks but peak hatching usually occurs within a week. If weather is favorable, newly hatched larvae forage; otherwise they stay around egg clusters until conditions become favorable. Larvae seek food through random searching and can live about a week without feeding.

Larvae up through the third instar feed by day and rest at night. With the fourth instar this pattern reverses and larvae feed at night and descend to cool protected places for rest during the day. (It is during this period that chemical treatment is normally applied to the tree foliage.)

The male larve normally go through five instars while the female goes through an additional or 6th instar.

During epidemic conditions, the feeding rhythm pattern of all instars changes and larvae may feed continuously.

Fully grown caterpillars are from 1.5 - 2" long, with a brownish or gray background color. There are three light stripes along the back. Each segment except the first has a pair of tubercles; the first five pairs are blue; the last six brick red.

c. Pupal Stage —— The gypsy moth pupa is a typical dark brown lepidopterous pupa that is never enclosed in a cocoon. It is attached to objects with a few silken threads, usually on or near the ground if cool, moist cover is available. On hot, dry, open sites larvae normally pupate in the tree. Pupation lasts from 10 days to 2 weeks and occurs in late June and July.

d. Adult Stage —— Male moths have slender brown bodies with brown wings irregularly crossed with dark lines. Wingspread is about 1.5". The female moth has a heavy, stout body with white wings crossed with dark lines. The wingspread is about 2.5".

Emergence of adults is at its height in mid-July and continues to mid-August. The male emerges a few days before the female, is a strong flier, and normally flies in a zig-zag pattern near the ground. The female, because of her heavy body, cannot fly and deposits her eggs near where she emerged from the pupal stage.

Oviposition begins soon after fertilization which occurs within a day or two after emergence. Soon after egg laying, the female dies. The male also lives for a short time (about a week) and neither adult take any food.

Dispersal

Inasmuch as female moths are unable to fly, natural dispersal is through wind dispersion of newly hatched larvae. These are very small, light and hairy and when disturbed spin down on silken threads and are easily dislodged. Epidemic conditions generate continuous disturbance and fosters this dispersal.

There is also the possibility of older larvae or bark with eggs attached being distributed by major storms. Under epidemic conditions with its attending food shortage, older larvae disperse by crawling but this movement is not great.

The principal means of artificial dispersal is transfer of egg masses on such items as nursery stock, forest products, stones, junk etc. Caterpillars have also been known to hitch-hike on cars, trucks, and/or campers passing through infested areas.

A-6.3 Alternative Control Methods

There are many methods of manipulating the forest environment and insect behavior with the aim of controlling insect populations. Although all the methods listed below are possible, many are not considered practical due to constraints of manpower, money, and technical development. Some of the possibilities of forest manipulation for insect control have been discussed by S. Graham[6.8], K. Graham[6.9], R. Anderson[6.10] and DeBach[6.1].

A-6.3.1 Silvicultural Techniques

In a managed forest, it has been shown that it is possible to increase the resistance of a forest to insect damage by regulating the composition, density, vigor, age distribution, ground cover, and sanitation of that forest. These actions are directed at manipulation of three main environmental factors: food, microclimate and organisms antagonistic to the pests.

It is self-evident that stand resistance could be increased, if economically feasible, by reducing or removing the favored species and/or by replacing susceptible species with insect-resistant ones. Resistance will also be increased by any measures that increase the vigor of susceptible trees since this reduces chances of attack by secondary pests and ensures maximum recuperative powers after an attack by defoliators.

It is also feasible to manipulate the population of insects in a forest by silvicultural practice that provides an environment that is either adverse to a pest insect or is beneficial to the enemies of that insect. For example, a moist, deep, ground cover encourages development of a complex of mammal and insect predators that help control a potential pest that spends some stage of its life cycle on or in the ground.

Examples of silvicultural control of the gypsy moth are presented in a paper by N. Turner [6.11] excerpts of which follow.

"Control of Gypsy Moth by management of woodlands was proposed by Clement & Munro (1917) and renamed silvicultural control by Behre, Cline, and Baker (1936)."

"They advocated the removal of susceptible species, especially those of low commercial value and encouragement of growth of resistant species. On dry sites, the proportion of oaks, gray birch, and aspen would be reduced sharply and growth of hemlock and white pine encouraged. On moist sites, the percentage of favored species could be considerably higher without risking heavy infestation".

"A large commercial forest has been under such management for many years. During the course of two outbreaks of Gypsy moth in Norfolk, that forest has remained relatively free from infestation. Several large tracts in state forests have had similar management. One tract in an area of heavy gypsy moth infestation escaped serious damage".

Nickols [6.12], in discussing gypsy moth work in Pennsylvania, notes that while silvicultural control has held some promise in New England where coniferous and mixed coniferous-hardwood forest types prevail, it would not only be impossible but entirely impractical to attempt to change the vast oak forest cover that predominates over most of the forested area south of New England. He concludes that silvicultural control will never play more than a very minor part in the control program.

A-6.3.2 Genetic Controls

A promising alternative to the type of controls previously discussed is exemplified by work reported by Knipling [6.13] in using sterile-male technique to eradicate screw worms.

During the past few years the federal government has been mass rearing gypsy moths to evaluate this control technique. While results on a laboratory scale have been reported as promising, problems associated with rearing and radiating millions of insects still have to be resolved. Then, too, radiated males have shown a tendency to be less aggressive than normal males, reducing their competitive efficiency in a natural habitat. Work is continuing to solve these problems in the hope of providing a "clean" technique to handle infestations in highly populated areas.

A-6.3.3 Behavioral Controls

In the past few years, the identification and synthesis of members of the three major groups of hormones which control insect development give rise to the hope of developing a new generation of insecticides by disarranging an insect's normal development, resulting in self-destruction. While this holds exciting possibilities for the future, nothing, at present, has been done for control of gypsy moth (Meltzer [6.14], Schneiderman [6.15]).

In the field of pheromones, that is, chemicals secreted by insects which influence the behavior of other members of the same species, synthesis of the female gypsy moth sex attractant has played a major role in control programs aimed at this pest.

The use of gypsy moth sex attractant provides a unique method of detecting the presence of this pest in suspect areas. Used with a standard gypsy moth trap (a hollow cardboard cylinder with hole in either end and lined with sticky material to capture the attracted moth), this has provided a relatively cheap and effective method of scouting to ascertain spread of this insect.

To the present time, traps, as such, have not been widely used as a direct control but have been the basis of surveys to locate new colonies and to map the spread of infestion. Using such traps baited with a synthetic female sex attractant, the federal government annually monitors suspect areas over a large part of the eastern United States. Special attention is given to such areas as camp or picnic grounds, and military installations because of the probabilities that a visitor, arriving from the New England area, might bring gypsy moth eggs or larvae attached to a house trailer. There is strong evidence that such a "house trailer vector" was responsible for the recent introduction of this pest into Alabama [6.16].

The earliest techniques used such a trap baited with a virgin female gypsy moth. This was soon replaced by the natural sex attractant obtained by clipping the last two abdominal segments of virgin female moth, extracting segments with benzene and processing the extract chemically to stabilize the lure. This procedure entailed field collection of large numbers of female pupae and allowing the female moth to emerge before segments could be secured. Not only the expense involved but the difficulty of securing larvae during periods of low gypsy moth population limited use of this sex attractant.

In 1960, Jacobson and co-workers synthesized gypsy moth sex attractant (gyptol) and reported its homolog (gyplure) was also a highly active gypsy moth sex attractant. When preparations of these compounds by other workers were reported as inactive, re-investigation showed these substances to be active because of traces of another substance. This has been identified and synthesized as disparlure [6.17].

Activity of the disparlure was confirmed in a controlled field tests in 1970 in Massachusetts. Male moths, reared in the laboratory, were released periodically in the vicinity of eight traps; four were baited with 1 μg each of the synthetic sex attractant and four with a potent extract of natural gypsy moth sex attractant equivalent to ten abdominal tips, the amount used in survey traps. In the 10-day test, the synthetic attractant caught 110 moths, the natural attractant caught 3.[6.18].

Synthesis of a gypsy moth sex attractant that "out-drew" the virgin female moth made possible the investigation of two control techniques based upon extensive use of the sex attractant.

Since the male gypsy moth depends upon the sex attractant to locate the rather immobile female, it should be possible, by permeating the atmosphere with the synthetic sex attractant to mask the virgin female and/or confuse the male moth so that fertilization does not take place. Although several field trials (including two trials in New York during 1971) have been conducted using this technique but the results have been rather disappointing. This method is still being investigated and further tests are planned for 1972.

Use of the gypsy moth sex attractant and for that matter any chemical broadcast for control purposes will require that the material be registered for gypsy moth control. This will involve a delay of 2 to 5 years while the material undergoes the necessary toxicity tests.

A more recent use of traps is to distribute enough traps with sex attractant to capture male moths in an area of light infestation. It is estimated that this would require from 2000 to 5000 traps per square mile (at least as many as there are female moths present). This method was tested in Pennsylvania during 1971 with unsatisfactory results; further tests on this technique are planned for 1972.

Among several other possible methods of utilizing traps in a control program are:

(a) Traps baited with sex attractant plus a sticky coating or an insecticide would be a direct control if disseminated in sufficient quantities to remove a significant number of males.

(b) Traps baited with sex attractant plus an infectious disease. In this case the male would not be captured but attracted, infected and released to spread the disease.

A-6.3.4 Direct Controls

This grouping includes those direct physical-mechanical efforts aimed at collecting and/or destroying some life stage of the insect.

(a) Collection and Destruction—The first almost successful attempt to eradicate the gypsy moth in Massachusetts in 1890's relied mainly on the detection and destruction by creosoting of the gypsy moth egg masses[6.19]. This was also an effective major part of the federally funded CCC crew's attempt to combat the gypsy moth in New York and New England in the 1930's and early 1940's.

(b) Barriers—Mechanical barriers are another type of direct technique that have been successfully used as a part of early gypsy moth control efforts. Such barriers are currently not used to any appreciable extent because the availability of inexpensive chemical pesticides coupled with economic application techniques have m. 'e he manpower requirements associated with barriers unattractive. This apparent disadvantage is much less important in the protection of shade and ornamental trees where the recognized value of the trees are high and the number of trees per acre is low relative to the woodlands.

Barriers are effective against an insect such as the gypsy moth because of certain peculiarities in its life cycle, viz:

(1) Egg masses are normally deposited on rubble on or near the ground and the newly hatched larval must climb the tree to reach the foliage.

(2) Late-stage larvae feed normally at night and spend the day time resting in the moist, cool undergrowth.

A barrier may be simply a band of burlap around the tree trunk under which the larvae may seek shelter and be easily destroyed, or a band of sticky material such as "Tree Tanglefoot" which they cannot cross during ascent of the tree.

(c) Traps——Traps as used in control programs against defoliating insects are typically a small container baited with light, food or a sex attractant to lure flying male adults. The trap is normally lined with a sticky material to capture the insect once it enters the container.

A-6.3.5 Biological Controls

Biological control, defined here as the use of parasites, predators and pathogens to regulate the population of another organism, dates from the early 18th century with the discovery of the nature of insect parasitism.[6.1, 6.20] Its use as a valid tool in regulating insect populations is generally credited to the spectacular success of the introduction of the vendalia beetle in controlling the cottony-cushion scale that threatened the citrus groves of California in 1889.

Balch [6.21] notes that the mechanism of this control method is based on the theory, elaborated chiefly by Nicholson, that density-dependent factors are the essential component of any regulating mechanism. Milne [6.2] holds that their relationship is "imperfect" and while this "imperfection" allows natural enemies to play an important part in maintaining low populations between outbreaks they are unable to control rapid increases brought about by such environmental factors as extremely favorable weather and/or extremely favorable forest types. This is the reason that native insects occasionally escape control and reach pest status.

Excluding the direct control exerted by CCC crews during the 1930's and early 1940's and the use of chemical insecticides since that time, the field of biological control has been the focus of control efforts against the gypsy moth since the Federal Government, in cooperation with the State of Massachusetts, undertook control measures in New England in 1906. Even before this time, however, economic entomologists concerned with the gypsy moth were advocating the importation of predators and parasites of the gypsy moth although only minimal action was taken since Massachusetts was committed to a policy of total eradication [6.19].

During the winter session of 1904-5, Congress appropriated $2500 to fund importation of parasites of the gypsy moth. This began a cooperative biological control program between the Federal Government and the New England States that lasted until 1929.

The first stage of this program, lasting until 1911, is reported by Howard and Fiske [6.22]. Table 6.II lists the known parasites of the gypsy moth as well as those reared in this country. Table 6.III shows the status of the introduced parasites in 1911 when the program was halted due to European hostilities.

After World War I, work was resumed and continued until 1927. Burgess [6.23] summarizes the work on the whole program. Table 6.IV lists all the parasites and predators colonized, as listed by Burgess.

In discussing the results of this program, Burgess made the following observations.

(1) From 1905 to 1916, the severity of forest defoliation showed no decrease in intensity.

(2) Foreign natural enemies were being introduced in substantial numbers with many species becoming established and increasing.

(3) From 1920 to 1924 the acreage defoliation gradually decreased until only a few completely defoliated areas could be found.

(4) The combined percentage of parasitism increased and reached a maximum in 1923 but decreased the following years.

(5) After 1929, the gypsy moth population increased rapidly in eastern Massachusetts and reached its former severity over most of the older infested area.

(6) The parasite population reached low ebb in 1925, made a slight increase in 1926 and a noticeable increase in 1927.

TABLE 6.II

KNOWN AND RECORDED PARASITES
HYMENOPTEROUS PARASITES OF THE GYPSY MOTH (Porthetria dispar L.)

BRACONIDAE

Reared at laboratory	Recorded as parasites
Apanteles fulvipes (Hal.)	Apanteles fulvipes (Hal.).[1,2]
Apanteles solitarius (Ratz.).	Apanteles solitarious (Ratz.).[1,2]
	Microgaster calceata Hal.[1,2]
	Apanteles tenebrosus (Wesm.).[1]
	Microgaster tibialis Nees.[1]
	(Microgaster) Apanteles fulvipes liparidis (Bouche).[1,2]
	Apanteles glomeratus (L).[1,2]
	Apanteles solitarius var. melanoscelus (Ratz.).[1]
	Apanteles solitarius? ocneriae Svanov.
Meteorus versicolor (Wesm.).	Meteorus scutellator (Nees).[1]
Meteorus pulchricornis (Wesm.).	
Meteorus japonicus Ashm.[3]	

ICHNEUMONIDAE

PRIMARY

Pimpla (Pimpla) instigator (Fab.).	Pimpla (Pimpla) instigator (Fab.)[1,2]
Pimpla (Pimpla) porthetriae Vier.[3]	
Pimpla (Pimpla) examinator (Fab.)	Pimpla examinator (Fab.)[1]
Pimpla (Pimpla) pluto Ashm.[3]	
Pimpla (Apechthis) brassicariae (Poda).	
Pimpla (Pimpla) disparis Vier.[3]	
Theronia atalantae (Poda).	Theronia atalantae (Poda).[1,2]
Limnerium (Hyposoter) disparis Vier.	Campoplex conicus Ratz.[1]
Limnerium (Anilastus) tricoloripes Vier.	Casinaria tenuiventris (Grav.).[1]
Ichneumon disparis (Poda)	Ichneumon disparis (Poda).[1,2]
	Ichneumon pictus (Gmel.).[1,2]
	Amblyteles varipes Rdw.[2]
	Trogus flavitorius [sic.] lutorius (Fab.)?[1,2]
	(Cryptus) Aritranis amoenus (Grav.)[1]
	Cryptus cyanator Grav.[1]

[1] Recorded by the senior author in a card catalogue of parasites kept in the Bureau of Entomology.

[2] Recorded by Dalla Torre in Catalogus Hymenopteroru.

[3] Japanese species.

TABLE 6.II (CONT)

PROBABLY SECONDARY BUT RECORDED AS PRIMARY

	Mesochorus pectoralis Ratz.[1,2]
	Mesochorus gracilis Brischke[1,2]
	Mesochorus splendidulus Grav.[1,2]
	Mesochorus confusus Holmgr.[1]
	Mesochorus semirufus Holmgr.[1]
	(Hemiteles) Astomaspis fulvipes (Grav.)[1], =A. nanus (Grav.) according to Pfankuch.
	Hemiteles bicolorius Grav.[2]
	Pezomachus hortensis Grav.[2]
	Pezomachus fasciatus (Fab.)[1]=Pezomachus melanocephalus (Schrk.).

CHALCIDIDAE

	Pteromalus halidayanus Ratz.[1]
	Pteromalus pini Hartig.[1]
	Dibrachys boucheanus Ratz.[1] (Secondary)
	Eurytoma abrotani Panzer[1,2]=appendigaster Swed. (Secondary)
Eupelmus bifasciatus Fonsc.	Eupelmus bifasciatus Fonsc.[1,2]
Monodontomerus aereus Walk.	
Chalcis flavipes Panz.	Chalcis callipus Kby.[3]
Chalcis obscurata Walk.[4]	
Schedius kuvanae How.[4]	

FOREIGN TACHINID PARASITES ON PORTHETRIA DISPAR

Blepharipa scutellata R. D.	Argyrophylax atropivora R. D.
Carcelia gnava Meig.	Carcelia excisa Fall.
Compsilura concinnata Meig.	Compsilura concinnata Meig.
Crossocosmia sericariae Corn.	Echinomyia fera L.
Dexodes nigripes Fall.	Epicampocera crassiseta Rond.
Parasetigena segregata Rond.	Ernestia consobrina Meig.
Tachina larvarum L.	Eudoromyia magnicornis Zett.
Tachina japonica Towns.	Exorista affinis Fall.
Tricholyga grandis Zett.	Historchaeta marmorata Fab.
Zygobothria gilva Hartig	Lydella pinivorae Ratz.
	Meigenia bisignata Schin.
	Parasetigena segregata Rond.
	Phryxe erythrostoma Hartig.
	Ptilotachina larvincola Ratz.
	Ptilotachina monacha Ratz.
	Tachina larvarum L.
	Tachina nocturarum Rond.
	Zenillia libatrix Panz.
	Zygobothria gilva Hartiz.
	Zygobothria bimaculata Hartig.

TABLE 6.III

THE PRESENT STATUS OF THE INTRODUCED PARASITES (1911)

PARASITES OF THE GYPSY MOTH

EGG PARASITES

ANASTATUS BIFASCIATUS Fonsc.

Received first in 1908. Colonized unsuccessfully in 1908 and successfully in 1909. First recovered in immediate vicinity of colony in 1909. Increased notably in 1910, but indicated dispersion is only about 250 feet per year. Artificial dispersion necessary. Apparently well established.

SCHEDIUS KUVANAE How.

Received first in 1907, dead, and in 1909, living. Successfully colonized in 1909. Recovered in immediate vicinity of colony site in 1909. Doubtfully recovered in 1910. Establishment very doubtful on account of climatic conditions.

HYMENOPTEROUS PARASITES OF CATERPILLARS

APANTELES FULVIPES Hal.

Received first in 1905, dead, and in 1908, living. Colonized unsatisfactorily in 1908 and under exceptionally favorable conditions in 1909. Two generations recovered in immediate vicinity of colony site in 1909. Not recovered in 1910 except from recent colony. Establishment doubtful on account of lack of proper alternate hosts.

TACHINID PARASITES

COMPSTLURA CONCINNATA Meig.

First received in 1906 and colonized same year. Colony strengthened in 1907. Recovered doubtfully in 1907 from immediate vicinity of a colony site. Certainly recovered and found to be generally distributed over considerable territory in 1909. Marked increase in 1910. Apparently established.

TABLE 6.III (CONT)

CARCELIA GNAVA Meig.

Doubtfully colonized in 1906. Satisfactorily colonized in 1909. Not recovered from field. Establishment hoped for.

ZYGOBOTHRIA GILVA Hartig.

Doubtfully colonized in 1906. Satisfactorily colonized in 1909. Not recovered from field. Establishment hoped for.

TACHINA LARVARUM L.

First received in 1905 and colonized in 1906. Much more satisfactorily in 1909. Not recovered. Establishment doubtful on account of hybridization with similar American species.

TACHINA JAPONICA Towns.

First received and poorly colonized in 1908. A better colony put out in 1910 Recovery doubtful on the same account as above.

TRICHOLYGA GRANDIS Zett.

Doubtfully received and colonized in 1906. Satisfactorily colonized in 1909. Recovered from immediate vicinity of colony site in 1909. Not recovered in 1910, but establishment hoped for.

PARASETIGENA SEGREGATA Rond.

First received in 1907 and colonized in 1910. Not recovered. Establishment hoped for and expected.

BLEPHARIPA SCUTELLATA R. D.

First received in 1905. Colonized under very unsatisfactory conditions in 1907. Satisfactory colonization for first time in 1909. Recovered from immediate vicinity of colony site in 1910. Establishment confidently expected.

TABLE 6.III (CONT)

CROSSOCOSMIA spp.

First received in 1908 and colonized in 1910 under fairly satisfactory conditions. Not recovered. Establishment rather doubtful on account of unsatisfactory colony.

PARASITES OF THE PUPA

MONODONTOMERUS AEREUS Walk.

First received in 1906. Colonized in 1906. Recovered, generally distributed over considerable area, in winter of 1908-9. Firmly established and dispersing at a very rapid rate.

CHALCIS OBSCURATA Walk.

First received in 1908. Colonized in 1908 and 1909, but not satisfactorily. Establishment doubtful on account of small size of colony.

CHALCIS FLAVIPES Panz.

First received in 1905. Colonized in 1908 and 1909 but in unsatisfactory numbers. Recovered from immediate vicinity of colony site in 1909. Not recovered in 1910. Establishment doubtful on account of small colony.

PREDACEOUS BEETLES

CAOSOMA SYCOPHANTA L.

First received in 1906. Colonized same year. Recovered from immediate vicinity of colony site in 1907. Found generally distributed over limited area in 1909. Firmly established and increasing and dispersing rapidly.

TABLE 6.IV

FOREIGN ENEMIES OF PORTHETRIA DISPAR AND NYGMIA PHAEORRHOEA LIBERATED IN NORTH AMERICA

Species	Number of individuals of foreign stock liberated	Number subsequently liberated: By reproduction from foreign stock	Number subsequently liberated: By reproduction from established stock	Number subsequently liberated: From New England field collections	Total numbers of enemies liberated
Anastatus disparis Ruschka	138,680			65,505,513	65,644,193
Apanteles lacteicolor Vier	55,000			255,245	310,245
Apanteles liparidis Bouche	76,702	[1] 37,370			114,072
Apanteles melanoscelus Ratz	23,476		132,177		155,653
Apanteles solitarius Ratz	[2]22,546				22,546
Apanteles porthetriae Muesebeck	12,065	22,522			34,587
Brachymeria intermedia (Nees)	20,798				20,798
Brachymeria obscurata (Walk.) (?)	394				394
Carabus arvenis Fab	108				108
Carabus auratus L	478				478
Carabus glabratus Payk					
Carabus violaceus L	63				63
Carabus nemoralis L	136				136
Carcelia laxifrons Vill	9,742				9,742
Carcelia separata Rond	[3]17,061				17,061
Calosoma chinense Kirby	140	128			268
Calosoma inquisitor L	259	27			286
Calosoma reticulatum Fab	83	27			110
Calosoma sycophanta L	2,711			[4]63,870	66,581
Compsilura concinnati Meig	25,134			122,625	147,759

TABLE 6.IV (CONT)

Species	Number of individuals of foreign stock liberated	Number subsequently liberated: By reproduction from foreign stock	Number subsequently liberated: By reproduction from established stock	Number subsequently liberated: From New England field collections	Total numbers of enemies liberated
Crossocosmia flavoscutellata Schiner (?)	700				700
Crossocosmia sericariae Corn					
Ephialtes (Ephialtes) examinator Fab	402				402
Ephialtes (Ephialtes) instigator Fab					
Eudoromyia Magnicornis Zett	4,568				4,568
Eupteromalus nidulans Foerst		[5]530,000			530,000
Hyposoter disparis (Vier.)	12,543				12,543
Lydella nigripes Fall	10,692				10,692
Masicera sylvatica Fall	23				23
Meteorus japonicus Ashm	5	395			400
Meteorus pulchricornis Wesm	4	118			122
Meteorus veriscolor Wesm	3,113			7,887	11,000
[illegible]ntomerus aereus Walk	15,541				15,541
Pales pavida Meig	582				582
Phorocera agilis R.D	18,445	2,278			20,723
Procrustes coriaceus	75				75
Schedius kuvanae How	1,703		[6]25,675,884		25,677,587

TABLE 6.IV (CONT)

Species	Number of individuals of foreign stock liberated	Number subsequently liberated: By reproduction from foreign stock	By reproduction from established stock	From New England field collections	Total numbers of enemies liberated
Sturmia inconspicua Meig.	13,364				13,364
Sturmia nidicola Towns	3,500				3,500
Sturmia scutellata R.D	11,097			73,546	84,643
Tachina japonica Towns	471				471
Tachina larvarum L	42,152				42,152
Tachinids unclassified	[7] 9,420				9,420
Tachinids unclassified	[8] 10,499				10,499
Telenomus phalaenarum Nees			[9] 4,650		46,650
Trichogramma spp			[9] 76,000		76,000
Tricholyga segregata Rond	9,323				9,323
Xylodrepa quadripunctata Schr	100	15			115
Zenillia libatrix Panz	504				
TOTAL	574,402	673,530	25,808,061	66,028,686	93,084,679

[1] From a beginning of 288 individuals

[2] Some doubt as to this species

[3] Some of these Carcelia gnava Meigen

[4] Some of this number were obtained by reproduction work with foreign and established stock

[5] Number of foreign stock received not known, but it was very many less than the number given

[6] Some reproduction from foreign stock but mostly from established stock

[7] Includes some of multibrooded tachinids liberated from 1906 to 1907

[8] Mostly Tachina larvarum in 1926

[9] Number of foreign stock received not known

The foregoing program was cited in some detail to underline the fact that biological control of the gypsy moth is not a new concept. It has been used rather extensively with varying degrees of success. It is not a panacea offering an immediate and perfect solution to the gypsy moth problem but, apparently, can have beneficial effects. The preceding tables should also serve to illustrate not only the magnitude of early efforts, but also the need for patience in this type of time-consuming effort.

Dowden[6.24] states that it is generally believed that the gypsy moth is as well controlled by biotic factors in North America as in Europe but that the increased use of insecticides against the pest makes a definite appraisal very difficult.

Biological control programs aimed at the gypsy moth received little attention from 1930 through the 1960's being replaced by work of the CCC crews and then by aerial application of chemical insecticides. Present day work in biological control is exemplified by work being done by New Jersey and is discussed later.

Although biological control also includes the use of predators, both vertebrate and invertebrate, little attention has been given until recently to the role of vertebrate predators in controlling gypsy moth populations. While vertebrate predators (both birds and mammals) can have only a minor effect in regulating rapidly increasing host populations, they do have a significant effect in maintaining low population densities.[6.8,6.9,6.1]

Bess, Spurr and Littlefield [6.25] noted that both the short-tailed shrew and the deer mouse, voracious feeders on larvae of the gypsy moth, were most abundant and important in forest stands with moist, deep, forest floor. Exposed, dry sites both restrict the presence of predators and inhibit the normal descent of gypsy moth larvae to the ground to expose them to predation. Presently, the United States Forest Service is conducting basic studies on the predation of the gypsy moth by the deer mouse, as well as a fundamental elucidation of the predator life cycle.

The third aspect of biological control, namely pathogens, has long been observed as causing sudden, dramatic collapse of epidemics of the gypsy moth. Doane[6.26] among others, has identified this gypsy moth "wilt" as caused by a nuclear-polyhedrosis virus (NPNV) and streptococcus faecilis. The epizoatic of disease resulting in sudden collapse of host population appears to be dependent upon high density of host larvae and the rapid spread of the pathogens enhanced by behavior of larvae during the early instars.

Rollinson, Lewis and Waters[6.27] report a successful attempt to create an epizootic of NPHV with a water spray from truck-mounted mist blower. Virus-caused mortality occurred up to 34 days after application with peak kill at 19 days.

The possibility of using a microbial insecticide to control leaf-feeding lepidopterous pests became a reality in the late 1950's with the commercial production of Bacillus thuringiensis. In spite of successful use of this material to control several agricultural pests, aerial application of this material against gypsy moth larvae has been disappointing[6.28]. With improved formulations and application techniques, this bacterium may show promise as an effective biotic control for the gypsy moth[6.29,6.30].

At this time, Bacillus thuringiensis is the only pathogen commercially produced and registered for used against the gypsy moth.

A-6.4 Control Alternatives

A-6.4.1 New York

Since the gypsy moth first invaded New York, continuous attempts to eradicate this pest have been conducted. These included the use of pesticides, sex lures, the introuduction of parasites and predators and direct physical assault in destroying egg masses, banding of trees, purning infected trees and the destruction of protected egg-laying habitat. This phase of the campaign against this pest is treated more fully in a later section discussing the work of the CCC crews during the 1930's and early 1940's.

While these early measures proved to be very useful, little effort has been made in New York since 1945 to resort to these practices. Although the State has cooperated with the Federal Government in experimental releases of some parasites and predators and sex attractants, there is no evidence of a concerted effort to use these agents in an active, integrated control program.

New York is not alone and while there is interest in the potentiality of biological control agents in this and in all threatened states, New Jersey is the only state that has manifested a commitment.

A-6.4.2 New Jersey

As long as DDT was being used, the gypsy moth in New Jersey was effectively controlled and its range reduced. However, in 1963, the substitution of Sevin for DDT, plus increased infestations along the northern borders of the state, resulted in an "explosion" of the gypsy moth throughout the state. Intrusion of the moth was so great, in fact, that the state abandoned its policy of eradication for one of control - an integrated control program employing both chemical and biological means to regulate populations of the gypsy moth.

Since New Jersey had long been active in the collection and rearing of parasites to control introduced agricultural pests, it was a logical step to adopt biological control measures as an important element of this program. Accordingly, in 1963, work began with field collection of six of the nine gypsy moth parasites that had become established in New England, with their subsequent release in New Jersey. In addition, the other three parasites were reared in New Jersey and also field released.

Since the remote forested areas of the northern part of the state were so badly infested as to leave little hope of any economically acceptable control, this area was selected as the focal point for establishment of biological controls. Threatened high-value, forest urban areas were given immediate protection through use of chemical insecticides (Sevin at 1 lb/acre).

The main objective of the New Jersey program is to establish populations of various insect parasitoids throughout the distribution of the gypsy moth in that state. It is anticipated that these efforts, part of an integrated approach to managing this pest, will assist in maintaining gypsy moth populations at a level where their impact on the forest and urban ecosystems can be tolerated, both economically and ecologically.

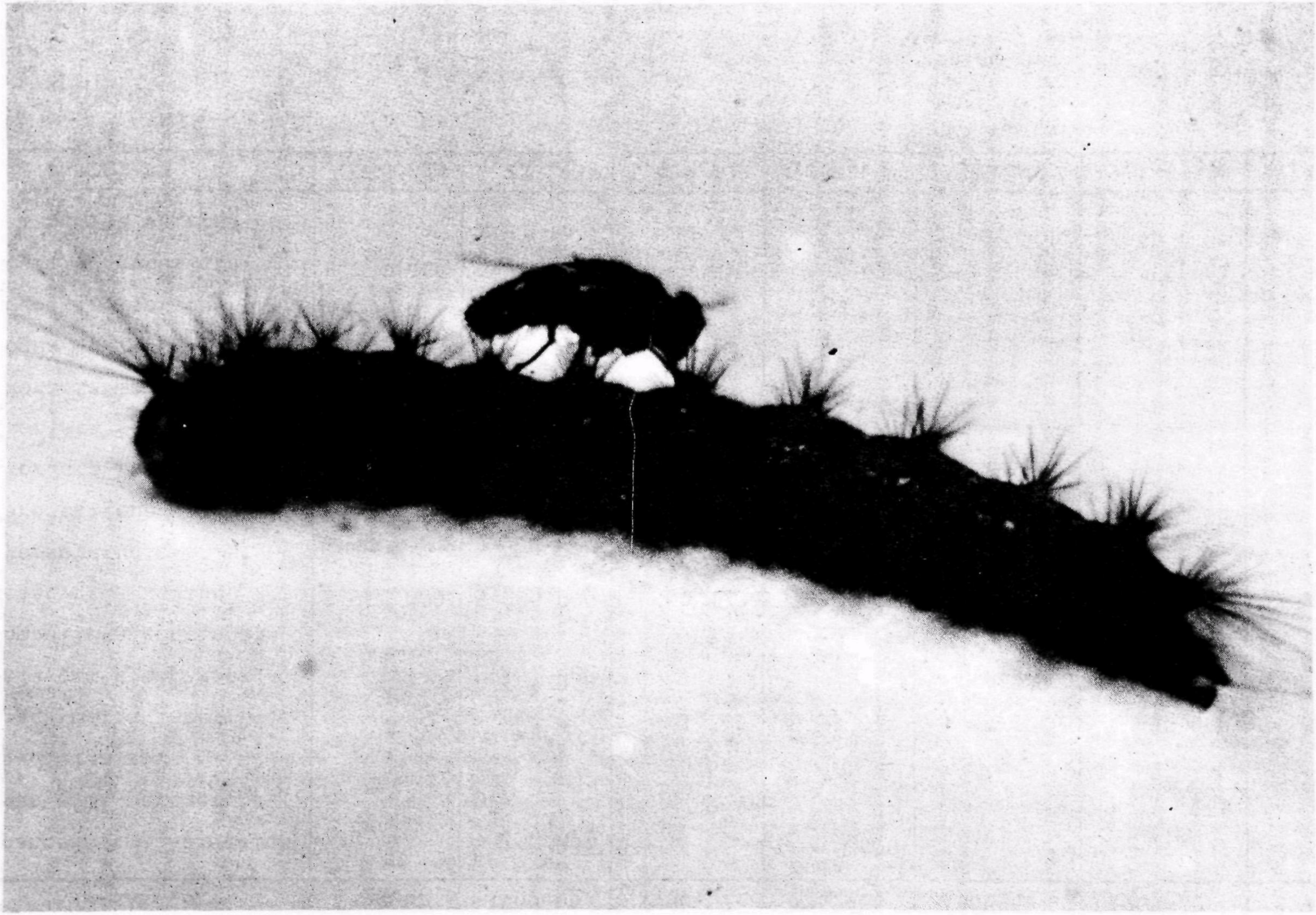
Table No. 6.V listing all of the egg, larval, and pupal parasites released under this program for each of the last 7 years, shows the variety and numbers of parasites being handled. In addition to these, during spring of 1968, mass-rearing of gypsy moth larvae was initiated for use in both parasite rearing and in male sterilization programs.

Figure 6.2 shows one of the exotic parasites being reared and released under this program. This particular larval parasite, Exorista segregatta, is shown depositing its eggs on a later instar gypsy moth larva.

Table 6.V

GYPSY MOTH PARASITE RELEASES
STATE OF NEW JERSEY

PARASITE	YEAR OF RELEASE							TOTALS
	1964-65	1965-66	1966-67	1967-68	1968-69	1969-70	1970-71	
Apanteles melanoscelus		137		400		17,497	11,422	29,456
Apanteles porthetria						145		145
Apanteles sp.							6,189	6,189
Brachymeria intermedia			1,763	53,315	334,266	393,060	326,273	1,108,677
Calosoma sycophanta	1,139	338			294	247		2,018
Compsilura concinnata			427					427
Ooencyrtus kuwanae	3,985,000	5,235,000	1,497,120	3,028,500	15,425,800	18,664,500	37,271,000	85,106,920
Hyposoter disparis							136	136
Parasetigena agilis					2,281	12,505	11,140	25,926
Exorista rossica					9,964	35,616	38,360	83,940
Exorista segregata					16,912	45,877	45,534	108,323
Exorista larvarum							4,539	4,539
Rogus sp.						1,127	1,127	
Rogus indiscretus							295	295
Sturmia scutellata	460	2,359	612	1,620		14,184		19,235
Tricholyga segregata				1,826				1,826
TOTALS	3,986,599	5,237,834	1,499,922	3,085,697	15,789,517	19,184,758	37,714,885	86,499,215



COURTSEY: NEW JERSEY DEPT. OF AGRICULTURE

Figure 6.2 PARASITE EXORISTA SEGREGATTA OVIPOSITING ON GYPSY MOTH LARVAE

The biological program is divided into two parts; insect rearing and field evaluation. The insect rearing facilities and techniques used are well organized, staffed and maintained. The rearing and releasing techniques developed by New Jersey should serve as excellent models for the establishment of similar facilities in other states.

The most critical part of the program, however, is the field evaluation undertaken to determine the success or failure of the biological control effort. It is too early at this time to critically review this part of the project, although it is evident that the main interest is in determining whether or not populations of various parasitoids had become "established" at the various release sites. Establishment is considered successful if a particular species is recovered from field collections after 3 years of releasing an individual parasitoid.

However, mere "establishment" of populations of various parasitoids in the gypsy moth life system is not sufficient evidence for determining the success or failure of the program. Unfortunately, basic research is lacking on both the individual parasitoids that are being used, and the sampling techniques employed for field evaluations. This is unfortunate and is a manifestation of constraints of time and the need for additional scientific manpower. The importance or potential of a particular parasitoid can only be determined, in most cases, by a detailed examination of the biology, behavior, ecological adaptability, and responses (functional and numerical) of individual species to changes in host density.

It has been intimated that biological control efforts in New Jersey have successfully reduced the duration of heavy defoliation from 3 to 2 years in some areas. Also, field observations to date suggest that certain parasitoid applications are playing a significant role in stabilizing gypsy moth populations at tolerable levels, although, as noted above, sufficient information is not available at this time.

However, it must be noted that biological control requires time to become established. The results are not instantaneous as with chemical sprays and losses must be both expected and accepted. The following table shows mortality sustained in a 17,855-acre forest on the Newark watershed subjected to heavy defoliation for 3 years before the gypsy moth infestation collapsed from disease and parasitism.

Year	Percent Oak Mortality	Total No. Dead Oaks in Affected Forest
1968	6.5	116,693
1969	14.3	257,112
1970	38.0	686,881
1971	57.7	1,033,269

A-6.4.3 Other Alternatives

In the Newark example cited the loss of over 1,000,000 oak trees may be considered too high a price to pay for nonchemical control. The value of the woodlands in one state is not necessarily the same in another state. This is, in fact, the reason for different treatment philosophies within the northeastern states.

Examination and study of historical and technical literature, coupled with discussions with several individuals, have revealed that modern integrated control procedures basically ignore the use of manpower as a central ingredient. In the past personnel have, with minimal training, served as effective gypsy moth control agents. Efforts have included scraping and creosoting of egg masses, trapping and disposal of larvae, banding of trees, and the destruction of protected egg-laying habitat. These measures have, in the past, been effective in minimizing the ravages of this pest. Hundreds of personnel have been involved in this work. Year-round efforts are possible in not only overt control but also in the inspection and evaluation of woodlands for evidence of the pest. There is no reason why this technique should not or could not be resurrected and relied upon in integrated control efforts.

Once areas of infestations have been discovered through trapping, scouting surveys conducted in these areas during the fall and winter will determine the extent and intensity of the infestation. Then effective control measures of the gypsy moth can be taken, including destruction of eggs and the destruction of caterpillars. Methods used to destroy the pest are delineated in the following paragraphs. The methods discussed herein as to how the destruction may be accomplished do not include chemical spraying and introduction of parasites.

It should be noted that evidence indicates that no matter how effective each method is, no one method can be depended upon for eradication of the gypsy moth. Nature often upsets an attempt to exterminate by a single method by a single process at a particular season of the year. The extermination program must proceed day after day throughout the year in order to ensure success.

(1) Destruction of Eggs

Most of the life cycle of the gypsy moth is spent in the egg stage from July or August until the following spring. The eggs are generally deposited on trees and are of a conspicuous buff color and thus, provide an excellent opportunity for scouting and locating gypsy moth colonies during the fall and winter months when trees are devoid of leaves. Each egg cluster deposited upon trees and other objects contains potentially 300 to 1400 caterpillars. It is apparent that destruction of the egg cluster eradicates the forthcoming hatch of caterpillars, which would otherwise spread out and feed upon nearby foliage. It appears to be more feasible to eliminate the insect when it is grouped and stationary rather than after it has hatched and scattered in search of food.

In the late 1880's, when the gypsy moth had become well established in the woodlands surrounding Medford, Mass., the Commonwealth of Massachusetts appropriated funds to control the pest. In doing so, they consulted with entomologists from European countries where the gypsy moth was the native pest. The Europeans recommended egg-killing as the first and chief method of preventing the spread and costly destruction of the pest.

Control of the gypsy moth by destruction of eggs was initiated in Massachusetts[6.19] and later employed as a control measure in the States of New York[6.31] and Pennsylvania[6.12] A review of the literature indicates that egg-killing was employed as a chief method of control during the time period up through about 1944 when DDT was first experimented with to determine its value in gypsy moth control and eradication work. It appears that egg-destruction as a method of control is presently employed only on egg clusters found on materials being shipped from quarantine areas. Because of the ban on use of DDT as a control measure of the gypsy moth, it is recommended that consideration of a renewed major effort be expended in egg destruction as a means of eradication of the pest.

During the past, egg killing has been accomplished by various methods, namely:

1. Burning gypsy moth eggs.
2. Killing with chemicals.
3. Destroying by gases.

The methods are more fully described in the following discussion.

A. Burning of Gypsy Moth Eggs

The most effective method of egg killing employed by Massachusetts in the early years of their eradication program was to scrape the egg clusters from the trees and burn them. The eggs were scraped and cut away from the trees, fences, buildings, etc., collected in cans and burned in large brush fires or stoves. When exposed to a steady intense heat, the eggs burst with a popping sound like corn in a corn popper.

Naptha burners (blow torch) were later employed against egg cluster deposits as a more effective method than scraping and then burning egg clusters. The flame reduced the egg clusters to ashes although occasionally some of the clusters, exposed to intense heat, burst and scattered some of the eggs. Use of the burner against clusters deposited on young trees caused damage to the tree whereas a mature tree with thicker bark was not seriously affected. The burner could be used effectively to destroy egg clusters deposited in cavities of trees or rocks.

Where large deposits of egg clusters were found in underbrush and wasteland, it was not feasible to scrape every bush and schrub so experiments were conducted to destroy the eggs by more expeditious means. In one experiment, fire was run through dead leaves and debris, but it was not found effective because the heat was not intense enough. The hairy covering of the egg clusters apparently acted as an insulator thus rendering the eggs insensitive for a time to sudden intense heat. It was found that it takes minutes of applied intense heat before all the eggs are destroyed in a cluster. Heat from a running brush fire, at the most, may scorch the outside of a cluster, killing those eggs in the outer layer.

In another technique, crude petroleum was sprayed over the ground and vegetation and then ignited. The fire was violent enough to destroy most of the eggs in the brush on the upper layer of leaves, but eggs under roots or rocks were not affected. Also, there was considerable inefficiency since the oil soaked into the ground and the flame fed from this oil was not as intense as that sprayed on the brush.

As a result of the limited success in the experiments conducted in undergrowth, investigations were made to devise a more efficient way of destroying eggs in underbrush. After numerous experiments, an apparatus known as the "cyclone burner", was devised. It consisted of a 15-gallon tank, a Johnson hand-pump, a length of hose and pipe at the end of which was attached a cyclone nozzle. Crude oil and later "parrafin gas" oil was used as a fuel. Two men were required to move and operate the apparatus; one to pump and one to direct the nozzle. A fine spray, generated by the pumped oil passing through the nozzle, was ignited and produced an intense flame that "destroyed every living thing in its path". When an area was carefully covered, no eggs escaped destruction except those hidden in ledges or holes in the ground.

This burner was also used in the destruction of gypsy moth egg clusters deposited in stone walls. This was partially successful as those egg clusters within reach of the flame were destroyed, whereas those clusters under the lower stones of the wall were unharmed even though some of the stones were cracked and broken by the heat.

In the 1930's, New York successfully used a large weed burner fueled with kerosene to destroy egg masses that were laid on or within stone walls[6.32].

Fire was used in hollow trees wherein the eggs deposited by the moth were destroyed by burning out the decayed wood. It was found that if judiously done there was no injury to the tree. In fact, some of the old trees seemed to benefit by such burning since the trees exhibited better growth in the following season. To accomplish the burning, oil was poured into the top of the cavity and a small opening was made at the bottom of the cavity to provide a draft for the burning oil. Such work was done in the winter when the sap was dormant.

B. Killing with Chemicals

Early in the eradication program in Massachusetts it was found that it was impossible to detach the egg masses by scraping without scattering and losing some of the eggs. As a result, it was deemed that it would be more practical to destroy the eggs without removal from the place of deposit. This led to an extensive study of substances which might be advantageously used for this purpose. The criteria for selection were that the substance:

(1) be effective wherever applied,

(2) leave a permanent stain or color thus enabling one to distinguish treated egg clusters from untreated, and

(3) be low in cost.

A variety of liquid and gaseous materials were evaluated. Three types of mixtures that were evaluated in the field are described.

Creosote

Of the many substances investigated it was found that application of creosote to the egg clusters provided the most effective and economical method. The creosote required no preparation nor complex application apparatus. It could be readily drawn from a can and applied with a brush. The creosote rapidly penetrated the egg clusters and killed all the eggs. Creosote has a tendency to thicken in cold weather. During cold weather, a mixtrue consisting of 50 % creosote, 20 % carbolic acid, 20 % spirits of turpentine and 10 % coal tar was used. The coal tar was added to color the egg clusters when treated because creosote alone often faded after application thus making it difficult to distinghish treated egg clusters from untreated ones.

Where coal tar was not added to the mixture, a white circle was painted around an egg cluster treated with creosote. For this purpose, a pocket receptacle containing a tube of creosote and a tube of white paint (each of which had a stopper with a small paint brush) was issued as standard equipment to workers in Massachusetts.

Creosoting of eggs proved to be an effective method of gypsy moth control in New York as shown in Table 6.VI. This table summarizes the eradication work in New York State over the period from 1924 through 1942. New York State Legislative Documents (LD) during the years 1925-1943 were used to develop this data compilation. In this table, where numbers are separated by a slash, those preceding the slash refer to egg clusters.

Careful examination of this table shows that in 25 of the 32 towns where colonies and egg clusters were found, creosote treatment of the egg clusters resulted in an eradication or reduction of egg count in subsequent years.

<u>Acids</u>

Another effective method of destroying egg clusters that was used early in the Massachusetts control effort was the application of a 50-50 mixture of carbolic acid and turpentine. When placed on an egg cluster it readily penetrated and killed all the eggs. To ensure destruction, a jet of nitric acid was then

Table 6.VI

GYPSY MOTH CONTROL BY DESTRUCTION OF EGG CLUSTER

LOCATION	NUMBER OF EGG CLUSTERS FOUND		REMARKS
	DISCOVERY YEAR	SUBSEQUENT YEAR(S)	
LD (1925)			
Greenport	1000+(June '22)	5 (1924)	"...this year campaign has further reduced, if not completely eradicated, these infestations."
Patchogue	1000+(June '22)	15 (1924)	
LD (1927)			
Chesterfield and Morian, Essex Co.	Colonies (1925)	0 (1926)	"...gratifying to learn that suppression campaign of 1925 had completely eradicated those colonies."
LD (1928)			
New York - New England	328/15,583 (Jun'23-30 Jun'26)	25/4,055 (Jul'26-30 Jun'27)	
Essex Co.	(?) (1926)	(None) (1927)	Scouting project in vicinity of G.M. Colonies found previous. Year revealed no additional colonies or signs of G.M. were found.
Long Island	1926 and previous years	(None) (1927)	Same as above except in Brooklyn
LD (1929)			
Ulster Co.	1927	1928	Survey within 1 mile radius of G.M. colony found in 1927 revealed a colony within short distance of 1927 colony.
Long Island	1927	1928	Small colony found in immediate vicinity of 1927 colony.

Notes: 1. G.M. denotes gypsy moth
2. 328/15,583 (example) denotes 328 colonies and 15,583 clusters
3. L.D. denotes N.Y. Legislative Documents.

Table 6.VI (CONT)

LOCATION	NUMBER OF EGG CLUSTERS FOUND		REMARKS
	DISCOVERY YEAR	SUBSEQUENT YEAR(S)	
LD (1930)			
New York State	Up to 1928	1929	The effectiveness of control practices has been well proven. On only very rare occasions has any indication of re-infestation been found at the colonies where such control measures have been properly applied.
LD (1931)			
Southold - Suffolk Co.	1929 or earlier	3 (1930)	Taken from "Summary of Checking Work in Vicinity of where G.M. have heretofore been found".
Douglaston - Queens Co.	1929 or earlier	3 (1930)	
LD (1933)			
Rye, Westchester		1/7 (1932)	1700 sq. miles of scouting
LD (1937)			
Long Island	42/2282 (1935)	24/237 (1936)	"The size of actually infested area is considerably less than at any time since the control program was inaugurated."
LD (1938)			
Long Island	24/237 (1936)	14/94 (1937)	

Table 6.VI (CONT)

	NUMBER OF EGG CLUSTERS FOUND		
LOCATION	DISCOVERY YEAR	SUBSEQUENT YEAR(S)	REMARKS
LD (1938) (Cont)			
Shawangunk, Ulster Co.	Thousands (Jul'36)	0 (1937	"Present indications are that an outstanding record with regard to extermination was achieved. At least it is positively known that where thousands of G.M. egg masses were in evidence last September not a single one was seen in the same locality this year".
LD (1939)			
New York State	102,968 (1937)	16,015 (1938)	
Putnam Co.	73,000 (1937)	308 (1938)	"Despite handicap of rugged terrain, it is believed extermination program has been very effective".
Mamaroneck and New Rochelle, Westchester Co.	Small colonies (1937)	None (1938)	
Bronx	12,527 (1935)	127 (1936) 19 (1937) 0 (1938)	
Ulster Co.	28,000+ (Sept.'36)	15 (1938)	
LD (1940)			
Ulster Co.	28,000	20 (1939)	"...good progress has been made in the Ulster Co. G.M. extermination program".
Bronx	12,527 (1935)	0 (1939)	2nd consecutive year - no evidence of G.M. found

Table 6.VI (CONT)

LOCATION	NUMBER OF EGG CLUSTERS FOUND		REMARKS
	DISCOVERY YEAR	SUBSEQUENT YEAR(S)	
LD (1940) (Cont)			
Newcastle Westchester Co.	? (1938)	0 (1939)	Outbreak found in New Castle in 1938 was completely eradicated in 1939. This was revealed by inspection.
Putnam Valley	73,000+ (1936)	87 (1939)	Continuous extermination program during the 3 years.
Warren Co. (Trumbull Mt.)	15,000+ (1937)	1 (1939)	
New York State	102,968 (1937)	163 (1939)	State Summary
LD (1941)			
Yonkers (Westchester Co.)	147 (1939)	2 (1940)	"Careful and frequent inspection of burlap and larvalefood used extensively in Yonkers area during larvae season failed to reveal any sign of G.M.,..."
Putnam Valley and Vicinity	73,000+ (Oct.'36)	186 (1940)	Infestations has been reduced to a few (15) small but isolated colonies.
Trumbell Warren Co.	15,244 (Fall'37)	60 (1940)	Note a reduction for the time period but up from the previous year.
Shawangunk, Ulster Co.	Thousands (Jul.'36)	13 (1940)	"...control operations have been quite successful; complete extermination expected at an early date."
Wawarsing, Ulster Co.	Thousands (Jul.'36)	290 (1940)	
LD (1942)			
Ticonderoga Essex Co.	? (1939)	0 (1940) 3 (1941)	

Table 6.VI (CONT)

LOCATION	NUMBER OF EGG CLUSTERS FOUND				REMARKS
	DISCOVERY YEAR		SUBSEQUENT YEAR(S)		
LD (1942) (Cont)					
Warren Co.	15,000+	(1937)	77	(1941)	Note up from last year. Seven colonies found this year. Majority of colonies consisted of a single egg cluster, which might indicate reinfestation was originated through wind dispersion from heavily infested New England areas - no evidence of G.M. has been noted in full work.
Putnam Co.	21/380	(1940)	11/215	(1941)	
Shawangunk, Ulster Co.	13	(1940)	1	(1941)	Believe complete extermination has been attained.
Esopus (Ulster Co.	4582	(1940)	508	(1941)	-not expected that extermination has been achieved.
Long Island			5	(1941)	Work of current year believes extermination is about achieved. Fall scouting of area revealed no evidence of G.M. infestation.
LD (1943)					
Ticonderoga (Essex Co.)	3	(1941)	0	(1942)	
Rampo (Rockland Co.)	Small colony		0	(1942)	
Esopus (Ulster Co.)	508	(1941)	5/34-N, 34-0	(1942)	

directed on the treated egg cluster. The nitric acid alone will not penetrate egg clusters, although it was sufficient to kill the eggs once they were devoid of the hairy covering. Although the acids were effective, they were expensive and presented a hazard to the men using the method. Clothes, ropes, tools and apparatus were also affected by the acid fumes. This method gave way to the creosote method described previously.

Gases

Many experiments with various gases were conducted to obtain a practical method which would destroy the gypsy moth eggs deposited in hollow trees, stone walls and other inaccessible places. The more effective gases were bromine or chlorine. However, because of the difficulty of providing a tightly sealed chamber or compartment about the egg deposits, the use of the gases was found to be only partially effective.

(2) Destruction of Caterpillars

Gypsy moth eggs hatch in date April or early May following a period of warm weather. The male larvae undergoes five instars or growth stages while the female matures through six instars. The last instar of both occurs about mid-June.

The larvae emerge from the eggs and usually remain near the egg cluster for several hours. If the weather is cold or stormy they will remain 2 or 3 days outside the cluster. The larvae find food by random movement since no evidence has been found that they can select a favored tree from an unfavored one without examining the foliage first. The newly hatched larvae can live about a week without feeding and if cold, wet, weather is prolonged for this time period, the initial mortality is very high. The young larvae, about 0.062" long when grouped about the egg cluster can be quickly destroyed by the flame of a naptha or propane burner or by applying creosote or kerosene. Methods of destroying the larvae, once after they leave the egg-cluster and ascend the tree in search of food, are discussed below.

A. Banding Trees

Banding of trees was employed in Europe and in Massachusetts, New York and Pennsylvania as a means of combating the gypsy moth. Some bands consisted of a sticky material which prevented larvae from ascending trees in search of food and from descending in cases where larvae hatched in tree crevices above the bands. Also some banding was employed as a cover to which the larvae retired during the daytime. The specific details of the various types of bands are described below.

Tarred Paper Bands

In 1891 and 1892 many of the large street trees in Malden, Medford and Somerville, Massachusetts were banded with strips of tarred paper. To accomplish the banding about a 6" wide ring of bark of the tree was scraped or planed to a reasonably smooth surface at a height about 6' above the ground. A cotton waste band was placed on the scraped ring and then wrapped with a band of tarred paper. The paper was then tightly tied with a cord. Cotton waste was employed beneath the paper to prevent the first instars from crawling under the band. The tarred paper was covered with the following mixture:

3 parts	tree ink
1 part	pine tar
1 part	petroleum (residuum oil)

Several applications of the mixture was required to saturate the paper. After the initial saturation of the bands, the mixture was applied at least twice weekly during the larvae season on the trees that lined the dusty streets. Those trees in the fields required less frequent applications.

Raupenleim Bands

Raupenleim, which translated from German means "caterpillar glue", was introduced in 1892 in Massachusetts on the recommendation of Mr. B. Fernow, Chief of the Division of Forestry of the U. S. Department of Agriculture. Raupenleim rings had been used very effectively in Europe for about 10 years prior to being introduced in the United States. It was used in the gypsy moth work as a replacement of the tarred paper bands because, when properly placed upon the tree, it remained soft and viscous for several months. When applied shortly before the hatching clusters, it prevented the ascent of nearly all larvae.

Many different devices were devised for applying the Raupenleim to the trees, namely the Eichhorn, Hochleim, Eck, Sertz and Hauenstein lime machines Essentially these were extrusion-type devices in which the lime, as it extruded from a wide nozzle, was applied to the tree trunk. The lime was also applied by spades or trowels.

It was found that an effective lime band was one that was about 2.5" wide and varied in thickness from about 0.25" at the top to more than 0.5" at the lower edge. The oil, which oozed from the mixture when exposed to direct sunlight, would trickle down to the bottom edge and hang there forming an impassable obstacle to the caterpillar.

The insect lime had the disadvantage of being messy, e.g., oil exuded from the mixture in hot sunlight; cattle and horses rubbing against the bands plastered their coats; cats having come in contact with the lime in climbing trees tracked the lime over carpets in the home.

Dendrolene Bands

Dendrolene was invented by Professor F. L. Nason as a result of experimenting to obtain a domestic product similar to Raupenleim. It, as well as Raupenleim, was made of a crude petroleum base. Dendrolene was applied to trees in the same manner as Raupenleim. It appeared that Dendrolene remained soft longer than its counterpart, which in some cases required two or three applications because of hardening. Both types of bands installed near dusty areas required occasional renewal in windy weather. No injury to trees was observed as a result of banding with Dendrolene or Raupeleim.

Tree Tanglefoot

Tree Tanglefoot[6.8] was developed around 1920 by the Gypsy Moth Laboratory of the U. S. Department of Agriculture, and proved to be a very effective banding material against larval ascent. It was extensively used in gypsy moth control in New York and Pennsylvania during the 1930's.

Other Methods of Viscous Banding

Viscous banding of trees other than the types just described was employed in Europe. Bands of pitch or tar were frequently used in Russia, but these soon became dry and required replacing. In Crimea, a banding material made of two parts of boiled tar and one part rope oil, thoroughly heated together, was used about 1890. Another Crimean banding mixture of 10 lb of lard, 20 lb of hemp-seed oil and 80 lb of coal tar was recommended for use in Massachusetts. Evidently this mixture remained soft a long time since, after applying it directly to the tree, it required renewal only twice a year.

Dr. Richard Hess in "Der Forstscnutz" published in Leipzig in 1887 and 1890 recommended that orchard trees should be smeared with a mixture of lime, black soap, potash and cow dung to prevent larvae from ascending to the foliage.

Burlap Bands

Burlap bands were used on trees as early as 1891 in Massachusetts and also were used in the gypsy moth control in New York and Pennsylvania. The purpose of the bands was to assemble the larvae so that they could be readily found and then destroyed.

Observation of the gypsy moth revealed that before the larvae reached half their growth, they daily leave the foliage which they fed upon during the night and cluster in sheltered places, such as cavities in the bark and underneath limbs. As the larvae grow larger, search for shelter during the day became more apparent. The caterpillars often leave the trees upon which they were feeding, if the tree offers no shelter, in search of a hiding place such as stone walls, rubbish heaps, etc. It was also observed that they would cluster during the day under a piece of cloth left in a tree.

As a result of these observations an investigation was launched to devise an inexpensive, durable shelter which could readily be examined and serve as a trap. It was found that inexpensive 8-oz burlap, was the best material for the purpose. The burlap, cut into 1-ft wide strips, was wrapped around the trunk of the tree and held in place by twine. The upper half of burlap, above the twine, was folded over to provide a double thickness of burlap around the tree. If the trunk and/or branches offered no hiding places for the larvae, they would climb down, morning after morning, crawl under the burlap and remain there during the day. The burlap bands were tended daily at which time the assembled caterpillars were killed by crushing or cutting.

To ensure that each band was examined every day the following plan was utilized. When the burlap was checked the first time, the folds were turned up, the next day the folds were left down. Thus, by this method any band that was missed during a particular day could be readily identified. Whether the folds of the bands were left up or down did not affect the number of caterpillars trapped.

The use of burlap bands is an effective method for collecting the larvae so that they can be killed easily. In one experiment, a medium sized apple tree upon which caterpillars were feeding was burlap-banded and fenced off. The tight board fence enclosed an area 18-ft square and 5-ft high. A Raupenleim band was placed on the inside of the fence thereby confining all the caterpillars within the area. Observations were made daily over a 10-day period on the location of the caterpillars. Although the number of caterpillars varied on the tree, the number found each day in the same place and position was found to be quite constant. The number found under the burlap band varied between 52 % to 72 % whereas those found on the underside of branches constituted about 29 % of those on the tree; the number on leaves and on the trunk constituted less than 3 %.

<u>Other Methods</u>

Experiments were conducted in 1895 to determine the resistance of caterpillars to water. The results showed that the gypsy moth larvae are able to live in water for 2 or 3 days. Thus, water would not be an effective means of killing collected larvae; rather a liquid such as a petroleum distillate or turpentine should be used. This experiment points out that the ability to live in water for this time period enables it to be transported long distances in swiftly moving water and thus establish colonies distant from known infested area.

A-6.4.4 Control Personnel Used

An attempt was made to correlate manpower loading and the efficacy of various control measures. Records pertaining to forest pest control[6.10,6.33] in New York during the 1930's did not categorize the manpower use with the control method and efficacy although creosoting the egg masses apparently was effective (see A-6.4.2). In addition, during the mid-to-late 1930's, thousands of trees were banded. For example, in 1938 over 400,000 trees were so treated. Throughout this period, 100-200 men/month were utilized. It should be remembered, however, that many of these personnel were utilized in scouting operations.

A more interesting account of manpower use has been presented by Forbush and Fernold[6.19]. The manpower loading per month during 1890-1894 inclusive are plotted in Figure 6.3; a schematic representation of the gypsy moth life cycle is also presented. This chart shows that the employment peaks occurred during the larvae, pupa and adult stages of the life cycle of the gypsy moth. A summary of early gypsy moth control within the state for the above time period is presented in Table 6.VII. Use of this table in conjunction with Figure 6.3 gives some indication of manpower used for specific methods of gypsy moth control. In 1891, the peak employment period occurred during the larval stage, where control measures available at that time period were burlapping and spraying. Since spraying methods in 1891 utilized cumbersome equipment and required considerable manpower and since a large number of trees (177,415) were sprayed as compared to subsequent years, it may be concluded that a high percentage of the manpower was utilized in spraying. Further for 1891, the banding of 12,000 trees would have occurred during April, before the emergence of the larvae, and would have required an average of about 120 men to accomplish this task. The remainder of the year,

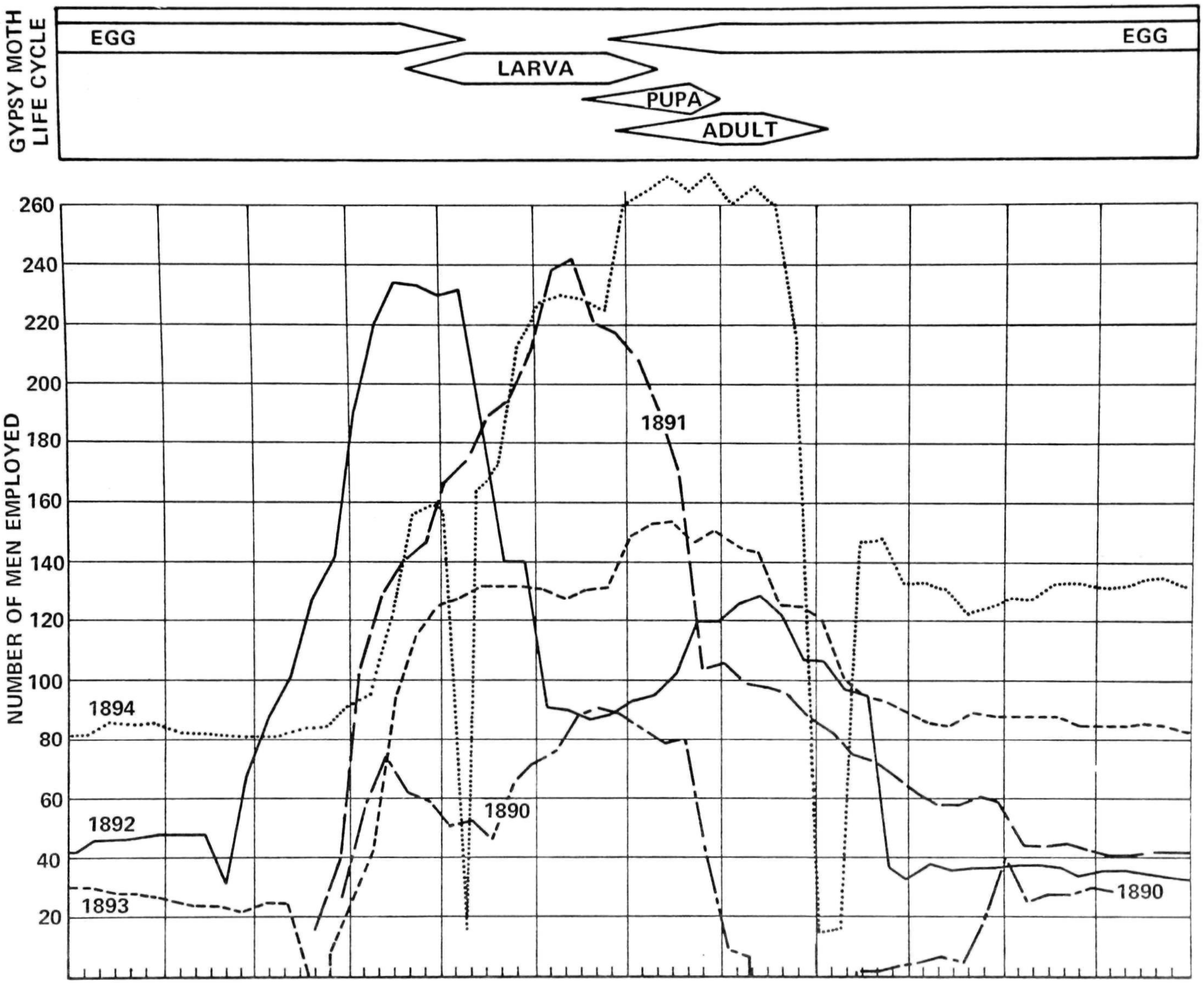


Figure 6.3 GYPSY MOTH LIFE CYCLE AND WEEKLY EMPLOYMENT FOR GYPSY MOTH CONTROL IN MASSACHUSETTS

TABLE 6.VII SUMMARY OF EARLY GYPSY MOTH CONTROL IN MASSACHUSETTS

	1891	1892	1893	1894
Trees (fruit, shade and forest):				
Inspected	3,591,982	2,109,852	4,108,494	6,828,229
Found to be infested with caterpillars, pupae, moths or eggs	213,828	108,428	44,716	48,752
Cleared of eggs	212,432	99,989	2,068	2,176
Cemented	19,296	12,172	4,583	7,844
Banded (insect lime or tree ink)	12,000	21,251	19,453	-
Burlapped	68,720	110,108	419,434	624,673
Sprayed	177,415	7,372	5,145	14,857
Trimmed	-	-	1,906	8,618
Scraped	-	-	2,406	6,068
Cut	-	395	4,055	10,296
Acres of brush land and woodland cut and burned over	120	115	184	336
Buildings:				
Inspected	87,536	22,102	8,828	27,430
Found to be infested	3,647	1,557	348	508
Cleared of eggs	3,574	1,427	232	55
Wooden fences:				
Insected	53,219	24,936	15,092	35,276
Found to be infested	6,808	2,365	713	798
Cleared of eggs	6,570	2,159	541	99
Stone walls:				
Inspected	-	2,213	814	1,620
Found to be infested	-	672	225	423
Cleared of eggs	-	354	93	44
Number of each form of the moth destroyed by hand				
Caterpillars	-	935,656	1,173,351	1,153,560
Pupae	-	80,021	77,029	92,225
Moths	-	9,338	5,655	18,084
Hatched or infertile egg clusters	-	40,954	6,868	18,036
Unhatched and probably fertile egg clusters	-	99,790	46,101	94,706

August through December, would have been devoted to inspection and destruction of eggs. Here, most likely the fences, stone walls and trees would have been inspected and cleared of eggs after mid-September, when the vegetation would be clear of foliage. During this time period the average manpower requirement was about 55 men.

This rationale can be applied to the years subsequent to 1891. Further, it should be realized that the life cycle, indicated on Figure 6.3, would vary and shift, one way or another due to weather and amounts of food available, the time and length of stages. A shift in the larvae stage from May and June to July and mid-August in 1894 is indicated by reference to Figure 6.3 and Table 6.VII because employment peaked to about 265 men during this period and 624,673 trees (the most of any of the 4 years) were burlapped.

A word of caution in viewing Table 6.VII, Forbush and Fernold note that the vast number of gypsy moth destroyed by wholesale methods as spraying, fire and, presumably, banding, are not included in the table. Even so, the destruction of the pest is significant when it is remembered that each egg cluster or mass contains about 400 eggs.

A-6.5 Summary

Many pest control alternatives can be used either in conjunction with chemical pesticides or as a substitute for them. However, there is no obviously apparent, practical rationale' by which chemical pesticides can be totally abandoned. The recipe by which chemical pesticides and their alternatives are invoked must depend on a thorough assessment of the impact that lack of pest control will manifest. Such an assessment should include not only the economic losses associated with reduced timber supply, recreational opportunity and watershed development, but also the overt impact of pest depravation on the environment itself. Within this context, however, it is demonstrable that useful alternatives to chemical pesticides do exist.

Biological control shows promise although it is clearly not rapidly invoked. Further, these methods appear to have minimal short-term impact on epidemic pest populations.

There do appear to be other alternate methods that have worked in the past and, while not as efficient as chemicals, will provide significant impact on pest populations. Foremost among these methods is the collection and/or destruction of egg masses. While these and other methods can be useful, the requirement for relatively much manpower has apparently mitigated against recent consideration in integrated pest control. Therefore, it appears prudent to examine current economic feasibility relative to the use of manpower as a central ingredient in integrated gypsy moth control on the basis that technical feasibility has been established and that manpower can potentially bridge the gap between the short-term efficiency of broadcast chemical treatment and the long time associated with the establishment of biotic control agents of acceptable efficacy.

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