EFFECT OF FOREST SPRAYING WITH DDT ON AQUATIC INSECTS OF SALMON STREAMS

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ABSTRACT

Number and volume of aquatic insects emerging from tributaries of the Miramichi River of northern New Brunswick, where forest-covered watersheds had been sprayed from the air with 0.5 pounds of DDT per acre, are compared with insect emergence from unsprayed streams. Adult insects were captured as they emerged from the water in yard-square cage-traps. In the streams affected by DDT fewer kinds of insects, particularly of the larger species such as caddisflies, were found. The sprayed streams had, generally, larger numbers than the unsprayed but in all sprayed streams the volume represented was significantly lower because of the relative scarcity of the larger forms. The insect fauna of the sprayed streams was found to be deficient in the kinds of insects on which the salmon were mainly feeding in the unsprayed streams.

Early in the summer of 1954, an extensive forest area in the northern part of the province of New Brunswick was sprayed to control a serious outbreak of the spruce budworm, *Choristoneura fumiferana* (Clem.). In 1956, as the epidemic spread, other areas in the same general region were sprayed. DDT in oil was applied from aircraft at the rate of 0.5 pounds of DDT per acre.

As a result of the spraying in 1954, many young Atlantic salmon, *Salmo salar* L., were killed in the Miramichi River system, one of the better salmon streams of the Maritime Provinces. An examination was made of the bottom fauna about a month after the spraying and in the most affected parts no aquatic insects were observed. Sections of the same river outside the spray area were found at this time to have an abundant and varied fauna. During the spraying, collections were made of many individuals of the larger and more conspicuous species of aquatic insects that were found dead. These are species which, if their life cycles had not been interrupted, should have been in evidence when the streams were examined later in the summer. They were found in the unsprayed parts of the river at this time.

Therefore, as part of their programme of research on the Atlantic salmon, the Fisheries Research Board of Canada decided to investigate the effect of the spraying on the aquatic insects. The Northwest Miramichi River was selected as the locus of the work with headquarters in a small field laboratory at Curventon, Northumberland County. The condition of the fauna has been followed through the summers of 1955 and 1956. In the former the field work and preliminary analysis of data was carried out by D. A. Hurley and in the latter by J. Malia, student assistants. Dr. J. L. Hart, director of the Biological Station at St. Andrews, N.B., Dr. C. J. Kerswill, in charge of Atlantic salmon investigations and other members of the staff of the station provided facilities and gave general supervision.

Use and Location of Insect Cage-Traps

For the 1955 programme four tributaries of the Northwest Miramichi River were selected. Two of these, the North Branch of the Big Sevogle and one of its small tributaries, were examined at points more than five miles within the spray boundary. The other two, Millstream Brook and Trout Brook, were more than five miles outside the spray boundary. This arrangement minimized the possibility of contamination of the controls by spray and also mitigated against the re-establishment of insects in the sprayed streams by immigration from unsprayed ones. The emerging insects were sampled by means of cage-traps, two of which were placed adjacently in rapids at each location. Those in the North Branch of the Big Sevogle and those in the Millstream Brook were placed approximately fifteen miles downstream from their sources. The cage-traps were placed in Trout Brook and the small tributary of the Sevogle River at approximately nine miles and one mile respectively from their sources. The Millstream Brook and the Big Sevogle River were similar in size, rate of flow, type of bottom and in thermal conditions at the study stations. The other two streams were smaller and colder, the small tributary of the Sevogle River being the coldest. The 1955 collections gave a basis for comparing the insect populations of streams a year after they had been sprayed with DDT with the insect populations in the two control streams which had not been sprayed at any time.

In 1956 the watershed of the North Branch of the Big Sevogle River was not sprayed, thus affording an opportunity to study the fauna of aquatic insects in the second year following spraying. Trout Brook was sprayed for the first time in that year and this gave an opportunity to evaluate the effect of the spray on the insects in the year of spraying. The Millstream Brook was not sprayed in 1956 and so remained as a control. The locations of the cage-traps in the Big Sevogle River, Trout Brook and Millstream Brook were approximately the same in 1956 as in 1955 but the small tributary of the Big Sevogle was not examined in 1956. Three cage-traps were placed in each of the three continuing stations in 1956 instead of two as in 1955.

The cage-traps are a yard square and are designed to catch and retain the insects which emerge from the surface of the water of the rapids (Ide, 1940). In order to insure that the traps would retain the smaller insects three sides and the top were covered with a glazed wire screening, "windowlite," and the fourth side with 25 mesh copper screening rather than being entirely of 15 mesh as specified in the original description. The cage-traps were emptied at approximately 24-hour intervals and the collections analyzed for the kinds, numbers and total volumes of insects. The collections began in the first week of June and ran until the first week of September. During this period collections were made on five days of each week in 1956 with the exception of one daily collection for eight cages and two daily collections for one cage which were missed. In 1955 several daily collections were missed from all cages owing to freshets, particularly in the early summer. The fact that six daily collections were generally taken each week compensated for these losses.

The emergence of insects into the cages at the different stations was compared on a sixty day basis although the number of daily collections from different cage-traps varied from 58 to 70 for the season.

Insect Emergence from Sprayed and Unsprayed Streams

The results will be presented under three headings:

(1) Effect of the spray on the aquatic insects in the year of spraying; (2) effect of the spray on the aquatic insects in the year following spraying and (3) effect of the spray on the aquatic insects in the second year following spraying.

Emergence of Aquatic Insects in the Year of Spraying

Trout Brook was the only stream of the sample series which was sprayed in 1956, the same year in which its insect fauna was studied. Figure 1 shows the change in the average number and corresponding volume of insects emerging daily into the three cage-traps used in sampling at this station. The spray was applied June 14 to 17. Before this period the number of insects emerging was not large but the corresponding volume was relatively high. In the three weeks following the spraying the emergence of insects was almost negligible. From the middle of July to the middle of August there was, however, a great increase in the number of insects emerging but it is evident from a comparison of the peak of the number curve (B) with the corresponding peak of the volume curve (A) that most of the insects were small. There were large numbers of minute chironomids which have little bulk. The sharp rise in the curve of volume at this time can be attributed mostly to caddisflies, larger insects, which emerged during the second and third weeks of July and may have been in the pre-pupal or pupal stage when the spraying was done. In Figure 2 are the corresponding volume (A) and number (B) curves of emerging insects taken from Trout Brook in 1955, the year before it was sprayed. The ratio of volume to number illustrated by these two latter curves and in comparison with the curves of Figure 1 indicates that the insects emerging were fewer but on the average of larger size in 1955 than in 1956. Table 1 gives a further comparison of kinds and quantity of insects emerging at this station in the two years. In Table 1 the emergence of insects

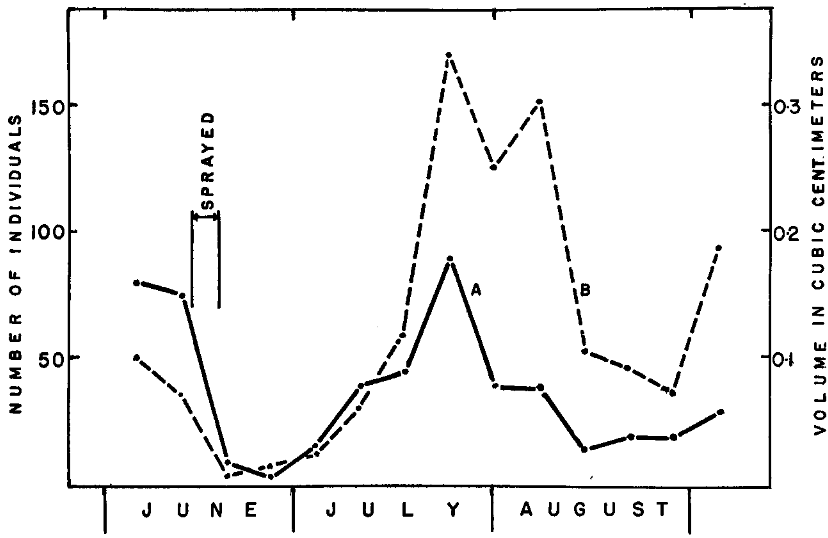

FIGURE 1. Weekly change in number (B) and volume (A) of insects emerging daily into three yard-square cage-traps in Trout Brook in 1956, the year in which the stream was sprayed. Each weekly point is the average of five square-yard 24-hour collections.

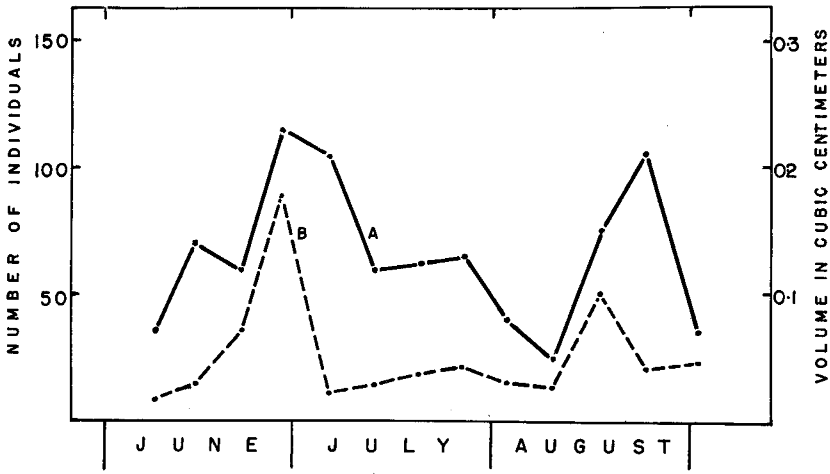

FIGURE 2. Weekly change in number (B) and volume (A) of insects emerging daily into two yard-square cage-traps in Trout Brook in 1955, the year before any spraying had been done in the area. Each weekly point is the average of from four to six square-yard 24-hour collections.

after June 15 in both years is compared on a 60-day basis. Although the number emerging in each cage in 1955 was lower than in 1956 the corresponding volumes were higher in the former year and the insects were of larger size on the average as shown by the ratio of volume to corresponding total number in the last column.

Emergence of Aquatic Insects in the Year Following Spraying

The programme of 1955 was designed to find out the effect of spray on the insects in the North Branch of the Big Sevogle River and its small tributary both of which were sprayed in 1954. The results have been reported on earlier (Kerswill 1956, Hurley 1956). The cages in the Big Sevogle produced less than half the bulk of insects produced by the cages in the Millstream Brook control stream. The insects in the former were small species giving an average size of about one half that of the control. The relatively large number of chironomids was instrumental in determining this size relation. The small tributary of the Sevogle which was also sprayed was not as drastically affected as was the main river. Three species of caddisflies were represented in the collections from its cages as compared to none in those of the Big Sevogle. In both, however, there were significant qualitative differences between the faunas of the sprayed streams and their corresponding controls as shown in Table 3.

Table 1. *Numbers and volume of insects emerging into yard-square cage-traps in Trout Brook from June 15 to September in 1956 and 1955. Trout Brook was sprayed for the first time June 14 to June 17, 1956. All figures are for 60 days.*

Year of Sampling	Cage-trap number	Percentage Number						Total Number	Volume in cubic centimeters	Volume in cubic centimeters / Total number
					Diptera					
		Plecoptera	Ephemeroptera	Trichoptera	Simuliidae	Chironomidae	Miscellaneous			
1955	TV	5.6	11.9	10.6	2.7	66.4	2.8	1493	5.1	0.0034
	TVI	3.3	23.4	15.5	3.9	51.6	2.3	1604	8.2	0.0051
1956	TI	0.9	1.3	3.4	0.1	89.6	4.7	3638	4.1	0.0011
	TII	0.5	0.7	1.4	0.0	95.0	2.5	3973	3.2	0.0008
	TIII	0.6	1.2	2.1	0.2	95.7	0.2	4337	3.5	0.0008

Emergence of Insects in the Second Year after Spraying

In 1956, the second year after the Sevogle area had been sprayed, daily samples of aquatic insects were again collected from the stations in the North Branch of the Big Sevogle. These were compared with those from Millstream Brook which served again as a control. Table 2 shows this comparison. For 1956 the volumes of aquatic insects taken by all cages of the Sevogle series were less than those of the control cages in Millstream Brook although the two highest numbers of insects per cage were taken by two of the Sevogle cages. The ratio of volume to total number in each cage-trap also shows that fewer individuals of species of larger size were represented at the Sevogle than at the Millstream. The percentage representation of the different groups of insects as shown in Table 2 throws further light on this relationship. All but about one thousand of the insects from trap SIII in the Sevogle River were chironomids. The chironomids taken in the survey were mostly minute species of the subfamily Orthocladiinae, in general under three millimeters in length. It was estimated that the 13.5 thousand chironomids taken in this trap gave the same bulk as the remaining thousand which were mainly Ephemeroptera and Plecoptera, all of moderate size. Large Plecoptera were taken only in the Millstream Brook. Some of these were as much as an inch and a half in length and contributed greatly to the bulk of insects taken in samples there. The Trichoptera were in insignificant numbers at the Sevogle, although they formed a significant component of the fauna of the Millstream. Two caddisflies of a species characteristic of slowly flowing water and five microcaddisflies were the only caddis to emerge from the 27 square feet of rapids in the Sevogle covered by the cage-traps during the 70 days of sampling in 1956. None was taken from the 18 square feet of the same rapid sampled in 1955. In contrast 143, 172 and 146 were taken in the three cage-traps of the Millstream Brook series in 1956. Since several species of Trichoptera which had been killed by the spraying of that year were found at the Sevogle station in 1954, it is concluded that this group of insects was almost eliminated from this section of the stream by the spray and in the second year following spraying had not reappeared to any appreciable extent. This decrease in numbers of Trichoptera, which are mainly predatory, may account for the increased abundance of small insects, mainly chironomids, on which they ordinarily feed.

Effect of DDT on Stream Invertebrates

The effect of DDT on invertebrates of streams has been investigated mainly in relation to three operations: (1) forest pest control (2) experimental treatment to evaluate the effect on fish and their food and (3) black fly control. The present investigation fits into the first category. One method of applying the DDT in these three operations has been to spray from aircraft with a solution of the insecticide in oil. Results obtained by this method are of most interest in the present discussion. Results obtained by other methods are also relevant when these methods give concentrations of the poison in the water comparable to those obtained by aerial spraying.

The development of methods for applying the insecticide has led gradually to the adoption of fairly standard procedures. Pertinent literature includes Hoffman and Merkel (1948), Hoffman and Surber (1949), Hoffman and Linduska (1949), Brown (1951), Kerswill (1956) and Hurley (1956) dealing more particularly with forest operations, Hoffman and Surber (1945), and Savage (1949) dealing with experimental applications to streams and Arnason *et al* (1949), Brown (1951) and Jamnback and Collins (1955), on black fly control. In addition, testing of the toxicity of DDT formulations to various forms of stream life has been carried out in the laboratory as is reported by Eide *et al.* (1945), Gjulin *et al.* (1949) and Savage (1949).

Aerial spraying of approximately one pound of DDT per acre has been adopted as a satisfactory dosage for control of many forest pests but a dosage of 0.1 pound per acre or less has been adopted for black fly control.

TABLE 2. *Number and volume of insects emerging into yard-square cage-traps in the North Branch of the Big Sevogle River (SIII-SV) and into cage-traps in the Millstream Brook (MI-III) from early June to early September in 1956. All figures are for 60 days.*

	Year of Sampling	Cage-trap number	Percentage Numbers						Total number	Volume in cubic centimeters	Volume in cubic centimeters / Total number
			Plecoptera	Ephemeroptera	Trichoptera	Diptera: Simuliidae	Diptera: Chironomidae	Diptera: Miscellaneous			
Sevogle River Sprayed in 1954	1956	SIII	1.5	4.1	0.0	0.8	93.5	0.1	14505	8.4	0.0006
		SIV	1.9	8.0	0.0	1.9	87.5	0.7	7330	6.3	0.0009
		SV	1.7	13.9	0.0	3.4	75.4	5.6	4422	5.5	0.0012
Millstream Brook Unsprayed	1956	MI	8.6	9.6	4.2	0.3	74.8	2.5	3418	11.2	0.0033
		MII	12.6	11.4	4.9	1.1	67.2	2.8	3526	11.2	0.0032
		MIII	7.7	8.9	3.0	0.8	77.7	1.9	4874	13.6	0.0028

TABLE 3. *Approximate number*[1] *of species in the orders Plecoptera Ephemeroptera and Trichoptera which were identified in collections of 1955 from one cage-trap at each location in four streams.*

Order	Category (Genus, Family or Sub-family)	Approximate Number of Species			
		Sprayed Streams		Control Streams	
		SI	SIV	TVI	MVII
Plecoptera (Stoneflies)	Acroneuria	0	0	1	2
	Isogenus	0	1	0	1
	Isoperla	1	1	1	1
	Alloperla	2	2	2	1
	Leuctra	2	2	2	1
	Nemoura	1	1	1	1
	Total	6	7	7	7
Ephemeroptera (Mayflies)	Ephemerella	3	4	5	5
	Paraleptophlebia	1	1	2	2
	Baetis	0	1	4	5
	Pseudocloeon	0	1	2	2
	Heptagenia	0	1	1	1
	Iron	1	2	2	1
	Rhithrogena	0	0	1	0
	Total	5	10	17	16
Trichoptera (Caddisflies)	Rhyacophilidae	1	0	7	6
	Philopotamidae	1	0	1	1
	Psychomyidae	0	0	1	1
	Hydropsychidae	1	0	3	3
	Hydroptilidae	0	0	1	0
	Leptoceridae	0	0	1	1
	Lepidostomatidae	0	0	2	1
	Helicopsychidae	0	0	1	1
	Brachycentridae	0	0	0	1
	Limnephilidae	0	0	1	1
	Total	3	0	18	16
	Grand Total	14	17	42	39

[1]Most species were distinguished but some closely related ones were identified to species group only. This was more frequently done for the more complex faunas of the controls so that the numbers for these are probably disproportionately low.

The former concentration gives good control of many forest pests and it is claimed that it does little lasting damage to other elements of the fauna of the forest (Hoffman and Linduska, 1949). The latter dosage gives good control of the susceptible larvae of the black flies without seriously affecting the other stream arthropods (Jamnback and Collins, 1955). For both operations evidence has been advanced which indicates that dosages lighter than standard were ineffective in bringing about control of the pest and that dosages heavier than standard resulted in elimination of some important components of the fauna.

It follows therefore, that, because of the heavier dosages employed in forest spraying, this operation rather than black fly control measures presents the greatest danger to the life in streams. The dosage reaching a stream in a forest spraying operation would be considered a serious overdosing in a black fly control operation.

In the forest spraying of a watershed there is danger under certain weather conditions that heavy concentrations of the insecticide may reach the streams in runoff. This danger is not present in black fly control operations where only the stream is sprayed.

In the New Brunswick forest spraying already considered, the dosage has been 0.5 pounds of DDT per acre, half the "optimal" amount as referred to above. Nevertheless the resulting differences between the fauna of aquatic insects in sprayed and unsprayed streams was pronounced. The conclusion that these differences are a result of the DDT is supported by similar results reported in the literature. It has been shown by the experiments of several workers including Eide *et al.* (1945), Gjulin *et al.* (1949) and Savage (1949) that concentrations of DDT which result from such sprayings are highly toxic to many kinds of aquatic insects and other organisms. Savage (1949) found that the insect mortality was caused by the DDT and not the oil solvent. The data presented show marked difference between the pre- and post-spray fauna of Trout Brook (Figures 1 and 2 and Table 1) and the fauna of the North Branch of the Big Sevogle River the year following spraying and the fauna of Millstream Brook, a control stream of similar character. In the second year after spraying even more pronounced differences between the fauna of these latter two streams were found, as illustrated in Table 2, and the big differences were in the quantity of insects that emerged, especially when bulk, rather than number, is the criterion of quantity. Pronounced qualitative differences in the fauna of the sprayed and unsprayed streams were also found and are illustrated in Table 3. The small number of species surviving in the sprayed streams contrasts with the larger number in the unsprayed. Some of the species which were absent from the North Branch of the Big Sevogle River and present in the Millstream Brook in 1955 were collected dead from the former at the time of spraying in 1954 which is strong evidence that they were eliminated by the spraying.

In 1956, the second year after spraying, the fauna at the Sevogle Station was little changed qualitatively from 1955 but the proportional representation of the insect groups had altered. The total number of individuals emerging at this location was also greater in 1956 than in 1955. The number emerging into two of these cages in 1956 was greater than the emergence into any of the Millstream Brook controls. However, despite the large numbers, smaller volumes, ranging from a little less than one-half to slightly more than two-thirds those of the corresponding controls, were taken in 1956 as shown in Table 2. Similarly the population of the Trout Brook was numerically higher but volumetrically lower in 1956, the year of spraying, than in 1955 as Table 1 shows. From the above it seems evident that the spraying had been selective in its action, eliminating many species, but that there were many species which survived. Of those which survived, the small species, particularly chironomids increased prodigiously and were present in greater numbers even in the year of spraying than in normal years. This increase is attributed to short life cycles and fewer predators and competitors. The sprayed streams were low in production of bulk of insects as compared with their controls in all years following spraying in spite of larger numbers of insects emerging in most of their cage-traps.

The population which developed after spraying was qualitatively different from the pre-spray population. Small chironomids were disproportionately abundant and larger forms scarce. The bulk of insects remained relatively low in the sprayed streams and this observation finds little confirmation in the papers cited. Possibly this is because of difference in sampling methods used. The usual apparatus for sampling bottom fauna of rapids is the Surber sampler (Surber, 1937) or modifications of it, the best known of which is that described by Hess (1941). Both are square-foot samplers operated so as to collect aquatic invertebrates from the enclosed area of bottom. The resulting catch gives a measure of the "standing bottom crop" and may be expressed as number or volume or weight of organisms. Such a sampler is particularly suitable for obtaining the total volume or weight since loss of some small individuals, which is inevitable, does not introduce a large percentage error in the result. The sampler is adequate when used, as it was by Surber, to measure the quantity of fish food organisms on the bottom. When, however, the sample is to be expressed as number of individuals, a serious error may result and this error increases with increase in numbers of small animals in the population. In using this sampling technique or others which involve picking over the bottom the author has found that the larger invertebrates are taken but that small species or the young of larger species are poorly represented in the sample. This happens even when it is known from subsequent collections made of emerging adults that larvae were numerous at the time the bottom sample was taken, Ide (1940).

The cage-trap method has drawbacks but would seem to be particularly efficient for taking adults of the small insects, including chironomids, black flies and empids, which are proportional to and more nearly representative of the population on the bottom than are samples taken by other methods. The cage-traps cover a large area and thus a large sample of all emerging insects is obtained. It is not feasible, however, to operate many such traps and therefore the method does not lend itself to extended sampling of surveys. As a research technique it may however provide information which would be of value in interpreting samples taken by other means.

The large number of chironomids and the almost complete absence of caddisflies are the most conspicuous features of the sprayed streams examined in the present investigation. Davies (1950) has reported on a phenomenal increase in black flies in a stream in the years following DDT treatment. The stream had been sprayed in 1944 from a helicopter with DDT at a rate of six pounds of DDT per acre. Using cage-traps Davies had sampled the populations of emerging black flies from 1939 to 1947. Although almost no black flies emerged in the year that the stream was sprayed the emergence increased in the years thereafter until over 80,000 emerged from a square yard during the summer of 1947 which was about seventeen times the average emergence of the five prespray years. These small flies were the dominant group in this stream after spraying.

Th more serious effects of spraying on the fauna from the standpoint of the fish would appear to be the reduction in bulk of fish food and the high proportion of this lessened bulk which is made up of insects which are so small as to be unsatisfactory for the larger young salmon. As much as half the volume of the aquatic insect food of the sprayed streams has been estimated to be these minute insects, leaving only a small quantity of insects which may be more readily utilized. Qualitative changes in the insect populations are significant as it has been shown by Allen (1941) and the present author (1942) that the salmon and trout which are characteristically insectivorous in their younger stages utilize some kinds of insects more than others, depending on availability. Caddisflies are very frequent in the stomach contents of both salmon and trout.

Another and perhaps the most serious consequence of the spraying is that many of the insects which were eliminated have not become reestablished even in the second year after spraying. Many of these aquatic insects do not disperse widely and consequently it may be many years before they will be rehabilitated by natural means. In the meantime the fish feed on other organisms, not normally utilized, which persist in the stream after spraying. Hurley (1956) found, for instance, that the salmon fingerlings in the dirth of aquatic insects of suitable kinds fed largely on snails.

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