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CHAPTER 10

Effects of Pesticides (Toxicants) on Stream Life

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The rapid water habitat differs from that of static water mainly in factors dependent on turbulence and transport of properties and materials downstream.

The biota is predominantly aquatic insects and insectivorous fish. The large populations of the former are dependent primarily on allochthonous vegetable detritus for food. Where populations are large, a high percentage are filter-feeding insects.

Because of these special circumstances, the fauna is extremely susceptible to toxicants particularly if in particulate form as oil droplets or powders.

Streams or lotic fresh waters are bodies of water in which the medium flows in one direction under the control of gradient, momentum, and friction. This unidirectional flow, together with turbulence owing to the relatively small volume, shallowness, and irregular bottom, is responsible for the many features distinguishing lotic water from the static water of lakes. There is a continual transport of properties and materials, according to the competence of the current, from headwaters to mouth. Through erosion there is also a continual addition of much new organic and inorganic particulate matter. Because of turbulence the properties, including the more finely divided particulate matter, become evenly distributed throughout the water mass. Coarser particles are sorted to produce a complex bottom.

Biologically, the stream is much less a microcosm that is a lake, deriving much more of the primary food supply as vegetable detritus from the surrounding terrain. Percentages averaging 65 are given by King and Ball (1967) for this allochthonous primary food with the figure dropping to nil for reservoir areas and rising to 91% below the effluent of a sewage treatment plant. Odum (1957), Nelson and Scott (1962), and Teal (1957) have recorded similar findings for more restricted situations.

It is proposed to restrict this discussion to the rapidly flowing sections of streams since these best characterize the stream ecosystem and have been the most seriously affected by spraying operations (Hoffman and Surber, 1948; Savage, 1949; Graham and Scott, 1959),

The Biota of Rapid Water

Flora. Because of current there is no indigenous plankton and the algae are encrusted on the surface of stable bottom particles or other fixed support as periphyton. The macroflora is mainly species of mosses (*Fontinalis*) or branching algae such as *Cladophora* or *Batrachospermum*, attached to stones with a few trailing angiosperms rooted in the bottom in protected crevices. The indigenous flora is generally not productive enough to supply the associated primary consumers with sufficient food (King and Ball, 1967).

Fauna. There is no indigenous zooplankton in rapids of rivers and very little in other parts where there is appreciable current. The fauna is, therefore, of species which are fixed or cling to the substratum. Microbenthic organisms are generally closely associated with the periphyton on fixed objects. The dominant group is the macrobenthos which is either attached or able to move about over the substratum without being dislodged. A few species are able to swim short distances in the current to reach new positions. Drifting of some of these organisms, particularly at night, has been demonstrated by several investigators (Holt and Waters, 1967). With some species, this may be compensated by upstream flying of the ovipositing females (Roos, 1957).

The predominating group of the macrobenthos is the aquatic insect group represented by many species in several characteristic orders. There are also representatives of other arthropodan groups including Crustacea and Arachnida. There are also Mollusca, the annelidan groups, Hirudinea and Oligochaeta, and the Turbellaria, but these are of secondary significance in most situations as compared with the insects. By many special adaptations, structural, physiological, and behavioural, in all stages of their life cycles, a very heterogeneous fauna of these animals is able to maintain populations in the fast water. With the exception of most beetles, this requires adaptations for emerging successfully from the water as adults and ovipositing in such a manner that the eggs will not be swept downstream out of a suitable habitat.

The most characteristic of the insects are some species of Ephemeroptera (mayflies) and Trichoptera (caddisflies), practically all species of Plecoptera (stoneflies), species in families of the Diptera including the primarily aquatic Chironomidae (midges), the rapid-water Simuliidae (black flies), a few species in each of the Empidae (dance flies) and Tipulidae (craneflies) and smaller families. Riffle beetles, of three small families, Elmidae, Dryopidae, and Psephenidae, are the chief representatives of the Coleoptera. Some other characteristic groups are the Odonata (dragonflies and damselflies) and Megaloptera (alder and dobsonflies), but these are generally few in number although of large size and predatory.

The macrobenthal fauna includes herbivores (primary consumers), carnivores (secondary consumers) and omnivores (Chapman and Demory, 1963; Minshall, 1967). Some obtain their food by filtering, others by grazing on periphyton and detritus, and a very small number by mining in or defoliating higher plants. The great dependence of this fauna on allochthonous vegetable detritus has already been mentioned.

The only animals of the rapids association which are strong enough swimmers to stem the current for any length of time are fish. The trout and salmon are the best known of these and they are primarily insectivorous (Clemens, 1928; Ricker, 1934; White, 1936; Morofsky, 1940; Keenleyside, 1967), the former to a length of 9 or 10 inches and the latter until they go to sea as smolt.

A proportion of the food is terrestrial insects taken at the surface, but this fraction is generally small except under special conditions. Because of short life cycles of aquatic insects and the differing seasons for growth and emergence as "rises," the insectivorous fish are dependent on a heterogeneous fauna for a continuous supply of food. If food is abundant fish have been shown to be selective in their utilization of it (Leonard, 1947; Allen, 1941) but the connection between this and availability is not clear.

The general relation of primary, secondary, and tertiary food chain levels for a relatively simple rapid water situation, with insignificant contribution of allochthonous detrital material, has been investigated by McConnell and Sigler (1959). They used amount of chlorophyll "a" for the estimation of primary production of periphyton during the year. The amount corresponded with an average standing crop (dry weight) of plant material of 25 g/m^2. The average standing crop of macrobenthos (almost all aquatic insects) and fish was 5% and 1.6% respectively of the plant crop. At points lower down the same river the chlorophyll "a" increased 3 or 4 times in amount.

Heterogeneity of the Stream Fauna

The complexity of the rapid water fauna is evident when the structure, physiology and behavior of its diverse component organisms are considered. Simplifying by grouping them in broadly inclusive taxonomic categories as is so frequently done by many investigators, including myself, usually obscures the ecological relations. The practical difficulties in identification, and lack of information on physiological and behavioral characteristics resulting in an underestimating of the divergence in these traits within taxa, have contributed to this practice.

Some examples of the number of species of the macrobenthos in relatively unpolluted streams will give some information on this qualitative aspect. From 1945 to 1955 the author studied the bottom fauna of Black Ash Creek, a spring-fed stream flowing approximately 7 miles from its source high up on the Niagara Cuesta to Georgian Bay in the outskirts of Collingwood, Ontario. The collecting was intensive at seven stations along its course. These were visited through the season at weekly or fortnightly intervals in 2 of the years and aquatic and aerial adult stages sampled. The species of mayflies taken numbered 34, caddisflies 51, and stoneflies 12. The Diptera were less thoroughly sampled because of the small size of many species. This was particularly true of the lower stations. The number of this order recorded and identified was, however, over 90 and included 28 chironomid species from the vicinity of the spring source alone, 26 species of craneflies and smaller numbers of species of black flies, ceratopogonids, psychodids, empids, and minor families. For the crustaceans, molluscs, and fish, 6, 10, and 8 species respectively were recorded. The macrobenthic organisms recorded totalled 225, but it is estimated that between 300 and 350 would be a more realistic estimate for this small stream. Identifications were made or in some cases the author's verified as follows: Trichoptera, C. Betten and H. H. Ross; Plecoptera, W. E. Ricker; Coleoptera, M. Sanderson; dipterous families Chironomidae, L. Brundin; Tipulidae, J. S. Rogers; Ceratopogonidae J. A. Downes; Simuliidae, D. M. Davies; Psychodidae, L. Quate; other Diptera, G. Shewell, J. G. Chillcott, J. R. Vockeroth and J. F. McAlpine.

More satisfactory data on numbers of species are available for the larger insects of the wholly aquatic orders Ephemeroptera, Trichoptera, and Plecoptera. These, also, are most important in the diet of the insectivorous fish except in their early fry stages for which the chironomids are of prime importance. From a headwater stream about 15 miles long in Algonquin Park in the Laurentian shield area of Ontario, by daily sampling of emerging adult insects at several points along the stream, 40 species of Ephemeroptera, 46 species of Trichoptera, and 22 species of Plecoptera were taken through the season (Sprules, 1947).

In larger rivers, more species are represented in most groups because of a greater range of environmental conditions. The number of species of one order, Ephemeroptera, inhabiting restricted rapid sections will illustrate this. In 1934 the author examined two rapid sections, one about 18 and the other about 56 miles from the source in the Credit River of Southern Ontario. By intensive sampling through the season of both aquatic and aerial stages, 38 species were recorded for the former and 43 for the latter. Only 23 of these were common to the two stations giving a total of 58 for this reach. By a similar method, in 1935, 74 species were taken from the Remic rapids of the Ottawa River near Otawa, Ontario, approximately 650 miles from the uppermost source of the river. A similar distribution would be found for most other groups but some, the stoneflies for instance, are represented by fewer species in the lower section (Sprules, 1947).

Increase in number of species downstream and resulting higher numbers in large rivers applies also to fish. In intensive sampling along their length, 42 to 45 species of fish were taken from four rivers of Southern Ontario ranging in length from 90 to 120 miles and from 18 to 29 species in four rivers ranging from 25 to 60 miles long (Ide, 1964).

Streams of comparable size and character in different geographical regions may have different numbers of species. Salmon streams in New Brunswick, a region with a maritime climate, have fewer species of some of the major orders of salmon and trout food insects than inland streams. Trout Brook, a small tributary of the Miramichi River sampled at one station about 9 miles from the source was found to have only 17 species of mayflies, 18 species of caddisflies, and 7 species of stoneflies in prespray sampling (Ide, 1957).

Populations

The numbers of individuals in populations of aquatic insects may be very large but vary greatly according to environmental factors. They vary greatly also in the proportions of component members.

Table 1 (adapted from Ide, 1940) gives data on the net production of adults from two locations in a rapids about 200 feet long at the outlet of a small lake in Algonquin Park, Ontario, a source of much plankton (Solman, 1939; Cushing, 1963). Yard-square emergence traps, #4 at the head and #1 approximately 100 feet below, were installed and the insects removed daily from soon after the ice left the lake until emergence had practically ended. The net production at #1 corresponded with an average standing bottom crop, the result of 5 yard-square bottom samples taken at regular intervals through the summer, of 10 cm^3/m^2, in the order of 0.2 g/m^2 in dry weight. In addition to illustrating the net numbers of individuals produced at the two locations, their contribution to the net biomass is indicated. The table also, by arranging some of the species according to significant differential distribution at the two locations, shows which groups contributed to the overall increase in numbers at the upper (#4) station and their contribution to the biomass. The large mayfly, *Isonychia,* primarily a filter-feeder (Clemens, 1917), *Hydropsychidae* and *Psychomyiidae,* net-building filter-feeders, and *Climacia,* whose hosts, spongillid sponges, are filter-feeders and black flies, classical example of filter feeders, are particularly significant in this increase. The one species, *Isonychia bicolor,* for instance, produced more net biomass at #4 than did the populations of all insects at #1. Black flies, although small insects, contributed significantly to the greater biomass at #4 because of their great abundance. Filter-feeding insects contributed nearly two thirds of the estimated biomass at #4 and less than one seventh at #1. Grazers (Brown, 1961) were more equally represented at both.

Classifying the insects, therefore, according to similarities in feeding behaviour and other characteristics of stages in the life cycle which determine susceptibility to insecticide, would appear to be particularly useful in studies of stream insects in connection with pollution problems.

Effects of Toxicants

Stream fauna, particularly the rapid water community, is known to be especially affected in spraying operations involving extensive coverage as in forest spraying. This is not

TABLE 1. *Numbers and corresponding volumes of aquatic insects emerging at the head (#4) and at a point 100 feet lower down (#1) of a rapids at the outlet of Costello Lake, Algonquin Park, Ontario, from May 4 to Sept. 18, 1938 (adapted from Ide, 1940)*

Category	Number				Volume		
	per m^2		%		cm^3 per m^2		%
	#1	#4	#1	#4	#1	#4	#1
Ephemeroptera (25 sp at #1)	5477	7832	30.0	19.4	22.0		54.8
Plecoptera (10 sp at #1)	316	886	1.7	2.2	1.5		3.7
Trichoptera (17 sp at #1)	1200	1807	6.6	4.4	3.3		8.3
Diptera	11390	30120	61.4	74.5	13.1		32.7
Neuroptera	7	119	<0.1	0.3	0.02		0.5
Total (all insects)	18084	40582			39.9	>150	
More abundant at #4							
Ephemeroptera, *Isonychia bicolor*	288	2980			5.8	59.5	
Baetis flavistriga	528	1082			0.6	1.0	
Trichoptera, Hydropsychidae and Psychomyiidae	244	528			1.4	3.1	
Diptera, Simuliidae	5110	23880			7.2	33.5	
Neuroptera, *Climacia*	7	119			0.01	0.24	
More abundant at #1							
Ephemeroptera, *Paraleptophlebia mollis*	2610	812			4.3	1.6	
Ephemerella invaria	210	0			1.7	0.0	
Trichoptera, Glossosomatinae	44	4					
Philopotamidae	1120	264			3.8	0.8	
Diptera, Miscellaneous	400	216			2.2	—	
About Equal at #1 and #4							
Ephemeroptera, *Heptagenia pulla*	120	148			3.5	4.2	
Diptera, Chironomidae	5880	6025			5.1	5.0	

surprising when the stream's propensity for turbulent mixing and transport of particulate matter downstream, especially when the particulate matter is a highly lethal insecticide, is realized. The various insecticides used, their formulation, and the techniques of their application is a very extensive subject which it would be impossible to deal with adequately in a paper such as this. It will suffice to remark that the chemical industries have produced many powerful toxicants and that the techniques of applying them have been developed to the point that efficient control of many pests has been achieved. This subject has been dealt with very fully by Brown (1951; 1967) and others. Serious side-effects of spraying affecting the public interest have, however, been demonstrated for many operations and these indicate that compromise is required between efficiency of control and these damaging side-effects.

The effects of toxicants on stream life have been the subject of many investigations particularly since the advent of the chlorinated hydrocarbon, DDT, following the Second World War. Since early papers (Cottam and Higgins, 1946; Hoffman and Surber, 1948; Savage, 1949; Langford, 1949) there have been many others dealing with the subject and the findings have been evaluated in the controversial book, *Silent Spring* (Carson, 1962) and in Rudd (1964); both with many references. The main contributions to the field have stemmed from two operations, the control of black flies and forest spraying. In this paper the reference will be principally to these two operations and the examples will be mainly of DDT effects because this insecticide has been most widely used and its effects on stream life most investigated.

Black fly control. There have been programs of black fly control aimed at reduction of species which are vectors of diseases of animals and man, particularly in tropical regions, and others, aimed at lessening the nuisance aspect in northern forested recreational areas and in the subarctic. Jamnback and Collins (1955) give an extensive bibliography dealing with the problem of control and also with the effects of this on other stream arthropods and other animals. Although other methods of application, including plaster blocks, were used, aerial spraying with DDT in oil applied at a rate of 0.1 pounds DDT per acre proved most satisfactory (Jamnback and Collins, 1955). This treatment gave, according to post-spray tests, almost complete control of black fly larvae with little, if any, damaging effect on other aquatic forms. Control required a repeat spraying during the summer but this had little effect on other forms also. This program has continued for many years and according to the checks made the composition of the benthos has altered very little when considered at ordinal levels. The checks, as carried out, gave results which would seem to indicate that the Simuliidae are the most susceptible to DDT of all the aquatic insects and that a virtually specific control of these troublesome pests has been possible by controlling dosage and timing of operation. Hocking et al. (1949) concluded, however, that spraying from the air at a rate of 0.26 pounds DDT per acre was more damaging to stream life than introducing the toxicant directly into the water in such a way as to give a dosage of 1:10,000,000 for 30 minutes but that in both instances the mortality in arthropods other than black flies was great. Exposure to the latter concentration for 15 minutes, however, had little adverse effect. Hynes and Williams (1962) noted that in a stream in Central Africa treated with DDT in such a way as to maintain a dosage of 1 ppm in the river water for 30 minutes there was evidence of significant mortality in some of the insects particularly in *Neoperla*, *Hydropsyche*, and *Cheumatopsyche*, all predators and the latter two filter-feeders. The black flies are the classical example of filter-feeders and it may be this habit which is most pertinent in determining their high susceptibility.

Fredeen (1953) reports on the control of black fly larvae in the Saskatchewan River over 90 miles downstream from the point of inoculation and attributes this to the adsorption of the formulation on particulate matter of the turbid water and the absence of marked turbulence.

The results from black fly control operations indicate that methods which have been developed have been effective with minimal adverse effect on other stream arthropods but that in some situations there may be differential selection against some other equally or slightly less susceptible insects and that these may be other filter-feeders and carnivores. Repeated spraying in the same year or over many years does not appear to be more detrimental than a single treatment on the major components of the fauna considered at the ordinal level (Jamnback and Collins, 1955).

Forest insect control. These are the operations which have produced alarming side-effects the most noticeable being spectacular fish and occasionally bird and mammal kills (Rudd, 1964). Again DDT has been a standard toxicant which is applied from aircraft generally as a spray of a formulation of DDT dissolved in oil. For effective control of the defoliating insect pests of forest trees higher dosages are used than in black fly control. A rate of delivery of one pound of DDT per acre was standard in earlier operations and heavier doses were not unusual but since 1952 0.5 pound per acre was used in operations in New Brunswick and 0.25 pound per acre was used in many cases with control resulting (Kerswill, 1967). With any of these amounts, however, the immediate effect in forest streams is pronounced with mortality in the aquatic insects of the benthos varying from nearly 100% down to 30% or 40% of active larval stages. There has been much study of this effect on stream fauna and an extensive literature has resulted for which some papers such as Gorham (1961), Rudd (1964), Elson (1967), Hitchcock (1965), and Dimond (1967) give good bibliographies.

Large tracts of coniferous forest in New Brunswick, Canada, have been sprayed with DDT in oil from aircraft from 1952 to 1962 (Webb et al., 1961; Kerswill, 1967). The applications were at 0.5 pound DDT per acre but dosages of half this amount were employed in later years following trials. For full history see Kerswill (1967).

The distribution of the spray formulation in the water was followed in 1961 in an experimental spraying of the Molus River watershed with 0.25 pound DDT per acre. Small amounts, maximum of about 8 μg/liter, were detected in the subsurface water (Hopewell, 1962) and this amount only at the passage of the slug. Large quantities were found, however, in vegetable debris and plant material of the bottom. Similarly, heavy accumulation was found in material screened from the current giving readings as high as 606 ppm and considerable DDT was detected in such materials up to 8 days after the DDT became undetectable in the water samples. Since sampling was not continued beyond this time it probably remained for considerably longer than the 8 days. With increased flow of the river after heavy rain, screened material showed rises in DDT content and this was also detected in water samples. Hitchcock (1965) and Hoffman and Drooz (1953) also discuss the distribution of DDT oil spray in streams and arrive at similar conclusions. They find, further, that a stream rids itself of DDT sooner than a static body of water and, therefore, the possibility of the stable toxin accumulating in parts of the food chain is less than in the latter situation.

The effects of spray on stream arthropods from a single application, whether the rate of dosing is 1, 0.5, or 0.25 pound per acre, is severe though variable results have been shown for local areas. The variability is partly because of different amounts of spray reaching the water owing to different terrain, tree cover, and meteorological conditions. The transport of the insecticide downstream, the turbulent mixing of the oil droplets throughout the water mass, and the affinity of these for other particulate matter, particularly of the bottom, results in a maximum exposure of rapids benthos to the toxicant. Lower dosages may lessen the effect in the stream as a whole but concentrating of the material by bottom detritus and mosses as shown by Hopewell (1962) and others may locally counteract low dosage. Some elements of the fauna, which filter-feed, and these are important as fish food, are particularly exposed to contact with particulate matter and the susceptibility of black fly larvae to light dosage may be mainly because of this habit. In faster flow with low concentration they may encounter as much material as in slower current with high concentration.

Reductions in the bottom-living insects ranging from near 100% down to 30% are given for forest spraying operations and the mortality is very variable depending on many factors. This immediate effect means there is a marked reduction in food elements normally utilized by insectivorous fish. The insect survivors are mainly in tolerant egg or pupal stages (Hynes and Williams, 1962) and diapausing larvae, e.g., *Neophylax* and *Pycnopsyche* of the Trichoptera and are essentially unavailable as food. Some nymphs, e.g., species of the *Ephemerella invaria* group show a high tolerance (Hoffman et al., 1946; Hynes and Williams, 1962; Ide, 1957, 1967; Hitchcock, 1965). Also a riffle beetle, *Promoresis,* has highly tolerant larvae and very sensitive adults (Hitchcock, 1965). Both these examples, perhaps indicating physiological tolerance as demonstrated for other species (Jensen and Gaufin, 1964; Sanders and Cope, 1966; Hitchcock, 1965) are exceptional and of little significance in bridging the food gap.

In the New Brunswick forest spraying, the aquatic insects were sampled by trapping emerging adults on a daily basis (Ide, 1957; 1967). The almost complete cessation of emergence for a period of from 3 to 6 weeks following spraying was noted. Then, small chironomids began to emerge and through the remaining summer season increased to large populations, in some cases more than under control conditions. The few large insects taken in late summer were species of caddisflies which passed the summer in diapause within their cases. Surviving bottom stages such as mayfly nymphs, many recently hatched, were developing during this interval but did not reach the adult stage until the following year when they contributed to the net production. The overall result in the spray year was a paucity of fish food during several weeks with initial recovery involving mainly small organisms suitable for young fry (Keenleyside, 1967). Double sprayings were carried out in 1961 and 1962 and presumably more of the newly hatching insects were killed with adverse effect on recovery.

Elson (1967) followed the effect of the 1954 spraying with 0.5 pound of DDT per acre on the populations of young salmon in tributaries of the Miramichi River. At three sites of annual sampling by electrofishing no fry of the 1953 spawning were taken and the overyearling parr were greatly reduced in numbers as compared with several prespray years.

In the year following spraying, more of the larger insects, mayflies, stoneflies and caddisflies, were represented. Some of these were quite large populations which had survived from eggs (Hynes and Williams, 1962) laid prior to spraying and from which they hatched successfully after the toxic effect was lost, or from populations of nymphs or larvae tolerant of the toxicant because of physiological resistance (Hitchcock, 1965), or behavioural traits which protected them from contact (Corbet, 1958). The first mechanism seemed to be more important than the others in rehabilitation. There were, in addition, other species which were eliminated as far as sampling showed or reduced to very sparse numbers. These increased slowly by reproductive multiplication probably aided by immigration from unaffected areas.

The year following the 1954 spraying of the Northwest Miramichi River the sampling gave very large fry counts, much higher than the usual prespray numbers, but those of overyearling parr were very low, reflecting the kill of the 1953 fry (Elson, 1967). Despite this compensatory increase in fry spawned in the fall of 1954, the salmon fishery was adversely affected by spraying. Kerswill (1967) attributes a slump in catches from 1959 to 1962 to forest spraying from 1953 to 1958..

The long-term recovery in stream insects following single sprayings was assessed from 1955 to 1962 on parts of the Northwest Miramichi. In Trout Brook, sampling of emerging insects was carried out through the summers of 1955-1962. It was sprayed in 1956 only. Recovery to near prespray conditions, using bulk of the benthos and its heterogeneity as criteria, took 2 or 3 years (Fig. 1). Small species, however, emerged in large numbers, larger than in prespray years, in the spray year. The figure shows the trend in recovering populations up to 1962, including the effect of the severe freshet in early summer of 1961 which reduced populations greatly that year. In some other locations, more severely affected by spraying in 1954, recovery, particularly in caddisflies, was slower than for Trout Brook, in some cases requiring 4 or 5 years for some components of the benthos to approximate prespray conditions.

The above discussion has been of forest spraying operations which usually do not require repeating the treatment each year. When treatment was repeated annually for

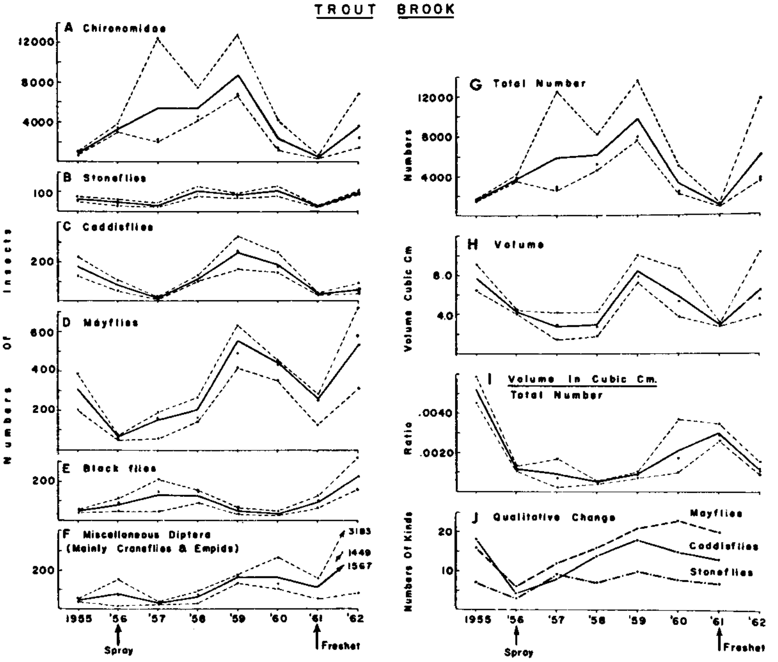

FIG. 1. a-f. Comparative annual numbers (60-day equivalents of actual numbers taken by two yard-square cage-traps operating for six 24-hour periods a week in 1955 and three such traps operating 5 days a week in other years from the beginning of June to the first week of September of emerging insects 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. *(By permission, from Journal of Fisheries Research Board of Canada)*

several years of a test plot in New Brunswick the fauna was changed more or less drastically in composition and the change was characteristic for individual streams (Webb et al., 1959). This is in sharp contrast to black fly control where light dosing twice in the season and over several years had little effect on the composition of the bottom fauna (Jamnback and Collins, 1955).

Accumulation of Toxicant in Vertebrates

The accumulation over a period of time of chemically stable toxicants such as DDT in fish with resulting high concentrations in some of the tissues has been shown to occur. The adverse effect of this on reproduction in land-locked salmon and lake trout has also been discussed (Burdick et al., 1964; Anderson and Everhart, 1966). However, high concentrations of DDT in tissues of large river salmon have not been detected and this is related to the anadromous habit of the fish of going to the sea and doing most of their feeding in this environment (Elson, 1967).

Less stable chemicals may be detoxified in fish food organisms and thus not accumulate or be transferred to higher trophic levels as Schoettger and Olive (1961) have shown for toxaphene in damselfly nymphs.

Immunity to DDT

The development of resistance to DDT by the continual selection for the resistant individuals inherent in the population is known to have occurred in many insects (Brown, 1958). There is evidence (Webb et al., 1959) of increasing populations of one species of mayfly in a small stream in Northern New Brunswick sprayed annually in experimental treatments for several years. This evidence suggests that this may be a case of such resistance developing. This is of considerable academic interest, but unless the phenomenon was common to many species representing all groups, a heterogeneity sufficient to give satisfactory supplies of food to insectivorous fishes would be unlikely with repeated spraying. It is of more practical concern that immunity to DDT is shown to be increasing in the target species, the spruce budworm, in areas which have been repeatedly sprayed (Randall, 1965).

Other Toxicants

As for effects on the stream fauna of insecticides other than DDT and other pesticides, e.g. piscicides, lampricides, herbicides, etc. similar ecological principles are involved except probably with water-soluble toxicants for which the special vulnerability of the rapid water system to particulate matter would not apply. Regarding differential toxicity, Toxaphene has been shown to be more toxic to mayflies than to some fish (Grzenda et al., 1964). Carlson (1966) found that three organophosphates tested were more toxic to aquatic insects, particularly larvae of hydropsychid caddisflies, than to blue gills. The systemic insecticide, Phosphamidon, used successfully in forest spraying has, however, been found to have little effect on the aquatic insects as compared with DDT (Hitchcock, 1965; Grant, 1967).

SUMMARY

It has been shown by Hoffman and Surber (1948) and many others that the communities of the rapids of streams are especially vulnerable to aerial spraying of the forest,

particularly with formulations of DDT in oil. A contributing condition is the high proportion of aquatic insects in the benthos, the main source of food for insectivores such as salmon and trout, and the sensitiveness of most of these to this insecticide. Contamination by the toxicant is likely because of the efficiency of the turbulent water in distributing the oil as droplets through the water mass and carrying these down the rapids (Hitchcock, 1965). The oil has an affinity for other particles in suspension and of the bottom, thus contaminating them. Some of these are vegetable detritus of allochthonous origin which has been shown by King and Ball (1967) to provide the bulk of the food for primary consumers of the benthos in many situations. Of this group of insects, those which filter their food from the flowing water are particularly vulnerable to contamination by the insecticide (Hynes and Williams, 1962). The larvae of black flies, a classical example of filter-feeders, are among the most susceptible of all aquatic insects to DDT in oil. This has made it feasible to control them by dosages which are so low as to have minimal deleterious effect on other fauna preyed on by insectivores (Jamnback and Collins, 1955). In forest spraying, however, such low dosages do not give control of the forest insects and heavier ones are used. Even in the lowest concentrations employed, DDT has a pronounced effect, killing a high percentage of the larval and nymphal stages of all but the most tolerant species. This is enough to reduce the food of fish significantly over several weeks, in severe cases removing practically all the insect food and forcing the surviving fish to feed on a sparse supply of other animals not usually utilized (Keenleyside, 1967). Recovery of insects, however, begins in the latter part of the summer of the spray year with hatching and growing to maturity of very large numbers of minute chironomids, suitable food for fry but too small to be efficiently utilized by larger fish (Ide, 1957; 1967). Consequently, there is a dirth of food for the latter until larger insects, also mainly from eggs, reach a size when they become available. This results in more food of a satisfactory size in the summer following a spraying. If the stream is subjected to spray again there is a repetition of this sequence, but if not, the recovery continues. Recovery may be slow in some insects which were entirely or almost eradicated locally so that their increase is dependent on reproductive multiplication or immigration from unaffected parts of the same or other streams. Some species of caddisflies, important in the diet of the fish, are rehabilitated more slowly than some mayflies (Hitchcock, 1955; Ide, 1967). Annual spraying, generally unnecessary in forest spraying but carried out as a field experiment (Webb et al., 1959), produced marked changes in the composition of the bottom fauna which was characteristic for the different streams. In one of these there was a gradual resurgence of the population of one species of mayfly and it was considered that it might be an example of a species with an immune strain in the population. Such a phenomenon has been shown (Brown, 1958) for a number of other insects. The spruce budworm, a main target in forest spraying operations is apparently another (Randall, 1965). Because of its chemical stability, DDT has been shown to persist in the environment for long periods. It persists in streams for a shorter time than in soil or standing water (Hitchcock, 1965). This is because of the downstream transport of materials. The accumulation of this and other stable toxicants in organisms and transfer of these to higher levels of the food chain is minor for the stream association because food organisms with sublethal amounts of DDT are few and host species such as the salmon are exposed to contaminated food for a short part of their lives as most of their growth is while in the sea (Elson, 1967). The same species and others in lakes have been shown to build up significant amounts of DDT in their tissue, one result being the production of sterilized eggs (Anderson and Everhart, 1966; Burdick et al., 1964). Other toxicants used in forest spraying are for the most part less toxic to the stream fauna as for example the systemic insecticide, Phosphamidon (Hitchcock, 1965; Grant, 1967). Affecting the stream fauna also in varying degree are other toxicants introduced as piscicides, lampricides, herbicides and those for molluscs, hosts of flukes. Some of these produce serious temporary side-effects on the insects much like those of DDT when their susceptibility is greater than that of the target organisms. For some piscicides this is frequently the case (Grzenda et al., 1964).

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