Impact of Forest-Based Industries on Freshwater-Dependent Fish Resources in New Brunswick

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FISHERIES RESEARCH BOARD OF CANADA

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IMPACT OF FOREST-BASED INDUSTRIES ON FRESHWATER-DEPENDENT FISH RESOURCES IN NEW BRUNSWICK

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P.F. Elson, J.W. Saunders and V. Zitko

(A position paper, requested by the New Brunswick Forest Resources Study, on freshwater-dependent fisheries of New Brunswick in relation to forest resources. This paper and "A position paper on the inland fisheries of New Brunswick," coordinated and edited by C. Leslie Dominy of the Fisheries Service, Halifax, are complementary.)

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Introduction

New Brunswick forests have been the mainstay of the region's economy for two hundred years. Fish have also made an important contribution to the economy - as the basis for an industry, as food for New Brunswickers and to a greater extent in recent decades as a basis for recreation and recreation-based fishing industry. The New Brunswick commercial fish industry is based primarily on marine species not directly susceptible to any side effects springing from use of forests. But diadromous species spending their juvenile years in New Brunswick inland waters are vulnerable to environmental changes which may accompany harvest and use of forest products.

Principal freshwater-dependent teleost fish of value to New Brunswick commercial and recreational fisheries

Most important of these species is the anadromous Atlantic salmon which must have clean, well-oxygenated, cool, rapid water flowing over gravel beds for spawning and the first 2 to 4 years of juvenile life. Salmon form the basis for commercial and recreational fisheries. Indeed, New Brunswick salmon are renowned throughout the western world as a most desirable sport fish (New Brunswick Dept. of Natural Resources, 1971) and a gourmet's delight. In contrast to strictly marine species they may, on spawning journeys, travel several hundred miles inland, thus bringing the harvest from the sea to inland areas.

Brook trout are indigenous in practically all New Brunswick water systems. In some streams anadromous trout, called sea trout, migrate to sea and return as much larger fish than those that remain in fresh water. There seems little doubt that more New Brunswickers fish trout for recreation than fish salmon - partly because trout are ubiquitous.

Two other anadromous species - the striped bass and the shad - attract limited attention in New Brunswick as sport fish, although very important in the New England states. Here their potential for recreation has received little notice and both are caught primarily for the limited commercial fishery.

Alewives and smelt form the basis for important commercial fisheries and like other anadromous species spawn in fresh water - the smelt in clean, swift, gravel-bottomed streams, and alewives in lakes or stream stillwaters. Both species require comparatively unobstructed streams to reach their spawning grounds. Tomcod, spawning in the heads of estuaries, are processed incidentally for pet food. They have some seasonal value for sport south of the border.

The American eel is the only catadromous species in New Brunswick. Eels enter our freshwater systems as 3-inch long elvers, grow in streams or lakes and with the approach of maturity return to the ocean where they spawn and eventually die. During their freshwater phase many eels live in salmon streams. Indeed, their total biomass in such places may equal or exceed the combined biomass of juvenile salmon and other species (Elson, 1962). For outlines of the life history, ecology and values of the above species the reader is referred to Leim and Scott, 1966.

Other freshwater fish which have local recreational value include the introduced smallmouth black bass, chain pickerel and the indigenous white perch. Summarized listings and life histories of these and other freshwater New Brunswick fish are available in Scott (1954) and Scott and Crossman (1959).

Environmental changes observed and anticipated from forest-based industries

Physical changes in environment

Until about the middle of the twentieth century impacts of forest utilization on the aquatic environment were comparatively simple. They included removal of forest cover, sometimes of sufficient extent to be a direct cause of faster run-off and erosion. Such erosion results in silting of stream beds and perhaps lake bottoms and alteration of stream bed by widening and consequent shallowing. Stream bank vegetation may be removed either by cutting or by erosion, thereby increasing exposure of the stream to summer sun. Stream driving of logs and pulpwood sometimes hastened bank erosion and stream widening. Occasionally it resulted in smothering stretches of stream bottom with bark from the logs. These changes can result in warming of stream water, which may or may not be deleterious or advantageous, depending on degree of warming and species of fish involved. For most of the past two hundred years New Brunswick inland fish lived fairly well with such environmental changes. In total, they probably seldom affected large areas at any one time. To some extent they were reversible as cut-over forests were left to renew themselves over spans of 30 to 50 years.

Chemical additions to environment

Beginning in the early 1950's forestry practices changed. The commencement of large-scale aerial spraying of the persistent chlorinated hydrocarbon, DDT, in 1952 had a heavy impact on the local fish but less damaging non-persistent organophosphates like fenitrothion replaced DDT in 1968. There is currently a move towards extending the practice of clear cutting which could, if not properly supervised, produce (cause) increased run-off. This in turn could lead to erosion and degradation of the high quality water necessary for good salmonid production. Intensifying forestry practice seems likely to be accompanied by wide use of mineral fertilizers and herbicides as well as insecticides. These will introduce new parameters to aquatic environments.

Impact on lake-dwelling species

Literature on effects of forest-harvesting practices on lake-dwelling fish is lacking. As pointed out above, silting from increased run-off could be locally deleterious. In some instances removal of shore line vegetation could induce changes in the littoral zone. Bank erosion and increased development of beaches are possibilities. Temporarily increased fertility from washed down forest humic soils is a possibility. Increases in both submerged and emergent vegetation could result from greater insolation on the littoral zone. Such changes need not necessarily be bad and might in fact be advantageous.

Of more concern would be the addition of chemical additives, insecticides, herbicides and fertilizer, through direct aerial application from aircraft and through run-off over a much more protracted post-application period. Pesticides are likely to have adverse effects. Fertilizers may well add to productivity since most New Brunswick lakes must be classed as oligotrophic (Smith, 1963).

It must be born in mind that many New Brunswick lakes, especially those in the northern half of the Province, excluding the Madawaska area, were subjected to DDT spraying between 1952 and 1967, inclusive. Because of its persistence in the environment - half life stated to be about 13 years - it must be assumed that DDT derivatives, mostly DDE and some DDD, are still recycling in these waters and will be present for some years. Studies of DDT persistence in the aquatic environment in New Brunswick and adjacent Maine have been largely restricted to streams (e.g., Dimond et al., 1971; Yule and Tomlin, 1971). Anderson and Everhart (1966), however, report that lowered reproductive potential and decreased size for a given age resulted from the presence of DDT in lake fish in Maine. Even though concentrations measurable in waters and bottom sediments are minute, the DDT reservoir is apparently sufficient to assure enough recycling through and concentration in predacious fish, which includes all our game species, to result in measurable concentrations. The "no effect" level of DDT and metabolite residues is not known with certainty. Burdick et al. (1964) were among the first to report substantially lowered reproductive success from parents with sublethal DDT concentrations. Macek (1968a) noted lowered reproductive potential for sexually maturing yearling brook trout fed sublethal DDT dosage, with heaviest mortality of resulting fry occurring (in a hatchery) in the 15th week of development. Egg mortality was above normal if even one of the gametes came from a DDT-treated fish. Macek (1968b) also reported decreased resistance to stress in underyearling trout fed sublethal DDT (about 2 ppm in the food). Anderson (1971) summarized a number of changes in the physiology and behaviour of Atlantic salmon and brook trout subjected to sublethal DDT treatment. These include such adverse changes as an upward shift in temperature selection responses and decreased reaction to stimuli causing avoidance and/or shelter-seeking behaviour.

It is to be born in mind that any new stresses from adding herbicides and pesticides to New Brunswick lake environments will be added to any remaining effects from earlier DDT deposition.

Impact on non-salmonid anadromous fish

Among non-salmonid anadromous species in New Brunswick gaspereau, shad, smelts and striped bass are used quite heavily in fisheries. The last three have some value and perhaps even more *potential* value for recreation. Requirements of these species are mostly limited to lower reaches of freshwater streams, or in the case of striped bass, the upper ends of estuaries.

Smelt spawn in small streams and large rivers, usually requiring clean bottom gravel and moderate current on which to deposit their eggs. Access to spawning areas can be blocked by minor obstructions of logs or detritus or by small falls such as often occur at mouths of culverts (McKenzie, 1964). Because smelt are not strong swimmers and do not leap, forestry practice should ensure against blockage of streams right down to tide water.

Shad and gaspereau are materially stronger swimmers and may move far upstream, but again are not proficient at leaping falls. Even low apron spillways with a 1- to 1 1/2-ft drop, such as occurred on old driving dams, can bar gaspereau even though the dam gates be open. While shad seem to be restricted to larger streams, gaspereau will climb quite small inland brooks if there is a suitable spawning lake above. Hence, assurance of passage unimpeded by log jams and poorly designed culverts is necessary for their conservation. When such small streams are used for passage to lakes, assurance of necessary minimum flows at the time the young migrate seaward can also be an important measure. Shad customarily spawn in shallow, not too rapid, sections of rivers with fine to medium gravel bottom. Gaspereau may do the same in systems lacking lakes. Maintenance of satisfactory water quality and flow would appear to be the chief conservation measures available. Alteration of stream bottom from excessive sedimentation caused by accelerated run-off seems likely to be less important for these species than for salmon and trout.

A far more serious threat to shad, gaspereaux and smelts is degradation of water quality through wide-scale application of pesticides. The Fisheries Research Board of Canada has records to indicate that the first spraying of the Northwest Miramichi with DDT, in 1954, was followed by virtual elimination of gaspereau, shad and possibly smelt runs in that stream above the Curventon counting fence.

From 1950 to 1954 the heavy gaspereau run was a hindrance to operation of the salmon counting fence. The counting fence was never installed early enough in the year to give much of an idea of the magnitude of the smelt run, but judged subjectively (and by local repute) it too has virtually disappeared. The following notes on fish recorded at Curventon are judged informative:

Year	Gaspereau	Shad	Smelt
1953	good run (many bbls)	good run	few
1954	" " "	" "	none
1955	few	few	"
1956	"	"	"
1964	30	1	30
1965	4	0	0
1966	1	0	1
1967	2	0	0
1968	0	0	1

It seems likely that from 1960 on heavy copper-zinc pollution precluded re-population by these species in the lower 20 miles of the river. But the abrupt change from abundance in 1954 to extreme scarcity in 1955 and subsequently correlates with the onset of forest spraying practice.

Whether the presently used organophosphate fenitrothion spray has adverse effects on these species has not been examined. But the possibility should not be ignored that insecticides and herbicides applied to substantial forest areas might gravely increase the stress on these fish populations which run upriver in spring and the very small young which remain in fresh water until early or even mid-summer.

Impact on salmon and trout

Physical changes in stream environments

Extensive removal of forest cover inevitably alters run-off patterns and hence stream regimens. The forest floor mat is altered in as much as tree root systems, moss etc., are killed. This facilitates run-off by giving less impeded downhill flow. Balancing this to some extent, water loss by transpiration will be greatly reduced while that lost by evaporation may be increased. Providing no serious soil erosion accompanies or follows logging practice, ground water levels apparently need not be reduced and might conceivably even benefit. This could happen even though immediate run-off might cause heavier freshets in streams. If logging leaves low vegetation or is soon followed by a growth of such, then rain water percolation would seem likely to be enhanced and since forest transpiration is greatly reduced ground water could be increased (see Tolman, 1937, especially p. 179-180 and 477-479). Building tree-harvesting roads and piling slash windrows along contour lines rather than across should minimize erosion and facilitate percolation. Much data on management of forest lands for conservation of water have been gathered at the Coweeta Hydrologic Laboratory, North Carolina (Hewlett, 1964). Burns (1972) provides the most recent study of effects of logging practices on stream fish production.

When the Northwest Miramichi basin was cut over in the mid and late fifties some, but by no means all, of the slash windrows indicated a degree of contour harvesting had been employed.

Data on physical characteristics of short (approx. 20 yd) sample sections of the Northwest Miramichi have been collected each August since 1951. Measurements recorded in connection with annual assessment of juvenile salmon populations in these sample areas included width of stream at upper and lower end of area, average channel depth and depth of pools or pockets in the stream, character of bottom (i.e., sand, gravel, cobble, or bed rock, etc.) and water temperature at approximately hourly intervals between about 9-10 AM and 3-4 PM. These can be compared with air temperature and rainfall measurements made at Chatham, N.B., and with water height and water temperature records at the Curventon salmon-counting fence of the Fisheries Research Board. Table 1 gives the average of all available records from the seining operation as well as the meteorological data from Chatham and the hydrological data from Curventon. Table 2 indicates that the upper half (20 to 30 miles) of the river experienced somewhat different changes than the lower half.

The data in Table 1 indicate some widening of the river bed. This is attributable to removal of bank-side vegetation and bank erosion in some areas, but by visual inspection appears to be mostly the result of heavier run-off at times of rain and spring ice run. Widening of the channel is accompanied by a general shallowing. Small pools and pockets in the bottom have become filled so that there is a general levelling of the stream. Most large pools are comparatively unaffected. This is to be expected because such pools are usually located at places of rock outcrop, rock gorges, steeper rapids or abrupt bends in course. Such features result in increased digging power of the water. Increased run-off patterns usually produce only temporary, if any, filling of such pools. But the loss of smaller pockets in the main channel does represent a loss of fish habitats which are involved in segregation of different sizes and species of fish le 1. Average changes in some physical characteristics of the Northwest Miramichi River following extensive harvesting of forests, as measured at five headwater and three lower reach fish sampling stations in August of each year. (*Water height in feet above mean sea level)

	River above Curventon				Curventon		Chatham Daily means for month	
	Width (ft)	Depth (ft) channel	Depth (ft) pools	Mean water temp.°C	Water ht*	temp.°C	Rain-fall (in.)	Air temp.°C
ore and ing cut 51-57)	85	1.4	2.4	16.4	92.7	18.7	0.84	17.7
er cut 65-71)	93	1.1	1.4	16.9	92.7	19.6	0.98	18.0
nge	+9%	-21%	-42%	+3%	0%	+5%	+17%	+<1%

le 2. Changes in some physical characteristics of the upper part of the Northwest Miramichi River following extensive forest harvest, compared to changes in lower half.

	Upper part (5 stations)				Lower part (3 stations)			
	Width (ft)	Depth (ft) channel	Depth (ft) pools	Water temp.	Width (ft)	Depth (ft) channel	Depth (ft) pools	Water temp.
ore cut 51-57)	63	1.2	2.1	15.0	107	1.6	2.7	17.8
er cut 65-71)	64	1.1	1.3	14.1	122	1.1	1.5	19.6
nge	+2%	-8%	-38%	-6%	+14%	-31%	-45%	+10%

(see Elson, 1967, Fig. 2). Although there appears to have been some warming of summer river water after the cut, Table 2 shows that this happened entirely in the lower part of the river. There it is probably related to the widening and shallowing of the bed with a consequent greater degree of insolation.

The upper river shows a tendency to slight cooling. It seems quite possible that this could come from increased spring seepage to the river following removal of the forest cover. However, despite the apparently favourable temperature change, the loss of habitat through general levelling and shallowing of the river is conspicuous.

Another factor which may contribute to this loss of "character" of the river bed is the absence of fallen trees, log jams and other obstructions which often contribute small pools through local acceleration of the water current and consequent digging of holes in the stream bed. "The eroding power of water varies as the square of the velocity, and the carrying power varies as the sixth power of the velocity" (Hubbs et al., 1932).

Although fish censusing operations show a marked decrease in young salmon in recent years it is not possible to relate such decrease to the changed habitat. Pollution of lower reaches and overfishing at sea have played a large share in depopulating the headwaters by removing spawners.

Trout populations in the upper river are somewhat less dependent than salmon on spawners recruited from the estuary. Moreover, most anadromous trout which contribute to headwater recruitment ascend in late May and June, a period when the delaying effects of downriver and estuarial pollution are frequently sufficiently ameliorated to permit adult trout to ascend above all pollution points. For the years 1953 and 1955-1957 the average trout abundance in the three uppermost sampling stations was 9 per 100 yd^2. The year 1954 has been excluded because of heavy mortality to trout from DDT spraying. For the last five years (1967 to 1971) the comparable index was 8 per 100 yd^2. The drop in mean summer temperature in upper reaches (Table 2) should favour trout production; so too should increased insolation and basic productivity from some removal of bankside vegetation. The change in population densities is so low as to be of questionable significance, but it may reflect some diminution in underwater cover formerly provided by generally deeper water, numerous small pools and deeper pockets now partially filled with gravel.

Kanid'ev (1968) found that given time - 5-10 or more years - salmon rivers of Sakhalin recovered from the effects of bad forest practice.

A review of literature on effects of forest harvesting practices on salmonid streams is provided by McLeod (1972) in Chapter 6 of the "Position paper on the inland fisheries of New Brunswick" prepared by Halifax personnel of the Fisheries Service, Department of Environment. The account of Research Board observations on the Northwest Miramichi shows that there is need for development of new forest harvesting practices to provide better protection of stream environments.

Chemical changes in stream environments

This section deals only with use of chemical pesticides and fertilizers. Changes in natural chemistry of streams resulting from forest cutting are covered in McLeod's review (see paragraph above).

Wide use of fertilizers could provide some enrichment of stream waters. Since most New Brunswick streams are low in minerals, as shown by measurements of electrical conductivity (e.g., Elson, 1967, Table 1) such additions, though possibly not very consequential in total amount, seem more likely to be advantageous than adverse. Situations such as reported by Smith (1959) for Prince Edward Island streams in heavily fertilized agricultural areas do not seem likely to arise in most forested New Brunswick streams. Nevertheless, should such practice develop, studies of possible changes from altered water quality in run-off and ground seepage should be inaugurated.

Of more concern are the side effects of pesticide application to control unwanted vegetation (herbicides) and insects (insecticides).

Herbicides have not in the past posed any reported serious problems for salmonids. Should such chemicals be widely spread over forests, however, they are bound to find their way into aquatic ecosystems. Study of their possible impact should be undertaken in advance of large scale application. In general, herbicides like 2,4-D and 2,4,5-T appear to be much less toxic than many insecticides. However, impurities associated with 2,4,5-T (e.g., TCDD, limited by registration in Canada to less than 0.5 ppm in 2,4,5-T) can have very high toxicity. They are also reported to have mutagenic effects by reason of intercalation with DNA (Hussain et al., 1972).

Insecticides, especially such persistent types as DDT, have already been shown to drastically reduce fish production. In the late fifties and early sixties New Brunswick salmon angling suffered severe depression as a result of earlier widespread DDT spraying of forests (Elson and Kerswill, 1964;1966). How such pesticides function in depressing both fish and their food has been thoroughly documented (Kerswill; Kerswill and Edwards; Elson; Ide; Kennleyside; and Grant - all in 1967). Keenleyside (1959) showed that not only young salmon but all resident fish were greatly reduced in number.

Although DDT has not been used since 1967 it is still present in aquatic ecosystems, and still apparently capable of exerting some sublethal and subacute effects, as reported under the section on lake-dwelling fish. Most of the work reviewed by Anderson (1971) was done on salmon or trout. Sprague et al. (1971) show total DDT-and-derivative residues of up to 1.8 ppm 1 year after spraying, up to 0.5 ppm in fish which were spawned 6 to 9 years after spraying. Although no DDT has been applied to Miramichi forests since 1967, 2- and 3-year-old parr collected in Miramichi headwaters in 1971 had 0.51 to 0.65 ppm of DDT and metabolite residues and those collected in lower reaches had 0.64 to 0.72 ppm. These residues are mostly DDE. The effects of DDE are not known and thus the physiological significance of these small amounts of DDT and metabolites cannot be stated.

Moreover, the effects may well be additive with other chlorinated hydrocarbon residues such as polychlorinated biphenyls (PCB) - found at levels of 1.20 ppm in headwater parr and 0.45 ppm in parr from lower reaches of the Miramichi in 1971.

Physiological effects of PCB are not fully understood. They accumulate in the biomass and act by inducing mitochondrial enzymes and by causing fatty degeneration of the liver. The acute toxicity of PCB to salmon is lower than that of DDT (Zitko, 1970), but the threshold levels for chronic PCB effects are not known. They may increase the stress load already present in young Miramichi salmon from subacute levels of DDT and metabolites.

Anderson and Elson (1971) have shown that subacute poisoning of smolts by DDT is followed by only 60% as many returning adults as from similarly treated smolts not exposed to DDT. In their experiment a sample of DDT-treated fish had DDT-residue contents of 0.9 to 2.8 ppm, but most of a control sample had about 0.3 ppm. These controls thus mostly had residue content comparable to fish reported by Sprague et al. (1971) from streams which had not been sprayed for up to 9 years. The 1971 parr collections had residues intermediate (0.6 ppm) between most of the Anderson-Elson controls (0.3 ppm) and their experimental fish (average 1.6 ppm). Threshold values for effects of DDT residue on viability of smolts are not known. But it is not impossible that stress imposed by these residues has contributed in some degree to recent low levels in New Brunswick salmon populations.

It may be of interest to note that the DDT residue is much reduced in fish which grow to large size at sea.

Fish	Average residue of p,p'-DDE (ppm)
Smolts treated with subacute DDT before liberation (whole fish - 12/lb)	0.68
Fish of same lot taken in Greenland (muscle tissue, approx. 7-lb fish)	0.02
2-sea-year fish of same group taken at Curventon (muscle tissue, approx. 10-lb fish)	0.07
Native grilse taken at Curventon (muscle tissue, approx. 3-lb fish)	0.22

Future forestry practice should take into account that any new stresses placed on populations of young salmon may be added to those still present from DDT residues in the ecosystem.

Fenitrothion, an organophosphate insecticide, has replaced DDT in forest spraying operations beginning in 1968. In comparison to DDT it is non-persistent. Moreover, its lethality to young salmon is comparatively low - 24-hr LC50 = 7.4 ppm (Wildish et al., 1971). Wildish has calculated that the content in stream water immediately after a single application at the usual 2 oz/acre forest spraying operation would be about 0.045 ppm.

Field observations on changes in aquatic invertebrate and fish fauna after operational spraying with fenitrothion are somewhat difficult to interpret.

Hatfield (1969) observed a few dead salmon fry in fyke nets set in a stream sprayed with Sumithion (2 oz/acre applied twice) a few days after spraying, but none in fyke nets in control streams.

One thing seems to be clear - excepting only Hatfield's report, no evidence of acute toxicity to fish has been reported. On the other hand there are rather puzzling data to indicate that local stream populations of salmon and trout may be substantially depressed in the autumn following spraying or after several successive years of spraying (see account by J.W. Saunders, below). Whether this is a direct toxic effect or an indirect effect of food reduction is not clear.

Penney (1971) has summarized a number of studies on side effects of fenitrothion on fish. He himself found in 1971 that on a very small, single-stem brook the average biomass of aquatic insects was not reduced following double application of fenitrothion once at 3 oz/acre plus once at 2 oz/acre, each application made in a single day. However, in another study stream having a large, multi-branched watershed requiring 3 consecutive days for each coverage, two applications of 2 oz/acre were followed by a 27% reduction in biomass of aquatic insects. He found that stoneflies, but not caddisflies, mayflies and Diptera accounted for most of the reduction. On the other hand, studies in Maine, quoted by Penney, indicated a reduction in Chironomid populations after application of fenitrothion. In Newfoundland aquatic insects were found to be reduced in one year but not in another. In some New Brunswick studies Penney reports that reduction of aquatic insect biomass followed experimental fenitrothion spraying in 1966 and 1967 but none was observed following operational spraying in 1968, 1969 and 1970. The above observations pertain to single season studies on different brooks each year.

The Fisheries Research Board, St. Andrews, N.B. Station, has been studying environmental parameters in relation to salmon and trout production on Trout Brook, a tributary of the Northwest Miramichi, and on Nashwaaksis Stream, tributary to the Saint John, since 1966. Operational forest spraying has been one of these parameters. An account of these unpublished studies follows. It was prepared by the scientist-in-charge, J.W. Saunders.

Ecological studies in Trout Brook (Miramichi) and Nashwaaksis (Saint John)

Background

Ecological studies were begun in 1966 in Trout Brook, tributary to the Northwest Miramichi, and Nashwaaksis Stream, in the Saint John system. The Nashwaaksis is the representative basin of the New Brunswick Sub-committee of the International Hydrological Decade (IHD). The objective of the study is: to determine salmon and trout production in small streams, tributary to large salmon rivers, or from a practical viewpoint, to explore methods whereby salmon and trout production in such streams can be increased.

The Fish and Wildlife Branch, New Brunswick Department of Natural Resources, has provided assistance to the program in the way of a counting fence on Trout Brook, field laboratories, and funds for casual labour and student assistance. Forest Protection Limited provided two students in 1971 and will provide similar assistance in 1972.

This report deals with the impact of operational forest spraying on the flora and fauna of small streams; emphasis is on observations made in Trout Brook.

Spray history

Nashwaaksis Stream was sprayed with DDT from 1963 through 1966, and with fenitrothion (2 oz. fenitrothion/ 0.15 U.S. gal/acre) from 1969 through 1971. Trout Brook basin received DDT in 1956 and 1957 (prior to the present investigation). DDT, with a Phosphamidon safety zone along the stream, was applied in 1966. The brook was not sprayed in 1967-68. Fenitrothion was applied from 1969 through 1971.

Aquatic flora and fauna

Phytoplankton

To determine possible effects of fenitrothion on algal communities, pre- and post-spray collections were made in Trout Brook in 1969 and 1970, both fenitrothion years. In 1969 an unsprayed nearby stream was used as a control.

The flora on the plastic collectors set in the stream in advance consisted almost entirely of diatoms;

35 species representing 13 genera in both streams. Although there were differences in community types between the two streams, the differences could not be attributed to fenitrothion.

Macroinvertebrates

Bottom invertebrates were sampled every 2 weeks in summer at 17 stations in Trout Brook and 12 in Nashwaaksis by means of a surber-type ft^2 sampler; additional samples were taken in spray years. Collections were also made on artificial substrate samplers in both streams. As a further check on pre- and post-spray populations of invertebrates in 1969 through 1971, counts were made of the insects on similar stones in selected areas.

The dominant orders of aquatic invertebrates in both streams were: stoneflies (Plecoptera), mayflies (Ephemeroptera), caddisflies (Trichoptera), and midge and blackfly larvae (Diptera). Others taken by one or both methods of sampling were: Coleoptera, Megaloptera, Odonata, miscellaneous Diptera (mainly Tipulidae), Gastropoda (largely snails and a few limpets), and annelida (Oligochaeta and Hirudinea). At times water mites (Hydrocarina) were abundant in Trout Brook.

In 1966 when Nashwaaksis was sprayed with DDT and Trout Brook with DDT and Phosphamidon, Diptera (largely tendipedid larvae) was the dominant order (50%) in the bottom fauna of Trout Brook; the other major component was Hydrocarina (30%). In the same year in Nashwaaksis mayflies were the dominant group (43%); Diptera were scarce (13%). Densities of mayflies, caddisflies, and Diptera increased in both streams in 1967 (no spray) but stoneflies were slow to recover in Trout Brook and remained at relatively low levels through 1971; they never reached the 1966 level in Nashwaaksis. Large numbers of mayflies and Diptera in both streams in 1967 probably resulted, in part, from the relative scarcity of predators (stoneflies).

The fluctuations observed among the bottom fauna in both streams were somewhat similar to those observed by Ide (1967) among imagines taken in cages; reduction in number of individuals of most groups immediately after spraying (DDT) followed by an increase in 2 or 3 years after spraying, then a decrease in numbers.

In the week following the application of fenitrothion on Trout Brook in 1969, the numbers of all organisms in the

Surber collections fell markedly (two-thirds) from pre-spray levels. Percentage declines among the 4 major orders ranged from 28 (Plecoptera) to 50 (Trichoptera). With the exception of Diptera, post-spray reductions were more severe on artificial substrate samplers; Ephemeroptera 67%, Plecoptera and Trichoptera 71%. Plecoptera and Diptera showed some post-spray recovery in early July and then decreased.

Following fenitrothion spraying on Nashwaaksis in 1969 there was no evidence of severe post-spray mortalities among invertebrate populations, but numbers were consistently below Trout Brook levels throughout the summer.

After spraying in 1970 and 1971 population densities of stream invertebrates in both streams, during the normally productive summer months, were below the record lows established in 1966 following DDT spraying.

The severe immediate post-spray mortalities among the aquatic stages of insects observed in 1969 probably resulted from differences in spray application in that year. A block across the upper stream was sprayed in the evening and a block immediately down stream was sprayed early the next morning. This could have resulted in a fairly heavy concentration of spray in the stream.

Fish populations and behaviour

Fish were counted into and out of Trout Brook at a 2-way counting fence near the mouth of the stream. In spray years pre- and post-spray movements within the stream were studied with fyke (hoop) nets. Population estimates (electrofishing) were made each August in Trout Brook and Nashwaaksis Stream.

Adult salmon entering Trout Brook in autumn have been, with few exceptions, male grilse. Large females from the Curventon counting fence and the Millbank estuarial trap have been relocated in Trout Brook to mate with the grilse.

Standing crops of juvenile salmonids in Trout Brook varied between years. Numbers of trout and salmon per 100 yd^2 for the different years are given in Table 1.

Table 1. Indices (number per 100 yd^2) of trout and juvenile salmon in Trout Brook in summer.

	1966	1967	1968	1969	1970	1971
Trout fry (age 0)	1.73	3.32	0.43	2.00	0.75	0.36
Over 15 cm (2+ and older)	0.37	0.25	0.27	0.65	0.30	0.38
Salmon fry (underyearlings)	1.29	12.10	6.48	8.05	1.37	0.76
Parr	6.03	2.81	5.61	6.29	5.00	2.28

Salmonids and other stream species exposed to DDT in late spring of 1966 suffered heavy mortalities in autumn when water temperatures fell below 5°C. Among salmon, mortalities were largely confined to large (> 10 cm) sexually mature males. Over the range encountered, 11 to 25 cm, size did not appear to be a factor in trout mortalities. The loss of large parr was reflected in the poor (5%) survival of the 1966 parr to smolts in the spring of 1967 (in the 2 non-spray years, 1967 and 1968 survival was 10 and 19%).

Many fish descended into the counting fence at the mouth of Trout Brook in autumn and died there. Captures at the counting fence in October and November, 1966, with number of fish that died at the fence in brackets, are shown in Table 2.

Table 2. Captures at the Trout Brook counting fence in autumn 1966. Dead fish ( ).

	Entering the stream		Leaving the stream	
	Brook trout	Salmon parr	Brook trout	Salmon parr
Oct.	9	Nil	18(2)	38(23)
Nov.	92	Nil	37(16)	130(40)
Total	101		55(18)	168(63)
Mortality (%)			33	38

The low densities of older trout (> 15 cm) in Trout Brook from 1966 through 1968 (Table 1) are probably attributable to the DDT spray in 1966. Stocks of trout fry in 1968 were insufficient to provide good numbers of older trout in 1970; survival of the 1969 trout fry to the stream in 1971 was poor. The record low for fry densities was established in 1971. There has been little production of brook trout in Nashwaaksis since 1966.

As previously noted, stocks of juvenile salmon have been maintained through the introduction of large female spawners into Trout Brook; there are no salmon in Nashwaaksis. There has been little relation between spawners and subsequent underyearling densities in Trout Brook. Number of spawners, potential egg deposition, and resulting underyearlings are given in Table 3.

Table 3. Number of female salmon spawners relocated to Trout Brook, potential egg deposition, and survival to underyearlings.

Year of spawning	No. of females	Potential egg deposition No/100 yd^2	No. of underyearlings next year No/100 yd^2	% survival egg-underyearling
1966	6	57	12.10	21
1967	5	47	6.48	14
1968	17	160	8.05	5

Only in 1968 did egg deposition approach the 200 per 100 square yard suggested by Elson (1957) for the production of underyearlings at a density of 20/100 yd^2. Elson's rates were for larger salmon rivers.

Movements of fish both up and down stream were recorded at the Trout Brook counting fence. From 1966 through 1971 about 1,400 trout were recorded at this fence. Major runs out of the stream are in May, June, and November; trout move into the stream in June, July, and November. Few trout home to Trout Brook after descending into the Northwest Miramichi. Subsequent recaptures by anglers (5-15%) indicate that many of these trout moved up the Northwest where the majority were taken in Crown Reserve waters.

Of interest, because of the possible effects of forest spraying on movements, are the fall movements down out of the stream in autumn. Numbers of trout that descended from Trout Brook in various years are given in Table 4.

Table 4. Number of trout that left Trout Brook in autumn.

	DDT	Unsprayed		Fenitrothion		
Year	1966	1967	1968	1969	1970	1971
No. of trout leaving Trout Brook in autumn	57	17	2	106	101	45

The number of trout that left the brook in autumn was greatest in spray years (1966, DDT; 1969-71, fenitrothion). Movements were not a function of numbers of trout in the stream since there were substantial numbers of trout, within the size range that ran in other years, in the stream in both 1967 and 1968.

Juvenile salmon, ripe male parr, also displayed a tendency to leave the stream in the autumn following spraying. The estimated numbers of parr in the stream in successive summers and the percentage of those that left in the following autumn are given in Table 5.

Table 5. Estimated summer parr populations in Trout Brook and number and percentage that left stream in autumn.

	DDT	Unsprayed		Fenitrothion		
Year	1966	1967	1968	1969	1970	1971
Summer parr population in Trout Brook	6500*	3000	5600	6500	7000	2200
Number that left stream in autumn	130	15	31	448	780	7
% of summer population that left stream	2.0	0.50	0.55	6.89	11.14	0.32

*High mortality of this stock in autumn, 1966, following exposure to DDT in spring

With the exception of salmon parr in 1971, both trout and salmon moved in greater numbers during spray years. The autumn of 1971 was unusual in that water levels remained low and there were few freshets. It is inferred that exposure to the pesticides (although DDT was last used in 1966 it is probably still being recycled in the stream environment) plus stresses induced by low temperatures and high water velocities resulted in downstream movement of fish in autumn.

Of considerable concern is the apparent loss of the salmon parr after they left the brook. All were tagged at the counting fence but, with the exception of a few individuals taken at the Curventon fence in the next spring, none has been recaptured in the sport or commercial fishery.

Aberrant downstream movements were also noted for other stream fish in Trout Brook. The common shiner *(Notropis cornutus* (Mitchill*))* descends into the Northwest in late spring and autumn, the majority usually in late spring. As shown in Table 6 autumn movements were more prominent in the three fenitrothion years. Data for 1966 are not available.

Table 6. Downstream autumn movements of common shiners expressed as percentages of total yearly movements out of Trout Brook.

	Unsprayed		Fenitrothion		
Year	1967	1968	1969	1970	1971
% of fish in total runs each year that left brook in autumn	6	7	35	25	71

Of interest was a downstream movement of 200 shiners and 50 suckers shortly after the spraying in 1971; the movements were associated with a slight (3 inch) rise in the water level. A 5-inch rise before the spraying failed to move fish.

Discussion and summary

Fenitrothion did not have observable effects on phytoplankton in Trout Brook.

There were severe mortalities among the aquatic stages of insects (prominent food items for salmonids) in one year (1969) when the brook was sprayed on two successive days. In the other two years standing crop of aquatic invertebrates was low (30 to 40 organisms per ft^2 compared to 200 in 1967) during the normally productive months following spraying.

Salmonids and other stream species, exposed to DDT in late spring, suffered heavy mortalities in autumn when water temperatures fell below 5°C. Among salmon, mortalities were largely confined to large (fork length greater than 10 cm) sexually mature males.

There was no evidence of immediate post-spray mortalities of fish following spraying with DDT or fenitrothion. Our observations indicate that production of brook trout is at very low levels in both Trout Brook and Nashwaaksis; a contributing factor could be pesticides either acting directly on the fish or indirectly by reducing available food organisms for salmonids.

A forest fire in 1965 removed much of the bankside vegetation from the lower part of Trout Brook. The lack of shade caused high summer temperatures and low water levels. New growth has provided more shade in recent years and, with respect to summer water temperatures and levels, the stream has improved as an environment for salmonids, particularly brook trout. But the improvement in the environment has not resulted in increased salmonid production.

Aberrant downstream movements of stream fish were observed in most spray years. The loss to the stream of parr in autumn is a matter of concern because tagging returns indicate they are lost to both the commercial and sport fisheries. An examination of the 1970 run of autumn parr and the 1971 run of spring smolts gives an idea of the extent of this loss; 780 pre-smolt parr descended in the autumn of 1970, but only 906 smolts ran from the stream in the spring of 1971. The autumn descent of parr thus represented a loss of 45% of the potential smolt run for 1971.

Aside from Saunders' data presented above, evidence of delayed after effects of organophosphate insecticides like fenitrothion is lacking. Zitko et al. (1970) found inhibition of acetylcholinesterase activity in minnow and sucker brains, but no loss in salmon or trout, shortly after forest spraying with fenitrothion. No delayed effects were evident in the physiological system studied up to 5 1/2 months after spraying.

Hatfield and Anderson (1972) used fenitrothion under the trade name Sumithion in studies of vulnerability of young salmon to predation by trout. After exposure to 1.0 ppm for 24 hours the salmon were significantly more vulnerable than their untreated brothers. But Sumithion at 0.1 ppm had no noticeable effect. Even 0.1 ppm is far above the 0.045 ppm postulated by Wildish et al. (1971) as a likely treatment for wild fish in streams (spray at the rate of 2 oz/acre falling on water 1 ft deep). However, as the latter authors point out, it is possible that toxic effects might accumulate as a result of ingesting poisoned insects.

Yule and Duffy (1971) found that about 70% of the fenitrothion present on sampled foliage 1 day after spraying had disappeared by 30-60 days later. But 336 days after application they still found residues amounting to about 10% of the day 1 content. They do not suggest whether these lower amounts are available to foliage-eating insects, or whether they can pass through ecosystems by other food chains during the period when quick lethality to leaf-eaters no longer occurs. The possibility that insect-eating fish could concentrate such residues to their own eventual harm should not be ruled out. The long-term observations reported by Saunders, above, provide a basis for reserving judgement on the long-term harmlessness of fenitrothion.

Effects of secondary industries

The above account is concerned only with the impact of maintenance and harvesting procedures of forest management on fish. Secondary industries such as sawing or processing wood for structural use, and production of pulp can also have heavy impact on fish production and utilization. Bark and sawdust in streams can smother bottom fauna and produce noxious chemical changes in water quality, as well as increasing oxygen demand from the water. Effects of such industries are more or less localized to the dispersion area of wastes and effluents. They may nevertheless be serious. For example, Elson et al. (1970) showed that effluents associated with pulpmills and other urban waste so contaminated the Miramichi estuary as to delay upstream migration of salmon. Keachie (1972) summarized information on how pulp and paper mill effluents damage aquatic ecosystems. Such industries not only produce their own wastes but indirectly increase the load by providing needs for urbanization (more sewage) and transport (more oil spills). A point to be remembered is that any segment of the forest-based industries is an interwoven unit in a much vaster ecosystem.

Discussion

It should be not only possible but feasible and desirable to manage New Brunswick forests, on a long-range basis, to give optimum wood yield while at the same time maintaining associated fishery resources. To quote Professor John D. Hewlett (1964), a specialist in forest hydrology, "A point sometimes overlooked is that good resource management and good water management are often the same, right down to particulars." To the non-professional, inspection of past forest practice in the Maritime region leads to the impression that water resources have received almost no consideration in either short- or long-range planning of forest harvesting procedures. Probably only the fortuitously patchy pattern of past cutting and the fact that many forests of the area are on hard rock-based hills has forestalled more serious ground erosion. In the Maritime region water, except where streams were used for log driving, seems to have been regarded as much as a nuisance as an advantage in forest management. To quote further from Hewlett, "To repeat a basic premise, the success or failure of any program for managing forest and wild land rises or falls with the long-range effect such management has on the water resources." To the fish biologist this seems to imply that a healthy, well managed forest should automatically supply one of the prime prerequisites for good stream and lake production of fish - an ample and balanced supply of water run-off and seepage well distributed throughout the year. To the extent that such principles are accepted, but only to that extent, usable forests and fish should be entirely compatible. Any trend to change from patch cutting to clear cutting of large areas should be accompanied by much more effective planning of associated water conservation than has been practised in the past. To quote once more from Hewlett, "A little careless logging every ten years can keep enough silt and debris moving to ruin a good trout stream, or to require expensive processing before human use." A degree of such careless logging appears to have produced some degeneration in the Northwest Miramichi, as evidenced by the data presented earlier. The damage does not appear to be very severe, but neither has recovery been complete 15 years after the cut.

Finally, it should be remembered that forestry practice can affect ground water supplies and wells many miles away from the actual site of logging operations. It may require long periods of time (months and even years) for ground water to move from the precipitation site to wells where the water is used and perhaps to some stream discharge areas (Tolman, 1937, especially chapters VII to XI).

Good cutting and good road-building practices can assure an ample supply of water reaching streams at all seasons. The quality of that water is also an important consideration. To the extent that modern forestry practice turns to increasing use of chemicals spread over stream basins water quality may be affected. This can happen through the agencies of direct run-off, sub-surface seepage or ground water springs. At the Munich Conference on Water Pollution (1966) one of us (P.F.E.) was told of an incident in which a Swiss forest some 60 miles from a large town was sprayed with insecticide (lindane?) in oil. Some 6 to 8 months later the town water supply, from wells, became distastefully tainted, the off flavour being confidently related to the spray by the senior scientist who commented on the undocumented incident.

Use of non-persistent pesticides on New Brunswick forests should help to minimize any adverse effects of these poisons on fish. But it will be important to maintain constant monitoring of these new environmental parameters if fish production is to be maintained at satisfactory levels.

In summary, to obtain the stated objectives of the New Brunswick Forest Resources Study, good forest management must become good wild land natural resource management with much consideration given to conservation of fresh water in respect to both quantity and quality.

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