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**Effects of Forest Spraying with DDT on Aquatic Insects
of Salmon Streams in New Brunswick^{1,2}**

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ABSTRACT

Sampling of emerging aquatic insects by cage-traps on a 24-hr basis showed the effects on the stream fauna of spraying forests with DDT at $\frac{1}{2}$ lb/acre in June. Except for a few individuals that presumably emerged from unaffected pupae and nymphs, there was an interval of several weeks after spraying when no emergence occurred. From about the middle of August, however, large populations of very small insects, mainly chironomids, emerged in the spray year. The year after spraying, as compared with the spray year, there was an increased variety including some larger species.

In following years there was further recovery by increase in larger forms through reproduction from residual small populations. The caddisflies recovered more slowly than other groups. After a single application of spray the fauna had practically recovered qualitatively in 2 or 3 years in some groups but usually not for 4 years or more in caddisflies. With a further similar spray applied within 3 years a reduction occurred equal in severity to that of the original spraying.

From the standpoint of feeding of the young salmon, significant facts are: (a) the severe reduction in the bottom fauna of larvae and nymphs of all sizes in the first weeks after spraying; (b) the large populations of small larvae, mainly chironomids, developing in late summer of the spray year and so available to fry; (c) increasing numbers of larger insects the year after spraying and subsequent years.

INTRODUCTION

AERIAL SPRAYING with DDT of large tracts of forest in New Brunswick was carried out from 1952 to 1962 with the exception of 1959. A Crown company, Forest Protection Limited, carried out the spraying program, the purpose of which was to control an outbreak in the balsam and spruce forest of the spruce budworm, *Choristoneura fumiferana* (Clem.). This insect has periodically increased to serious infestation numbers in eastern Canada causing much destruction to the forest trees. Details concerning the southward movement of the budworm and the spray operations are outlined by Webb et al. (1961). The details of spray application from planes and other relevant data are outlined by Kerswill (1967).

The Miramichi River is one of the most important salmon rivers in eastern Canada. In 1950 it was selected by the Fisheries Research Board of Canada as

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the site of long-term investigation of the causes of variation in salmon populations. Kerswill (1967) explains how forest spraying with DDT became important in the salmon's environment, leading to inclusion of the new factor in the investigations.

As part of this program an investigation was begun on the effects of the spraying on food organisms in the streams, particularly the aquatic insects, an important component of the diet of young salmon. A cursory survey of sprayed and unsprayed streams of the Northwest Miramichi system was made approximately a month after spraying in 1954. Major differences were noted between some sections of the sprayed streams and unsprayed tributaries of comparable character. At two sprayed locations, one at Station S (Fig. 1) on the North Branch of the Sevogle River, a tributary of the Northwest Miramichi, the other at Crawford Pool (near N) on the Northwest Miramichi itself, no insects were apparent in an examination of several stones picked from the bottom, although other organisms were observed, including aquatic mites, snails, and planarians. A similar absence of insects was noticed farther down the Northwest Miramichi at Camp 42 (Station N). The stones of the bottom at these three places were densely coated with algae, making them slippery and altering the appearance of the bottom. At a fourth location, a small stream in the sprayed area, the only insects observed were numerous small chironomid larvae which had recently hatched. By contrast, two unsprayed streams of the same drainage system, Trout Brook (Station T) and Millstream Brook (Station M), contained insect nymphs and larvae in the variety and abundance characteristic of the region. This examination of the stream bottom a month after spraying gave, however, an erroneous impression of the severity of the effect of spraying. Subsequent examinations indicated that many insects survived, some in the egg stage, some as pupae, and a few of the more tolerant species as nymphs or larvae.

Intensive sampling of the aquatic insects in some sprayed and unsprayed streams of the Northwest Miramichi River system was begun by the Biological Station of the Fisheries Research Board of Canada at St. Andrews in 1955 and continued each summer to 1962 under the author's supervision. A preliminary report (Ide, 1957) has been made for 1955 and 1956 in which methods have been given in detail.

RIVER SAMPLING STATIONS

In Fig. 1 the Northwest Miramichi River is shown, with the locations of the insect sampling stations and the spray areas. Information on the river system is given by Kerswill (1967).

Station S on the North Branch of the Sevogle was operated 1955-56-57-58 and 1962 and was in the spray areas of 1954, 1957, and 1958. This location was selected because of the severe effect of the 1954 spray on the aquatic insect fauna observed in the cursory examination of the bottom. Since the area was resprayed in 1957 and 1958 there was no opportunity of following the recovery in insect populations affected by the 1954 spraying. It therefore was discontinued

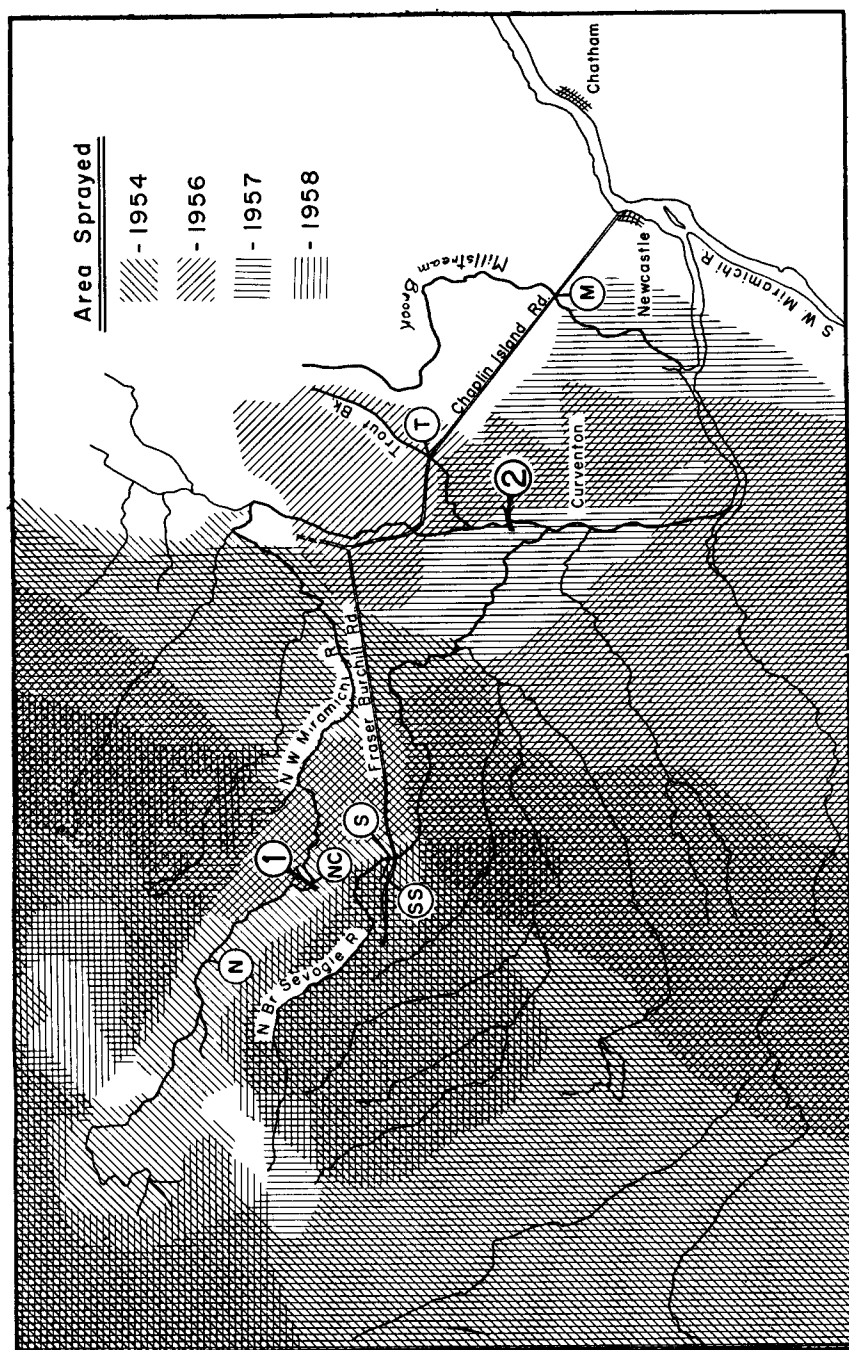


FIG. 1. Northwest Miramichi River showing locations of sampling stations and spray areas.

after 1958 except for checking in 1962. An adjacent station, SS, on a small tributary of the North Branch of the Sevogle was sprayed in 1954 and used only in 1955. The station on Trout Brook, T, was selected as a control stream in 1955 and was in operation for the years 1955–62. Trout Brook was outside the spray area of 1954, but was sprayed in 1956. In 1957 this stream was again sprayed downstream from the Chaplin Island road but the area of the station itself and the stream above the station were not sprayed. A station on Millstream Brook, M, was then selected as a control, particularly to assess effects of spraying on the Sevogle, because of its remoteness from the 1954 spray area. It was maintained from 1955 until 1958 and then discontinued. Although not sprayed in 1957 it was very close to the upper border of the spray area and may have been affected somewhat. The stream differed from the North Branch of the Sevogle in the more discontinuous nature of its rapids at the station site and in the fact that it emptied into the estuary of the Northwest Miramichi below all rapid sections.

The Camp 42 station, N, on the Northwest Miramichi was established in 1957 and was maintained through 1961. It was selected as a substitute for the station on the North Branch of the Sevogle since it had the same spray history originally and, in the subsequent cursory examination of the bottom in 1954, showed a similar extreme reduction in insects. Also, the bottom presented much the same condition with respect to its fauna as the North Branch of the Sevogle. Further, Camp 42 was in a reserve area exempted from spraying after the initial spraying of 1954. Camp Adams, NC, about 10 miles downstream from Camp 42 on the Northwest, was selected in 1959 to supplement the station at Camp 42 and was operated until the fall of 1962. It was less affected by the 1954 spray than Camp 42, judging by the stomach contents of fish taken in the area. However, an area of forest bordering the north side of the river from a point approximately 3.5 miles upstream from Camp Adams and extending for about the same distance downstream was sprayed in 1956 (Fig. 1) and this may have affected the station.

METHODS

The changes in the populations of aquatic insects of sprayed and unsprayed streams over the years 1955–62 were followed at several stations on the Northwest Miramichi. The sections of the streams designated as stations (Fig. 1, 3) were determined by inspection. All were in rapids having comparable flow rate and bottom type. They were selected in different streams or in different parts of the same stream to include areas with a variety of spray histories. They also included control stations in streams which had not been sprayed.

Insects emerging from the water were sampled by means of cage-traps (Fig. 2). The traps, each covering a yard-square area (0.915 m^2), catch and retain the insects which emerge from the surface of the water of the rapids (Ide, 1940, 1957). They do not prevent aquatic stages of insects moving into or out of the yard-square area of bottom over which the cage sits but capture the adults emerging from the surface of the enclosed area. To ensure that the traps

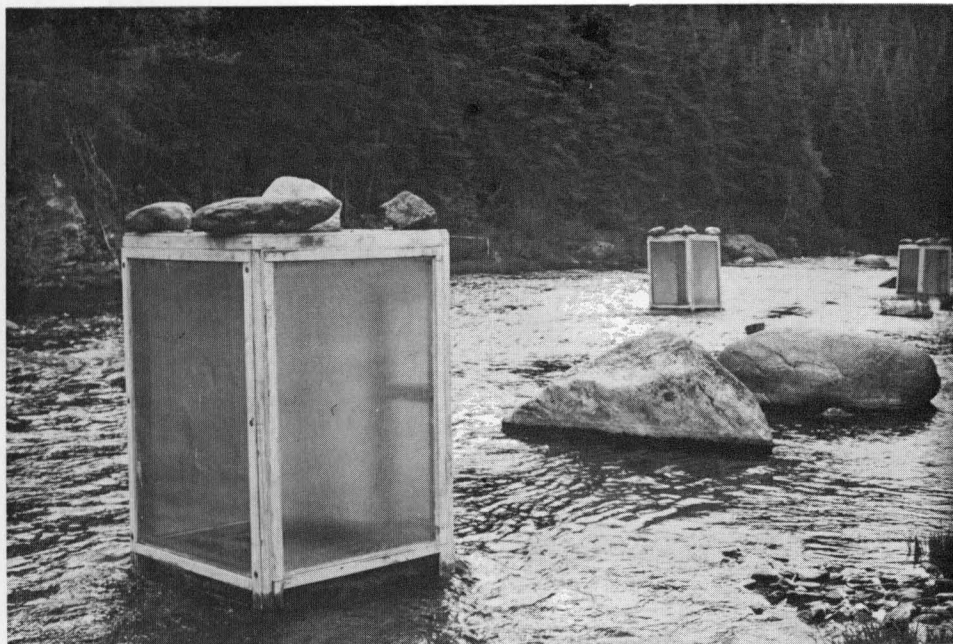


FIG. 2. Close-up of cage-traps in position at North Branch of Sevogle River (Station S).

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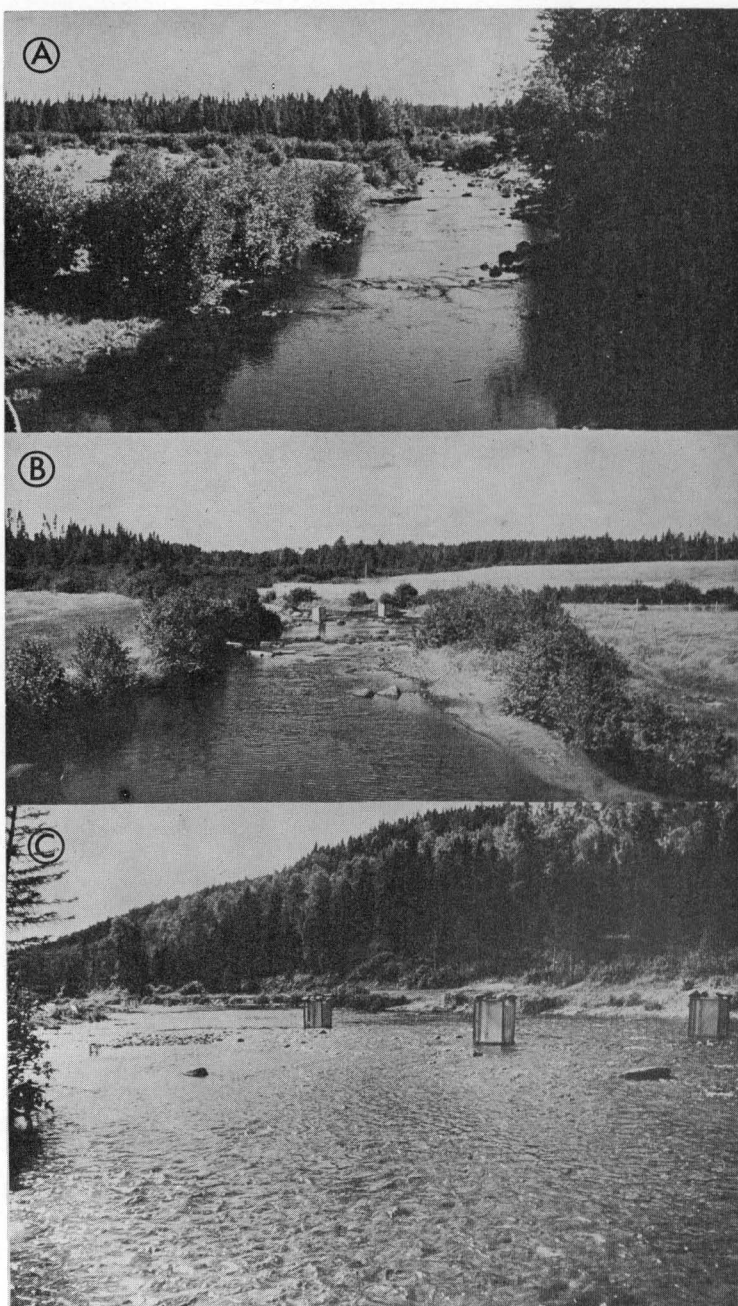


FIG. 3. A, Trout Brook, below Station T; B, Millstream Brook, unsprayed control (Station M); C, Northwest Miramichi at Camp 42 (Station N).

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would retain the smaller insects, three sides and the top were covered with a glazed wire screening, "Windowlite," and the fourth side with 24-mesh (10 per cm) copper screening (0.707-mm apertures), rather than being entirely of 15-mesh copper screening as specified in the original description (Ide, 1940).

In 1955 a pair of yard-square cage-traps were employed at each station, but in all later years three such traps were used at each station. These were designated by numbers, for example T1, T2, and T3 for Trout Brook, T1 being in the upstream position. Collecting was begun in late May or early June and continued until late August or early September, the period over which most emergence takes place. The cage-traps were cleared of insects at approximately the same hour of the day so that collections gave the number retained over a 24-hr period. At Camp Adams, in 1962 only, the procedure was modified when for a 72-hr period in the last week of August collections were made at hourly intervals. This presumably gave somewhat higher readings (Sprules, 1947), but would result in only a negligible percentage difference in the annual figures for 1962 as shown in Fig. 11 and 12 and Appendix VI. In 1955, six collections were made from each cage each week. In 1956 and later years, five collections were made from each cage. Since the total number of collections varied in the different summers, the results for annual totals were made comparable by changing them all to 60-day equivalent values. The figures used in comparing emergence in different years are, therefore, calculated values for insects emerging during 60 24-hr periods in a period of about 100 days of the summer. Summary data are provided in Appendices I-VI.

The insects were collected from the inside surfaces of the cage-traps using a moistened swab, or with forceps for the larger individuals, and placed in vials containing 70% alcohol. They were identified under a binocular microscope, counted, and volumes determined by displacement of water in a 5-ml graduated cylinder.

Results of collections from the cage-traps are presented in the following three ways.

- (1) As histograms showing daily emergence of various groups of insects (Fig. 4-6).
- (2) As graphs showing the emergence of all insects and of chironomids from week to week (Fig. 7-9).
- (3) As graphs and tables showing the emergence of insects of major groups from year to year (Fig. 10-12, Appendices I-VI). The summer refers to the period from approximately June 1 to September 7. In these graphs, a solid line is drawn for the average of two cage-traps in 1955 and three in other years, and the original points are also shown. High and low numbers are connected with dotted lines to show spread in numbers between cage-traps. The spread in these points is great in some cases but with few exceptions the trends are similar. The objective in selecting cage sites was to place the cages over similar bottom with similar depth and rate of flow. The differences in the samples probably reflect mainly differences in bottom, which were not apparent at the time of making the selection, and seasonal

changes in current, which were difficult to anticipate. The number of organisms taken in a cage was generally low where the stones were partially imbedded in silt or sand, but high where moss grew on the stones; these features were more pronounced for some groups of insects than for others.

DAILY EMERGENCE OF INSECTS OF MAJOR GROUPS (EXCEPTING CHIRONOMIDS)

TROUT BROOK (STATION T) (FIG. 4)

Daily emergence of insects of major groups, excepting chironomids, is shown in Fig. 4 for Trout Brook for 1955-62. The spray was applied June 14-17, 1956, as indicated by an arrow. An extremely heavy freshet occurred in late May in 1961 before sampling began.

Mayflies (Ephemeroptera) emerging in 1956 were greatly reduced in numbers after the spray (Fig. 4A). In 1957 there was an increase, most marked in the second half of the summer and accounted for mainly by second generation individuals of small species. By 1958 the early emerging individuals were again well represented. These were mostly early univoltine species (one generation per year), or first generations of bivoltine species (two generations per year), which had been affected by the spraying in mid-June 1956. The numbers emerging were highest in 1959, higher than in the pre-spray year, and declined through 1960 and 1961. In 1961, the numbers emerging early in the season were particularly low. The extremely high flooding in May of 1961 may have been a factor contributing to this, for in 1962 there was a marked increase in numbers as compared with 1961. These insects are mainly herbivores.

Stoneflies (Plecoptera) were not as numerous as the mayflies, but some of the species were of large size. The numbers were higher in 1956, the spray year, than in 1957, when they were lowest (Fig. 4C). But the 1956 numbers include those for the 2 weeks before spraying when early species of stoneflies were emerging. The numbers were high in 1958, somewhat lower in 1959, high in 1960, reduced below the pre-spray year again in 1961, and up in 1962. This group includes some predatory species.

Caddisflies (Trichoptera) emerged in small numbers before the spraying in June 1956, but after the spraying a large number emerged in July (Fig. 4D). Nearly all these were species of case-bearing Rhyacophilidae of the subfamily Glossosomatinae which were in the pupal stage at spray time and apparently little affected. Some of the individuals emerging in late summer were of two species of limnephilids which diapause in the larval stage during the summer months and were apparently unaffected by the spray. In 1957 the numbers of caddisflies were minimal and much below the numbers of the pre-spray and spray years. The numbers were highest in 1959. The two peaks in both 1959 and 1960 show the re-establishment of the early and late summer generations. In 1961 the numbers were low again, much below the pre-spray numbers. The almost complete lack of emergence in June 1961, may reflect the effect of extremely high floods in late May of that year. The 1962 numbers were appreciably higher than those of 1961.

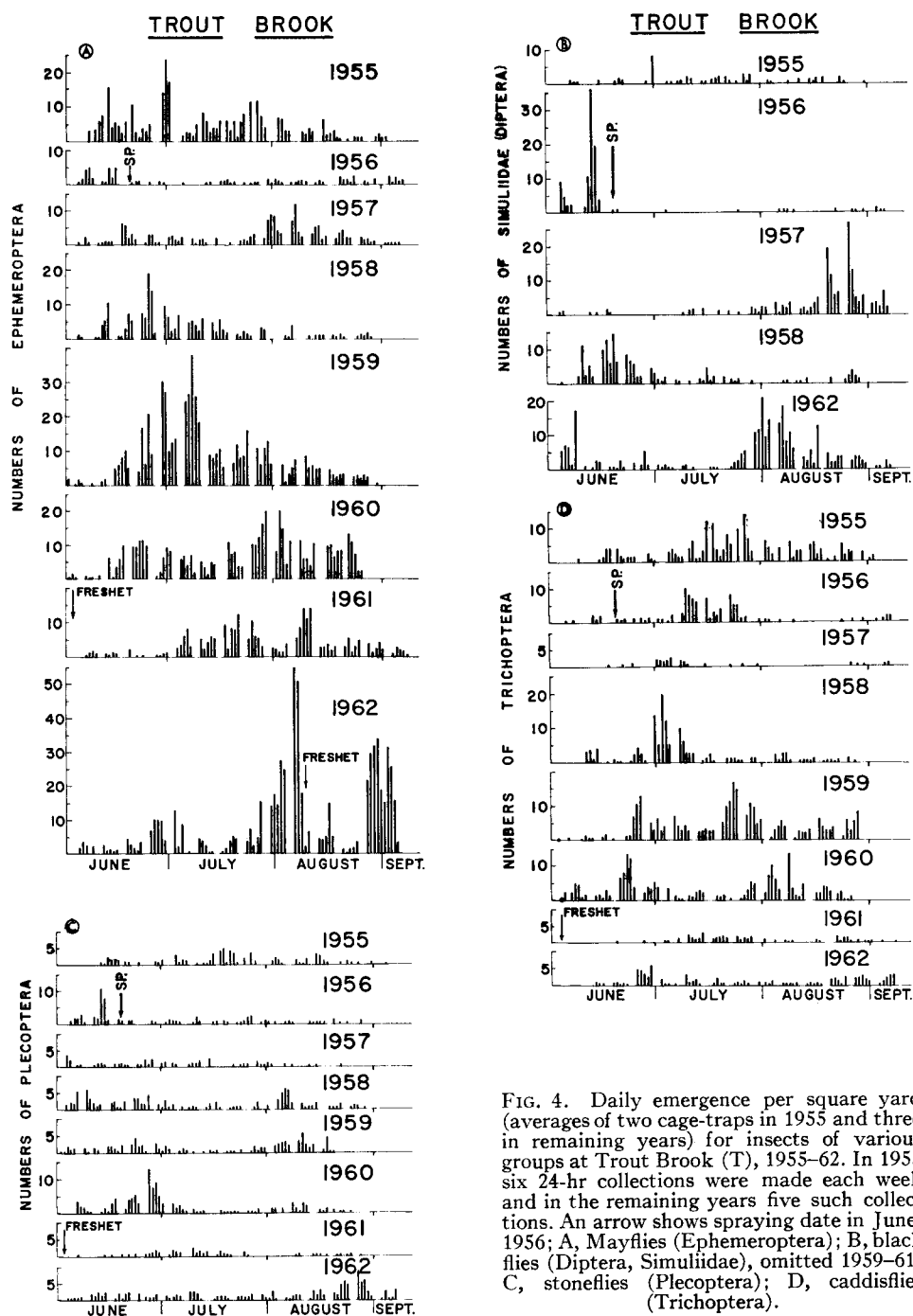


FIG. 4. Daily emergence per square yard (averages of two cage-traps in 1955 and three in remaining years) for insects of various groups at Trout Brook (T), 1955-62. In 1955 six 24-hr collections were made each week and in the remaining years five such collections. An arrow shows spraying date in June, 1956; A, Mayflies (Ephemeroptera); B, black flies (Diptera, Simuliidae), omitted 1959-61; C, stoneflies (Plecoptera); D, caddisflies (Trichoptera).

Black fly (Diptera: Simuliidae) emergence was low in 1955, the pre-spray year (Fig. 4B). In 1956 many emerged in June, before spraying, contrasting with the small numbers which emerged after spraying. The numbers remained low through the first half of the summer of 1957, and there were a large number of second generation individuals in August and early September. It is probable that this large group was the progeny of ovipositing females which immigrated into the area from unsprayed streams. In 1958 a large population of first generation individuals was evident, among which were probably the progeny of the second generation individuals of 1957. A second generation was poorly represented in 1958, but well represented in 1962.

NORTH BRANCH OF SEVOGLE RIVER (STATION S) AND MILLSTREAM BROOK (CONTROL-STATION M) (FIG. 5)

The North Branch of the Sevogle was sprayed in 1954; Millstream Brook was unsprayed and was selected as a control. The latter is a tributary of the Northwest Miramichi of comparable size and rather similar in character to the North Branch of the Sevogle; it was over 5 miles outside the spray boundary at the sampling point.

In 1955, the year after spraying, fairly large numbers of *mayflies* were produced in the Sevogle, yet the numbers both of individuals and of species were fewer than in the Millstream Brook control.

Stoneflies emerged in greater numbers at the Sevogle station than at the Millstream Brook control in the year after spraying. Almost all were small stoneflies of the genera *Leuctra* and *Nemoura*, the latter and some of the former being early-season species.

Caddisflies were not represented in the samples taken at the Sevogle station in 1955, and in the following year only eight individuals were taken and these were of three species only. Many individuals, representing an estimated 16 species, were taken in the samples in 1955 at the Millstream Brook control. Unfortunately no intensive sampling was done of the Sevogle before spraying in 1954 but some collections were made of the insects killed at the time of spraying. At that time several kinds of caddis larvae were found which did not appear in the 1955 sample series, an indication that there had been reduction in number of species.

NORTHWEST MIRAMICHI RIVER AT CAMP 42 (STATION N) (FIG. 6)

Station N was studied briefly in 1954, the one year in which the area was sprayed, and in detail from 1957 to 1961. It replaced the Sevogle station when the latter, because spraying was repeated in 1957 and 1958, became unsuitable for following the rehabilitation of the aquatic insects.

When examined in 1954 after the spraying, the insect fauna was found to be drastically reduced as compared with that in control areas. The river at this point seemed to have been as severely affected by the spray as it was at a point 2 miles upstream and as the Sevogle was at station S. It is impossible to know

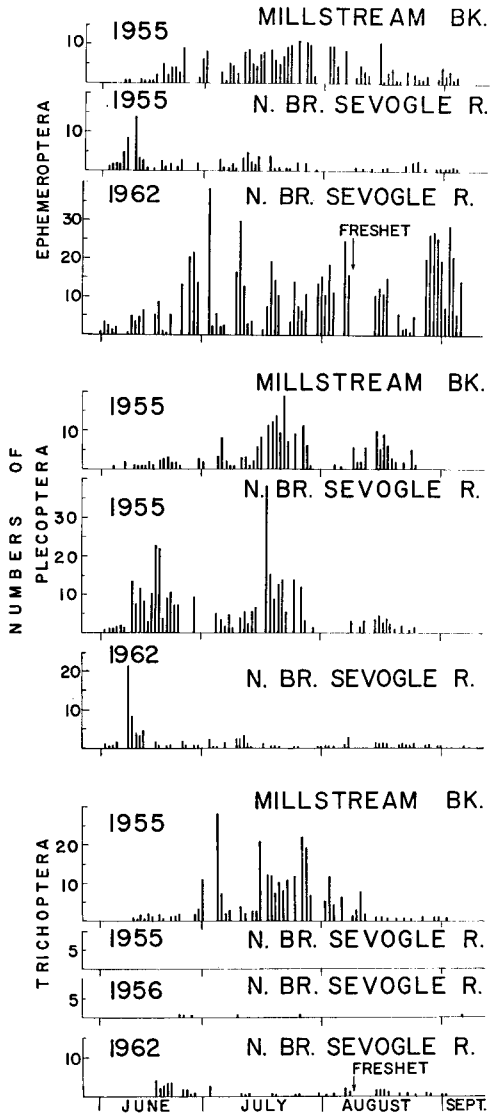


FIG. 5. Daily emergence of insects of various groups at Millstream Brook (M) (unsprayed control) and the North Branch of the Sevogle River (S) (sprayed in 1954, 1957, and 1958). The comparison is of results for Millstream Brook in 1955 with those for the North Branch of the Sevogle in 1955 (1956 also for Trichoptera) and 1962.

definitely the trends in insect populations in 1955 and 1956, although these can be surmised by comparison with the North Branch of the Sevogle, a stream of similar type and similarly affected by spray in the same year, and with Trout Brook, which was sprayed in 1956.

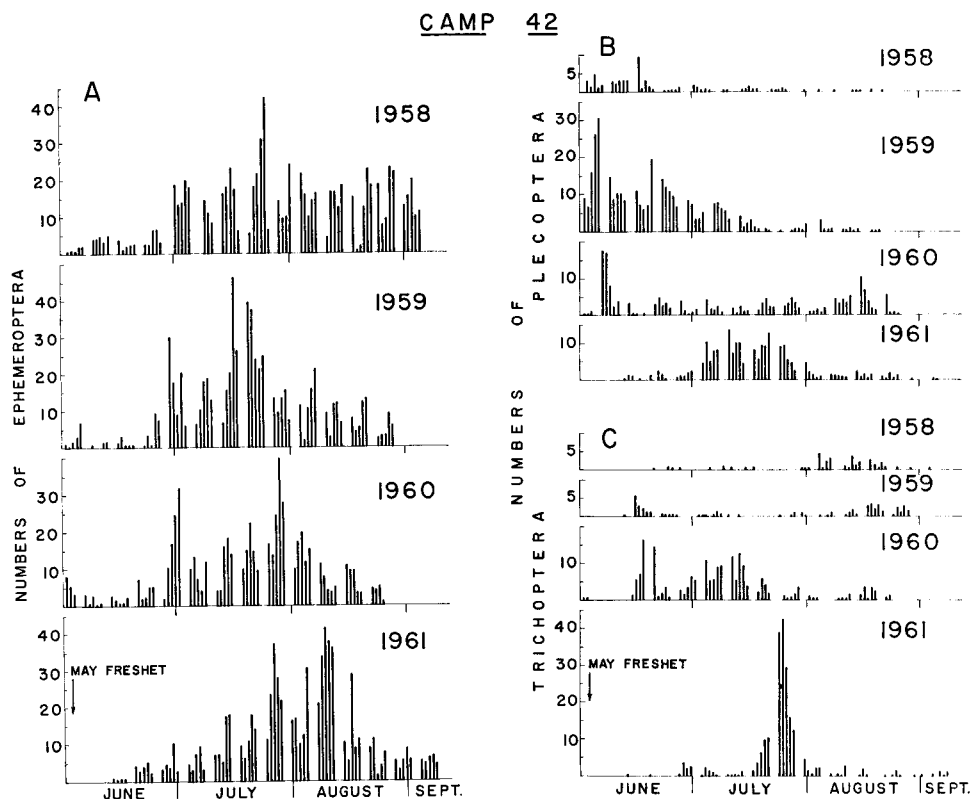


FIG. 6. Daily emergence of insects of various groups from the Northwest Miramichi River at Camp 42 (N) (sprayed in 1954 only).

From 1958 to 1961 *mayflies* were well represented in numbers of individuals (Fig. 6A). The numbers had been considerably lower in 1957, however (Appendix V). *Stoneflies*, on the other hand, were low in numbers of individuals in 1958 (in 1957 also) but were high in 1959 and decreased somewhat in 1960 and 1961 (Fig. 6B). *Caddisflies* were low in 1959 and the 2 preceding years, and it was not until 1960 that a substantial increase occurred (Fig. 6C). This was a year later than for the stoneflies and 2 years later than for the mayflies. The lag in recovery of this group of insects at this station was 5 years, in comparison with 3 years for Trout Brook. The recovery in populations of caddisflies was mainly accounted for by many individuals of a rather small number of species as compared with Millstream Brook (control).

WEEKLY EMERGENCE OF ALL INSECTS AND OF CHIRONOMIDS

Figures 7–9 show the emergence of all insects and of chironomids from week to week, as average numbers emerging per square yard per day, and, similarly the average volumes of all insects. The chironomids (Diptera) are small and very numerous insects, so the curves of their numbers generally parallel closely those of the numbers of all insects.

TROUT BROOK (STATION T) (FIG. 7)

In the pre-spray year 1955 there were rather large numbers of the larger insects (that is, those other than chironomids), a correspondingly high volume, and two main peaks of emergence. The early summer peak consisted mainly of univoltine species and first generations of bivoltine species and the later summer peak mainly of the second generations of bivoltine species. In the spray year 1956 there was an immediate drop in emergence after spraying to a low figure that coincided in time with the early peak in 1955. This illustrates the initial drastic effect of spraying on emergence.

Although the drop in numbers emerging in the 3 weeks after spraying was pronounced, some insects did emerge during this period, including rather large numbers of a case-making caddisfly of the subfamily Glossosomatinae; these are presumed to have been in the relatively non-vulnerable pupal stage at the time of spraying. Figure 7 also shows strikingly the 1956 emergence of many chironomids in the latter half of July and the first half of August. Most of them probably developed from eggs laid before spraying, and the remainder from eggs laid by insects which were in the pupal stage during spraying and survived. The large numbers of chironomids coincided with a scarcity of other insects which ordinarily compete with them for food (e.g. some mayflies), or which prey on them (e.g. some stoneflies and caddisflies).

In 1957 and 1958 chironomids were again predominant, peak numbers being earlier in the latter year. The large numbers of late July and early August in 1956 were replaced by an almost coincident trough by 1958. In 1959 numbers of chironomids were high, especially from mid-June to the end of August. In 1960 they were low, not only in absolute numbers but also relative to the numbers of other aquatic insects. The pattern of emergence was notably different than in 1959, with high numbers in the latter half of June and from the first half of August to September. The emergence in 1960, the fourth after spraying, was thus more similar to that of 1955, the pre-spray year, than to any earlier post-spray year. In 1961 the numbers of insects emerging were lower than in any other year of sampling, the small numbers of chironomids being the most significant factor. Insects other than chironomids were relatively more numerous and the volume disproportionately higher than when smaller insects predominated. Many of the larger insects, such as some of the stoneflies and caddisflies, are known to feed on chironomids and other small insects in the water (Muttkowski and Smith, 1929) so that changing numbers of chironomids relative to those of other insects may reflect utilization of the former as food. In 1962, however, the numbers of chironomids and all other insects were higher than in 1961 with an accompanying increase in bulk. Extreme flooding of near record height in May 1961, causing removal of silt and drastic modification of the stream bottoms, was probably a factor in the low populations of 1961.

NORTH BRANCH OF SEVOGLE RIVER (STATION S) (FIG. 8)

Station S was sprayed in June of 1957 and 1958; it had also been sprayed

TROUT BROOK

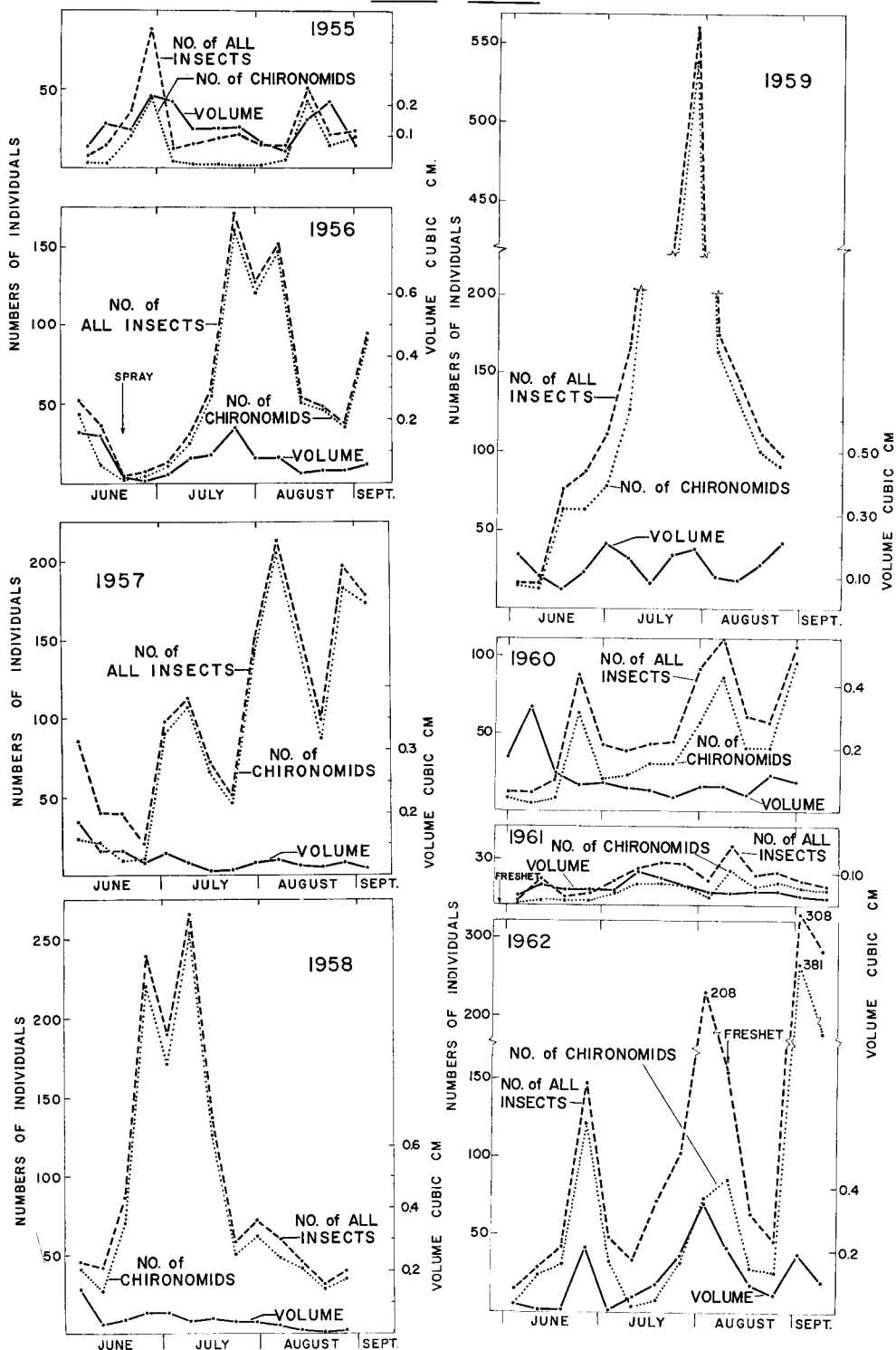


FIG. 7. Emergence of insects from week to week, as average numbers emerging per square yard per day, for Trout Brook (T) (sprayed in 1956 only) for the summers of 1955-62. Numbers of chironomids, numbers of all insects including chironomids, and corresponding volumes are shown. Each weekly point on the graph is the average of 15 yard-square collections (three cage-traps collected for five 24-hr periods) except for 1955, when each point is the average of 12 yard-square collections (two cage-traps for six 24-hr periods).

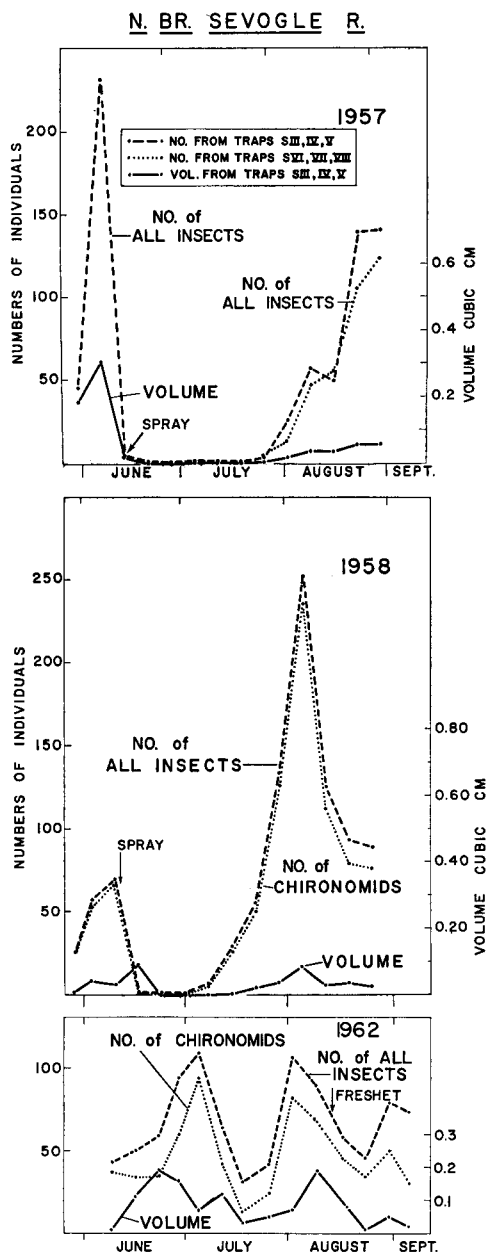


FIG. 8. Emergence of insects from week to week, as average numbers emerging per square yard per day, for the North Branch of the SevoGLE River (S) (sprayed in 1954, 1957, and 1958) for the summers of 1957, 1958, and 1962.

in 1954, but there had been marked recovery in numbers of insects emerging between 1954 and 1957. There was a severe reduction in emergence in the period immediately after spraying, lasting for 6 weeks in 1957 and 4 weeks in 1958. A duplicate set of three cage-traps (designated S VI-VIII) placed about 300 ft upstream in 1957 gave results similar to those from the original set. After 4 years without spraying, sampling in 1962 showed a greater volume of insects emerging as compared with 1957 and 1958. This was mainly because of the increased numbers of insects other than chironomids. The prominent peaks in early and late summer of 1962 are further evidence of recovery; they resemble the pre-spray condition at Trout Brook (Fig. 7).

NORTHWEST MIRAMICHI RIVER AT CAMP 42 (STATION N) AND CAMP ADAMS (STATION NC) (FIG. 9)

Both stations were seriously affected by spray in 1954 but subsequently they had different spray histories. Camp 42 and the river above it was exempt from spraying after 1954 but Camp Adams was probably affected by spraying in 1956 as mentioned earlier. The river below Camp Adams was sprayed again in 1957. Camp Adams, farther downstream, was less affected by the 1954 spray than Camp 42.

If the spread between numbers of all insects and of chironomids is taken as an indicator of recovery, populations at Camp 42 evidently recovered, in general, by 1959, 5 years after spraying. Similarly, at Camp Adams, populations evidently recovered within 5 or 6 years.

ANNUAL EMERGENCE OF MAJOR GROUPS, TROUT BROOK

Figure 10 indicates annual emergence of major groups of insects for Trout Brook. Other insects, e.g. dragonflies and alderflies, occurred in insignificant numbers. Small riffle beetles, mostly of the family Elmidae, were abundant at some stations but, since they remain in the water as adults, were not taken in collections.

CHIRONOMIDS (FIG. 10A)

There were great differences in emergence between cages. Trout Brook is a rather small stream and it was not possible to place the three cage-traps in uniform conditions. However, the numbers were higher on the average in 1956, the spray year, than in the pre-spray year, mainly owing to the high emergence of chironomids from July to September (see Fig. 7).

STONEFLIES (FIG. 10B)

These insects were comparatively low in numbers. They are of moderate to large size, and some species prey on other insects. They were not reduced as greatly in numbers as some of the other groups. The numbers reached a low in the post-spray year, 1957, partly owing to the considerable number which

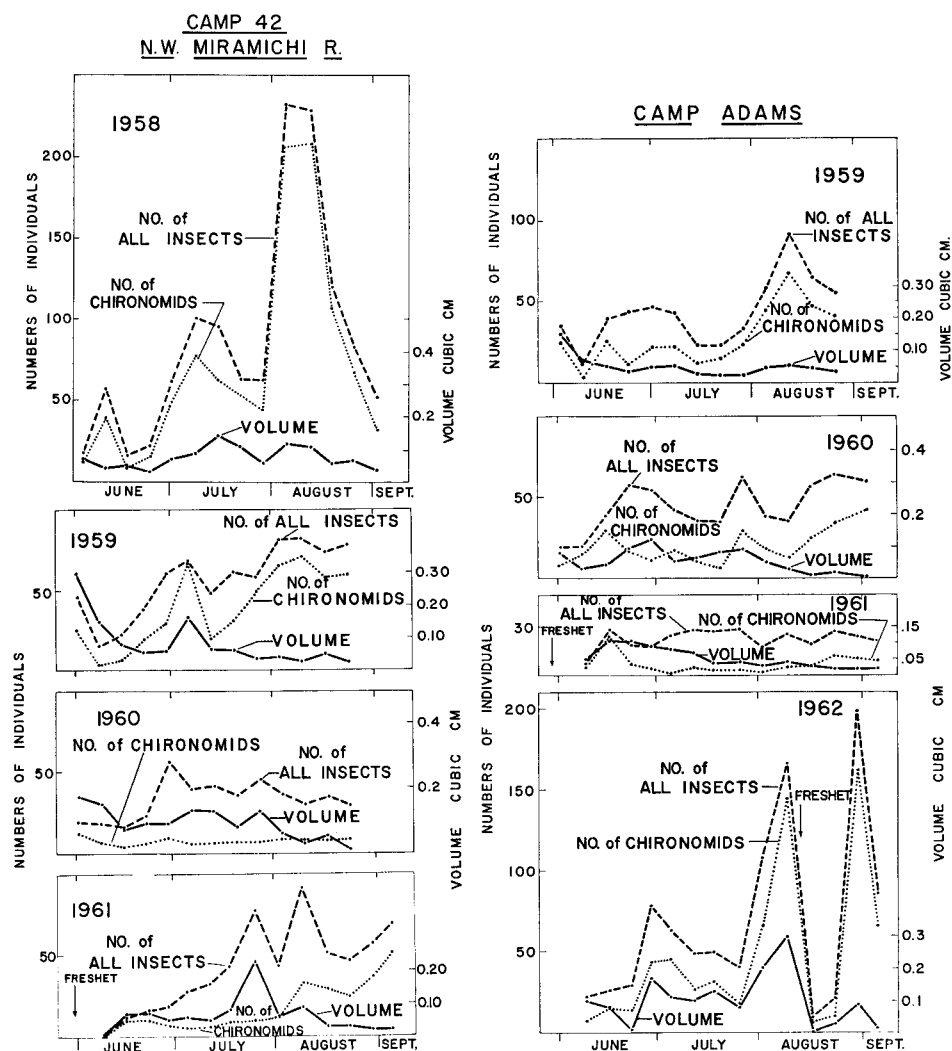


FIG. 9. Emergence of insects from week to week, as average numbers emerging per square yard per day, for two stations on the Northwest Miramichi River: Camp 42 (N) (sprayed in 1954 only) for summers of 1958 to 1961, and Camp Adams (NC) (sprayed in 1954 and probably affected by spray in 1956, when the north bank of the river was sprayed in the vicinity) for the summers of 1959 to 1962. Camp Adams was near the eastern border of the spray area in 1954.

emerged in the 2 weeks before spraying in 1956 (Fig. 4C). The numbers were above pre-spray numbers in 1958–60 and in 1962; in 1961 they dropped to a level about that of the low figure of 1957. Excessive flooding in May 1961 may have contributed to the low number of that year by reducing the populations of species which normally emerge in the early season.

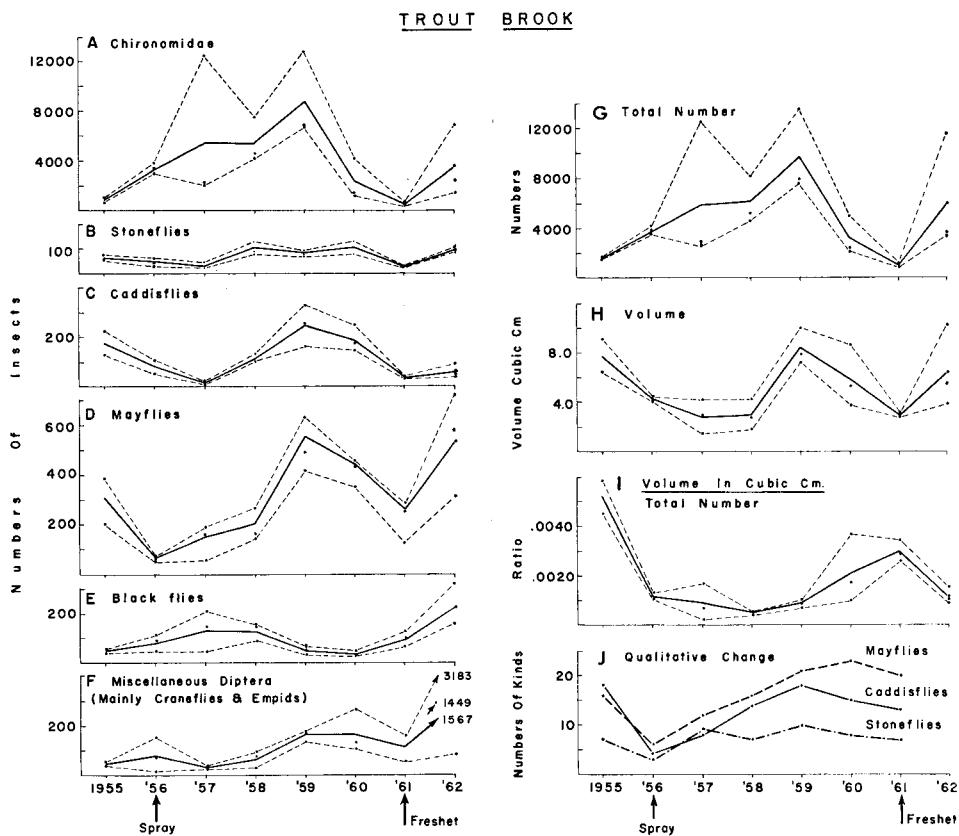


FIG. 10. A-F. Comparative annual numbers (60-day equivalents of actual numbers taken by two yard-square cage-traps operating for six 24-hr periods a week in 1955 and three such traps operating 5 days a week in other years from the beginning of June to the first week of September) of emerging insects of various groups for Trout Brook (T) for pre-spray year 1955, spray year 1956, and post-spray years 1957-62. G-J. Comparative annual data on total numbers and volumes of insects, average size, and estimated numbers of species for Trout Brook, 1955-62.

CADDISFLIES (FIG. 10C)

The numbers of caddisflies were lowest in 1957, the year after spraying. Two influences evidently account for the higher numbers in the spray year than in the following year. Firstly, figures for 1956 include the individuals which emerged in the 2 weeks before spraying. Secondly, a large number emerged after spraying, nearly all of species of case-bearing Rhyacophilidae (Glossosomatinae); these are presumed to have been in the pupal stage at the time of spraying and, therefore, relatively unsusceptible to DDT. In 1957 these species were poorly represented and the numbers of all caddisflies (Fig. 4D, 10C) were low. The numbers were highest in 1959; they remained high in 1960 but in 1961 were lower than in 1956 but not as low as in 1957. Extremely high floods in late May of 1961 probably contributed to the low numbers in that year. In 1962 there was a slight rise in numbers.

MAYFLIES (FIG. 10D)

The numbers of mayflies were lowest in 1956, the spray year. Exclusion of the individuals which emerged in the 2 weeks before spraying would have resulted in a still lower point for that year. Through 1957 to 1959 there was a continual rise in numbers; a decline in 1960 and a further decline in 1961 brought the numbers near those of the pre-spray year; in 1962 they were about the same as in 1959. This example shows clearly the greater disparity between the numbers for the different cage-traps when the numbers were high than when they were low, a reflection probably of differences in conditions of the bottom. The mayflies are in general herbivores (Muttkowski and Smith, 1929), and their increase in the years after spraying to higher than pre-spray numbers may have resulted from the sudden post-spray increase in food in the form of algae and the relative scarcity of predators (stoneflies, caddisflies).

BLACK FLIES (FIG. 10E)

Changes in numbers of black flies resembled those of the chironomids more than any other group. Black flies are extremely sensitive to DDT in the larval stages (Jamnback and Collins, 1955; Jamnback and Eabry, 1962). Large numbers emerged early in the season of 1956, before the spraying was done, and the total for 1956 was greater than for the pre-spray year 1955 (Fig. 4B). The increased numbers in 1957 may represent progeny of ovipositing females from adjacent streams not affected by the 1956 spray, as discussed earlier. The females of some black fly species are known to disperse widely. The numbers from the cages varied widely in some years but were consistently low in 1959 and 1960, when caddisflies and stoneflies were abundant. The numbers of black flies were high in two of the three cages in 1957 and 1958 and again in 1961. None of the other groups of insects exhibited a comparable rise in 1961. In 1962 the black flies showed an even greater increase in numbers in the samples. The habit of aggregation of the larvae makes representative sampling difficult.

MISCELLANEOUS DIPTERA (FIG. 10F)

The predominant forms in this group included species of *Antocha* (Tipulidae) and Empididae. Some Tipulidae are predatory, feeding on aquatic insect larvae (Muttkowski and Smith, 1929). Some Empididae are known to be predacious as adults, feeding on adult chironomids and small mayflies; their larvae eat larval stages of aquatic insects. By 1959 these insects were notably more abundant than in the pre-spray year, as were mayflies and chironomids. They remained well above the pre-spray numbers in 1960 and 1961, when other insects except black flies decreased in numbers. In 1962 they increased markedly in numbers. Their numbers varied widely between the different cage-traps in some years, one cage being high even in 1956, the spray year. There was also evidence of aggregation similar to that of the black flies.

TOTAL NUMBERS (FIG. 10G)

The curves of total numbers of all aquatic insects followed closely those of the chironomids, because the latter generally contributed a high percentage of the totals.

TOTAL VOLUMES (FIG. 10H)

Total volumes corresponded fairly well with the numbers of the larger insects such as caddisflies; there was a peak in 1959, the third year after spraying. Volumes were also influenced appreciably by the numbers of chironomids or other small insects when these were abundant. The volume was low in the spray year 1956, also in 1957, and again in 1961. Higher values were attained in 1958-60 and again in 1962. The 1961 low was associated with extreme flooding in that year, but intrinsic cyclic fluctuation of insect populations might also be involved.

RATIO OF VOLUMES TO NUMBERS (FIG. 10I)

These ratios, indicating the average sizes of the individuals in the samples, should be considered along with Fig. 10G, H. When the ratio was low the volume was made up mostly of small insects, such as chironomids, black flies, and the small species of mayflies. Thus in 1956-59 and in 1962 small insects predominated, whereas in 1955, 1960, and 1961, when the ratio was higher, larger insects contributed more to the bulk.

NUMBER OF KINDS (SPECIES) (FIG. 10J)

An attempt was made to list the numbers of species in the three major groups, stone flies, mayflies, and caddisflies, for 7 of the 8 years under consideration. Because of the technical nature of this work, it was impractical to complete the list in the time available. Many of the species, however, were recognizable and these were counted. For some closely related species, the group to which they belong was recognized and more than one species were treated as a unit. All stations were treated similarly and comparable results obtained. The counts were based on an examination of the samples from each year's collections; they represent the species recognized in the samples and not necessarily all that were taken. In some cases a species was represented by only one or two individuals in the samples of that year. This resulted in variable numbers of species being encountered even in later years of the survey when, presumably, the actual number should approach a constant value.

The smallest number of species for each group was represented in samples taken in the spray year, 1956, even though the sampling included 2 pre-spray weeks in that year. The mayflies and caddisflies showed this particularly, the stoneflies not so clearly because of the smaller number of species involved. In the two former groups the low point in the spray year was pronounced, and numbers of species near those of the pre-spray year were reached in 1958 by the mayflies and in 1959 by the caddisflies. The low points in all these qualitative

curves occurred in the spray year even though the emergence of stoneflies and caddisflies had not yet reached their lowest numbers (Fig. 10B, C). It is significant that the severe flooding in 1961 did not reduce the numbers of species to near 1956 levels as with numbers and volumes in the populations.

It is not possible to conclude whether the increase in number of species in the years after spraying represented an increase from sparse residual numbers or whether there was immigration from other parts of the river system not affected by spray. There is some evidence from the small tributary of the Sevogle (Station SS, Appendix II) that headwaters sections of streams may be less affected by spray than an intermediate section (Station S, Appendix IV). It is possible that there was some immigration from upstream sections in Trout Brook by either immature stages or ovipositing females. Also, since Trout Brook empties into the main Northwest Miramichi, which was not sprayed, some species of insects may have migrated into Trout Brook from this source. The habit of caddisflies of flying upstream and ovipositing has been investigated by Roos (1957), who showed it to be an important factor in upstream repopulation.

ANNUAL EMERGENCE OF MAJOR GROUPS AT OTHER STATIONS

The streams on which other stations were maintained for more than 1 year (Millstream Brook, North Branch of the Sevogle River, main Northwest Miramichi) are all parts of the Northwest Miramichi system and are all larger than Trout Brook at the station sites (Fig. 1). Millstream Brook (Station M) was used as a control, as described earlier.

The volume of all aquatic insects emerging at the control station averaged higher than at the sprayed station on the North Branch of the Sevogle (Station S) in every year and was also higher than at those (Camp Adams and Camp 42) on the Northwest Miramichi (Fig. 12). The numbers of insects emerging at the control station varied widely, not only from cage to cage but from year to year (Fig. 12), as did the figures for corresponding volumes.

Variable annual results for the control station would be expected as a result of differences in such factors as flooding, weather, and available food. Other variables are changing stream bottoms and exact cage positions. As mentioned earlier, Millstream Brook had less continuous rapids at the station site and the bottom was less uniform than at the Sevogle and Northwest Miramichi stations. The bottom under some of the cages was more silted or sandy than for others, causing embedding of stones and thus reducing the numbers of some groups of insects and increasing others. Another factor possibly affecting results for this station was the spraying. In 1957, although the plan called for exempting all of the Millstream Brook down to the station site, spraying was carried out over the lower reaches to a point within a quarter mile of the cages and it is not known whether the spray pattern was accurate enough to prevent some of the spray reaching the station site.

All the streams discussed below, except Millstream Brook, were included in the 1954 spray area and were seriously affected by spraying that year. The

Camp Adams site may have been affected again by adjacent spraying in 1956 (Fig. 1). The Sevogle site was sprayed for a second and third time in 1957 and 1958.

MAYFLIES (FIG. 11)

Mayfly numbers at Millstream remained fairly constant from 1955 to 1958 with somewhat higher numbers in 1956 than in the other years. At the Sevogle (Station S) they were lower in 1955, the first post-spray year, than at Millstream the same year. In 1956 the numbers were nearly six times those of the previous year, and more than twice as great as at the control. In 1957 and 1958 they were sharply lowered, however, as the area was sprayed again in both years. In 1962, when the station was again sampled, the numbers of these insects were near the 1956 level, showing good recovery numerically. At Camp 42, sprayed in 1954 only, the numbers were rather high in 1957 when first sampled; in the subsequent years 1958-61 they maintained a plateau at a still higher level. More variation was shown at the Camp Adams station; numbers were roughly comparable to those of the control in 1959 and more than double this figure in 1960, 1961, and 1962.

STONEFLIES (FIG. 11)

The Plecoptera showed considerable fluctuation in numbers at the control station. At the Sevogle a gradual decline in their numbers was evident after the 1954 and 1957 sprayings. The numbers were lowest in 1958, the year of the third spraying. The 1962 sampling showed larger numbers than in 1958 but gave evidence of only partial recovery as compared with the control. In 1955, the year after the first spraying, those emerging consisted almost entirely of small stoneflies of the genera *Nemoura* and *Leuctra*, mainly the latter. The numbers of these declined markedly in 1956, however, although no spraying was done in that year. At the Camp 42 station, the numbers of stoneflies were low in 1957 and 1958, the 3rd and 4th years after spraying. They reached a high in 1959 and dropped to less than two-thirds of the 1959 numbers in 1960 and 1961. At Camp Adams the numbers were high in 1959, 1961, and 1962 but in 1960 were only about a quarter as great.

CADDISFLIES (FIG. 11)

The Trichoptera seem to have been more severely affected by the spraying than other groups. In the larger streams they were more affected than in the smaller Trout Brook or in the small tributary of the Sevogle River (Station SS, operated in 1955 only, Appendix II). Despite the gradual drop in numbers of caddisflies at the control site from 1955 to 1958, the consistently small numbers taken from the North Branch of the Sevogle through these same years are in sharp contrast, there being only a slight increase in 1962. At Camp 42 their numbers were low in 1957 and 1958, as at the Sevogle, but by 1960 they increased to a level about that of the control stream in 1958; this indicates a

slower recovery than for the mayflies and stoneflies. The numbers of caddisflies at Camp 42 reached the level of those in the control in the 5th year after spraying. The mayflies showed about the same degree of recovery in 3 years and the stoneflies in 5 years. At Camp Adams the situation with respect to caddisflies was very different from that at Camp 42. The numbers were comparable to those in the control stream in 1959, a year earlier than at Camp 42. However, the large numbers emerging in one cage in 1959 were nearly all of one small species whose larvae were conspicuously aggregated. In 1960 and 1961 the numbers of caddisflies were markedly reduced at Camp Adams, being only about a quarter of those at Camp 42 in the same years. There was a slight increase in 1962.

It is difficult to clarify the apparently anomalous difference between caddisfly numbers at Camp Adams and Camp 42. The lower numbers at Camp 42 may have to do with the fact that the Camp Adams station was farther down the river, nearer the lower limit of 1954 spraying, and may have been repopulated by upstream migration earlier. The effect of spraying in the vicinity of Camp Adams in 1956 and below it in 1957 (Fig. 1) may also be involved. Also the river bottom at Camp Adams was more impregnated with silt and bark than at Camp 42 due to stripping of surrounding hills of timber.

BLACK FLIES (FIG. 11)

The black flies were highly variable in numbers at these stations. The averages at the Camp 42 station do, however, show a general rising trend through 1957 to 1961 except for the slight drop in 1959. Numbers were low in all years at the Millstream Brook control station.

CHIRONOMIDS (FIG. 11)

The Chironomidae showed great variability in numbers at the control and other locations when averages, and still greater variability when individual cage-trap results, are considered. The latter variation is considered to be mainly a result of differences in bottom. An anomalous feature for this group is the small numbers observed at the Millstream Brook and Sevogle stations in 1955 and at Camp 42 and Camp Adams in 1960 and 1961. In the intervening years, including spray years at the Sevogle, the numbers, in some cage-traps at least, were very high. Very large numbers emerged in one cage of the Sevogle series in 1956, 2 years after spraying and in one of the cages of the Camp 42 series in 1957, 3 years after spraying. Also, large numbers were noted particularly at Trout Brook in the latter half of the summer of 1956 and during the following 3 years (Fig. 7). Some of these high populations may be associated with reduction in the numbers of predatory insects which utilize the chironomids as food.

MISCELLANEOUS DIPTERA (FIG. 11)

The predominant groups in this category were Tipulidae and Empididae. The variation in their average numbers was small at Millstream Brook. There

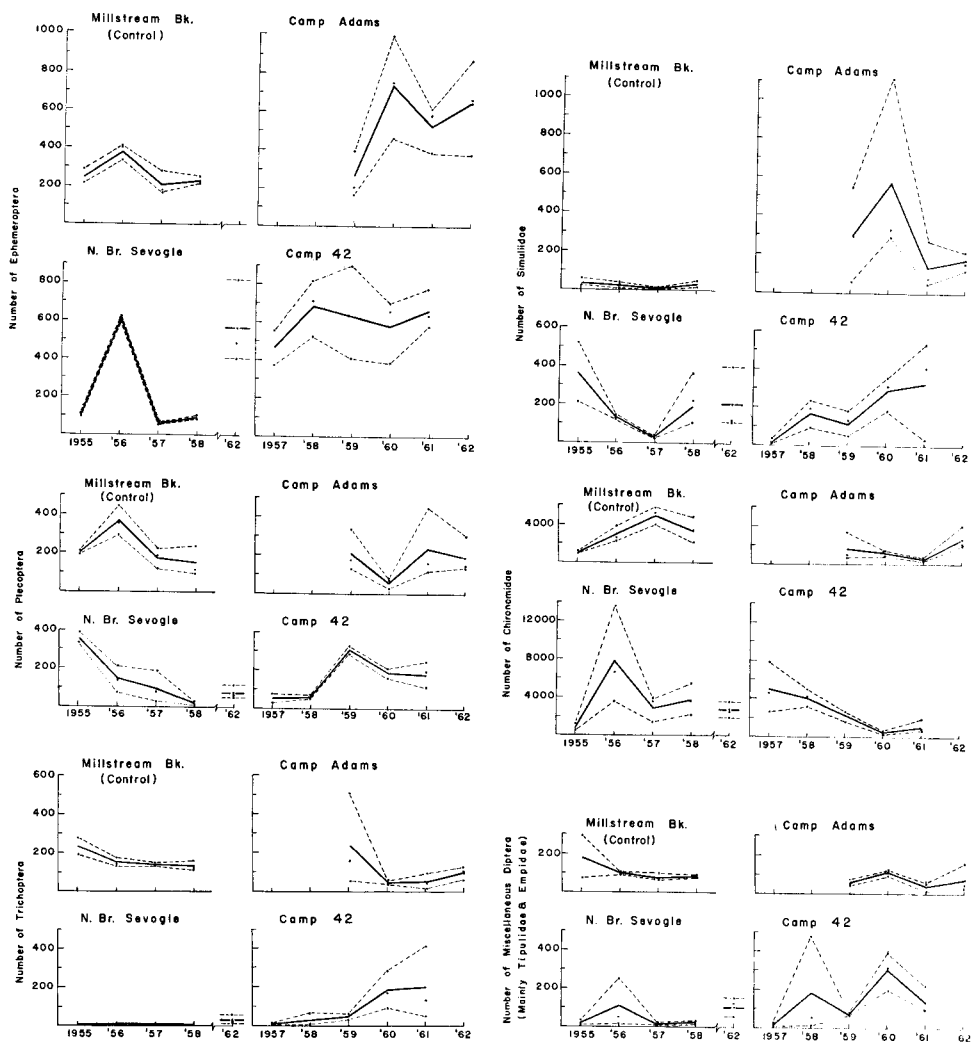


FIG. 11. Numbers of various groups of insects emerging annually at various stations (for further explanation see Fig. 10).

were, however, nearly twice as many of these flies emerging at this station in 1955 as in 1956, and the numbers were maintained at the lower level through 1957 and 1958. At the Sevogle, on the other hand, the numbers were low in 1955, the year after spraying. They increased to a point higher than the control numbers in 1956, then dropped to low figures in 1957 and 1958 with the second and third sprayings. At Camp 42 the numbers were low in 1957 but greatly increased in 1958–61; they were highest in 1960 and comparatively low in 1959. Camp Adams figures, on the other hand, show little variation in the numbers during the years 1959–62.

TOTAL NUMBERS (FIG. 12)

Total numbers of emerging insects followed those for the chironomids because of the predominance of this group (see Fig. 11, 12).

TOTAL VOLUMES (FIG. 12)

There was considerable variation in the values of this measure at the control station, but the averages were always higher than at any of the other three stations. The only year when the average volume of Sevogle insects approached that of the lowest figure for the control was in 1956, the second year after spraying, when mayflies were particularly numerous. The lowest volume for the Sevogle was in 1958, the year in which the station was sprayed for the third time. The numbers, however, were higher in 1958 than in 1957, but the insects were nearly all small in 1958 (Fig. 12). By 1962 the volume was still below that of 1955 and 1956 although no spraying had affected this location after 1958. The volumes for Camp 42 were lower than for the control in 1957 and 1958, increased slightly in 1959 and 1960, but decreased in 1961. The volumes for Camp Adams were somewhat lower than those for Camp 42 for corresponding years.

RATIO OF VOLUME TO NUMBERS (FIG. 12)

These ratios, indicating the average sizes of the individuals making up the samples, should be considered in conjunction with Fig. 12A, B. At the Millstream Brook (control) the average size changed markedly from a high in 1955 to a low in 1957, with a slight rise in 1958. For the Sevogle, average size was always well below that for the control station in the same year. It was highest in 1955, the year after spraying, mainly because of the presence of large numbers of stoneflies (*Nemoura*, *Leuctra*) and mayflies (*Iron*, *Ephemerella*); these are larger insects which presumably survived the 1954 spraying mostly in the egg stage. In 1956 average size was low mainly because of large numbers of small chironomids. The lowest ratio was for 1958, the year of the third spraying, when emergence was predominantly of small insects. At Camp 42 average size was small in 1957 and 1958, and increasingly larger in the 3 following years. This reflects increasing numbers of larger insects, mainly stoneflies and caddisflies, and decreasing numbers of chironomids. It seems likely that utilization of chironomids as food by these carnivorous insects underlies these changes. At Camp Adams there was also an increase in average size, particularly in 1961, but in this year caddisflies were much scarcer than in 1959 whereas stoneflies were numerous. Chironomids were at their lowest numbers in 1961 at this station. The decrease in average size for Camp Adams samples in 1962 reflected the increased number of chironomids after extreme flood conditions in 1961; similar increases occurred at other stations.

NUMBER OF KINDS (FIG. 12)

The numbers of species of mayflies, stoneflies, and caddisflies for the Mills stream control were nearly constant in 1955 and 1957; in 1956, more specie-

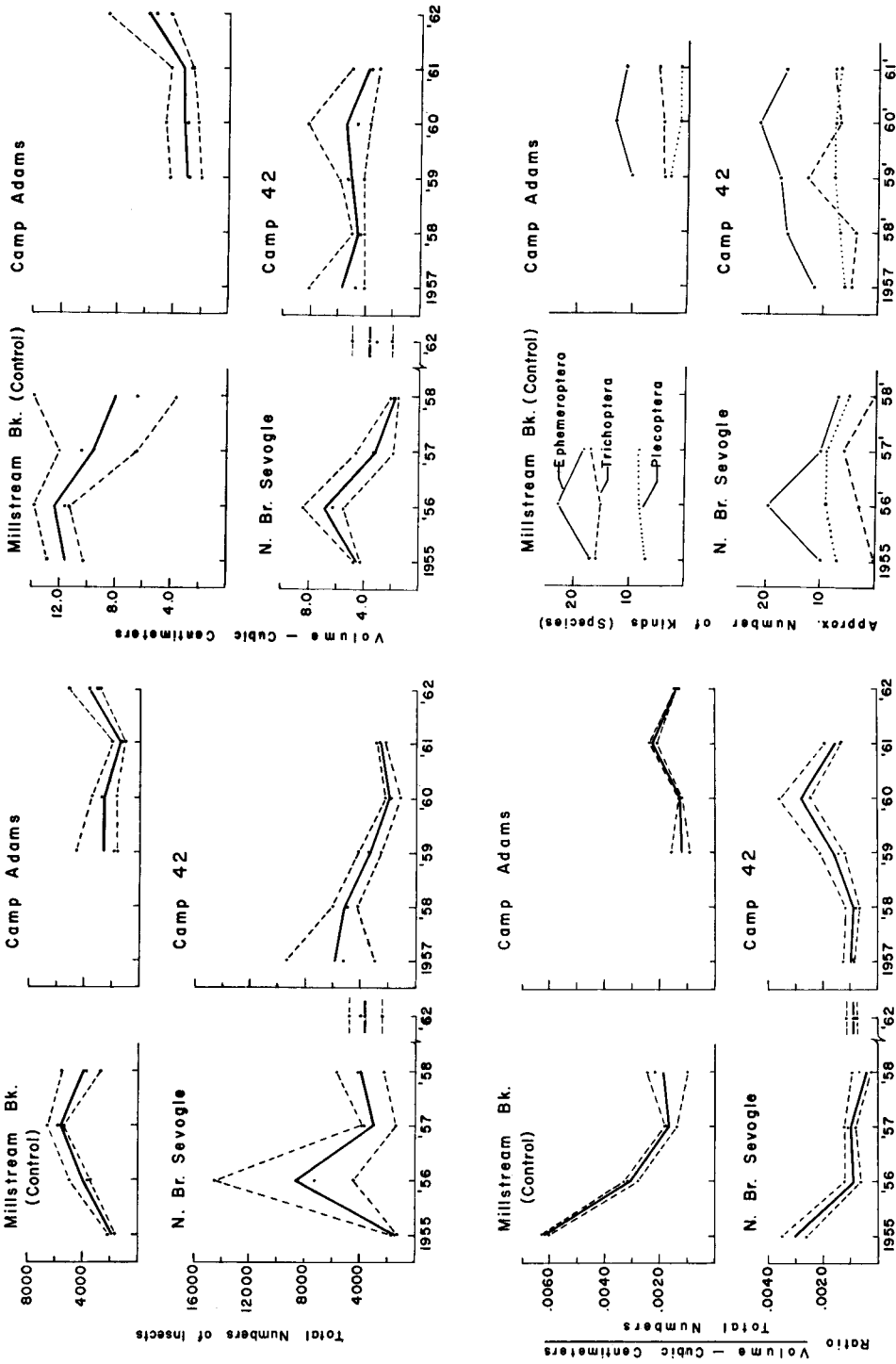


FIG. 12. Numbers of all insects emerging annually at various stations, volumes, ratios of volume to corresponding number, and estimated numbers of species of mayflies, stoneflies, and caddisflies (for further explanation see Fig. 10 and 11).

of mayflies were taken than in the other 2 years. There was a high total number of mayflies in samples of 1956 compared with other years, so that more species had a better chance of being taken. This finding should not be interpreted as indicating an increase in number of species at the station, but merely an increase in numbers represented in the samples. Similarly, the twofold increase in number of species of mayflies at the Sevogle in 1956 as compared with 1955 coincided with a larger number of these insects in the samples of the latter year. With spraying repeated in 1957 and 1958 the number of kinds in the samples was again down to the 1955 level in 1957 and lower in 1958. Caddisflies showed the most extreme change. None emerged in the three cages at the Sevogle in 1955. In 1956 three species were represented by small numbers, and in 1957 six species, showing a slow recovery. In 1958 the number of species was reduced to two which had survived the 1957 and 1958 sprayings. At the Camp 42 station the number of kinds of caddisflies was low in 1957 as compared with the Millstream Brook control; in 1959, 13 species were identified, and in 1960 and 1961 there were seven and eight respectively. The number of species recorded in 1957 at Camp 42 is a measure of the diversity in the fauna 3 years after application of the spray in 1954. The number recorded at Camp Adams in 1959 is a measure of the diversity in the same groups 5 years after the original spraying with a probable additional effect of spraying in the vicinity of the station in 1956.

GENERAL DISCUSSION AND CONCLUSIONS

INSECT FLUCTUATIONS WITHOUT SPRAYING INTERFERENCE

The normal course of emergence of the main insect groups through the season in the Northwest Miramichi area is suggested by the results of sampling in 1955 at Station T, Trout Brook (Fig. 4, 7), and from 1955 to 1958 at Station M, Millstream Brook (Fig. 5, Appendix III). The data for Station T show higher production of insects (chironomids not included) in the year before spraying than in those immediately after. Although details of day-to-day fluctuations in emergence of individual species are masked because the counts are totalled by major groups, some interesting features are apparent. For example, at both places the emergence of mayflies, stoneflies, and caddisflies was minimal at the start and end of observations for the season, and reached maximal daily levels around midsummer. Considerable variation within groups may occur for unknown reasons from one year to another, as indicated by the high production of black flies at Station T before spraying in 1956 as compared to the low emergence in the same early part of 1955.

Unusual natural occurrences may have severe effects on aquatic insect production, as shown by the extreme flooding conditions caused by a near-record freshet in May 1961. No unsprayed control stations were operated that year but marked effects of the freshet in cutting down production of three major insect groups for periods of a few days to several weeks is evident for stations T (Trout Brook) and N (Camp 42), where recovery from spraying was well advanced by 1961 (Fig. 4, 6).

SHORT-TERM EFFECTS OF SPRAYING

With $\frac{1}{2}$ lb DDT/acre used in forest spraying, reduction in numbers of the larval stages of aquatic insects ranged to 95% or even higher in local situations.

Trout Brook in 1956 and the North Branch of the Sevgole in 1957 and 1958 show the effect on emergence of aquatic insects in the year of spraying (Fig. 4, 7, 8). Figure 8 shows populations still recovering from an earlier spraying. The virtual cessation of emergence for up to 6 weeks after spraying occurred at a time of the year when large numbers of individuals of early summer species are normally emerging (Fig. 4, 7).

In a separate 1961 project on the Molus River, Kent County, N.B., to be published later, DDT was sprayed experimentally at $\frac{1}{4}$ lb/acre. Foot-square bottom sampling (Surber, 1937), before and after spraying, showed up to 97% reduction of bottom fauna as compared to actual increases in numbers during the same period in a nearby unsprayed control stream. Screens of 24-mesh copper (0.71-mm apertures), set to collect drifting spray casualties, took a heavy load of insects within an hour of spraying and the catch was heavy for several hours. This supports the conclusion that the 1956 drop in emergence at Trout Brook was a direct result of spraying DDT at $\frac{1}{2}$ lb/acre.

As mentioned earlier, one of the visible results of DDT spraying in some of the more seriously affected parts of the streams was a conspicuous growth of various kinds of filamentous algae on the stones, forming a virtual mat of a brownish or greenish-brown colour. Many of the insects, including species of chironomids, mayflies, and some stoneflies, are known to be vegetarian (Muttkowski and Smith, 1929) and consequently much food should be available to such insects. Low numbers of predatory species, including some stoneflies and caddisflies, which occurred at the same time, would mean that large populations of the primary feeders could be supported and more than pre-spray numbers of these might be expected. Thus chironomids were present and emerging in large numbers in the late summer of the spray year and in the following year.

Gorham (1961) reports on an investigation in the State of Maine, adjacent to the New Brunswick border, where in 1958 forests were sprayed with a dosage of 1 lb DDT-in-oil/acre. Using the Surber technique he concluded that recovery was good in some groups and fair in others, including caddisflies, by August 1959. Gorham states, "It is very unlikely that the 1958 spruce budworm control campaign caused or will cause the extinction of any species in the spray area or that it had any significant long-term or permanent deleterious effects on the populations of riffle insects." His conclusions are supported by the present paper as to the effects on major categories of insects. He has, for instance, demonstrated a rise in the number of chironomids above pre-spray numbers in late summer of the spray year, which agrees with the present findings but not with those of Webb and Macdonald (MS, 1958); Surber sampling by these workers indicated that chironomids were usually more abundant in unsprayed than in sprayed streams. Gorham's conclusion that it is unlikely that any species were eliminated is premature, since his identifications were not made to the species level.

RECOVERY IN THE SPRAY YEAR

Obviously the decreased emergence in the first weeks after spraying was due to a reduction in numbers of larvae and nymphs, the few insects which continued to emerge being mostly from viable pupae. Glossosomatid caddisflies, for instance, emerged in rather large numbers at Trout Brook after spraying in 1956 (Fig. 4D). These case-making types survived; they were probably pupae within sealed cocoons at spray time. The few chironomids which emerged in this period were also probably pupae when the spray was applied. An occasional mayfly and stonefly also emerged throughout this period, presumably having survived because of comparatively low susceptibility to DDT. The great increase in numbers emerging began, however, about 4 weeks after spraying at Trout Brook (Fig. 7) and after a somewhat longer interval at the North Branch of the Sevole in 1957 and 1958 (Fig. 8). These increases were mostly in chironomids, but black flies and other Diptera and a few caddisflies were also involved. The numbers of chironomids emerging in cage-traps of the Trout Brook series in the late summer peak of 1956 were higher than those of the pre-spray year (Fig. 10A). This large chironomid population is presumed to be mainly of the second-generation individuals of bivoltine species which survived spraying in June in the egg stage.

An observation made at Gill Brook a month after spraying in 1954 is pertinent in this connection. Stones picked from the bottom in rapids were found to be densely populated with recently hatched chironomid larvae, estimated to number about 700 per foot². It is possible that these were progeny of ovipositing females that immigrated from some unaffected stream, but this is improbable because of Gill Brook's distance from the spray border and the limited flight range of chironomid adults. It is more probable that they survived spraying in the egg stage.

A few specimens of two species of caddisflies of the family Limnephilidae, *Neophylax* sp. and *Pycnopsyche* sp., emerged at the end of August 1956 at Trout Brook. The species are both relatively large insects and their larvae live in cases. Both normally pass through most of the summer as prepupae in diapause, believed to afford protection against DDT.

There was, therefore, almost a complete absence of well-grown active larvae and nymphs for several weeks after spraying. Presumably viable eggs and pupae and some newly hatched individuals of a few species were present during this period. More nymphs and larvae became evident in July with the hatching of more eggs. This was followed by the emergence, in July, August, or September, of large numbers of insects (mostly chironomids). The populations of these were sometimes so large that numerical recovery occurred in the same season as the spraying. The bottom fauna was, however, deficient in bulk and variety.

RECOVERY IN SUBSEQUENT YEARS

In the year after spraying, insects of some groups, including mayflies, emerged in such large numbers that it was evident that they had not reached

these numbers by reproduction from a few survivors of the spray. For instance, three species of mayflies, *Iron pleuralis*, and two species of *Ephemerella*, emerged in considerable numbers at the Sevogle station in 1955, the year after spraying (Fig. 5). These are spring or early summer species, which oviposited before spraying in mid-June. *Iron pleuralis* lays eggs which remain in diapause for 3 months (Ide, 1935) and presumably these survived the spraying in 1954, hatched in numbers in the fall of 1954, and emerged in 1955. The early species of *Ephemerella* may be in the same category but in addition some of these have been observed in other years to be relatively tolerant of DDT, as demonstrated by their occurrence in post-spray Surber samples. Hitchcock (1960) mentions that he has found these insects to be somewhat tolerant of spray in the nymphal stages.

Some stoneflies also appeared in large numbers at the North Branch of the Sevogle in 1955, the year after spraying (Fig. 5). These were almost all species of *Nemoura*, early emerging stoneflies, and species of *Leuctra*, some of which are early and some mid- to late-summer species. Most are presumed to have survived the spraying in the egg stage but some may have survived as nymphs. The particularly large numbers of stoneflies emerging at Station SS on the small tributary stream of the North Branch of the Sevogle in the year after spraying (Appendix II) were mainly species of *Leuctra*.

The above are examples of survival of large populations because of tolerance to DDT in some stage of the life cycle. These particular examples are organisms which require a year to complete the life cycle so that large numbers the year after spraying imply survival in numbers and not an increase through multiplication. Despite the above-mentioned species emerging in appreciable numbers the year after spraying, the numbers of caddisflies and stoneflies in Trout Brook were lower in the year after spraying than in the spray year (Fig. 4C and D, 10). But the number of emerging mayflies was lowest in the spray year although the totals included an appreciable number emerging before the spraying. Also, the number of kinds or species was lowest in the spray year for the groups considered in this way (Fig. 10).

The result of the spraying on the insects of the streams may be summed up as follows: spraying was followed by almost 100% reduction in numbers of most insects which were in active stages of the life cycle, e.g. feeding larvae or nymphs. Species in tolerant stages, such as eggs, pupae or diapausing larvae, survived in appreciable numbers, but the total insect population in immediate post-spray years was mainly composed of a few species representing these survivors. Other species, because of greater vulnerability at the particular period when spraying was carried out, were greatly reduced or even eliminated from the local area. These species only increased to a significant element of the population after a lapse of time which allowed them to multiply either from residual small numbers or from natural reintroductions from less affected waters.

Most groups of insects appear to have been reduced in numbers of individuals immediately after spraying. In general, this was followed by an increase to numbers exceeding pre-spray numbers 2 or 3 years after spraying and

then a drop to near or below pre-spray numbers eventually for some groups. Figure 10 shows this for Trout Brook. The different times involved in phases of recovery may be the result of a number of influences including: food supply; whether the insects are mainly herbivorous or carnivorous; possession of DDT-tolerant stages in the life cycle; and rate of multiplication, which depends on whether the insects are small with a short life cycle, or large and slow-growing, and whether they are bivoltine or univoltine. Some of the large stoneflies, e.g. *Acroncuria* species, require 2 years to complete the life cycle and recovery in numbers of these by reproduction from survivors was comparatively slow.

After spraying in 1956, mayflies in Trout Brook, particularly some of the small Baetinae, increased to large numbers in 1957 and 1958 and a high in 1959, and then declined until 1961 (Fig. 4A, 10D). Stoneflies did not fluctuate as much as the mayflies and reached their greatest numbers somewhat later. Caddisflies, particularly the larger species, lagged still more. Black flies showed an increase in some cages similar to that of the chironomids, with a rapid rise in numbers after spraying (Fig. 10). They decreased earlier than chironomids, but increased in 1961 as well as in 1962. The "miscellaneous Diptera," mainly Tipulidae and Empididae, are mostly predacious. Some of the empids prey as larvae on the aquatic larval stages of insects and also as adults on adult chironomids and small mayflies. The numbers of miscellaneous Diptera (Fig. 10), although variable, showed a general trend in which their high numbers lagged behind those of their prey in a manner which has been observed in many predator-prey relations.

The curve for total numbers of insects for Trout Brook (Fig. 10G) follows closely that for chironomids because of the predominance of this group. The curve for corresponding volumes (Fig. 10H) does not follow that for numbers but in general shows a drop in bulk of insects through spray and immediate post-spray years; this is mainly because of large chironomid numbers. The ratio curve, indicating average size, shows a general rise from 1958 to 1961 in association with the increasing numbers of large insects in the population. A drop in 1962 was associated with a greater increase in numbers of smaller than of larger kinds after the 1961 freshet.

Respraying of the Sevgole in 1957 and 1958 interrupted the rehabilitation process there, but the increase in larger species at Camp 42, as shown for the caddisflies (Fig. 11), would indicate that the early rise in numbers of chironomids was followed within several years by a rise in other groups. Recovery at Camp 42 can probably be assumed to have paralleled that of the North Branch of the Sevgole through 1955 and 1956. Thus the two together give a continuous record of the probable pattern of recovery in insect populations for a river which was extremely affected by spraying in 1954.

Camp Adams, 10 miles downstream from Camp 42, shows some significant differences from the latter. Some of these may be a result of its closer proximity to the downstream limit of 1954 spraying and therefore to a less depleted fauna as a source of immigrants. The variety of caddisflies at Camp Adams in 1959

was considerably greater than at Camp 42 the same year, particularly in the presence of a number of Hydropsychidae, absent at that time from Camp 42. This was in spite of a 1956 spraying that possibly affected Camp Adams but not Camp 42.

Evidently numbers alone are not a valid criterion of recovery of aquatic insects in the streams after spraying. Volume gives a somewhat better indication, but even this is not completely satisfactory. If the volume is large merely because of high numbers of very small insects, it cannot meet the feeding requirements of all kinds and sizes of fish. A large volume made up of a considerable proportion of larger insects, as in pre-spray conditions, can provide satisfactory food for insect-eating fishes of all sizes, and should therefore be a better indicator of carrying capacity than numbers or volume alone.

From the standpoint of permanent damage to streams by spraying, and particularly by repeated spraying, the recovery in variety of aquatic insects would seem to be a most important indicator. Such recovery for mayflies, stoneflies, and caddisflies is shown for Trout Brook in Fig. 10J and for the Sevogle and the Northwest Miramichi in Fig. 12. From these it would appear that fairly good recovery of the three groups of insects took place, but that it was slower for caddisflies than for the other two groups. The Trout Brook station was not as severely affected as was the North Branch of the Sevogle or the Northwest Miramichi, perhaps because it was less remote from unsprayed areas. Such a situation has also been noted by Hitchcock (1960).

Summarizing, if numbers of insects were an adequate criterion, then at least some streams "recovered" in from 6 weeks to 2 months after being sprayed. But because of their small size these numerous insects are not satisfactory food for larger fish, although they are suitable for fry. When, however, the bulk of organisms and their individual size are taken as the criterion, recovery was much slower (Fig. 10I, 12). It then paralleled more closely the increase in number of species, eventually approaching the diverse fauna characteristic of the pre-spray condition (Fig. 10I, J). Present data indicate that this required up to 3 years for mayflies and 4 or more for caddisflies.

BOTTOM FAUNA AND FISH FOOD

The salmon fry are mainly insectivorous and feed on small insects, including chironomids and small mayflies. In the overyearling stage higher percentages of larger insects are used (White, 1936; Hurley, MS, 1956; Keenleyside, 1967).

As insects are preferred food of young salmon in streams, any treatment which eliminated them, even if molluscs, annelids, and other lower invertebrates were to increase, would be deleterious. Allen (1941) has shown that young Atlantic salmon are selective in their feeding. Hurley (MS, 1956) found that molluscs (Physidae) were extensively eaten (up to 92.6% of stomach contents) by salmon parr in the Northwest Miramichi River in 1955. Here bottom sampling had shown that they formed a high percentage of the bottom fauna particularly in the latter part of the summer, in contrast with low numbers at locations

outside the boundary of 1954 spraying. These molluscs were absent from the stomachs of salmon parr taken from areas outside the spray boundary in 1955 and from the stomachs of parr taken from all locations in the pre-spray year 1953. In the absence of aquatic insects normally utilized the young salmon did take the snails in this local situation but they are unusual components of their diet.

Since aquatic insects formed the largest component of the diet of young salmon before spraying (Keenleyside, 1967), changes in their numbers as a result of spraying had an effect on the diet and consequently on the population of the fishes. Detailed accounts of changes in the populations of young salmon in the Northwest Miramichi through the interval covered by this report are given by Kerswill (1967) and Elson (1967). In 1954, for instance, spraying resulted in the virtual elimination of salmon fry in the section of the Northwest Miramichi in which the Camp 42 and Camp Adams stations were located and a marked reduction in numbers of overyearling young salmon. The emaciated condition of survivors was indicative of poor feeding conditions.

Unfortunately intensive sampling of aquatic insects was not carried out on the Northwest Miramichi at this critical period nor for several years afterwards, because of inaccessibility of the area by road. However, it can be assumed that the immediate effect of spraying the Northwest Miramichi in 1954 was similar to that already described for the spraying of Trout Brook in 1956 and the Sevogle in 1957 and 1958. In all cases there was a high mortality among active stages of aquatic insects. One such case of the immediate effect of spraying was followed in detail on the Molus River in 1961 (see "Short-term Effects of Spraying"). Whether killing of the salmon fry was indirect, from feeding on poisoned insects, or by direct contact with DDT in the water, has not been satisfactorily determined.

For an interval after spraying there was a period during which very few insects were evident on the bottom. After this, newly hatched insects began to develop and eventually emerge, frequently in very large numbers late in the summer, as was described for both Trout Brook in 1956 and the Sevogle in 1957 and 1958. Most of these insects were very small species, predominantly chironomids. The salmon fry in the Northwest Miramichi did not survive this sequence of events in 1954 (Elson, 1967), but some overyearlings did, although some were in poor condition. The spawning in the fall of 1954 resulted in a particularly high population of fry according to sampling records made in the late summer of 1955 (Elson, 1967).

The abundance of chironomid adults at Trout Brook in 1956 and 1957 suggests that small larvae of chironomids, on which fry feed, were abundant when this large population of fry was feeding. In later years when these became overyearlings and larger, there was a higher proportion of larger insects, more suitable food for these larger fish. It would appear, therefore, that whereas the spray eliminated the fry that hatched in 1954, those that hatched in 1955 were probably provided with satisfactory quantities of suitable insects. Repeated

spraying in the same summer or in consecutive years (Kerswill, 1967) would, however, probably produce very deleterious effects on the aquatic insect food of young salmon.

OTHER EFFECTS OF DDT

Long-term records of Surber sampling on several streams, one of which, Ramsay Brook, was sprayed for the 7 consecutive years 1952-58 (Webb and Macdonald, MS, 1958; Macdonald, 1965), give a long and continuous record of spray effects on the bottom fauna. Some of the recovery in 1958 in Ramsay Brook was in populations of a small mayfly which was exceedingly abundant even after this history of spraying. This raised the question of the possible development of immunity to DDT in these insects, such as has been found for some species (Brown et al., 1963). Experiments started in summer 1965 at the Department of Zoology, University of Western Ontario, showed that mayfly nymphs in one species of the genus *Heptagenia* developed at least a 15-fold DDT-tolerance in areas of New Brunswick sprayed annually with DDT since 1956 with the exception of 1959 (C. D. Grant, personal communication).

The present studies do not include any examples of streams sprayed as many times as Ramsay Brook, the maximum being three (North Branch of the Sevogle). Consequently, the present work throws no light on the question of selection of DDT-resistant strains. But there are evidently cases where the spray caused little reduction in numbers because the insects were in the egg stage through the toxic period. Second generations of some of the small bivoltine mayflies appearing in late summer of the spray year (Fig. 4A) are presumed to be from eggs laid before spraying by the first generations. These are not considered to have been selected by the spray, although there may have been some selection against individuals which hatched soon after spraying when conditions were still toxic or against late individuals of the first generation exposed to spray.

SAMPLING PROBLEMS

In this investigation organisms other than aquatic insects, such as molluscs and annelids, were not considered since the method did not provide a means of sampling them. This is a shortcoming in the method, as Webb and Macdonald (MS, 1958) and Webb et al. (MS, 1959) point out. However, it is only a minor drawback when the predominant position of aquatic insects in the natural food of salmonid fishes is considered. Webb and Macdonald also note that cage-traps sample the insects after they have left the stream bottom, and conclude that the samples are not a good index of available food. Fish food studies show, on the contrary, that most aquatic insects become more vulnerable to fish predation in their last nymphal instar, when they move from their normal protected situations into positions suitable for emergence, and that they are exceptionally vulnerable just before and during emergence. Hence emergence records are more closely related to feeding opportunities than are bottom samples.

Apart from that, the cage-trap method has two great advantages over bottom sampling. One feature is its continuity, which reflects the course of

insect emergence, so that emergence records reflect the biological production of these animals better than bottom sampling. Some species complete their development in less than 3 weeks, e.g. some black flies; others take 2 or even 3 years, e.g. some stoneflies. The other advantage of the cage-trap is its greater efficiency in sampling minute insects such as the smallest chironomids, which are frequently very abundant and are utilized as food by salmon fry. Bottom sampling, however, may be a useful adjunct to cage-trapping in giving a comparative measure of the standing bottom crop of larger organisms.

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Appendices I-VI follow.

APPENDIX I. Annual emergence for Trout Brook (T), 1955-62. Annual numbers of insects emerging into two yard-square cage-traps operated for six 24-hr intervals per week in 1955 and three such cages operated for five 24-hr intervals per week in other years from approximately the beginning of June to the first week of September and made comparable by reducing all to 60-day equivalent values.

Year	Cage-trap	Numbers							Volume in cc	Ratio vol. in cc Numbers
		Ephem.	Plec.	Trich.	Diptera			Total		
					Chiro.	Sim.	Misc.			
1955	1	203	78	133	890	41	44	1389	6.4	0.0045
	2	384	53	228	735	58	41	1502	9.1	0.0059
1956	1	48	62	111	3005	90	150	3466	4.4	0.0013
	2	69	36	54	3430	111	69	3769	4.2	0.0011
	3	62	45	81	3860	45	15	4108	4.1	0.0010
1957	1	53	45	16	12400	43	22	12579	3.0	0.0002
	2	188	29	20	2090	148	28	2503	4.3	0.0017
	3	164	21	15	2200	208	33	2641	1.4	0.0007
1958	1	265	91	135	7550	85	76	8202	4.3	0.0005
	2	140	83	101	4260	152	23	4759	1.8	0.0004
	3	162	134	112	4630	145	88	5271	2.8	0.0005
1959	1	418	79	260	12800	30	176	13763	10.0	0.0007
	2	635	75	162	6640	51	134	7697	7.9	0.0010
	3	490	99	334	6780	61	169	7933	7.3	0.0009
1960	1	458	102	247	4130	25	123	5085	5.2	0.0010
	2	430	133	179	1300	43	266	2351	8.6	0.0037
	3	352	83	142	1500	29	100	2206	3.8	0.0017
1961	1	129	27	42	645	99	50	992	2.9	0.0029
	2	250	28	28	255	124	116	801	2.8	0.0035
	3	282	32	41	670	63	158	1246	3.2	0.0026
1962	1	720	93	104	7130	167	3183	11397	10.25	0.0009
	2	568	71	51	2364	339	90	3493	5.25	0.0015
	3	305	83	39	1540	167	1442	3576	3.91	0.0011

^aEphem. = Ephemeroptera (mayflies); Plec. = Plecoptera (stoneflies); Trich. = Trichoptera (caddisflies); Chiro. = Chironomidae; Sim. = Simuliidae (black flies); Misc. = miscellaneous Diptera (mainly Tipulidae and Empidae).

APPENDIX II. Sixty-day equivalent figures for two cage-traps at small tributary of North Branch of the Sevoyle (SS) in 1955. (See Appendix I for further explanation.)

Year	Cage-trap	Numbers							Volume in cc	Ratio vol. in cc Numbers
		Ephem.	Plec.	Trich.	Diptera			Total		
					Chiro.	Sim.	Misc.			
1955	1	393	527	11	355	15	69	1370	6.8	0.0051
	2	275	500	1	640	5	23	1444	4.7	0.0031

APPENDIX III. Sixty-day equivalent figures for Millstream Brook (M) (control) cage-traps 1955-58. (See Appendix I for further explanation.)

Numbers										
Year	Cage-trap	Ephem.	Plec.	Trich.	Diptera			Total	Volume in cc	Ratio
					Chiro.	Sim.	Misc.			vol. in cc
1955	1	282	214	278	968	55	288	2085	12.6	0.0061
	2	210	192	186	1110	22	66	1786	10.0	0.0063
1956	1	329	293	143	2557	9	87	3418	11.2	0.0033
	2	401	446	171	2371	38	99	3526	11.9	0.0032
	3	404	357	128	3625	35	92	4641	15.6	0.0028
1957	1	279	221	138	5610	5	94	6347	11.8	0.0018
	2	176	186	140	5100	3	59	5664	10.2	0.0018
	3	163	118	127	3910	10	64	4392	6.2	0.0014
1958	1	252	118	159	2110	33	82	2754	6.2	0.0022
	2	210	240	117	4730	15	85	5397	13.6	0.0025
	3	210	94	110	3180	51	70	3715	3.9	0.0010

APPENDIX IV. Sixty-day equivalents figures for North Branch of Sevogle (S) cage-traps 1955-58 and 1962. (See Appendix I for further explanation.)

Numbers										
Year	Cage-trap	Ephem.	Plec.	Trich.	Diptera			Total	Volume in cc	Ratio
					Chiro.	Sim.	Misc.			vol. in cc
1955	3	99	383	0	975	213	8	1678	4.3	0.0026
	4	109	335	0	337	524	27	1332	4.7	0.0035
1956	3	601	214	4	13545	124	17	14505	8.4	0.0006
	4	586	139	2	6418	138	49	7332	6.3	0.0009
	5	613	75	2	3330	150	247	4417	5.5	0.0012
1957	3	52	186	3	3470	27	4	3742	4.5	0.0012
	4	68	80	4	3680	37	9	3878	3.2	0.0008
	5	54	22	5	1254	36	6	1377	1.8	0.0011
1958	3	86	28	0	2050	110	33	2307	2.0	0.0009
	4	77	22	2	5360	196	10	5667	1.4	0.0002
	5	100	6	3	3570	378	22	4079	1.8	0.0004
	6	74	32	5	2810	24	23	2968	1.6	0.0005
	7	121	31	1	3270	142	81	3646	2.6	0.0007
	8	77	21	3	2980	48	60	3189	1.5	0.0005
1962	3	482	116	26	3620	119	146	4509	3.2	0.0007
	4	821	57	54	2769	400	124	4225	4.8	0.0012
	5	404	58	15	1967	125	57	2626	2.0	0.0008

APPENDIX V. Sixty-day equivalent figures for Camp 42 (N) cage-traps 1957-61. (See Appendix I for further explanation.)

Year	Cage- trap	Numbers							Volume in cc	Ratio vol. in cc Numbers
		Ephem.	Plec.	Trich.	Diptera			Total		
					Chiro.	Sim.	Misc.			
1957	1	467	31	4	4580	16	13	5111	4.8	0.0009
	2	550	49	5	7920	10	10	8544	8.2	0.0009
	3	373	77	13	2475	26	19	2983	4.1	0.0013
1958	1	815	57	3	5004	193	13	6085	4.4	0.0007
	2	520	65	65	3060	92	475	4277	5.0	0.0012
	3	710	49	15	4110	234	54	5172	4.1	0.0008
1959	1	890	324	59	2650	176	63	4162	5.9	0.0014
	2	404	308	46	1574	52	68	2452	5.3	0.0021
	3	595	282	31	2290	124	80	3402	4.1	0.0012
	4	439	130	37	1638	79	81	2404	2.3	0.0010
	5	903	190	111	3000	122	572	4898	6.2	0.0013
	6	479	79	35	1300	123	173	2189	1.9	0.0009
1960	1	698	160	285	489	313	387	2332	8.2	0.0036
	2	380	189	90	243	356	315	1573	3.7	0.0024
	3	649	207	172	552	178	197	1955	4.7	0.0024
	4	930	336	37	857	440	51	2651	6.5	0.0025
	5	665	396	49	807	434	235	2586	6.7	0.0026
	6	1085	349	41	1545	175	55	3250	6.8	0.0021
1961	1	575	188	51	1860	37	96	2807	3.6	0.0013
	2	771	105	133	660	405	218	2292	3.0	0.0013
	3	627	244	412	750	527	96	2656	5.0	0.0019
	4	476	119	95	1055	130	99	1974	2.3	0.0012
	5	375	161	18	1330	198	64	2146	1.9	0.0009
	6	620	98	21	730	464	74	2007	2.5	0.0012

APPENDIX VI. Sixty-day equivalent figures for Camp Adams (NC) cage-traps 1959-62. (See Appendix I for further explanation.)

Numbers										Ratio vol. in cc Numbers
Year	Cage- trap	Ephem.	Plec.	Trich.	Diptera			Total	Volume in cc	
					Chiro.	Sim.	Misc.			
1959	1	388	335	505	3170	55	48	4501	4.3	0.0009
	2	200	126	55	639	540	41	1601	1.9	0.0012
	3	159	178	156	912	287	74	1766	2.8	0.0016
1960	1	992	76	39	1135	1101	118	3461	4.6	0.0013
	2	745	62	52	1332	326	87	2604	3.0	0.0012
	3	457	25	38	774	284	120	1698	2.2	0.0013
1961	1	605	442	89	532	269	48	1985	4.2	0.0021
	2	380	155	14	452	73	12	1086	2.6	0.0024
	3	572	114	48	305	45	58	1142	2.7	0.0023
1962	1	652	143	61	2082	160	38	3136	4.6	0.0015
	2	875	305	130	3830	218	168	5526	8.6	0.0015
	3	381	138	102	2026	124	42	2813	4.0	0.0014