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The first three of the above papers were presented at a symposium on "The Effects of Chemical Control of Forest Insects on Fish Stocks," held by the Committee on Biological Investigations of the Fisheries Research Board of Canada in Ottawa, January, 1958. A fourth paper submitted, "Effects of Spruce Budworm Control on Stream Insects in New Brunswick," by Dr. F. P. Ide, Department of Zoology, University of Toronto, was published in the Transactions of the American Fisheries Society, Vol. 86, 1956, pp. 208-219.

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Minister of Fisheries

Aerial Chemical Control of Forest Insects with Reference to the Canadian Situation

by

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The Forest Insect Problem

The value of the Canadian forestry resource is no more impressive than are the problems of protecting it. Of the various factors responsible for forest losses other than man, none exerts a more consistent drain on timber inventories than insect damage (5). A generalization about Canadian forests is that they are chiefly of the Boreal type. This means that huge areas are covered by relatively uniform stands, often of the same age-class, comprised of relatively few tree species and usually dominated by one or two of the conifers (7). This type is uniquely valuable as a source of pulp and paper, but is a relatively unstable ecological association and successional changes are commonly sudden and violent. On the other hand, the cataclysmic natural events that have played a part for centuries in the periodic replacement of successive crops—chiefly fire, blowdown, and insect outbreaks—generally tend to perpetuate the kind of forest that they ravage. Aspen, pine, and spruce are typical post-fire types; in eastern Canada conditions for the reproduction and growth of the ubiquitous balsam fir are never better than following the destruction of mature stands of the same species by the spruce budworm (6). These natural catastrophes played a dynamic role in succession before man began to exploit the forest but only since the rapid development of the Pulp and Paper Industry, with its full use of the forest growth, have they become serious economic problems.

Some of the current problems with native insects arise partly from man's interference. Selective cutting of certain species or vigour classes may create a condition of higher susceptibility to insect and disease attack in the residual crop. From the point of view of the forest manager and the silviculturist, clear-cutting for pulpwood is often sound practice, yet it is the opinion of some that this is encouraging a higher proportion of balsam fir reproduction and intensifying the threat from the spruce budworm (16). The presence of large quantities of logging slash and logging injuries to residual trees sometimes increase the incidence of bark beetle and borer attack in surrounding uncut stands. Equally serious, numbers of foreign insects have been introduced over the years and some of these now pose major problems.* In short, insect problems and the need for protection have tended to increase rapidly with increased accessibility and exploitation of our forests (13, 14).

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The Place of Aerial Spraying in Forest Insect Control

Most forest entomologists subscribe to the philosophy that the ideal in forest insect control is prevention rather than cure. The creation of resistant forests, however, takes time and can only keep pace with the development of forest management. It must be based on intensive ecological research translated into practical economic silviculture. Such research is being undertaken and forest management is becoming more intensive but the completely resistant forest is likely to remain an ideal, at least for many years to come (2).

Biological control by the manipulation of parasites, predators, or disease organisms has been successful in some cases of introduced pests. The possibilities of their use against such native pests as the spruce budworm have been and are still being studied, but as yet without positive results.

Meanwhile direct measures must be applied if severe outbreaks are to be prevented from seriously reducing the supply of raw material of the forest industries and at the same time disrupting management plans on which sustained yield and the ultimate production of more resistant forests depend. If, for instance, the spruce budworm kills large areas of forest, the succeeding stand will be even-aged and of high balsam content—difficult to manage for sustained yield, and highly susceptible to future outbreaks (12).

The discovery of DDT and the development of aerial methods of application have made the use of insecticides against a number of forest insects practicable. This, combined with the increasing importance of the full use of our forest growth, explains the number of large-scale operations since the second World War (3).

Forest entomologists are fully aware of certain limitations and possible dangers in chemical methods of control. They have always been concerned with the population dynamics involved and have sought the aid of other workers in attempts to determine effects on fish and wildlife. However, when spraying presents the only means of protecting a forest from serious loss it becomes necessary to use it (1). At the same time this does not imply prolonged or continuous use of insecticides analogous to agricultural practices. In forestry it is not necessary to maintain insect populations at as low levels as in agriculture and large-scale use of aerial spraying in Canada has been limited to the prevention of tree mortality. These operations are being studied as closely as possible to determine their long-term effects on the population dynamics of the pest and associated insects (18).

Aerial spraying operations may range in size from a few hundred acres as in the case of plots, or plantations, to several thousands of square miles as against the spruce budworm. In most cases they involve defoliating insects for which dosages of 1 lb. DDT/acre or less have become more or less standard. Important adverse effects against other forms of life have seldom been reported from small operations using dosages of this order, and recovery is generally rapid (4, 15). Serious effects are more likely from blanket coverage of extensive areas, particularly when treatment is repeated. For purposes of the present discussion, therefore, it will suffice to consider only the larger type of operations involving extensive forest areas. These are listed for Canada to date in Table 1. Since the spruce budworm has been far and away the most serious problem to date in Canada and because of my own experience with it, I propose in the following sections to refer in particular to the recent large-scale operations in eastern Canada.

Table 1

History of Large-Scale Forest Spraying Operations in Canada. DDT-Oil Formulations Used in All Cases

Insect	Year	Province	Dose: DDT	Acres	Sq. mi.
Western hemlock looper	1946	B.C.	1 lb./acre	12,000	19
False hemlock looper	1948	B.C.	1 lb./acre	11,000	17
Black-headed budworm	1957	B.C.	1 lb./acre	156,000	240
Spruce budworm	1945	Ont.	1 lb./acre	64,000	100
	1946	Ont.	2 lb./acre	29,000	45
	1952	N.B.	1 lb./acre	186,000	290
	1953	N.B.	*½ lb./acre	1,800,000	2,800
	1954	N.B. and Que.	"	1,500,000	2,300
	1955	N.B. and Que.	"	2,200,000	3,400
	1956	N.B. and Que.	"	2,400,000	3,750
	1957	N.B. and Que.	"	6,500,000	10,200

*Approximately 25 per cent of 1953 area treated twice.

Aerial Spraying with Particular Reference to the Spruce Budworm

History of Outbreaks

Evidence can be found in forests of northeastern North America of outbreaks dating back over 150 years. Intervals between them have varied from about 70 years in northwestern Ontario to 35-40 years in New Brunswick. Severe infestations have been reported somewhere in eastern Canada practically every year for at least the last 40 years and an estimate has been made that between 1909 and 1946 outbreaks had killed some 250 million cords of balsam fir and spruce (5). Particularly widespread and severe outbreaks occurred between about 1909 and 1920 and from the late 1930's until the present time. In both these periods the outbreaks have shown a tendency to shift from west to east, beginning in northern Ontario and ending in the Atlantic regions of New Brunswick, Nova Scotia, and the Lower St. Lawrence-Gaspé regions of Quebec. At the present time outbreaks are at a relatively low ebb over much of Ontario and Quebec north of the St. Lawrence and are most severe in the Atlantic Maritime region. At the same time, however, trees are still dying from the attacks of the last 10 to 15 years over thousands of square miles in Ontario and Quebec and persistent pockets of infestation still occur in western Ontario that have been under more or less continuous attack for 15 years or longer.[1]

In New Brunswick the current outbreak first became severe in 1949 and some idea of the rate of spread is shown in Table 2. It is also illustrated in Figures 1-3 showing the areas involved in three representative years, 1952, 1954, and 1957 respectively. It

[1]*Annual Reports, Forest Insect Survey, Forest Biology Division, Science Service, Canada, Dept. of Agriculture,* 1937 et seq.

Table 2

Areas of Severe Attack by Spruce Budworm in New Brunswick and Areas Treated by Aerial Spraying

Year	Areas—sq. mi.		% severely attacked area sprayed
	Severe attack	Sprayed	
1949	200	0	—
1950	400	0	—
1951	2,200	0	—
1952	5,000	300	6%
1953	11,000	2,800	25
1954	13,000	1,800	14
1955	13,000	1,800	14
1956	16,000	3,100	19
1957	20,000	8,100	40
1958	?	(3,900?)	

Percentage of N.B. areas sprayed once: 13.7
twice: 55.5
three times: 28.3
four times: 2.5

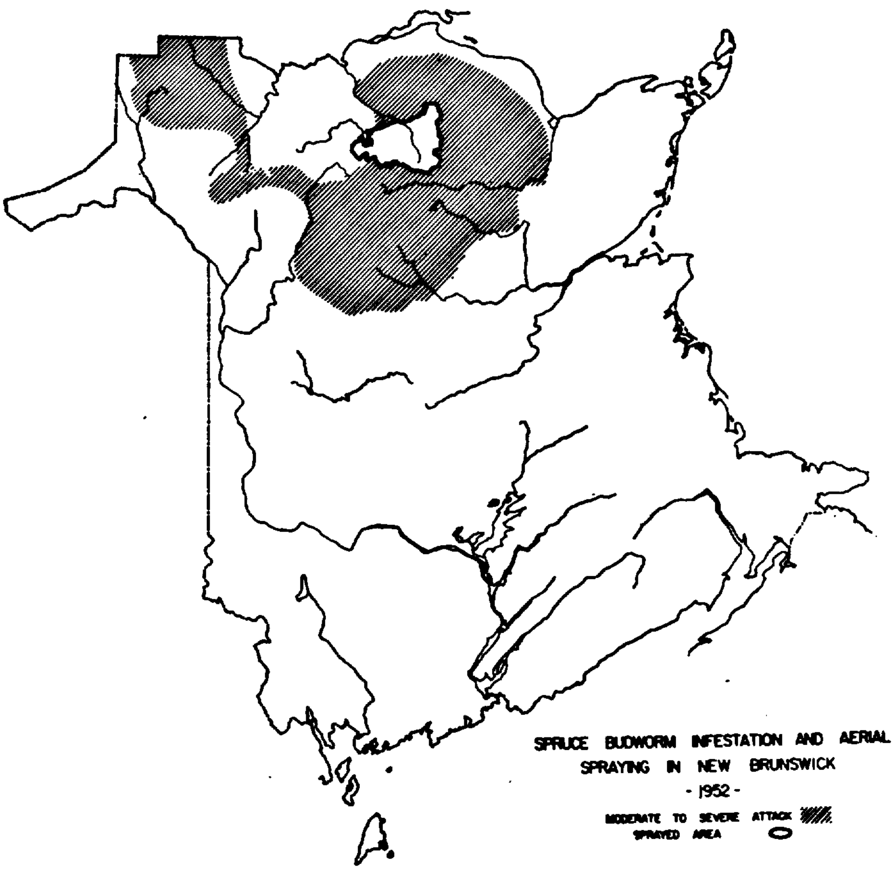

FIGURE 1

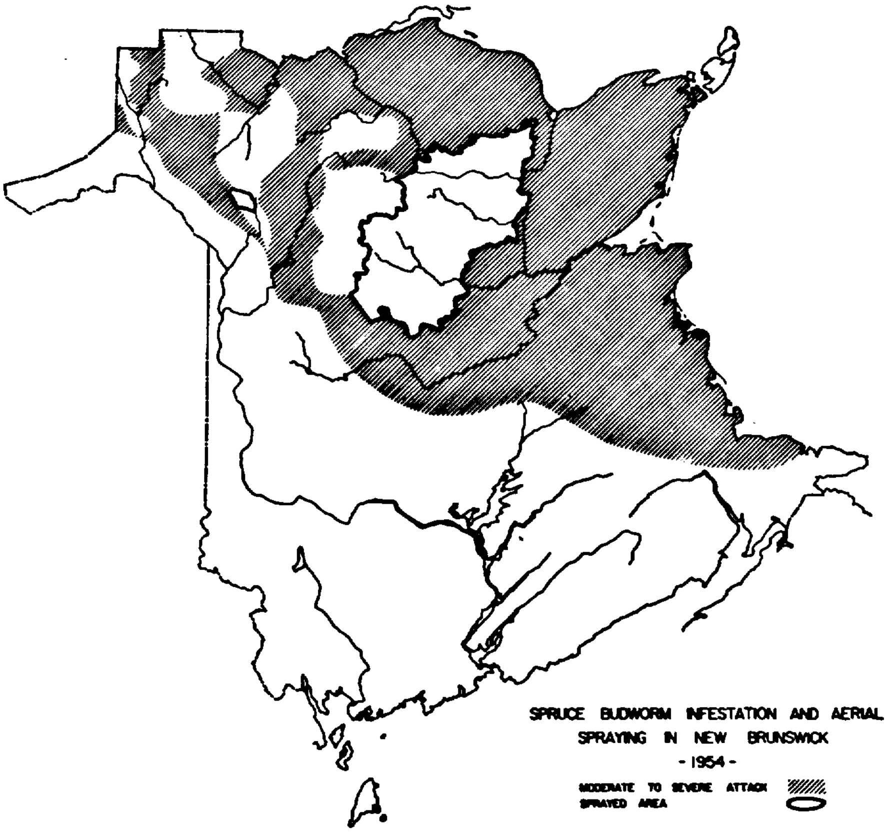

FIGURE 2

should be pointed out that the table and maps refer only to areas of severe attack and that there were also large areas of lighter attack in each of these years.

Brief History of the Aerial Method

The spruce budworm was not the first forest insect to be treated from the air, but it is of interest that 1957 was the 30th anniversary of the first spruce budworm aerial control project ever attempted. That was in Nova Scotia in 1927. The conclusion reached in those early years was that while dusting was a useful method against insects such as hemlock looper, it was not likely to be highly successful against the budworm until better insecticides and equipment were developed. The advent of DDT oil sprays during the War answered many of the problems and a good deal of work was done in the immediate post-war years in both Canada and the United States to develop suitable application equipment and techniques. In 1949, the first of a series of large-scale annual operations against the spruce budworm was carried out in the Douglas fir regions of Oregon and Washington and by 1955 these totalled nearly 4 million acres. Operations on a similar scale have been underway since 1953 in the Rocky Mountain regions from New Mexico to Idaho and Montana. The history of large-scale Canadian operations as summarized in Table 1 gives some idea of the relative importance of the spruce budworm problem as compared to other defoliators. The first budworm

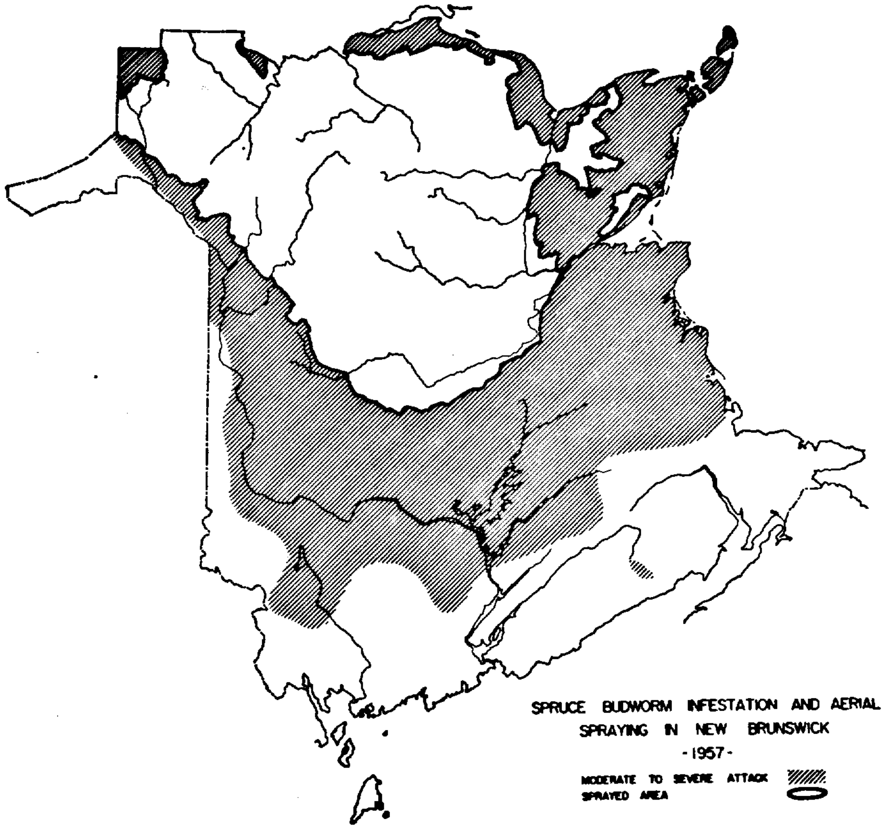

FIGURE 3

operations, totalling some 93,000 acres, were carried out in 1945 and 1946 in the Lake Nipigon area of Ontario (10). The largest operations of all, however, have been underway since 1952 in New Brunswick and since 1954 in adjacent areas of Quebec. These now total about 14.5 million acres including respraying. This is an acreage in excess of the land area of several European countries including Switzerland. All the more remarkable is the fact that nearly half this was sprayed in a single year, 1957—nearly 6.5 million acres in the two provinces. New Brunswick's share alone amounted to 5.2 million acres.

Organization and Direction of New Brunswick-Quebec Operations

The organization and direction of the New Brunswick operations is the responsibility of a provincial Crown Company, Forest Protection Ltd. Mr. B. W. Flieger is the Manager. Shares in the Company are held by the four leading pulp and paper Companies in the province and by the New Brunswick Department of Lands and Mines. Costs are shared equally by Canada, New Brunswick, and industry. The Division of Forest Biology has been closely associated with the project since its beginning and is responsible for various aspects of technical advice and assistance. These include timing the spraying, assessing immediate results, and estimating hazard from surveys of infestation and defoliation. A programme of long-term investigation is also under way to discover and evaluate ultimate effects on the epidemiology of the budworm and on the growth and survival of the forest (18).[1]

Quebec operations are carried out by Quebec Forest Industries Assn. representing landowners and leaseholders. Costs are shared equally between industry and the province. The operations in the two provinces are closely integrated. The same aerial fleet is employed for both jobs using identical timing, dosage, and techniques of application. A programme of assessment and investigation similar to that in New Brunswick is carried out by the Quebec Laboratory of this Division.

Spraying Policy

The stage of an outbreak at which spraying is undertaken will vary according to the objectives. Some of the operations carried out in recent years against gypsy moth in the United States have treated very light infestations with the objective of limiting the spread of this new insect beyond an established barrier zone. These and some other examples are often referred to as "eradication programmes"—usually with dubious justification in the light of experience. Fortunately the gypsy moth is not important in Canada and there is yet no comparable problem from the foreign pests that do occur.

The idea of spraying incipient outbreaks of native pests to prevent their rise and spread is an interesting possibility that deserves to be tested but it involves some difficult practical problems. The foci of outbreaks are not easily detected early in their development in forests the size of Canada's and are often very large in themselves. It will seldom, if ever, be possible to organize a large spraying operation against the same insect generation in which the outbreak is detected and difficult problems are involved in mapping the extent of spread of the next generation when this must be based on extended surveys of eggs or other minute immature forms. In addition, effective control at relatively low populations is likely to call for larger dosages than the minimum required against heavy infestations of defoliators owing to the greater concealment of larvae in the denser foliage of undamaged trees.

The alternative to early spraying to control outbreak trends is to delay treatment until it is necessary to prevent tree damage. In dealing with the operations listed for Canada in Table 1 a consistent policy has been followed of recommending spraying only when a further year's defoliation would seriously threaten the life of trees. This is a conservative policy that avoids the uncertainties of spraying incipient outbreaks and gives natural control factors the best opportunity to exert a regulating effect before resorting to applied measures. However, it calls for a degree of judgement and a good knowledge of the ability of trees to withstand attack.

Techniques and Procedures

FORMULATIONS AND DOSAGE: DDT is the most commonly-used insecticide again forest insects and has been used on all the large-scale aerial operations in Canada. This is because of its low cost and high toxicity, particularly against free-living defoliators. Its chief effect is as a contact poison but this is reinforced by

[1]*Annual Summary Reports on these operations have been published in the following issues of the Bi-Monthly Progress Rept., Div. For. Biol., Dept. Agric. Canada. New Brunswick: 8(4); 10(1); 11(1); 12(2); 13(3). Quebec: 11(1); 12(1); 13(3).*

stomach and residual poisoning. The most commonly-recommended dosage against forest defoliators in North America is 1 lb. DDT per acre, usually in one U.S. gallon of oil solvent. Only once in Canada has this been exceeded on a large scale—in northwestern Ontario in 1946 (10). It was used in the first New Brunswick operation of 1952. Since 1953, however, practically all the New Brunswick-Quebec spraying has been done at half this dosage by doubling the average distance between adjacent flights of the spray planes. With good timing and with some drift it has been found to give results nearly as good as the heavier dosage, especially when applied against conditions of very heavy infestation. In effect it has permitted the treatment of nearly double the area at the same cost and using the same aerial fleet and facilities. These advantages are considered adequate to make up for the somewhat lower average percentage of control that is obtained and for the slightly less uniform coverage that is inevitable.

A limited amount of the New Brunswick spraying has involved two applications at the ½-lb. dosage two to three weeks apart. The earlier application provides good foliage protection while a high percentage of kill is ensured by the later spraying. This technique is considered more effective than the single application at the 1-lb. dosage and is the safest way of ensuring good results in cases of extreme hazard or where the values at stake are particularly high.

SPRAY EQUIPMENT AND CALIBRATION: The most widely-used dispersal apparatus is the boom and nozzle type, fed under pressure from a tank in the airplane fuselage. The pressure and the nozzles are adjusted to give the appropriate rate of flow and the proper range of droplet sizes. The optimum droplet size is the minimum that will reach the trees before evaporation. Too-fine sprays drift excessively and reduce the average deposit. Coarse sprays are wasteful, give poorer coverage, and may be more hazardous to aquatic life.

FLYING PROCEDURE AND SPRAY COVERAGE: A wide variety of aircraft types have been used from the smallest single-engined planes to multi-engined transports and converted bombers. A helicopter was used for the 1948 operation against false hemlock looper in British Columbia but their use has not otherwise been common owing to excessive cost. Light conventional aircraft are generally preferred owing to their relatively low cost of operation, greater manoeuverability at low levels and their availability. The most widely-used type is the Stearman bi-plane converted from the World War II elementary trainer. It has been used exclusively in New Brunswick and Quebec except for one de Havilland Beaver used in 1952. The aerial fleet has varied from 20 planes in 1952 to 200 in 1957.

The procedure in most aerial spraying is to fly as close to the ground as is commensurate with safety and the problems of navigation. Forest spraying is commonly carried out at about 50 to 250 feet with the smaller airplane types depending mostly on topography. Pilots are assigned individual spray blocks of an average size of about 5,000 acres and coverage may be obtained by flying adjacent swaths from end to end over flat terrain or by "contouring" on slopes. In New Brunswick, the practice has been adopted of flying planes in pairs rather than singly. This has advantages in safety, simplifies the problems of supervision and control, and improves the chances of obtaining uniform coverage.

Good coverage depends largely on the skill of the pilot in low-level navigation. With the most precise flying possible, however, uniform coverage would be unlikely without drift. For that reason low wind velocities are often considered advantageous and experienced pilots are skilled in allowing for and taking advantage of drift. Experience has shown the necessity of isolating unsprayed check plots by at least one and preferably more miles from the nearest spray boundary and of spraying around such areas only with favourable winds. Although pilots are instructed to shut off the spray over open water, this seldom prevents some of the spray from entering streams and lakes. Water courses are some of the most easily-recognized topographical features and they very frequently form boundaries between spray blocks. For this reason coverage along some streams may average heavier than within the blocks.

TIMING APPLICATIONS: A good deal of the success of aerial spraying depends on the timing of applications. The objectives can be twofold: to achieve the maximum possible reduction of the insect population and to prevent defoliation. The first objective is best achieved by spraying when most of the feeding is completed and larval exposure is at a maximum; the second calls for early spraying, usually with some sacrifice of percentage of kill. The policy in New Brunswick and Quebec has been to achieve the best compromise by bracketing the optimum period as effectively as possible (17). With the spruce budworm this involves a period of about two weeks in a specific locality. Phenological differences within the areas under treatment vary as much as three weeks and advantage is taken of this to commence spraying in the more advanced southern areas and to shift operations farther north as conditions permit (19).

More precise timing than that described here for the spruce budworm would be difficult to put into practice owing to the uncertainties of weather and the exigencies of large-scale operations. However, where more leeway may be possible, as in small operations or against other pests, consideration should be given to the possibilities of adjusting timing to reduce adverse effects against parasites and predators and other forms of life that may be particularly vulnerable during some part of the spraying period (2).

ASSESSING RESULTS AND EVALUATING HAZARD: In most operations spray coverage is checked on the ground by means of test cards or plates that are set out to sample the deposit in representative locations. This technique was used in New Brunswick and Quebec in the first one or two years and it showed that good coverage of lethal deposits could be obtained over all types of terrain by good flying aided by drift. In the very large programmes that have followed, however, it has been necessary to place greater reliance on close aerial supervision of the spraying by inspection pilots. These men are experienced forest sprayers and they are also responsible for pre-flight briefing of spray pilots, and for judging the suitability of spraying weather. Ground assessment is still carried out on biological study areas and some use is being made of evidence of spray burn on hardwood and herbaceous foliage for extended spot checks.

Assessment of immediate biological results are necessary each year as a check on the efficacy of the toxicant and the effects of timing, weather, and techniques of application. Special problems are encountered in evaluating results and assessing hazard over very large areas such as those involved in New Brunswick and this has called for the development of suitable surveying and sampling methods. Aerial surveys have been used extensively every year to compare sprayed and unsprayed areas and to determine the boundaries of light, moderate, and severe attack throughout the Province. Large-scale ground surveys have been developed for two main purposes: (1) to measure immediate results of the spraying by comparing defoliation and post-spray budworm survival in sprayed and unsprayed areas, and (2) to measure egg populations of the next generation and combine this with the estimates of defoliation and damage for the purpose of gauging hazard. In both cases a system of sequential sampling has been developed that ensures the greatest economy of counting effort and takes the best advantage of limited time and staff.

Studies of ultimate results are a long-term proposition that should preferably consider the whole ecosystem and the New Brunswick-Quebec operations provide a unique opportunity to undertake such studies. In view of the aggressiveness of this insect and the huge areas of susceptible forest this is probably the severest test of chemical control that has ever been made. Intensive studies of the epidemiology of this insect and the possibilities of reducing its threat by forest management were already well underway in New Brunswick when spraying began, and these studies provided the best possible basis upon which to extend the investigation to the effects of spraying (12). Comparisons are being made of population trends in sprayed and unsprayed areas and these are being related to measurements of regulating factors. The effects of spraying on the growth and survival of the trees are under study and this is contributing annually to our knowledge of the ability of different host species to sustain attack. Extended observations are made each year for the purpose of detecting any unusual occurrence of other pests and gross measurements are being made of the effects of spraying on other insects—both terrestrial and aquatic.

Results

It is convenient to discuss results in terms of (1) insect populations including the pest and associated beneficial or destructive species; (2) the forest stand; and (3) fish and wildlife. A sound evaluation of all these effects is essential for an intelligent and balanced appraisal of the economic and biological values of forest spraying.

EFFECTS ON THE PEST AND ASSOCIATED INSECT POPULATIONS: Reports on the results of DDT applications against forest defoliators consistently show tremendous immediate reductions of most of the insects that are exposed at the time of spraying. Assessments of over 99 per cent control of the spruce budworm were obtained in 1952 in New Brunswick at the 1-lb. dose, and since 1953 at the $\frac{1}{2}$-lb. dose reductions have averaged between 80 and 100 per cent as compared with unsprayed checks. Results that compare favorably to these have been reported from the United States against this insect and from British Columbia against hemlock looper, and more recently, against black-headed budworm.

Results against the pest may also be judged by comparing sprayed and unsprayed populations in the next generation. In New Brunswick and Quebec rapid reinfestation of sprayed areas is a particularly troublesome aspect of the problem. It results not only from a resurgence of residual populations but also from large-scale reinvasions of moths from surrounding unsprayed areas. It is for this reason that most of the areas involved so far have been sprayed twice and some areas three and four times (Table 2, Figure 4).

Parasites and predators of the pest that are vulnerable at the time of spraying are often much reduced. Some of the more important parasites of the spruce budworm do not seem to be affected as severely as the host, however, and proportionately heavier parasitism in sprayed areas has been reported from both the United States and Canada

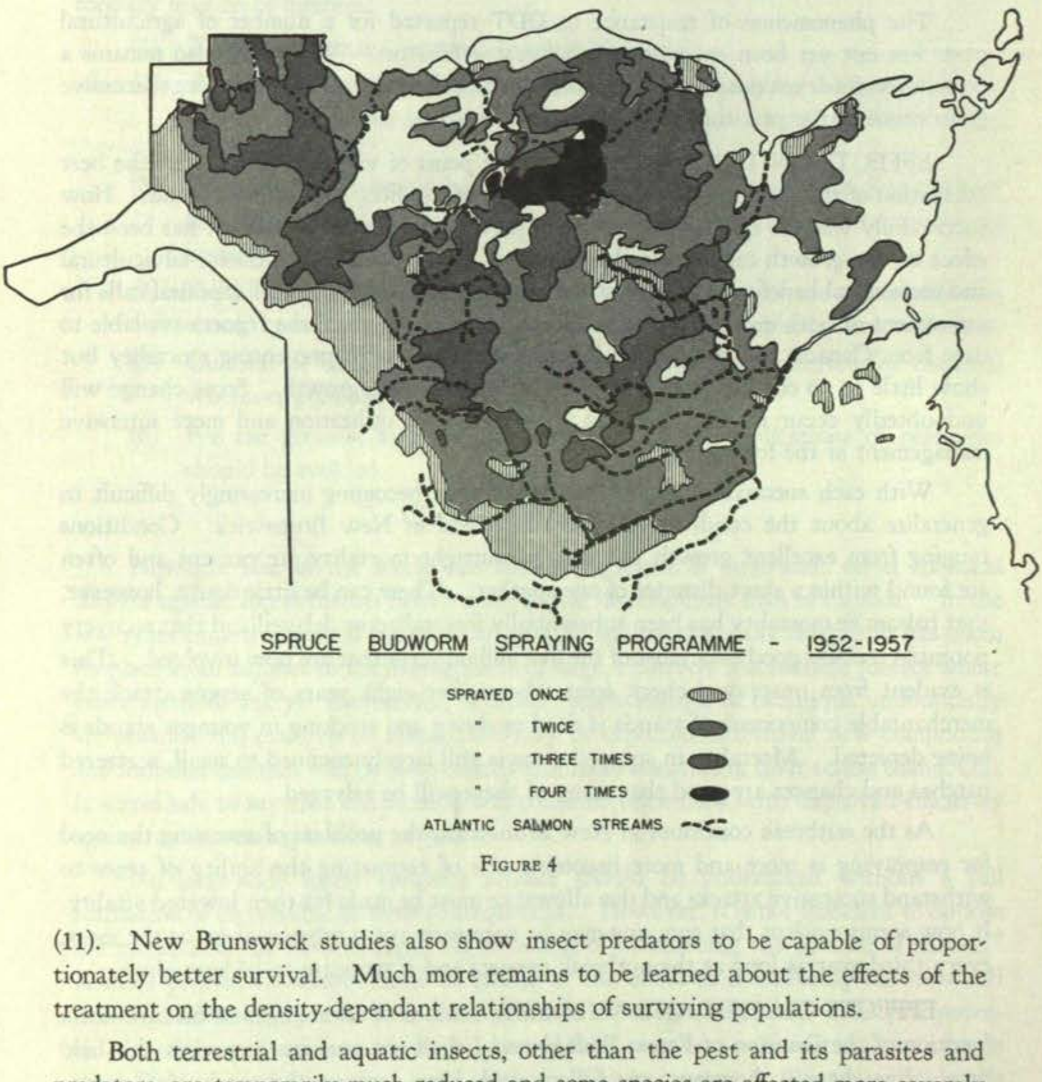

FIGURE 4

(11). New Brunswick studies also show insect predators to be capable of proportionately better survival. Much more remains to be learned about the effects of the treatment on the density-dependant relationships of surviving populations.

Both terrestrial and aquatic insects, other than the pest and its parasites and predators, are temporarily much reduced and some species are affected more severely than others. Excellent control of black flies and mosquitoes usually results. Most terrestrial groups, however, appear to be capable of quick recovery and total numbers of flying insects are often at least as great as in unsprayed areas later in the same season. An interesting study in the United States showed that a sprayed hardwood stand supported a larger general insect population than an unsprayed stand subjected to exposure by defoliation (8). More work is needed to distinguish between species that are severely affected and those that are not, and to assess the changes that undoubtedly occur in the complex of post-spray populations.

There are no signs yet in Canadian operations that other destructive species are being encouraged. A recent report of widespread mite damage in forests sprayed against spruce budworm in Montana and Idaho, however, emphasizes the fact that this remains a possible hazard.

The phenomenon of resistance to DDT reported for a number of agricultural pests has not yet been encountered in forest defoliators. While this also remains a possibility, its development will probably require the treatment of many more successive generations of the pest than has occurred so far.

EFFECTS ON THE FOREST: From the point of view of the forester, the best evaluation of the results of spraying is in terms of its effect on the forest stand. How successfully was the objective achieved of preventing mortality? What has been the effect on the growth capacity of the trees, and what will be the ultimate silvicultural and economical benefits? As in the case of effects on the pest, a full appraisal calls for assessment of both immediate and long-term effects. Most of the reports available to date from Canada and the United States tell of success in preventing mortality but show little or no concern with the preservation of annual growth. Some change will undoubtedly occur in this emphasis with the fuller utilization and more intensive management of the forest crop.

With each succeeding year of operations it is becoming increasingly difficult to generalize about the condition of sprayed forests in New Brunswick. Conditions ranging from excellent growth recovery to outright mortality are present and often are found within a short distance of one another. There can be little doubt, however, that balsam fir mortality has been substantially forestalled or delayed and that recovery potential remains good over most of the five million acres that are now involved. This is evident from unsprayed check areas where after eight years of severe attack the merchantable component of stands is dead or dying and stocking in younger stands is being depleted. Mortality in sprayed areas is still largely confined to small, scattered patches and chances are good that many of these will be salvaged.

As the outbreak continues in New Brunswick, the problem of assessing the need for respraying is more and more becoming one of estimating the ability of trees to withstand successive attacks and due allowance must be made for their lowered vitality. It now seems evident that spraying may be necessary every other year or, at the most, every third year as long as the outbreak persists and if trees are to be kept alive.

EFFECTS ON FISH AND WILDLIFE: Studies of effects against fish are not a function of the Division of Forest Biology and I shall not presume to review this field here. I might say, however, we follow with keen interest the work of Fisheries Research Board in connection with Atlantic salmon studies and we have welcomed the opportunity to supplement the work of Dr. Ide on the Miramichi (9) in a small way by surveying aquatic insect populations in some sprayed and unsprayed streams in another part of the sprayed area.

There has been relatively little intensive work done in New Brunswick or elsewhere in Canada on effects against wildlife. The concensus, both here and in the United States, however, suggests that dosages customarily recommended against forest defoliators are not likely to have serious adverse effects directly or indirectly against warm-blooded animals. This opinion is supported in an excellent review of the problem by Rudd and Genelly published recently as a Bulletin of the Game Management Branch of Department of Fish and Game, California (15). Some of their recommendations dealing with the use of pesticides in agriculture as well as in forestry may be of interest:

(1) The most selective (pesticide) should be used.

(2) Application should be in strict accordance with prescribed recommendations, should be used only where needed, and should be restricted to the minimum effective amount.

(3) Greater concern should be accorded to widespread application than to local use. Serious effects are more likely to result from treatments over large areas.

(4) Field biologists should participate in the formulation of use procedures and should be consulted at any time when pesticides are applied over a wide area.

(5) Cultural or biological means of control should be substituted for chemical wherever possible.

(6) For the greatest safety, "insurance" or routine applications of pesticides should be avoided.

Concluding Remarks

Nowhere else in the world has the development of large-scale aerial chemical control against forest insects been a more logical development than in Canada. In the few years since the method became economically and operationally feasible, it has taken its place as an adjunct to the management of large, relatively inaccessible forests where other methods are yet ineffective. Further improvements in technique undoubtedly are possible and research on insecticides may be expected to uncover new compounds and formulations that will be more effective, or more selective in their action than DDT. It seems safe to say that the method will continue to be used with improved efficiency against an increasing number of pests.

No large-scale forest spraying project should be undertaken without a full realization of its possible adverse consequences. However, it is not sufficient to oppose the method on the basis of some vague notion of "disturbing the balance of nature." A more precise knowledge must be gained of the effect of introducing the new and powerful control factor into an already complex biological system. The full potentialities of the method can only be determined from tests on a sufficient scale to achieve their purpose, and operations such as those of recent years in Canada provide the necessary opportunities. The biologist's task is to foster the idea that the problems of pest control are primarily ecological and, by means of properly integrated studies of the whole ecosystem, to ensure the safest and most intelligent use of direct control measures.

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Effects of Spruce Budworm Control on Salmon and Other Fishes in New Brunswick

by

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Each spring since 1952 large forest areas of northern New Brunswick have been sprayed with DDT in efforts to control a spruce budworm epidemic. The DDT has been mixed with a special solvent oil and sprayed from airplanes at a concentration of one half pound per acre (one pound per acre in 1952). Some areas have been resprayed at intervals of one, two or three years. In spite of these extensive and costly control measures, the budworm population continued to expand until in 1957 over five million acres of New Brunswick woodland was sprayed, much of it for the second or third time.

In the face of such widespread and repeated applications of DDT many biologists, sportsmen and naturalists have become increasingly worried about the side effects of the insecticide on fish and wildlife in the budworm-infested areas. Fisheries workers have been especially concerned because many species of fish are known to be extremely sensitive to DDT.

Fortunately, a unique opportunity has arisen to study the effects of this DDT spraying on the fish populations of some New Brunswick rivers. Since 1950 the Fisheries Research Board of Canada, through its Biological Station at St. Andrews, has carried out an annual fall census of the young salmon in several branches of the Miramichi River system of central New Brunswick. This programme has involved sampling the fish populations by seining with electrofishing at the same localities each year. Censusing began on the Northwest Miramichi River in 1950, was extended to the Dungarvon River in 1952 and to the Renous and Cains Rivers in 1955. In 1957 the work on the Dungarvon River was discontinued to enable censusing to begin on the Tobique River, the most important salmon angling tributary of the St. John River. A total of 34 census stations is involved: ten on the Northwest Miramichi, six on the Dungarvon, five on the Cains, three on the Renous and ten on the Tobique.

Effects of DDT spraying on young salmon

The relative abundance of young salmon in the Northwest Miramichi branch of the Miramichi River each year from 1950 to 1957 is shown in Figure 1. Data from the first year of censusing (1957) on the Tobique River are included in the figure for comparison. All data are expressed as numbers of fish per 100 square yards of river bottom. The fish are separated into three groups on the basis of size. The smallest fish are fry or underyearlings. Parr less than 10 cm. total length are classed as "small parr"; those over 10 cm. as "large parr". In general, these three size groups correspond to the first three years of life. In the Miramichi River system most young salmon go to sea as smolts at the beginning of their fourth summer.

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Populations of all three size groups of young salmon in the Northwest Miramichi increased gradually from 1950 to 1953 (Figure 1). This increase is probably related to the experimental merganser control which has been carried out on the river since 1950. Control of American mergansers on the Pollett River, N.B., between 1947 and 1950 resulted in a marked increase in the number of smolts leaving the river (Elson, 1950). Following this evidence that reduction of merganser populations benefited young salmon, merganser control was extended to the Northwest Miramichi on an experimental basis in 1950. The experiment was designed to determine whether control of mergansers would eventually increase the numbers of adult salmon from this river taken in the sport and commercial fisheries.

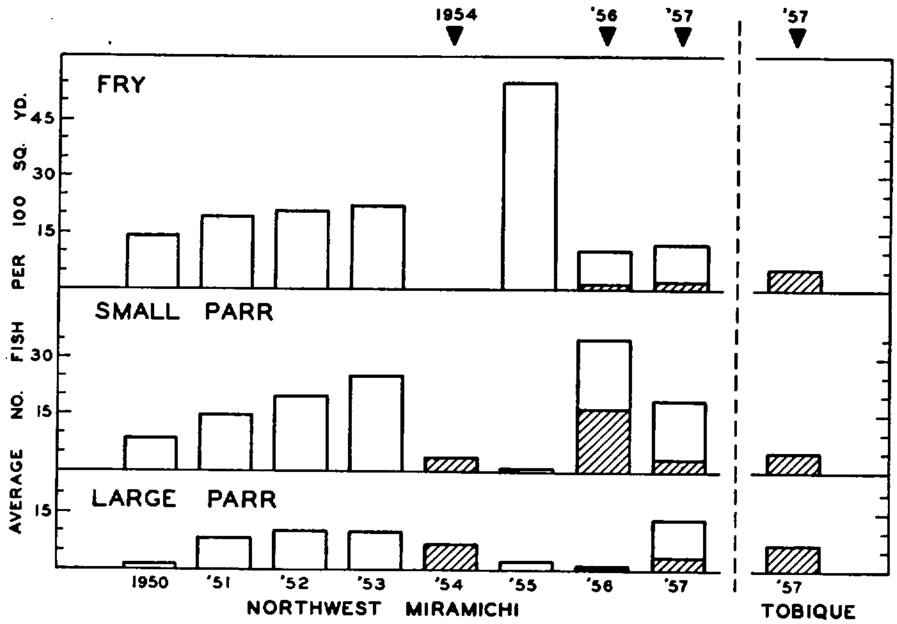

FIGURE 1. *Abundance of young salmon in the Northwest Miramichi and Tobique Rivers. Solid triangles indicate years when DDT was sprayed in the area. Cross-hatching indicates fish found in sprayed parts of rivers.*

In 1954 all stations sampled on the Northwest Miramichi were within the area sprayed with DDT for the first time. The drastic effects of the spray are clearly seen in Figure 1. Not one fry was found that year. Small and large parr were also reduced but to a lesser extent than the fry. Direct evidence of the harmful effects of the DDT was obtained in 1954 by holding salmon parr in cages in several parts of the Northwest Miramichi. From 63 per cent to 91 per cent of those held within the spray area were dead in three weeks, while only 2 per cent died in an unsprayed control stream during the same period (Kerswill and Elson, 1955). The extreme sensitivity of young salmon to DDT was also demonstrated by laboratory bio-assays carried out in the summer of 1957. The *median tolerance limit* (concentration killing one half a sample of fish) for small parr in DDT was 0.049 ppm. for a 24-hour period, and 0.047 ppm. for 48 hours (Keenleyside, —1958).

No spraying was done in the Northwest Miramichi region in 1955 and fry were unusually abundant that year (Figure 1). This heavy fry population may have been due to several factors: (1) less competition for food and space with salmon parr, many of which were killed by the 1954 spraying; (2) great abundance of aquatic Diptera larvae which, in contrast to many of the larger aquatic insect larvae, survive the budworm spraying and which form an important part of the diet of salmon fry in this area; (3) unusually successful spawning of adult salmon in the Miramichi area in 1954.

Small and large parr were scarce in 1955, due to the lethal effect of the 1954 spraying. Those small parr found in 1955 may have been fry which were missed in the 1954 censusing, or they may have been small parr in 1954 which failed to reach large parr size by the fall of 1955 when censusing was done. The aquatic stages of many caddisflies, stoneflies and mayflies are greatly reduced by the DDT spraying (Ide, 1957). Since these insects form the major part of the diet of small and large salmon parr in the Miramichi area, a reduction in their numbers may be reflected in slower growth of the fish.

In 1956 and 1957 only the lower part of the Northwest Miramichi River was within the spray area. In both years approximately the same extent of the headwaters was free of spray. The bars on Figure 1 for 1956 and 1957 are partly cross-hatched and partly open, to represent the proportions of fish found in sprayed and unsprayed parts of the river respectively. Clearly the best fry survival occurred in the unsprayed headwaters. In 1956 small parr were abundant, even in the sprayed section of the river. These were survivors of the very large 1955 fry class. Many of them were in poor condition in the fall of 1956, due to the scarcity of large aquatic insects on which they usually feed. Small parr were surprisingly abundant in the river in 1957. Most of them were found in the unsprayed headwaters, where they were more numerous than the fry of 1956. Some of these fish were probably small parr the year before which had not reached large parr size by 1957. Large parr were scarce in the Northwest Miramichi in 1956 as a result of both the 1954 and 1956 sprayings. In 1957 they were numerous due to growth of the big 1955 fry class, some of which should have reached large parr size by 1957.

All 10 census stations on the Tobique River were within the area sprayed in 1957. Some of them were also sprayed in 1953, 1955 or 1956. Figure 1 shows that young Tobique salmon were found in moderate numbers only in 1957. The figure for fry is misleading, since all fry found in the river were taken at one station, where hatchery underyearlings were planted shortly before censusing. No fry were taken at the other nine stations.

All the data obtained from population assessments on four branches of the Miramichi River since 1950 are summarized in Table I. The table includes the Northwest Miramichi data of Figure 1, but not the Tobique data. Fluctuations in abundance of young salmon over this larger area have been similar to those on the Northwest Miramichi branch. In years when DDT was sprayed populations of young salmon in streams within sprayed areas have been reduced. This reduction has been greatest among the fry. One year later, with no further spraying in the same areas, fry have been very abundant, while small and large parr have been scarce. In areas where no respraying was done for two or three years fry populations were similar to pre-spray levels. Parr, however, were more numerous than before, reflecting growth

Table I

Salmon abundance in the Miramichi River since 1950

—		Number of stations studied	Average no. fish per 100 sq. yds.		
			Fry	Small parr	Large parr
Before Spraying		58	23.5	16.7	8.1
Same Stations After Spraying Year of spraying		34	2.5	9.4	3.7
No Further Spraying	1 year later	17	50.8	0.6	2.8
	2 years later	6	24.2	43.9	2.6
	3 years later	3	27.8	48.4	29.7

and survival of fry of the first post-spray year. Also, slower growth of small and large parr, due to reduction of their food by spraying, probably results in some parr being included in the same size group for two consecutive years.

It should be emphasized that abundant post-spray populations of small and large parr have been found at only three census stations, where spraying has not been repeated for an interval of three years (bottom line of Table I). These three stations are in the headwaters of the Northwest Miramichi River, which is excellent parr-rearing water. Most of the Miramichi watershed within the range of the present spruce budworm outbreak has been sprayed on successive or alternate years since 1954. Since most young salmon in this area spend three years in fresh water before going to sea, respraying with DDT at intervals of less than three years can affect the same year-classes more than once and thus greatly reduce the potential salmon production of the affected rivers.

Effects of DDT spraying on other fishes

During the annual censusing of young salmon several other species of fish are regularly caught. . Changes in abundance of these species have also occurred following DDT spraying. The relative abundance of brook trout (*Salvelinus fontinalis*), eels (*Anguilla rostrata*) and four species of "minnows" in the Northwest Miramichi River since 1953 is shown in Figure 2. Under "minnows" are included four species of Cyprinidae, the black-nosed dace (*Rhinichthys atratulus*), the common shiner (*Notropis cornutus*), the fallfish (*Semotilus corporalis*) and the chub (*Couesius plumbeus*).

Trout are found mainly in the headwaters of the Northwest Miramichi, a section of the river that was sprayed in 1954 only. They were scarce in 1954, recovered gradually until by 1956 they were more numerous than before spraying, and by 1957 were present in about average numbers again (Figure 2). Since the fishing gear used in censusing does not capture trout underyearlings efficiently, only data for yearling and older trout are included in the figure. Fluctuations among these age-groups are similar to those among salmon parr in this headwater section of the river. They are most abundant two years after spraying, when spraying is not repeated.

Eels are present in moderate numbers throughout the Northwest Miramichi. They appear to have been severely affected by the DDT spraying (Figure 2). Their numbers were reduced in 1954 and in 1956, and by 1957 none at all were found.

Minnows are found only in the lower part of the Northwest Miramichi, where spraying occurred in 1954, 1956 and 1957. They have remained abundant throughout this period and were particularly numerous in 1956 (Figure 2). The relative proportions of the four species in this river have been approximately the same during this period. Dace are about 10 times as abundant as each of the other species.

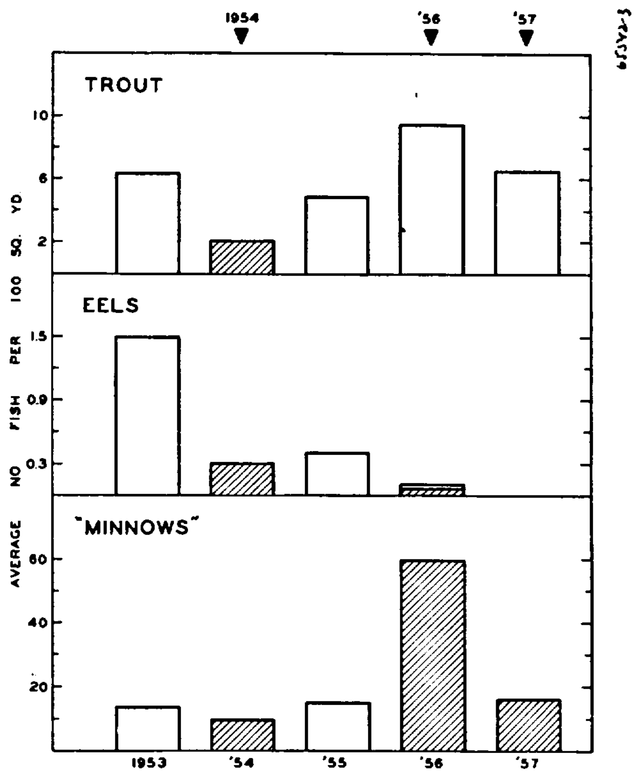

FIGURE 2. *Abundance of several species of fish in the Northwest Miramichi River. Symbols as on figure 1.*

Summary

Several species of fish in New Brunswick rivers have been adversely affected by the widespread aerial application of DDT to the forests of the province as a control agent for spruce budworm. Young salmon, brook trout and eels are reduced in number following spraying. Four species of cyprinids are relatively unaffected by the spray. Salmon populations appear to recover if spraying is not repeated over the same areas for an interval of at least three years. However, much of the budworm-infested woodland has been resprayed at intervals of less than three years. Under these conditions one age-class of salmon can be affected more than once and smolt production from rivers in the area will be seriously curtailed.

Acknowledgements

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Effects of Black-Headed Budworm Control on Salmon and Trout in British Columbia

by

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Introduction

An infestation of black-headed budworm, *Acleris variana* (Fern.), on Northern Vancouver Island had been under study by the Forest Biology Division of the Department of Agriculture Science Service since 1954. Surveys conducted in the fall of 1955 indicated that the infestation had reached high hazard proportions in the Port McNeill-Port Hardy-Quatsino Sound area. Defoliation within this area in 1956 was severe for the second consecutive year although a survey conducted in the fall of 1956 indicated that the egg count had declined 63 per cent from 1955. Scientists of the Forest Biology Division stated however, that unless over-wintering conditions in 1956 caused a collapse of the infestation, another defoliation would occur in 1957. They stated also that another defoliation, even of medium proportions, might cause tree mortality and top-killing within the high hazard area. For these reasons, it was recommended that consideration be given to carrying out control operations in the spring of 1957.

In June of 1956, an aerial control experiment was conducted within the affected area to determine the dosage and timing of effective DDT treatment.

To consider all aspects of this infestation, the British Columbia Loggers Association formed a Pest Control Committee in 1956. This committee met periodically with the Forest Biology Division and were kept well informed on the status of the budworm infestation. On the basis of the Forest Biology Division recommendation that consideration be given to carrying out control operations in 1957, the committee investigated the factors and requirements associated with the initiation of such a programme. Assurance of financial assistance was received from both the federal and provincial governments. The committee then instituted a plan to conduct an aerial spray programme in the high hazard area during the early summer of 1957. The final decision to spray was to be dependent upon the findings of a survey conducted by the Forest Biology Division in the spring of 1957, which would show if the infestation had significantly lessened over the winter. This survey indicated that severe defoliation would again occur in 1957 and plans for the aerial control programme were finalized.

The possibility that an aerial spray program might be conducted was first brought to the attention of the Department of Fisheries as a result of a report on the preliminary spraying experiment in June of 1956. Following discussion of the matter with the Forest Biology Division, technical personnel of the Department and the B.C. Game Commission were invited to attend meetings of the Pest Control Committee to discuss fisheries problems that might be associated with the proposed spray programme. Both groups remained in close contact with the committee throughout all stages of the operation.

The effects of DDT spraying on fish and fish-food in other regions were closely studied and these were reviewed with the Pest Control Committee. Information on the location of salmon and trout streams within the proposed spray area was presented along with estimates on the size of salmon populations that might be affected. Because of the extreme hazard of aerial DDT spraying to fish populations, it was pointed out to the committee that unless certain major fish producing areas were eliminated from the spray area, there was every probability that extensive fish mortalities would occur. The committee, although sympathetic to the problem, advised that if these areas were eliminated, the control programme would be rendered relatively ineffective and as a consequence they could not agree with the suggested modification. Results from the experimental spraying indicated that a dosage of one-half pound per acre might be effective and the fisheries groups proposed that the recommended dosage of one pound per acre be reduced. The Forest Biology Division indicated however, that there was insufficient evidence that the lower dosage was effective and accordingly could not take the responsibility of recommending a reduction in the dosage. In order to reduce to a minimum the probability of damaging fish populations, the committee did agree however to the following proposals:

(1) Streams would not be used as boundaries for spray plots. This would prevent streams from receiving a double dosage of spray as a result of overlapping.

(2) Pilots would spray parallel to the course of the major streams, keeping one swath width away.

(3) Spray would be shut off where it was necessary to cross streams.

When the final decision to spray was made, a co-operative program was initiated by the Department of Fisheries and the B.C. Game Commission to assess any damage that aerial spraying might cause to the fish or fish-food populations. The Committee agreed that such an investigation would be particularly desirable not only in connection with the proposed programme but also for future reference.

METHOD

Description of Spray Programme

During the period June 10 to June 20 inclusive, 155,000 acres of forest were treated as outlined in Figure 1. Spraying was to commence when the budworm population had developed to the point where the majority of larvae were in the second instar, and with the first and second instars about equally represented. Insect development varied with altitude however and consequently the lower elevations were sprayed first and higher elevations later.

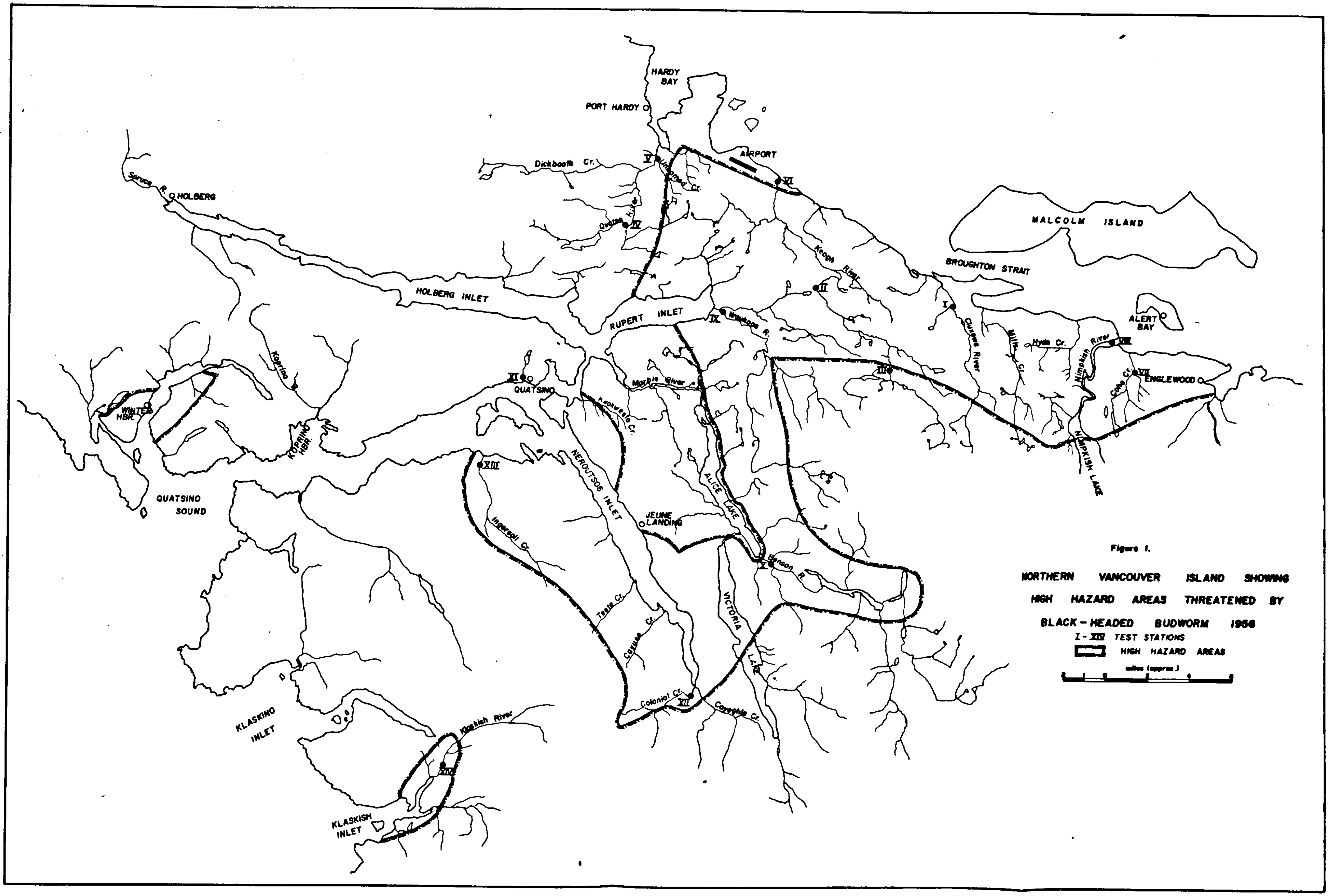

Figure 1—Effects of Black-Headed Budworm Control on Salmon and Trout in British Columbia

Four TBM Grumman Avenger aircraft, operating under contract with Skyway Air Services, conducted the spraying. These aircraft had a carrying capacity of 780 gallons of insecticide and operated at a speed of 150 miles per hour. The formulation constituted one pound of DDT dissolved in a wood penetrating oil with an emulsifier added and blended to one U.S. gallon with diesel oil. The rate of spraying was one U.S. gallon per acre.

In addition to the three preventative measures agreed upon to reduce the probability of severe fish mortality, the Pest Control Committee instituted the following:

(1) The concentration of DDT in the spray formulation was reduced to one-half pound per acre in the area between Englewood and the Nimpkish river, which contains a high proportion of second growth timber.

(2) Spraying on the lower watershed of the Keogh river, which consists partially of cedar swamp, was confined to stands of hemlock.

(3) The south-east side of Colonial Creek, which lies very near the border of the spray area, was not treated.

In order to supervise the control programme, the spray company operated an observation aircraft. The Committee agreed to fly a fisheries observer in this aircraft and an arrangement was drawn up whereby either a Fisheries Officer or an Officer of the B.C. Game Commission was available for every flight. These observations were conducted to determine if it were possible to carry out the suggested preventative measures and also because it was felt that having the officers observe would provide an added incentive for the pilots to effect those measures.

The Assessment Programme

Within the spray area, all five species of Pacific salmon, plus rainbow, cutthroat, and steelhead trout are indigenous. By spray date however, the seaward migration of pink, chum, and spring salmon fry and also that of coho, sockeye and steelhead smolts should have been completed as well as the movement of sockeye fry from stream to lake. The timing of the programme was such that adult salmon would not be present in the streams. Coho fry, trout, and juvenile stages of steelhead were the populations mainly affected by spraying.

The treatment area was situated in an isolated region and access to many of the streams was difficult. There was, however, a system of private and public roads between Port McNeill, Port Hardy and Coal Harbour and in that area, six stations were set up for intensive studies. These were: station I on the Cluxewe river, stations II, III, and VI on the Keogh river, station V on Unnamed creek, a tributary of the Quatse river and station IV, a control on the Quatse river. (See Figure 1).

At each of these stations three live pens were established and in these, coho fry, hatchery fingerling trout, and native steelhead smolts were retained. Mortality, water temperatures, and water levels were recorded daily and water samples were taken at stations II, III, and VI. Bottom samples were taken, using a Surber stream bottom sampler. Samples were taken prior to and during the spray programme and again in late July and in October. In addition, seining was conducted at station VI on the Keogh river. Spray cards supplied by the Forest Biology Division were set out at each station.

Nine stations, consisting of single live pens containing coho fry were established throughout the more remote regions. The mortality after spraying was recorded for comparison with that measured in the intensive study area. In October, bottom samples were taken at each of these stations and at five additional "outside" streams.

The water samples taken at the three stations were sent to the Nanaimo Biological station of the Fisheries Research Board of Canada, and were analyzed for DDT content. In addition, a series of bio-assay tests were made at the Biological Station, to determine the toxicity of both the spray formulation and its component parts to coho fry.

Results

The total loss of fish in the pens was recorded and corrected for natural mortality to give an estimate of the initial kill directly attributable to DDT. Three control

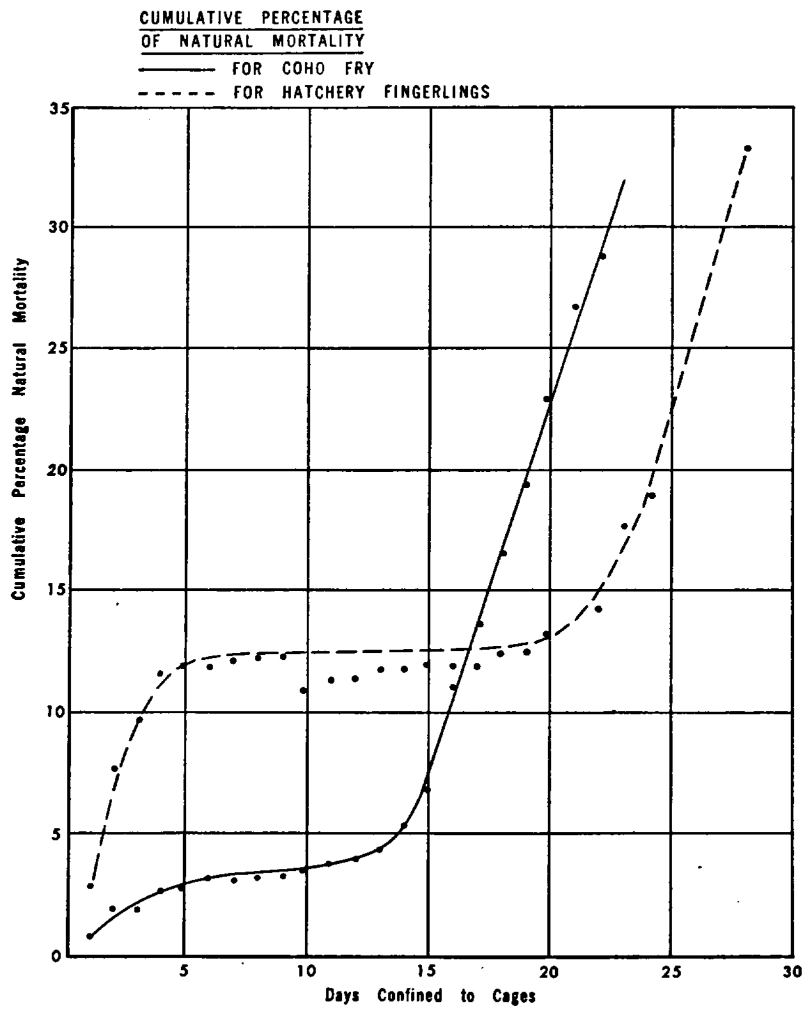

FIGURE 2. *The average natural mortality for fry and fingerlings as at stations I, II, III, V, and VI. The last measure of fingerling mortality represents only the loss at Station I.*

pens were set up outside the spray area; one on the Quatse river, another on the upper portion of the Keogh river and a third on Colony creek. Water temperatures rose to lethal levels at station IV on the Quatse river causing a high mortality, and pen number III on the upper Keogh river was inadvertently sprayed. The mortality in the remaining control pen, station X, was low but it was felt that one pen could not provide sufficient control data.

The natural mortality was calculated by grouping the fish stocked in pens I, II, III, V and VI, which were inspected daily, into one sample and calculating a total cumulative percentage mortality up until spray date. The initial total and the mortality for the individual streams were removed from the group totals as each was sprayed. The calculated percentage cumulative natural mortality for coho fry and hatchery fingerlings is shown graphically in figure 2. The initial DDT mortality figures for stations that were inspected daily have been corrected by taking the total loss after spraying and subtracting the expected natural mortality for that period as inferred from the graph. The figure for those streams that were checked only before and after, were corrected first by subtracting the inferred mortality for the period between the last observation after stocking and the spray date to give an estimate of the number of penned fish affected by spraying. The difference between that figure and the final number remaining alive was corrected again for expected natural loss for the period after spraying.

The corrected DDT mortalities, listed in table I, as measured by the pens range from 0 to over 90 percent. The variation reflects a number of factors such as visibility of streams from the air, drift of spray, forest cover, proportion of the stream sprayed, concentration of DDT used and meteorological conditions.

(1) *The Cluxewe River*—Station I

There was no measurable mortality of either coho fry or hatchery fingerlings attributable to spraying at station I. The portion of this watershed lying within the spray area was extensively logged and spraying was conducted on scattered patches of timber only. The spray formulation in this area did not contain an emulsifier but the scattered spraying probably accounts for the lack of mortality.

(2) *The Keogh River*—Stations II, III, VI

The Keogh river with an estimated escapement of 40,000 coho in 1956, was of vital concern. Three live pens were established on this river, one near the mouth (station VI), another eight miles upstream (station II), and a third (station III), six miles above that. Table I lists the initial mortalities of coho fry as 3.0 per cent at the lower station, 87.2 at the middle and 91.2 at the upper. The hatchery fingerlings suffered losses of 9.5, 84.7 and 51.7 per cent at these respective stations. Subsequent surveys in July and October however, indicated that salmonids were almost absent from the system. The Keogh watershed was sprayed on June 10 and 12. Seine hauls at the lower station on June 17 and June 21 netted an average of 91 and 75 coho fry respectively, four hauls in late July averaged 8 fry and four hauls at the same location in October netted no fish. At the middle station, a series of 25 hauls prior to spraying

Table I

The estimated 1956 escapement to streams within the spray area and the mortalities of coho fry and hatchery fingerlings in pens at the assessment stations.

Stream	Station	1956 Coho Escapement	Corrected Mortality	
			Coho Fry %	Hatchery Fingerlings %
Cluxewe R.	I	2-5000	0	0
Keogh R.		40,000		
	II		87.2	84.7
	III		91.3	51.7
	VI		3.0	9.5
Quatse R.	IV	Control	—	—
Unnamed Cr.	V	500-1000	0	0
Coho Cr.	VII	2-5000	29.7	—
Nimpkish R.	VIII	—	95.9	—
Waukaas R.	IX	500-1000	93.2	—
Colony Cr.	X	Control	—	—
Benson R.	XI	1-2000	72.0	—
Colonial R.	XII	500	94.9	—
Ingersoll R.	XIII	500	0	—
Klaskish R.	XIV	50C-1000	83.8	—
Mills Cr.	—	500-1000		
Hyde Cr.	—	50-100		
Lagoon Cr.	—	50-100		
Rupert R.	—	3-500		
Kwokwesta	—	50		
Cayeghle	—	50		
East Cr.	—	50-100		
Teeta Cr.	—	—		
Cayuse Cr.	—	50		

averaged 34 coho fry, six hauls immediately after averaged 3.8 and three hauls in October netted nothing. Seining was not conducted at the upper station but only three fry were observed in 100 yards of stream on October 9.

Coho fry appeared quite numerous at this time in each of the outside streams sampled for bottom organisms. Seining was conducted on two of these streams and on one, the Quatse river, six seine hauls averaged 10 coho fry and one trout fry per set. On the other, the Koprino river, four hauls averaged 17 coho fry.

The initial loss in the Keogh, although quite heavy at the upper and middle stations was negligible at the lower site. The lower four miles of the watershed were only partially sprayed but a heavy oil slick was noted at the pen site. It was felt at the time that the DDT must either have settled out or have been absorbed in some way and that the fry in this area had been unaffected. Analysis of water samples later showed however that toxic concentrations of DDT were present at this site for more than 48 hours after spraying and subsequent surveys indicated a near complete absence of coho fry throughout the system by October. There is a possibility that the coho fry were displaced downstream and eventually to the sea in search of food. Since there is no evidence that fry which enter salt water return as adults, it must be assumed that the mortality of coho fry and trout in the Keogh river approached 100 per cent.

The Keogh river courses through very flat terrain, its valley within the spray area is not well differentiated, and although the forest cover is not dense it largely obscures the actual channel from aerial observation. The lower four miles of the watershed, lying in a cedar-hemlock swamp, were only partially sprayed, as a fisheries benefit, and this may account for the low initial mortality at station VI. It was apparently impossible however to avoid directly spraying the remainder of the system.

The results of bottom sampling show a drastic reduction in aquatic insects at all three stations.

(3) *Unnamed Creek*—Station V

Only the headwaters of this stream, several miles above the pen site were sprayed. There was no measurable initial mortality of either fry or fingerlings and the bottom samples did not show a severe reduction after spraying. Since this is a slow moving stream choked with debris in the upper reaches, it is considered possible that the DDT was removed by adsorption before it could reach the live pen.

(4) *Coho Creek*—Station VII

This stream is small, has a dense forest cover and would not have been easily avoided. It was sprayed at a dosage of one-half pound per acre, as was the adjoining Nimpkish area. A 31.8 per cent total mortality occurred the day after spraying but this did not increase in the following five days and there were very few distressed fish observed in the stream. This relatively low mortality is probably attributable to a combination of good forest cover and the lower dosage of insecticide.

(5) *Nimpkish River*—Station VIII

The fry mortality at station VIII is listed in Table I as 95.9 per cent. The portion of the system sprayed however, between Nimpkish lake and the mouth of the lower Nimpkish river, is not utilized by coho and was presumably barren of juvenile salmon during the insect control program. Fry for the test pen were transported from Coho creek.

Although it is assumed that there was no mortality in the Nimpkish river itself, the insecticide which caused a loss in the pen was carried into the estuary, killing large numbers of chum salmon fry and a few juvenile coho and spring salmon which had moved into the estuary from Johnston Straits.

The Nimpkish is a large, wide river, easily seen from the air and is situated in an area that was treated with a one-half pound per acre dosage of DDT. The spray company agreed to fly the Nimpkish parallel to its course and to keep one swath width away from the river-bed. This stream should have been the most easily avoided in the spray area. The toxic concentration of insecticide must be attributed either to human error or to drift of spray.

(6) *Waukaas River*—Station IX

Station IX, sprayed on June 10, incurred a calculated DDT mortality of 93.2 per cent. A heavy oil slick was observed on the 10th, a 35 per cent mortality was recorded by the 11th, on the 12th numerous dead coho fry and trout yearlings were observed in the stream and the pen mortality had risen to 89 per cent. On June

15 a few coho fry were observed alive in the stream but by October there were virtually none in evidence. The October bottom sample was almost barren, the total catch being one mayfly nymph and one annelid in 10 square feet.

The Waukaas river lies in very flat terrain and has a medium forest cover. It would have been fairly difficult to avoid and the assessment results indicate that it received a full dosage of spray.

(7) *Benson River*—Station XI

The Benson river, which flows into Alice lake on the Marble system, drains a narrow steep valley and the river channel is quite visible from the air. Prior to spraying, the pilots felt that this stream could be avoided. The assessment results and observations indicate however that the actual mortality was severe, being recorded at 72 per cent in the pen. On the afternoon of spray day, June 18, a number of dead coho fry, yearling trout and sculpins were seen at the mouth of the river on Alice lake, and it was noted that an extremely heavy oil slick extended one-half mile into the lake. An oil slick was observed also on three lakes in the upper Benson watershed and a trout kill was reported in Victoria lake, which adjoins Alice lake.

There were no fry observed in the Benson river during the October survey and the bottom samples were extremely poor in aquatic insects.

(8) *Colonial River*—Station XII

The corrected mortality at the station XII pen, which was sprayed on June 14, is listed as 94.9 per cent. The stream was checked on June 19, five days after spraying. There were no dead fish of any kind in evidence but a reduction of coho fry was reported, based on observation only. In October, coho fry were fairly numerous and the yield of the bottom sample, although lower than that of control streams, was not poor.

The actual mortality of coho fry in Colonial creek was probably light. Heavy rain occurred on June 10 and June 16, increasing the volume and velocity of the stream flow. The pen was situated in an unprotected site and much of the mortality was probably caused by excessive velocity.

The valley of Colonial creek is not steep but the river channel is quite visible from the air. In addition, the south-east side of the valley was not sprayed. These two factors undoubtedly contributed to the success in avoiding severe mortality in this stream.

(9) *Ingersoll River*—Station XIII

There was no mortality, attributable to the spraying, recorded at station XIII. The river is situated in a well-defined, unlogged watershed and is easily located from the air. Observers report that the aircraft did not appear to spray within one-half mile of the river itself and also that no oil slick was observed at any time. The area was sprayed on June 19, there was a heavy rainfall on the 21st and 22nd and the pen was removed June 23. The number of aquatic insects in the bottom sample, taken in October was comparable to that of the control streams and there appeared to be no depletion of coho fry.

(10) *Klaskish River*—Station XIV

The DDT mortality of coho fry in the Klaskish river pen has been calculated at 83.8 per cent. On June 18, three days after spraying, several hundred coho fry and few cutthroat trout, measuring up to eleven inches long were found dead at the mouth of the river. A drastic reduction in the number of coho fry present in the stream was also reported at that time. In late October, a bottom sample was taken and several seine hauls were made. There were no coho fry either caught or observed but the bottom sample, although lower in aquatic insects than those of the control streams, was much better than the samples taken on the Benson, Waukaas or Keogh rivers which suffered similar fish mortalities. Only the lower two and one-haif miles of this stream, which includes most of the spawning and rearing area, were sprayed.

The insect populations were probably being repopulated from the upper areas.

The Klaskish river is situated in a mountainous area and is clearly visible from the air. Observers report that on at least one occasion, an aircraft crossed this stream emitting spray but in general the pilots did attempt to avoid directly spraying the river channel. The observers reported also, however, that the spray drifted very badly.

The fish mortality in the Klaskish river was apparently severe, that of the coho fry exceeding 80 per cent.

Bottom Samples

A series of nine bottom samples were taken at stations I to VI throughout the period from May 27 to June 24 and two further samples were taken on July 25 and 30. Between October 8 and 21 samples were taken at these same stations, with the exception of number V, and in the Waukaas, Colony, Benson, Colonial, Ingersoll and Klaskish systems. Seven streams outside the spray area but in the same general region were also sampled for bottom organisms during this period. These were White creek, a tributary of the Quatse river, the Koprino river and Colony creek flowing into Quatsino Sound, the Spruce river at Holberg and the San Josef and Fisherman river. on the extreme northern tip of Vancouver Island. The individual bottom samples taken from May to July were generally of one square foot in size, the October samples inside the spray area were ten square feet and those taken outside were five square feet.

The organisms of each bottom sample were enumerated, classified, dried and weighed. In general, mayfly larvae were the most numerous of the insect life, followed by stonefly and then caddis-fly larvae and various species of diptera and coleoptera. A species of oligochaete was present in most of the samples and at the locations where aquatic insect life was severely reduced, was sufficiently numerous to mask the loss of other forms on the basis of total number or total weight of organisms per unit area. Since these oligochaetes are not utilized for food by fish they were removed from the sample. Forms such as turbellaria, hirudinea and gastropoda were not common.

With one exception, the loss of bottom organisms in the individual streams parallels closely the loss of fish. Table II lists the weights and number of organisms per square foot of stream bottom for both spray and control streams from May to October. The weight data is shown graphically in Figure 3.

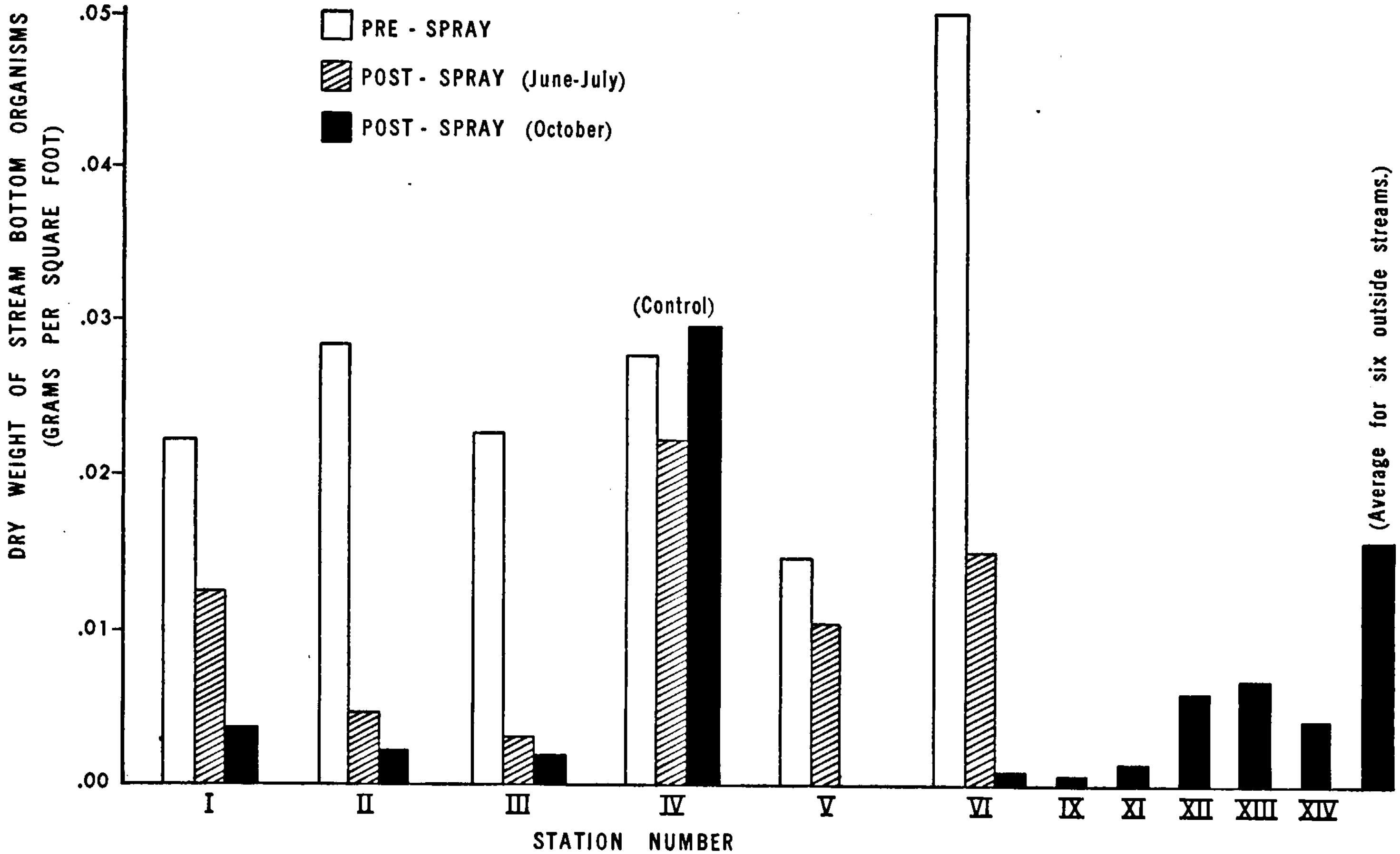

FIGURE 3. *The average weight of bottom organisms at several stations before and after spraying.*

Table II

The weight and number of organisms per square foot of stream bottom prior to spraying, immediately after and in October, Oligochaetes were excluded.

Stream Station		Prior to Spraying	After Spraying (June-July)	After Spraying (October)
STATION I	Number	23.5	5.25	6.7
(Cluxewe River)	Weight (Grams)	0.0223	0.0124	0.0024
STATION II	"	42.0	0.78	2.2
(Keogh River)		0.0285	0.0038	0.0021
STATION III	"	26.9	5.21	5.9
(Keogh River)		0.0226	0.0029	0.0018
STATION IV	"	24.5	12.6	13.0
(Quatse R. Control)		0.0287	0.0212	0.0295
STATION V	"	21.7	20.0	—
(Unnamed Cr.)		0.0144	0.0103	—
STATION VI	"	37.3	9.2	1.2
(Keogh River)		0.0500	0.0147	0.0004
STATION IX	"	—	—	0.1
(Waukaas River)		—	—	0.00002
STATION XI	"	—	—	0.8
(Benson River)		—	—	0.0010
STATION XII	"	—	—	11.4
(Colonial)		—	—	0.0058
STATION XIII	"	—	—	17.2
(Ingersoll River)		—	—	0.0065
STATION XIV	"	—	—	5.9
(Klaskish River)		—	—	0.0040
Average of 6	"	—	—	19.1
Outside Streams		—	—	.0153

Streams in which there was a severe fish mortality such as the Keogh, Waukaas and Benson rivers, demonstrated a drastic reduction in aquatic insect life. The number and weight of organisms in others such as the Ingersoll, Colonial and Cluxewe rivers, which did not suffer a large fish mortality, were within the range of the control stream samples taken in October. The single exception to this parallel was the Klaskish river. Although results from the live pen on this stream indicate a mortality to coho fry of over 80 per cent, and observations suggest that this measurement is minimal, the bottom sample does not show a paucity of insect life. Only the lower two and one-half miles of the Klaskish, which includes most of the available spawning area, were sprayed. By October, when the sampling was carried out, the insect life could have been repopulated from the upper areas.

As already stated, the most numerous forms prior to spraying were mayfly, stonefly and caddis-fly larvae in that order. Table III compares the average number of each of these forms at stations I, II, III, V and VI; prior to spraying in June, and after spraying in June, July and October. The mayfly larvae, although suffering the greatest reduction in numbers, were still the most numerous after spraying. Caddis-fly larvae by October were non-existent in the samples.

Table III

Comparison of the average number of Plecoptera, (Stone-flies), Ephemeridia (May-flies) and Trichoptera (Caddis-flies) per square foot of stream bottom before spraying, immediately after and in October at stations sprayed in the intensive study area.

—	Station	Plecoptera	Ephemeridia	Tricoptera	Total Area Sampled in Sq. ft.
Prior to Spraying (May-June)	I, II, III V, VI	2.5	20.0	4.0	22
After Spraying (June-July)	II	0.7	2.4	1.1	46
After spraying (October)	I, II, III, VI	1.2	1.7	0	50

Table II compares the number and weight of bottom organisms for the same three periods as above for each station and stream sampled. In general, the proportion of larger forms in the sprayed stream samples was considerably reduced after spraying. At stations I, II and III, the number of organisms per unit area showed an increase over the June-July samples but the average weight declined. Both the number and the weight of organisms were lower in the October sample at Station VI on the Keogh river, but the weight per unit area was disproportionately low.

In summary, the major fish food organisms of the Keogh, Waukaas and Benson rivers have been reduced to drastic proportions and will be of insignificant food value for at least the 1957 season. The abundance of major organisms in the other streams sampled varies, but the overall food production should not be greatly affected.

Bio-Assays

In conjunction with the assessment programme, a series of bio-assay tests were conducted at the Nanaimo Biological Station of the Fisheries Research Board of Canada, to determine the toxicity of the spray formulation and its component parts. The results of this bio-assay programme have been reported by Alderdice and Worthington (see page 41, this issue). On the basis of the bio-assay tests, Alderdice considered the "safe" concentration of spray formulation to be below 0.05 parts per million and that for the emulsifier, Atlox 2082A, to be 2.1 parts per million. Coho salmon under-yearlings were used as subjects for the tolerance studies.

Analysis of Water Samples

Water samples were taken at the three stations (II, III, and VI) on the Keogh river and at station IX on the Waukaas river. It must be emphasized that these were two of the streams most affected by spraying. The samples, taken between June 10 and 22, arrived at the Biological Station on July 12. They were placed in storage at 0° to 4° C. on arrival and were analyzed for DDT content between October 2 and 7. It would appear that the pH of the water samples had risen on standing and the possibility exists that some degradation of DDT in the samples may have resulted. Results of the analysis are listed in Table IV.

Table IV

Results of analysis for DDT content of water samples taken in the area sprayed for budworm control, Vancouver Island, June 1957.

Station	Date Sampled	Time	Date Analyzed	DDT. ppm.	P = .01 limits. ppm.	pH of sample (Oct. 24, 1957)
II..................	10 June	0800	7 Oct.	0.13	0.09 —0.19	9.6
	10 June	1930	3 Oct.	0.22	0.16 —0.32	9.7
(sprayed	11 June	0900	3 Oct.	0.20	0.14 —0.29	9.8
June 10)	12 June	0930	3 Oct.	0.03	0.019—0.044	9.85
	13 June	1100	2 Oct.	0.22	0.16 —0.32	9.9
	14 June	1000	4 Oct	0.18	0.13 —0.26	9.6
	18 June	0900	7 Oct.	<0.01	—	9.7
	20 June	0930	2 Oct.	0.40	0.28 —0.58	9.65
III..................	10 June	1000	7 Oct.	<0.01	—	9.7
	19 June	1000	7 Oct.	<0.01	—	9.85
(sprayed	19 June	1830	2 Oct.	0.37	0.26 —0.52	9.75
June 19)	20 June	0730	2 Oct.	<0.01	—	9.9
	21 June	0730	7 Oct.	0.03	0.019—0.044	9.75
	22 June	0730	3 Oct.	0.10	0.07 —0.15	9.8
	22 June	0800	2 Oct.	0.15	0.11 —0.22	9.5
VI..................	10 June	1330	3 Oct.	0.07	0.048—0.11	9.75
	11 June	1100	4 Oct.	0.28	0.19 —0.39	9.75
(sprayed	12 June	1300	2 Oct.	0.21	0.14 —0.30	9.75
June 10 and 12)	18 June	1200	7 Oct.	0.01	—	9.65
IX..................	10 June	1200	4 Oct.	0.06	0.042—0.090	9.6
	11 June	0930	4 Oct.	0.05	0.033—0.074	9.65
(sprayed	12 June	1600	3 Oct.	0.07	0.048—0.11	9.8
June 10)	14 June	1130	4 Oct.	0.02	0.013—0.031	9.1

The Waukass river was sprayed on June 10. On that date, the DDT content, as measured, was 0.06 p.p.m., and three days later the concentration was found to be 0.07 p.p.m. However on June 14 the concentration of DDT had dropped to 0.02 p.p.m., less than the safe level of 0.05 p.p.m. (Table IV). It can therefore be stated that a toxic concentration of the insecticide was present in the Waukass river for at least three days.

As outlined, previously, on the Keogh river, station VI was situated near the mouth, station II eight miles upstream and station III six miles above that. Most of the watershed below the upper station was sprayed on June 10 although a small part of the lower area was treated on June 12. The upper watershed, which included station III, was sprayed on June 19.

A water sample taken at the middle station 12 to 14 hours after spraying on June 10, on analysis, showed a concentration of 0.22 p.p.m. of DDT while that of a sample taken four days later was measured at 0.18 p.p.m. By June 18, eight days after spraying the concentration of DDT had dropped below the measurable limit of 0.01 p.p.m. but in a sample taken two days after the June 19 spraying of the upper area, the concentration had risen to 0.40 p.p.m. The middle portion of the Keogh river was subjected therefore to at least five days of toxic DDT levels.

A water sample taken at Station III, sprayed on June 19, had a DDT content of 0.37 p.p.m. on spray day. Four days later the concentration had only dropped to 0.15 p.p.m., very much above the safe level.

Water samples were taken at the lower station (VI) on June 10, 11, 12 and 18. In the first two days after spraying, the concentration was very high but by June 18, had dropped below the 0.01 p.p.m. limit. Since sampling was discontinued at this station on June 18, the effect of the upper watershed spraying of June 19 was not measured.

This was the station at which there was no measurable initial fish mortality but at which there were no juvenile salmonids present in October.

Discussion

As stated earlier, the hazards of aerial spraying with DDT to fish and fish-food populations were fully realized by the fisheries groups prior to spraying. Although it was also realized that the preventative measures agreed upon would not eliminate entirely the probability of severe fish mortality, they did constitute an improvement over current practices. The success of avoiding mortality was therefore dependent upon the ability of the pilots to effect those measures.

The actual spraying was kept under close observation by fisheries personnel. The air crews were well experienced in this type of spraying and all those concerned with the aerial control program, including the pilots, expressed repeatedly the desire to avoid damage to the fish populations within the area. The fisheries observers agreed that in general the pilots made a sincere attempt to carry out the preventative measures agreed upon. Presumably, the equipment and personnel used in the insect control programme were of the highest calibre, all practical preventative measures (short of non-spraying) were followed and a sincere effort made to implement those measures yet the mortality in at least four major streams approached 100 per cent. The meteorological conditions during the spray period, although possibly adverse for spraying, were not unusual for the region at that time of year.

There was a large variation in the effect of the DDT application on the fish population. The mortality of coho fry ranged all the way from zero on the Ingersoll to almost complete annihilation on the Keogh and Waukaas rivers. The reduction in aquatic insects paralleled quite closely the loss of fish. Although the effects of spraying varied with each stream, the following points might be noted:

(*a*) Fish mortality was high in large streams flowing through flat terrain with a fairly dense forest cover (e.g. Keogh and Waukaas rivers). The probable reason is that they are not clearly visible from the air.

(*b*) Fish mortality was high in large streams flowing through steep-walled valleys (e.g. Klaskish and Benson rivers). Watersheds of this type are sprayed on contours and in the particularly rugged terrain with its attendant unpredictable air currents, the control over spray deposition must be very slight.

(*c*) Fish mortality was low in streams situated in well differentiated but not particularly steep-walled valleys (e.g. Ingersoll and Colonial rivers). These streams are visible from the air and there is apparently better control of spray deposition.

(*d*) Fish mortality was relatively low in a small stream with a dense forest canopy (e.g. Coho creek). This stream was sprayed at a dosage of one-half pound of DDT per acre. In view of the heavy mortality of chum salmon fry in the Nimpkish river, which was also sprayed at the same dosage, it must be concluded that the reduction in concentration was not the significant factor in the low mortality in Coho creek.

(*e*) There was no measurable initial fish mortality in a small stream which was sprayed in the upper area only, several miles above the live pen (e.g. Unnamed creek). It is considered probable that the concentration of DDT was reduced below toxic levels by adsorption.

Loss of Salmon

Except for the loss of many thousands of chum fry which were killed in the estuary of the Nimpkish river, the damage to salmon stocks was confined to the mortality of coho fry. There are 18 salmon streams within the spray area, excluding the lower Nimpkish river which does not serve as a spawning or rearing area for coho, and in ten of these the 1956 coho escapement was estimated at 500 or more. The effects of spraying were measured in nine of those ten major streams as shown in Table I. In four of these, the Keogh, Waukaas, Klaskish and Benson rivers the mortality of coho fry approached 100 per cent and in a fifth, Coho creek, the loss was calculated at 30 per cent. In the four others that were sampled, the Ingersoll, Colonial, Cluxewe, and Unnamed creeks, there was not a large mortality. Mills creek, south of Port McNeill, was the only major stream where mortality was not assessed.

The damage to salmon stocks within the spray area was over-shadowed by the loss of coho fry in the Keogh river, where the progeny of an estimated escapement of 40,000 adult coho were almost completely annihilated. The escapement to the other three major streams affected by spraying totalled between 2,000 and 4,000.

The coho salmon has a predominant three-year life cycle and very little overlapping from other year classes can be expected. Even assuming that there was not a complete loss of fry in the four grossly affected streams, and assuming also that there will be some smolt production, judicious management will not restore the population for many cycles. The economic loss will then be accumulative until the escapement is restored once again to the 1956 level.

In order to alleviate this loss, the most obvious assistance to management would be artificial restoration. The only immediate measure would be the release of underyearlings, preferably from neighbouring streams. The problem of successfully transporting significant numbers to the streams in this isolated region, if the underyearlings were available, would be extremely difficult. In addition, it is doubtful if the streams in their present unproductive state could support a significant transplant. The best chance for success of artificial restoration may be the introduction in 1959 of large numbers of eggs. These could be flown to the Port Hardy airport and distributed to the respective streams.

Loss of Trout

Rainbow, cutthroat, and steelhead trout are indigenous to all streams in the region. It was not possible to estimate the number of trout within the spray area and knowledge on the size of the steelhead trout escapement is lacking. Unlike Pacific salmon, the steelhead and both species of trout spawn in the spring and by spray time in mid-June the spawn had probably reached the alevin stage. It is highly probable that the alevins are susceptible to DDT and in fact, a paucity of fry of the year were observed in October within the spray area. Seining was conducted in two control streams, the Koprino and Quatse, and trout fry were present in normal numbers.

In general, steelhead trout spawn in the spring, the fry emerge in the early summer, spend the remainder of that year and the whole of the following year in fresh water before going to sea in the late spring of the third year. In 1957, the seaward migration of smolts was well underway by spray date and only the latter portion would have been affected by DDT. Results from the holding pens indicate that the initial mortality to steelhead smolts was relatively light as compared to that of coho fry. The loss of migratory steelhead smolts, consequently, may not have been severe. The real damage to the steelhead populations would have been the loss of underyearlings and very probably the spawn of the year, in which case two consecutive year classes would have been affected. This loss was particularly noticeable in the Keogh river, where in October, there was a near complete absence of all juvenile salmonids.

In general, the relative mortality of trout in the affected streams could be expected to parallel the loss of coho fry. If this assumption is correct, of the major streams, the greatest losses would have occurred in the Keogh, Benson, Klaskish and Waukaas rivers. Of these four, only the Keogh is utilized at present to any degree by anglers, but the other three do have a potential. The resident trout of the Keogh river may repopulate quickly from several small lakes on the system but regeneration of the steelhead population will be a slow process. The trout population in the Benson river will likely be rehabilitated from the resident trout populations of Alice Lake. In October, angling was good in the lower portion of the stream. The Klaskish river is situated on the west coast of Vancouver Island and because of the isolated region, will not be an important angling stream for many years. Only the lower two and one-half miles of this stream was affected by spraying and repopulation should proceed rapidly from the upper areas. The Waukaas river is not a major angling stream, but it is considered that the resident trout and fresh water stages of steelhead trout were eliminated by spraying.

A few lakes received marginal doses of insecticide and although trout mortality was reported in the two largest, Alice and Victoria, it is considered that generally the losses were relatively small and will be quickly replaced by natural propagation.

In summary, the loss in number of trout by spraying was undoubtedly large. This district is however isolated and under the relatively light angling pressure imposed upon them at present, the stocks of trout should repropagate to pre-spray levels quickly. The steelhead trout on the other hand will take a number of years to overcome the effects of spraying which undoubtedly affected two consecutive year classes.

Reduction of Aquatic Insects

The reduction in aquatic organisms within the spray area as measured by bottom sampling, followed the same pattern reported by Ide (1956). The major loss was confined to aquatic insect larvae, particularly the larger forms of stoneflies, mayflies and caddis flies. Mayfly larvae were the most numerous form both before and after spraying but also suffered the great percentage reduction. Caddis-fly larvae by October were almost absent in the samples taken from the four major streams affected.

Ide (1956) reports that in a tributary of the Miramichi, which was included in the extensive Maritimes spraying of 1954, the emergence in the year of spraying consisted of large numbers of minute chironomids and very few of the larger insects. In the year following spraying the bulk of insects emerging was less than half that of the control stream and that was made up predominantly of small chironomids. There was a lack of caddis flies.

In the second year after spraying, the bulk of the emergence from the spray stream was still considerably lower than that of the control, and minute chironomids continued to dominate the emergence of the former. There were fewer species in the spray stream, stoneflies were still present in only insignificant numbers and large forms of stoneflies and mayflies were absent from the samples.

Kerswill (1957) found on the Miramichi that the normal diet of underyearling Atlantic salmon consists largely of small insects, but that older juveniles feed mainly on larger forms and do not appear to utilize the small forms even when the latter are abundant.

On the basis of these findings, the productivity of streams that are destitute of aquatic life at present will remain low for at least two seasons.

Summary

During mid-June of 1957, an aerial spraying programme was conducted on 155,000 acres of timberland on the northern portion of Vancouver Island, in an attempt to control an outbreak of black-headed budworm. The formulation used was one pound of DDT in a solvent with an emulsifier added and blended and one U.S. gallon with diesel oil. This was applied at the rate of one U.S. gallon per acre.

The damage to the fish and fish-food populations was assessed on the major streams and on four of these, was found severe. The fish mortality was confined generally to coho fry, trout, steelhead yearlings and possibly alevins of both trout and steelhead.

In the four major streams affected by spraying, the progeny of an estimated 1956 escapement of 43,000 coho adults and the juvenile stages of several thousand steelhead and trout was almost eliminated.

The reduction of aquatic insects parallels the loss of coho fry and the productivity of several streams is not expected to return to adequate proportions for at least two years.

A series of bio-assays was conducted at the Nanaimo Biological Station of the Fisheries Research Board of Canada. The tests indicate that a safe concentration of the formulation used in this insect control programme is below 0.05 parts per million. Analysis of water samples taken in the field showed that toxic concentrations of DDT existed at four test stations for more than three days after spraying.

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Toxicity of a DDT Forest Spray to Young Salmon

by

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In June, 1957 an aerial DDT spray programme was carried out to control black-headed budworm in an area of northern Vancouver Island, B.C. This report summarizes a series of laboratory tests conducted to determine the tolerance of a representative species of Pacific salmon to the DDT formulation used in the spray programme. The study provides information relating to an extensive field survey conducted to assess the effects of spray deposition on aquatic fauna within the sprayed area (Crouter and Vernon, 1959, see page 23, this issue).

Method

Following consultation with members of the Department of Fisheries and B.C. Game Commission, the following programme was undertaken:

(*a*) Examination of tolerance to Atlox 2082A, the spray formulation emulsifier.

(*b*) Examination of tolerance to the spray formulation used in the aerial spray programme.

(*c*) Comparison of the potency of the aerial spray formulation with a DDT-acetone standard.

Accordingly, the following materials were used in the tolerance tests:

(*a*) Emulsifier—Atlox 2082A, a preparation of "alkyl aryl sulphonate" and "polyoxyethylene sorbitan esters of mixed fatty and resin acids" manufactured by the Atlas Powder Company.

(*b*) Aerial Spray Formulation—made up in the following manner:

25 g. 100% Tech. "Montrose" DDT

7.14 g. Base Oil

3.6 g. Atlox 2082A

One volume of the above mixture is diluted with 1.2 volumes of medium grade diesel oil. The "base oil" used was "Standard Base Oil (Wood Treating)" manufactured by the Standard Oil Company. "Medium grade diesel oil" was obtained from the Imperial Oil Company of Canada. DDT was obtained from the Stauffer Chemical Company, Portland, Oregon.

(*c*) DDT-Acetone Standard—Maintaining the same proportions of DDT and Atlox 2082A as in the aerial spray formulation, acetone was substituted for the base oil and medium grade diesel oil.

Estimation of DDT content of solutions used in the tolerance tests and of the water samples collected in the spray area was carried out by a modification of the method suggested by Amsden and Walbridge (1954). A standard curve was prepared by analyzing for known amounts of DDT in acetone solution. No significant difference was obtained in a comparison of results from these standards with those obtained using aerial spray formulation added to water with subsequent separation of DDT with isopropyl ether. The resulting standard curve relating DDT concentration to spectrophotometric absorbance was used for estimating DDT levels in the succeeding tests. In all cases absorbance corrections were made with reagent blanks run concurrently. The method provided measurement of DDT down to 0.01 p.p.m. after extraction of the DDT from water. Colorimetric determinations were made using a Beckman DU Spectrophotometer at a wave length of 4700 A° and 0.03 mm. slit width.

Coho salmon (*Oncorhynchus kisutch*) underyearlings were considered as an appropriate species for determination of tolerance to DDT. The tests conducted with Atlox 2082A were carried out in August, 1957, and the coho underyearlings used averaged 6.89 cm. in length and 4.08 g. in weight. Test fish were exposed to various concentrations of Atlox 2082A at a ratio of 0.88 g. of fish per litre of solution. The tests conducted with the aerial spray solution and DDT-acetone standard were carried out in October, 1957. The coho underyearlings used averaged 8.81 cm. in length and 8.20 g. in weight. Test fish were exposed to various concentrations of the two materials at a ratio of 1.8 g. of fish per litre of solution. Fish used in the experiments were acclimated to and tested at 10°C.

One-half (23 litres) of the total volume of each test container was exchanged daily to minimize the possible diminution in DDT content by loss to the test fish. Daily determinations of DDT content were made by withdrawing one litre of each test solution and extracting the DDT with isopropyl ether. Such samples were taken at the beginning of each experiment, and immediately before each 23 litre solution exchange.

Results

Toxicity of Atlox 2082A to coho salmon underyearlings

Samples of 10 fish were exposed to each of eight concentration levels of Atlox 2082A from 500 p.p.m. to 10 p.p.m., along with a control. Times to 50 per cent

Table I

Time to 50 per cent sample mortality (ET_{50}) for samples of 10 coho underyearlings exposed to various concentrations of Atlox 2082A in fresh water.

Concentration of Atlox 2082A, p.p.m.	ET_{50}, minutes
500	33
100	98
70	290
50	380
40	680
30	1,125
20	2,450
10	>12,517
Control	No mortality

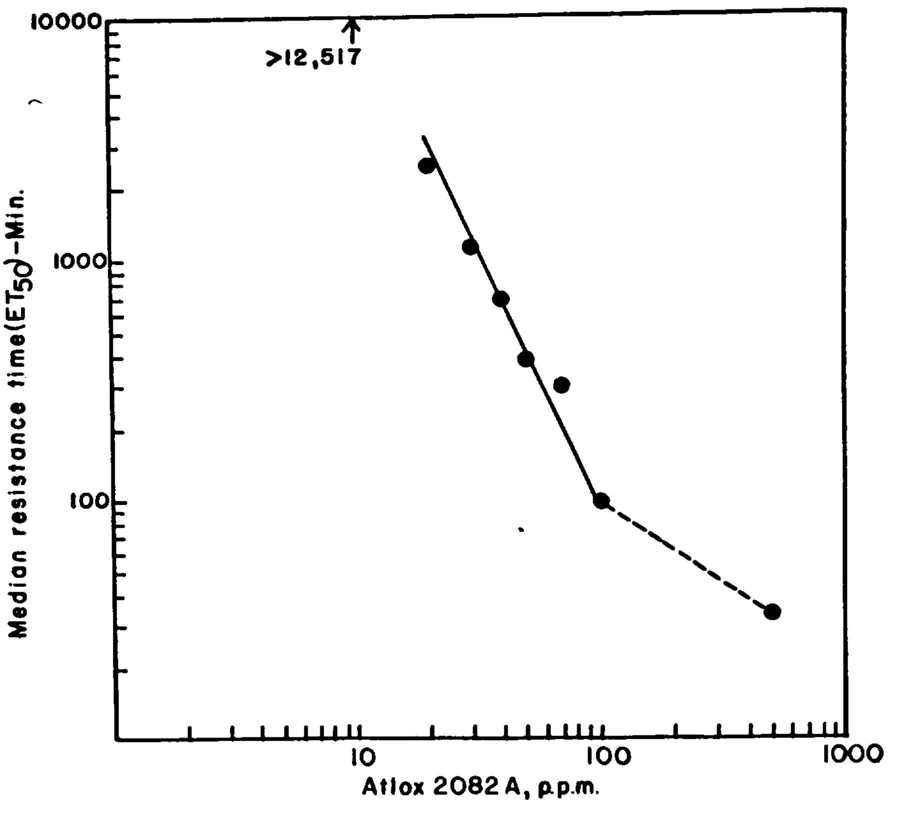

FIGURE 1—*Times to 50 per cent mortality in samples of 10 underyearling coho exposed to various concentrations of Atlox 2082A. The arrow in the upper corner refers to a test at 10 p.p.m. which was discontinued at 12,517 minutes.*

mortality in each concentration were calculated from the distribution of mortality times. Results of the tests are listed in Table I and illustrated in Figure 1.

Analysis of the transformed data provides an equation for the line from 20 to 70 p.p.m. From the equation the 48 hr. TL_m (median tolerance limit) (see Doudoroff, et al 1951) may be inferred and is estimated as 20.7 p.p.m. of Atlox 2082A. A safe level of Atlox 2082A, in terms of the experimental procedure, is estimated as 0.1 x 48 hr. TL_m or 2.1 p.p.m. Atlox 2082A. On the basis of the aerial spray formulation a unit of the spray in water containing 1 p.p.m. of DDT would contain about 0.15 p.p.m. of Atlox 2082A. Therefore, the concentration of DDT in a unit of water containing 2.1 p.p.m. Atlox 2082A would be approximately 14.0 p.p.m. DDT.

Toxicity of Aerial Spray Formulation to Coho Salmon Underyearlings

Samples of 10 fish were exposed to each of six concentration levels of the aerial spray formulation in water. The formulation does not form a stable emulsion in water and partition of the oil and aqueous layers occurred very rapidly. It was assumed for this reason that only a limited amount of the theoretical doses of DDT applied would be available throughout the water mass. In the higher concentrations tested a film of oil was visible on the water surface of the test containers. Subsequent tests also indicated a considerable amount of the DDT in the test tanks was being adsorbed upon sediment in the freshwater supply and precipitated with that sediment to the bottom of the tanks. The latter fact has been well documented in the literature (see Berck, 1953). For these reasons the remaining concentrations established for tolerance tests are reported both as theoretical doses (level of DDT concentration by volume dilution) and as actual doses (level of DDT by chemical analysis of water taken midway between the surface and bottom of the test containers). Results of the tests on the aerial spray formulation are listed in Table II. Probit response curves for the concentrations examined are illustrated in Figure 2. The ET_{50} values derived from these curves are illustrated in Figure 3.

The median resistance times describe a most unusual response distribution. Maximum response in terms of time to death occurs at a dilution of the spray formulation providing a theoretical dosage of 0.5 p.p.m. (actual dosage of 0.05 p.p.m.). Test fish were less susceptible to the solutions at dosages both less and greater than 0.05 p.p.m. DDT (actual dosage).

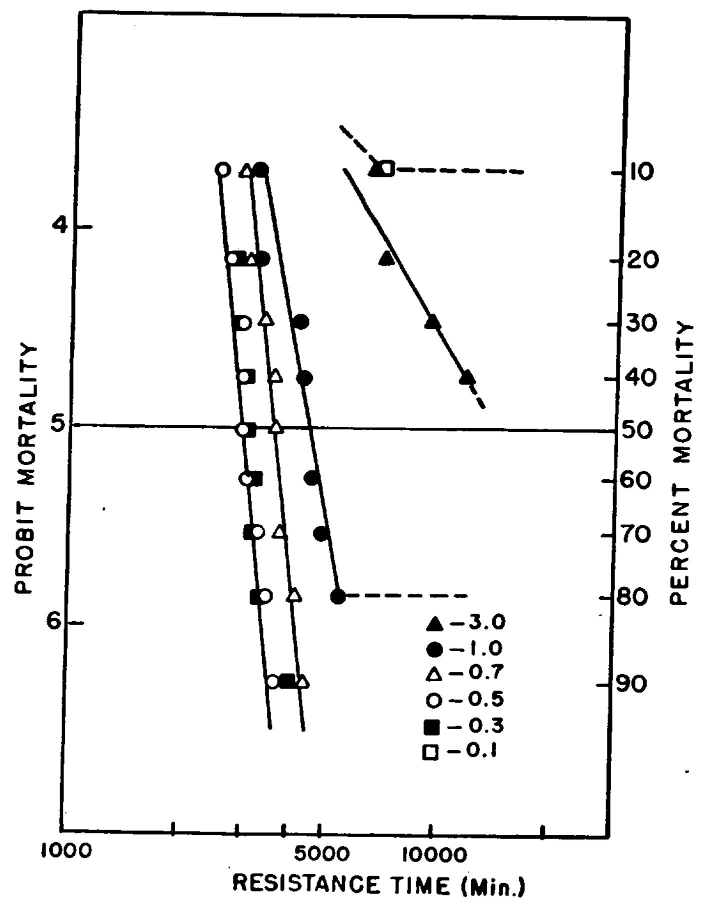

FIGURE 2—*Probit response curves illustrating the rates of mortality of coho underyearlings exposed to various concentrations of the aerial spray formulation. The curves are identified as to the theoretical concentrations of DDT applied, in p.p.m.*

Table II

Time to 50 per cent mortality (ET_{50}) for samples of 10 coho salmon underyearlings exposed to various concentrations of the aerial spray formulation.

Dilutions of aerial spray formulation providing DDT at the following theoretical concentrations, p.p.m.	Average concentration of DDT by chemical analysis, p.p.m.	ET_{50}, minutes
3.0	0.36	>12,492
1.0	0.19	4,400
0.7	0.11	3,600
0.5	0.05	2,950
0.3	0.10	2,950
0.1	0.07	>14,459
0.03	0.02	>10,031
Control	Control	No mortality

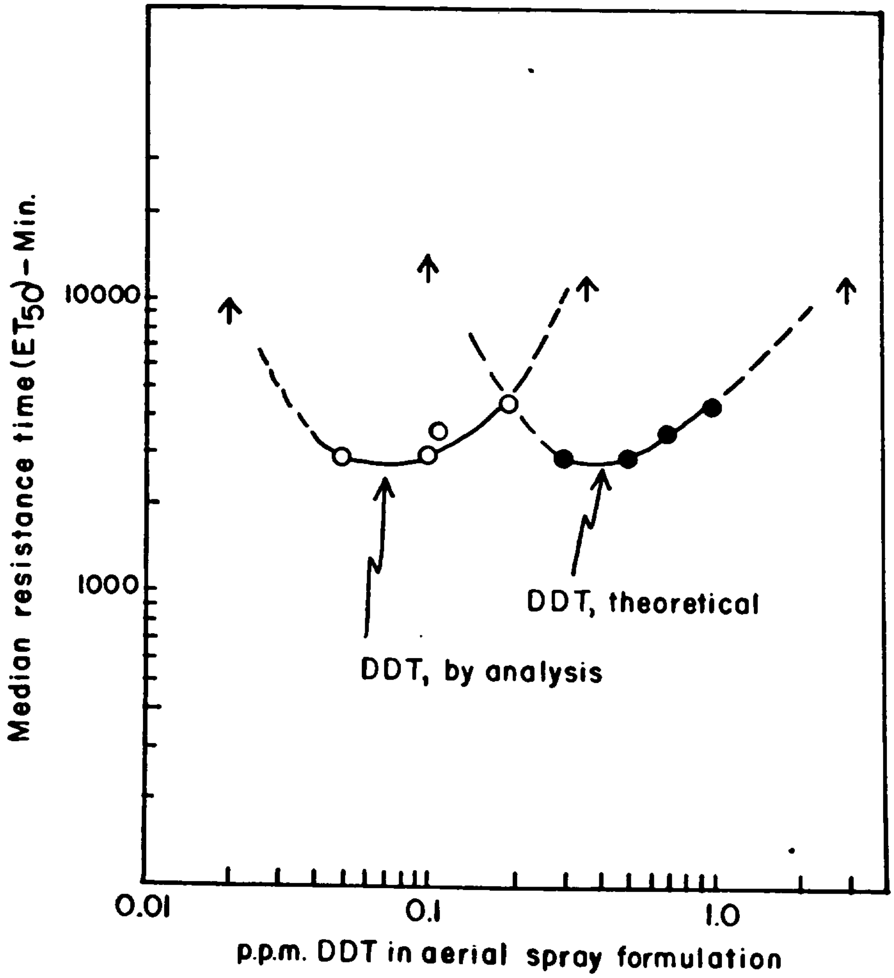

FIGURE 3—*Times to 50 per cent mortality in samples of 10 underyearling coho exposed to various concentrations of the aerial spray formulation. The arrows refer to tests in which 50 per cent mortality had not occurred at the times when the tests were discontinued.*

A further observation made in the 3.0 p.p.m. theoretical concentration (0.36 p.p.m. by analysis) supports field evidence of the Department of Fisheries (private communication). After 11,000 minutes of exposure almost all fish still living showed symptoms of blindness. Quite evident was the opacity of the lens of one or both eyes of these remaining fish.

Toxicity of DDT-Acetone Standard

Samples of 10 fish were exposed to each of six concentrations of a DDT-acetone standard. Although a highly stable emulsion was produced by the mixture of these materials, there was a tendency for the DDT to crystallize out onto the surface of the water solution, apparently on evaporation of the acetone carrier. Again it was suspected that DDT would be adsorbed onto particulate matter in the water, with a resulting diminution in the amount of DDT available throughout the water mass. Results of this series of tests are listed in Table III. The distribution of median resistance times is illustrated in Figure 4.

Table III

Time to 50 per cent mortality (ET_{50}) for samples of coho salmon underyearlings exposed to various concentrations of the DDT-acetone standard.

Dilutions of the reference solution providing DDT at the following theoretical concentrations p.p.m.	Average concentration of DDT by chemical analysis, p.p.m.	ET_{50}, minutes
3.0	0.31	850
1.0	0.29	730
0.7	0.06	850
0.5	0.05	1,100
0.3	0.09	1,150
0.1	0.08	1,750
0.07	0.05	>10,075
Control	Control	No mortality

In this series nearly all test fish died within the first 48 hours, consequently few analyses were possible for actual DDT content of each test solution. Some of the error in the response distribution for this series is undoubtedly connected with inability to sample at shorter intervals. A further source of error would be associated with variations in the amount of particulate matter in the test solutions.

Analysis of the transformed data indicates considerable variation in the distribution of resistance times; nevertheless, the trend in median resistance times is considered to be linear (Figure 3). Abrupt changes in slope within the probit response curves from 0.1 to 0.7 p.p.m. DDT theoretical dosage suggested that the response of the fish to the solutions might have been changing with evaporation of the acetone carrier.

Interpretation of Results

A limiting concentration of Atlox 2082A is estimated to be approximately 2.1 p.p.m. and, proportionately, this amount would be found at a DDT level of 14.0 p.p.m. The action of Atlox 2082A as a toxic agent would probably be found only at

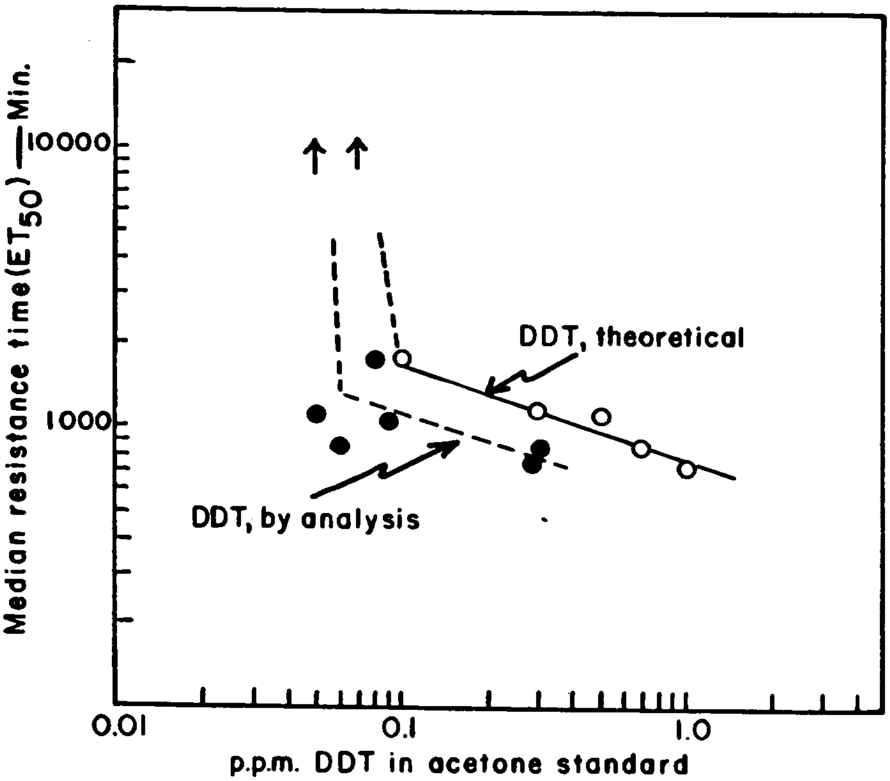

FIGURE 4—*Times to 50 per cent mortality in samples of 10 underyearling coho exposed to various concentrations of the DDT-acetone standard. For an explanation of the arrows, see Fig. 3.*

extremely high concentrations of spray formulation. It is doubtful if such concentrations would be found under spray conditions.

No valid statistical comparison can be made between the response distributions for the aerial spray formulation and DDT-acetone standard as that of the former is not linear. The bizarre distribution of resistance times for the aerial spray formulation suggests that the physical aspects of contact with the spray formulation or its components are dissimilar within the range of concentrations examined. In terms of DDT available in the water mass, the aerial spray caused mortality at and above 0.05 p.p.m. whereas 0.02 p.p.m. available DDT did not affect the test fish within the experimental period. In the case of the DDT-acetone standard, the lowest concentration producing mortality was again 0.05 p.p.m. available DDT. However, as the 0.07 p.p.m. test (0.05 p.p.m. available DDT) did not cause mortality within the experimental period, whereas the 0.5 p.p.m. (0.05 p.p.m. available DDT) did, factors may operate to determine toxicity other than that of the final amount of DDT available. Comparing the two response distributions from another aspect, the resistance times of the samples of young salmon exposed to the aerial spray are greater than those for the fish exposed to the same range of DDT concentrations in the DDT-acetone standard, even though this range ultimately was lethal in both cases.

In summary, and in terms of the test conditions, the aerial spray formulation may be regarded as "safe" to young coho salmon below approximately 0.05 p.p.m. where the measure of safety is regarded as the absence of mortality within an exposure period of one week at 10°C. An unusual response distribution was found for the aerial spray with resistance times increasing with increase in dosage over the higher portion of the concentration range examined. Associated with high concentration of spray, however, was development of blindness in the test fish. The series of tests tended to point up the complexity of the problem of interpretation of the action of associated variables. Besides the measure of DDT available to the test fish within the water mass, it is considered that the stability of the solution in such aspects as volatility, gravity stability, adsorptive potential of inclusions in the water supply and action of associated formulation components may have a considerable influence on the biological activity of the formulation used. Indeed, such factors may to a large extent be responsible for some of the diversity of tolerance estimates reported in the literature. A thorough study of the relation of such physical characteristics to biological effects on fishes would be a useful adjunct to such tolerance studies.

It should also be recognized that the criterion of safety applied here for young salmon does not necessarily relate to the impact on the total biological community. The tests do indicate, however, the range of concentrations of DDT and the related exposure times which could be harmful in the field.

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The Effects on Fisheries of Man-Made Changes in Fresh Water in the Maritime Provinces

by

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It seems inevitable that there will be a great deal of repetition in the presentations in this symposium. This is to be expected since we are all dealing with the same general subject—the influence of environment or changes therein on one type of animal—fish. There is no doubt, however, that there will be differences in emphasis as we consider different species, the variation in the patterns in industrial development, the different characteristics of each region and the differences in stress exerted in enlarging the economy in each district.

I should admit at the outset that I am glad to have such repetition since it will serve to stress again and again the problems facing the relatively recently developed Fish Culture Development Branch of the Conservation and Development Service of the Department of Fisheries of Canada. Our main responsibility is to overcome such problems to maintain and expand the runs of fish for use. We will be extremely happy if we can convince you of the challenge presented and perhaps persuade some of you to join us in our efforts.

The Maritimes area including New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland, in its original state was adequately, although in the opinion of some, not over-supplied with natural resources. Early settlers could be selective from the abundant forests, fish and minerals. As the population grew and the demand for raw materials increased, it soon became evident that some resources would be seriously reduced or wiped out if improperly managed. Man-made changes were the basic reason.

As would be expected, particularly in New Brunswick, Nova Scotia and perhaps Newfoundland (although the latter is at a relatively early stage of development) the forest industry must be held responsible for the major environmental changes affecting fish. These have been either directly or indirectly responsible for reducing the productivity of some of the finest streams in salmon, alewives, smelt and other anadromous fish.

Direct action has been taken to erect dams to create head ponds to store water for log driving and mills. Dams and jams have resulted from log drives and logging slash. A few of these might only have been temporary obstructions, but I am afraid that the vast majority at one time or another provided complete blocks which prevented spawning runs from reaching their destination.

An added threat has been the destruction of spawning grounds and the eggs and fry therein through the physical action of log drives. This method was and still is the chief means of transportation of timber to the mills and pulp plants, although fortunately for the fish, trucking is gaining ground. One would find it almost impossible to assess absolutely the damage from this source, but it has been heavy and the productive capacity of the rivers has suffered.

Logging has undoubtedly changed the environment through the removal of large blocks of timber. At the present this removal is proceeding to the very water's edge of some of our biggest and best streams. The adverse effects to fish must be rather obvious—the scouring of the redds from heavy freshets, the cutting of new channels, with the consequent dewatering of spawning nests and stranding of young fish, the heavy silting resulting from erosion and the rise in temperature in periods of low flow in the summer and early fall. I have always been convinced that the scientists have failed in not studying the effects of such changes more thoroughly. If we had, perhaps we could give firmer proof to support our generalizations. Pertinent studies are now taking place but the period of history is half finished.

Also associated with the forest industry but hardly its fault, is the necessity for control of forest insect pests. The outstanding example is the DDT spraying programme for spruce budworm. From 1952 to 1957, 11½ million acres were covered at a cost of over ten million dollars. This is well over half the forested area of New Brunswick. The chemical had disastrous effects on the young fish and stream insects.

The mills and pulp plants must also accept some blame. Perhaps without too serious consideration solids such as sawdust and chips have been discharged into the streams. The results are obvious in such rivers as the St. Croix where good river bed is blanketed for miles. The introduction of liquid effluent and chemicals with a high oxygen demand has served to set up conditions almost intolerable for fish. Perhaps the fault lies to some extent with the fisheries scientist since it is only relatively recently that methods have been devised to control such waste and use it to advantage.

Hydroelectric installations have had their direct and indirect effects on fish in the Maritimes area. It is true that the topography of the district does not encourage the development of high head economical power in large blocks, but large numbers of low-head installations have been built to provide the necessary energy for industrial and domestic consumption. In many of these, fish facilities have been incorporated but in others they have been neglected, probably due to the lack of appreciation on all sides of the contribution of small rivers to the total fish production. In some such as the Mersey in Nova Scotia, construction has been allowed to proceed on one dam after another until the stream is just a series of reservoirs with little resemblance to the original salmon habitat. Such is the struggle for power!

Main stream dams, the usual type in the Maritimes, even when provided with fishways, inevitably seem to cause delay to ascending adults. Often in late summer or early fall, shortage of water precludes efficient operation of such fishways. The fish may become the victims of flow regulation on week-ends or other periods of low water utilization. They are then usually more vulnerable to the sportsman, the poacher and other predators.

Main stem installations also alter stream conditions above the dam, flooding out spawning grounds, and changing the productive capacity of the nursery areas. The composition of the fish in these reservoirs could quite easily swing from competitors to predators.

Downstream migrants are also affected. Loss of young passing through turbines may be small or large depending on the type of machine in use. Migrants stunned in this passage are obviously more vulnerable to predators.

Only a few diversion type power installations are found in the Maritimes, but the problems which they pose for fish are equally if not more complex. To obtain sufficient transportation water to pass adults is difficult in an area where economical storage is limited and summer droughts threaten power production.

A unique but clear demonstration of difficulty encountered is seen in the recent power development at Beechwood on the main Saint John River. Because of doubtful footings a standard pool and step fishway did not seem possible. A conventional fish collection gallery was constructed along the power-house face leading to a skip-hoist device designed to lift the migrants over the 60-foot dam. These facilities were completed and in operating order before the salmon run but minor difficulties in the construction schedule made their efficient utilization impossible. The remains of a coffer dam below the power-house created adverse current conditions and the release of the water from the spillway gates across the dam rather than from the draft tubes appeared to attract the migrants away from the gallery. This certainly proved the necessity of adhering to a previously approved schedule. It was a real challenge to experiment and adjust and a real accomplishment to pass over twelve hundred fish.

Agriculture, superficially an innocent industry which normally has similar objectives of water and soil conservation, as does fisheries, has created some complex problems in the Maritimes. In recent years there has been a trend toward the development of somewhat unique flood control structures known locally as aboideaux. These are in effect dams to prevent tidal waters from inundating low marshland areas near the river mouths and thus reclaim from the sea agricultural land.

The large aboideaux built in recent years are replacing the simple river bank dykes formerly used. Equipped with special gates to allow the outflow of the stream and yet prevent salt water inflow on flooding tides, these present many difficulties to migrating fish. The large difference in tide level in the area where aboideaux are most effective in recovering land, e.g. Bay of Fundy, practically eliminates the use of conventional fish passes. Because of the water control, the environment in the stream and estuary is altered. There is little possibility left for adjustment to salt water for downstream migrants and there is also a sudden change from salt to fresh for those moving upstream.

Agriculture has been indirectly responsible for introducing toxic chemicals into some streams. We have experienced on occasion the results of paris green which as a result of unusual rains drained from the potato growing areas into the streams. One or two streams have been seriously affected by effluents from potato starch plants.

It is well known that the mining industry may adversely affect freshwater streams by releasing sludge and toxic chemicals. Fortunately, however, the development is only now starting and there is opportunity to prescribe remedial measures at the outset.

It is rather peculiar that in Prince Edward Island in one or two streams a great problem has been created by gravel removal. This is probably due to the fact that on the "Island" gravel deposits are limited and large operations are carried out where it does exist. Silting as a result is widespread with the result that large stretches of the streams become non-productive.

In closing, it is perhaps pertinent to mention the development of recreation and transportation, man-devised, since this is responsible for opening areas previously inaccessible. Undoubtedly the result has been beneficial in equalizing the fishing pressure but road building has frequently been responsible for undesirable changes through filling, dredging and improperly designed culverts.

It would appear from this presentation that everything is against fish and that there is no hope in the Maritimes. This idea should be dispelled because in the overall there is an appreciation of the fisheries interest. We must be prepared to suggest and implement the remedies. For this we need more knowledge of fish behaviour and reaction and more people prepared to accept the challenge of overcoming the difficulties. I can assure you that it is a worthwhile reward to solve any one of the problems. We have a whole series of experiments on a grand scale thrust at us through the economic development—we should use them to gain more knowledge.

The Effects on Fisheries of Man-Made Changes in Fresh Water in the Province of Quebec

by

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Introduction

This very broad subject must be reduced to a few remarks dealing with conditions characteristic to Quebec. French speaking men, unfortunately, abuse the freshwater fisheries in the same way as English speaking do in other provinces. The fast developing industries—mines, paper-mills, and hydropower installations usually overlook such a small thing as freshwater fisheries! Within a few years, after new automobile roads, railways and dams had been built, the forests chopped down, and logs (or locally "pitounes") driven down salmon or trout rivers, Quebec lakes and rivers were no more a paradise for fish. During the present decade, the yearly cutting of wood in Quebec averages close to 2½ million cords or 208 million cubic feet (Le Soleil, Nov. 30, 1957, p. 3). You can imagine easily that only a minimum quantity of this pulp is going to be used for scientific papers, the authors of which are trying to protect the natural resources.

In 1952, during the centenary of Laval University, a symposium on "The Conservation of Renewable Natural Resources" was presented. According to Desmarais (1953, p. 54), the Province of Quebec is not only the largest in Canada, with 600,000 square miles, but also its nap of fresh water is equal to 12 per cent of the total superficies. The annual precipitation varies according to the region, from 20 to 45 inches. There are 21 lakes with a superficies larger than 100 square miles and, in addition to the St. Lawrence, there are four rivers longer than 450 miles. The forests occupy 77 per cent of the whole province.

Unfortunately, the aquatic fauna of to-day's Quebec is not as rich as it was 400 years ago, when Jacques Cartier visited the St. Lawrence area in 1534. After spending the winter of 1536 at the estuary of the river, known today by his name, he wrote: "There are also to be found in June, July and August, plenty of large eels . . . . . and plenty of lampreys and salmon (Chambers, 1912, p. 20)".

Administration

The administration of Quebec fisheries, both fresh water and marine, by provincial authorities began only in 1883, that is 16 years after Confederation. However, long before that there existed in Canada a service of "Fisheries Protection". Dr. Pierre Fortin, a native of Verchères near Montreal and an M.D. from McGill University, was appointed in 1852 to direct this new service for Lower Canada, especially in the

Gulf of St. Lawrence from Pointe des Monts and Cap Chat to Baie des Chaleurs. Five years later another equally valuable man, of English birth, Richard Nettle, was appointed Superintendent of Fisheries with jurisdiction over the upper St. Lawrence, its tributaries, and interior lakes. Nettle can be called also "the father" of Canadian fish hatcheries. In effect, in 1857, in a house in Quebec City at the corner of St. Ursule and St. John Streets, he opened the first fish hatchery, which he called an "Ovarium". Both these men are well known also for their writings: "Reports" by Fortin and a small, but very interesting book, "The Salmon Fisheries of the St. Lawrence and its Tributaries" (1857) by Nettle.

The present administration of fisheries in the Province of Quebec is quite effective, especially for marine species. However, even here some more precision should be incorporated. For instance, according to the federal laws, applicable in Quebec as well, there are provisions regarding fishing for sturgeon, but the species is not mentioned. In the case of four eastern maritime provinces, there is no confusion, as there is found only one species sea sturgeon (*A. oxyrhynchus*); probably for Ontario and the Prairie provinces this law means the lake sturgeon (*A. fulvescens*). But how should it be interpreted for Quebec, as there are found two species *A. oxyrhynchus* and *A. fulvescens*. In British Columbia it is even worse as there live two very different species: white sturgeon (*A. transmontanus*) and green sturgeon (*A. medirostris*).

In the case of Quebec administration of freshwater fisheries, there are more complications. For instance, the Quebec Department of Game and Fisheries has jurisdiction only over fish and other animals, but not over the waters and woods wherein they live. If a company is planning to cut woods along a river, this company must secure, from the Commission of Running Waters and Department of Lands and Forests, permission to build dams to drive the logs. Then only this company obtains from the provincial Department clearing papers as to the necessity of erecting a dam with or without a fishway. The most important part of the law stipulates that upon completion of the period of exploitation of a given river, the company *must restore the original condition that existed in this river previous to exploitation.* I have always wondered and never found an answer as to how this can be done!

Man-Made Changes in Freshwater Environment

In the case of Quebec we shall mention only three types of human activities, which adversely affect the local fish and fisheries.

1.—*Paper Industry.* The principle abuses by this very important industry can be summarized as follows: fast thaw of snow, quick run-off of rain, and reduction in food supply especially for young fish (trout and salmon) due to excessive cutting of surrounding trees; building of roads for hauling logs; construction of dams to store water to drive pulp wood or operate hydro installations; and finally pollution of waters by bark, sawdust and industrial wastes ("black liquor").

To illustrate the influence of a papermill on freshwater fisheries a typical situation in the province where the plant is located near the mouth of a river will be described. This company produces its own power, has a large woods operation and manufactures a variety of paper products.

From an economic standpoint this establishment is very important, as it employs a large number of the local population, who work either in the mill, cutting and driving wood or at the hydro installations. Unfortunately, when a high dam was built across the river, provision was not made for a fishway. The results were that when the salmon returned to the river of their origin they found their ascent to the upper river spawning grounds had been blocked.

Water stored behind the dam throughout the summer is used during the winter to generate hydro-electric power required to run the mill. There is a 14-foot fluctuation in lake elevation between the late summer, when the reservoir is filled, and early spring when it is drawn down to its minimum elevation. The reduction in the lake level during the winter months results in the desiccation and freezing of aquatic plants and animals along the shoreline, which under natural conditions make a significant contribution to the food chain of resident fish populations. Storing surface water in the reservoir during the summer months prevents the temperature of the lower strata from rising above 40°F. The combination of the above factors in such an area are considered responsible for the slow growth of speckled trout in the lake.

Further damage to rivers is caused by removing the forest cover from large areas in these river systems. In recent years the amount of pulpwood cut in sections of the province has increased by two and one half times. Removal of trees accelerates spring thaws causing floods, reduces an area's ability to retain moisture causing floods and later drought. Stripping of trees from river banks reduces the natural stability of a stream.

Pulpwood in this part of the country is river driven, arriving at the mills about 60 per cent bark. Considering bark at approximately 600 pounds to the cord, bark deposition on some rivers amounts to several tons each year. Spawning areas may be reduced and rich food production areas may be completely smothered.

Several obnoxious substances known as "black liquor" are produced by mills during the production of paper products. "Black liquor" consists mainly of waste sulphuric acid, tannic acid and lignin. Serious losses to fish stocks may be caused by this pollutant if improperly treated before being released from a mill.

2.—*Mining Industry.* The mineral riches of Quebec are even higher than those of the forest. To-day we shall mention only the case of Black Lake, situated in the asbestos region, close to Thetford Mines.

This lake, of about 410 acres, is located 750 feet above sea-level. Its bottom consists of very rich deposits of asbestos. In 1956, work was started to drain this lake. Through an artificial canal of 6,000 feet, its water was directed to the Becancour River. So far about 57 feet of bottom deposit has been removed. This work required monthly removals of about 1,000,000 tons of bottom silt. Of course there are no more fish left in this lake. Apparently no obnoxious substances have been drained into the Becancour River, which is a popular fishing centre for small-mouth bass.

3.—*St. Lawrence Seaway.* Thanks to Mr. Cyrille Felteau, Information Officer of the St. Lawrence Seaway Authority, we were able to obtain the following data on the extent of work on this seaway.

The parts of this project that interest us most are the dredging of the channel and the building of locks and other installations. Altogether 112 new navigable miles, 27 feet deep, through the rapids, are being opened between Montreal and Prescott, Ontario. To accomplish this job, 73,440,400 cubic yards of rock and mud are being removed.

The building of seven new Canadian locks, which are 768 feet long, 80 feet wide, and 30 feet deep, required 2,010,000 cubic yards of concrete. The construction of the Quebec lock, located at St. Lambert, opposite Montreal, required the removal of nearly 2,500,000 cubic yards of rock and mud and the pouring of 450,000 cubic yards of concrete. In addition a hydro-electric plant is located at Cornwall, Ontario, with an artificial lake of 40,000 acres.

The changes in the St. Lawrence River due to the different undertakings in connection with the seaway are unfavourably affecting the local fisheries. Unfortunately there are no precise data as to the extent of these influences. Nevertheless we can suppose that the dynamiting and dredging of the channel have killed the fish found nearby. In effect, during the summer of 1956 we saw several dead fishes, especially lake sturgeon and pike-perch (*Stizostedion vitreum*), over a large area, from Sorel to Ste-Anne-de-la-Pérade. However, the exact causes of this mortality were not established.

We suspect also that the tremendous quantities of cement used, could easily raise the alkalinity of the surrounding water to the danger point. In 1947, for instance, we poured cement over the bottom of a laboratory aquarium. After washing and repeated changes of water, some fish were put in from another aquarium without cement. In about two hours one young lake sturgeon and one small-mouth bass were dead, while a brown bullhead was dying. The difference between the two aquaria was in the pH values: 9.2 in the aquarium with the cement and 7.0 in the other.

During the summer of 1956, the year of the fish mortality, we took some surface-water samples from Montreal to Ste-Anne-de-la-Pocatière. The pH of the St. Lawrence below Montreal is no higher than 8.2. Around Montreal it is 8.6, while near the new St. Lambert lock the readings were 9.20 and 9.75.

Another very unusual observation is that in 1957, throughout the St. Lawrence River, adult striped bass, which spawn in the Lake St. Peter area, were apparently reduced to a very small number. The exact reason for the reduction of the bass is unknown. Fishermen observed in the spring of 1957 some large striped bass (4-8 pounds) dead among ice floes at Ste-Angèle-de-Laval, opposite Three Rivers, and about 150 miles farther east at Rivière Ouelle. The causes of this mortality remain unexplained.

It is probably an opportune moment to ask the question: what changes in fishery conditions will there be in the St. Lawrence River in a few years from now, with the seaway in operation? There is no doubt that excessive alkalinity of cement and other material used in the construction of locks and hydro plants will gradually be washed out. The direction of the current will follow a new definite pattern. Some new pollution, especially by discharge of oil and petroleum products, will increase due to the much greater volume of navigation. The exchange among freshwater and anadromous fish species from the lower St. Lawrence and Great Lakes region will be accelerated.

Since 1944 we have studied closely changes in fish composition in the upper St. Lawrence River. Two native Great Lakes species, the gizzard shad (*Dorosoma cepedianum*) and white bass (*Lepibema chrysops*), and, recently introduced in Lake Oswego, the white perch (*Morone americana*) enter yearly in variable numbers in the Quebec section of the St. Lawrence River. The white perch is found in very small quantities; altogether from 1952 to 1957 only 43 specimens have been taken. The two other species are found in much larger quantities. The greatest number (3,098) of white bass was taken in 1954 and of gizzard shad (415) in 1955. The years 1956 and 1957 were very poorly represented, maybe due to the construction works on the St. Lawrence Seaway. We believe that Quebec will contribute "in exchange" a greater number of eels and sea lampreys.

4.—*Man Helps Nature.* In conclusion, we would like to bring to attention at least one case of man's activity which has helped increase the natural population of important animals. We would like to speak about the snow goose (*Chen hyperborea*) and Canada goose or outards (*Branta canadensis*). These two aquatic birds sojourn some months in Quebec in the spring and fall, during their migratory flights. The snow geese are found not very far from Quebec City, between Cape Tourmente to l'Islet, while the Canada geese extend through a much larger territory, from Kamouraska to Montreal.

Thanks to Mr. Louis Lemieux of the Canadian Wildlife Service, we can give the following information. There were, in 1957, about 20,000 Canada geese, weighing on the average nine pounds. They feed partially on aquatic vegetation and partially on grains from the farmers' fields. They are found quite often in the company of snow geese, and the duration of the sojourn for both species is about the same.

The second species, the snow goose, is far more interesting. It is the pride and joy of Quebec. Thanks to the protective steps taken by the authorities of the Quebec Department of Game and Fish and especially by the late Superintendent, Mr. Charles Frémont, the number of snow geese, from a skimpy flock of 3,000 in 1908, reached an estimated 100,000 in 1957. They sojourn in Quebec from the end of March to the end of May and from the middle of September to the end of November. Their average weight is about six pounds. They stay on the shores of the St. Lawrence River and feed on roots of the American bullrush (*Scirpus americanus*), locally known as "foin de gréve".

It will be important to find out the quantity of guano that the present Quebec flock of snow geese, amounting to 600,000 pounds of live birds, drops daily during its almost five months' sojourn on the St. Lawrence shores. Thus we consider both species of geese as very beneficial to local fish, due to the fertilizing effects of their guano in producing live fish food.

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The Effects of Power, Irrigation, and Stock Water Developments on the Fisheries of the South Saskatchewan River

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I. Introduction

The South Saskatchewan River system rises on the eastern slopes of the Rocky Mountains in a large series of mountain streams. These flow together to form several major rivers which emerge from the mountains in a north-south series from central Alberta to the international boundary. On the prairies these rivers ultimately join to form the South Saskatchewan River which flows eastward into Saskatchewan and then north eastward to meet the North Saskatchewan River on the northern fringes of the prairies.

The portions of the system which lie within and close to the mountains at altitudes of 3,000 feet and higher are natural trout waters. They are cold, swift and subject to severe run-off floods; the native fishes are *Salvelinus alpinus malma*, *Salmo clarki* and *Prosopium williamsoni* in the highest parts, with the addition of *Cottus ricei*, *Catostomus commersoni* and *C. catostomus* at slightly lower altitudes. Stocking has established *Salvelinus fontinalis*, *Salmo trutta* and *Salmo gairdneri* in many of the streams. Some of the streams rise in headwater lakes in which the cutthroat and Dolly Varden were the native fish. Two large lakes contain *Salvelinus namaycush*.

On the prairies the trout and char disappear and the rivers support suckers, cyprinids, percopsids, goldeyes, whitefish, northern pike and yellow walleyes.

One of the major mountain rivers of this system is the Bow and its tributaries; all of the high altitude developments to be described in this paper are on the Bow River. Three of the large irrigation systems outside the mountains also use Bow water. Other irrigation and stock water developments involve the St. Mary River system and smaller tributaries of the Bow, Red Deer and the South Saskatchewan rivers.

II. Power Dams on Bow River Headwater Lakes

Five headwater lakes have been dammed to store water for power production. They are Lake Minnewanka, in Banff National Park, The Upper and Lower Spray Lakes and the Upper and Lower Kananaskis Lakes, the latter four in Alberta. Table I shows the original areas and depths of these lakes, the new areas and depths produced by the dams, and the maximum draw-downs.

TABLE I

Headwater lakes of the Bow River

	Years Dammed	Original Area (Acres)	Original Mean Depth	New Max. Area	New Mean Depth	Draw-down
Minnewanka	1912, 1941	3,464	125	5,454	170	35
Upper Kananaskis	1936, 1942	1,440	20	2,100	58	52
Lower Kananaskis	1954	720	45	1,620	47	43
Upper Spray	1949	113	6	4,800	120	35
Lower Spray	1949	313	70			

Lake Minnewanka: This is the largest of the headwater lakes. A dam in 1941 increased its area by a little over one-third and its average depth by 45 feet. Biological examinations of the lake were made before and after the dam was built by Rawson, Stenton, Solman and Cuerrier. A summary of the findings has been published by Cuerrier (1954).

The physical and chemical characteristics of Lake Minnewanka and the plankton have altered little, if any, since the dam was built. The bottom fauna has changed profoundly; the annual draw-down of 35 feet exposes most of the littoral zone and littoral bottom animals have not become established. Midge larvae have increased from $52\frac{1}{2}$ to $93\frac{1}{2}$ per cent of the total fauna and sphaeriids have decreased from 38.6 to 4.6 per cent of the total fauna.

TABLE II

Main stream reservoirs of the Bow System (Upper)

	Year Dammed	Area (Max.)	Mean Depth	Draw-down	Years Studied
Ghost	1930	2700	approx. 50	25	1938, 1943, 1947, 1954
Barrier	1947	760	approx. 50	25	1938, 1946-7
Glenmore	1932	960	approx. 25	5-10	1947-8

The major sport fish was the lake trout, *Salvelinus namaycush*, which fed on an introduced species of cisco and on the native Rocky Mountain whitefish. Since the dam was built this fishery has degenerated very seriously. The trout do not reach sizes beyond about one pound; at this weight there is normally a change from plankton and bottom feeding to fish feeding. This change is not now made, and growth is arrested. The fluctuations in water level apparently result in an ecological separation of the trout and the forage fish on which they feed. An attempt to remedy this situation has been made by introducing the lake whitefish, *Coregonus clupeaformis*.

An interesting sidelight of the Minnewanka story is the discovery that lake trout will spawn at great depths. It was thought that the eggs would be exposed by the draw-down and destroyed; some suffer this fate, but a substantial portion of the eggs is deposited well below the limits of the draw-down.

THE SPRAY LAKES: Originally there were two Spray lakes; the upper had an area of 113 acres and was very shallow. Few fish lived in it but it produced enormous numbers of freshwater shrimps and longnose dace and, during summer, cutthroat and Dolly Varden from the lower lake foraged there. The upper lake drained by a creek into the lower lake, which had an area of 313 acres and an average depth of 70 feet. It had a meagre bottom fauna, comparable to other high oligotrophic lakes, but a fairly rich zooplankton of large copepods. A large population of fast growing, red-fleshed cutthroat trout provided excellent angling. The other game species was the Dolly Varden.

In 1949 a dam was built across the Spray River below the lakes. This created a lake of 4,800 acres, completely obliterating the original two, and increasing the average depth to about 120 feet. An annual draw-down of 35 feet alternately exposes and floods about half of the lake bottom.

After six years, M. J. Paetz found that the plankton was fairly abundant, but that the larger species of copepod had disappeared, possibly due to increased turbidity. No bottom fauna had become established on the new lake bottom which is steep and rocky. The fauna of the original lake beds was reduced and sparse.

The Alberta government carried out a compulsory creel census during 1953, 1954 and 1955. The results were analysed by W. H. Macdonald and a summary published in 1956. The catch of cutthroat trout fell off markedly after the first year of the census. In 1953, 4,334 fish were caught of which two thirds were cutthroat trout; in 1955, 2,875 fish were caught of which one half were cutthroat trout. Anglers' reports indicate the cutthroat have declined further since 1955.

The explanation of the deterioration lies to some extent in the poorer food supply that followed on the flooding. However, the main cause appears to be the elimination of spawning areas. Before the dam the trout spawned in the creek between the lakes and in the gravel below the Spray Falls just upstream from the lakes. Both these areas were eliminated and the nearest spawning gravels are many miles up the Spray River. Here the distinctive lake population has merged with the river population and apparently is losing its identity.

Ciscoes and lake trout have been introduced in the hope of providing angling when the cutthroat trout have become too scarce to be of value.

LOWER KANANASKIS LAKE: This 720 acre lake had an average depth of 45 feet; when the dam was built in 1954, the area at FSL was increased to 1,620 acres but, owing to the gentle contours of the flooded area, the average depth increased only to 47 feet. The lake was studied, prior to impoundment, by Rawson in 1936 and 1947 and by Miller in 1954. Post-impoundment observations have been made by Thomas in 1957.

The 43 foot maximum annual fluctuation alternately floods and exposes 900 acres, or more than half the maximum area of the lake. This has eliminated the littoral fauna. The plankton and deeper bottom fauna appear little changed. Physical and chemical characteristics remain about the same except for increased turbidity

The native game fish were cutthroat trout and Dolly Varden. In the late 1930's rainbow trout came down from the upper lake where they had been introduced. The present *Salmo's* are mostly hybrids between the rainbow and the cutthroat.

The fate of the *Salmo's* seems fairly sure—they will vanish. While reduced food is of some importance, the main cause is the elimination of spawning areas. Originally, the trout spawned in three places; in the Kananaskis River between the upper and lower lakes—this has been dry since the dam was built on the upper lake; in the river below the lower lake—this has been flooded by the dam which impounds the lower lake; and Bolton Creek—a small tributary. This last still provides some spawning, but less than before, as its lower reaches are flooded; also it is subject to violent fluctuations in level during spawning time.

The suckers of Lower Kananaskis provide an instructive lesson in the results of changing spawning facilities. In 1936, three years after the Kananaskis River between the lakes had been cut off, Rawson took 202 sturgeon suckers in one gill-net setting. Eleven years later in a comparable setting he took only three. In 1954 the author caught 166 common and one sturgeon sucker. The sturgeon suckers spawned in the river between the lakes; when this vanished, they dwindled to virtual extinction and their place has been taken by the common sucker, which spawns in muddy bays in the lake.

UPPER KANANASKIS LAKE: This lake is formed by the headwaters of the Kananaskis River. Its original area was about 2½ square miles and its mean depth approximately 20 feet. It contained cutthroat trout and, after 1935, rainbow trout. The main trout food was evidently the shrimp *Gammarus* which formed an appreciable part of the bottom fauna. The water was very cold, slightly silty, and supported a moderate plankton, rich in crustacean species.

Control dams were built in 1936 and 1942. The area increased at FSL to 2,100 acres. The dams permit a draw-down of 52 feet. Dr. Rawson examined the lake in 1936 and again in 1947 after the dam was built. He found the *Gammarus* had virtually disappeared and midge larvae predominated in the bottom fauna; the trout grew slowly and naturally spawned year classes appeared to be absent. Fishing in the lake is poor and it is now little visited by anglers. The deterioration again seems largely due to interference with spawning facilities, with some influence due to change in the bottom fauna, induced, of course, by the fluctuating water level.

In summary of Section II it may be said:

Headwater power dams lead to deterioration of trout resources. The deterioration is produced by several factors:

(1) Interference with spawning grounds; in the Kananaskis lakes the trout are cut off from their spawning by the dams. In Spray the spawning areas are now remote from the lake.

(2) Reduction of the portion of the bottom fauna utilized by the trout.

This is caused by the seasonal changes in water level which do not interfere with midges but do cut down on amphipods, littoral may-flies and sphaeriids.

III. Power Dams on the Bow River, or on Large Tributaries

The major main stream reservoirs are the Ghost Reservoir on the Bow River, Barrier Reservoir on the Kananaskis River and the Glenmore Reservoir on the Elbow River. These have been examined at various times by Rawson and by Miller, Macdonald, Paetz and Thomas.

GHOST RIVER RESERVOIR: This reservoir was formed in 1930 by building a dam across the Bow River just below the mouth of the Ghost River, a large Bow tributary. It was examined in 1938 and 1947 by Rawson, in 1943 by Miller and in 1954 by Thomas.

At maximum level the reservoir has an area of 2,700 acres, a mean depth of approximately 50 feet, and it is subject to an average annual draw-down of 25 feet. The draw-down occurs in April; the reservoir fills again in June.

The plankton was sparse and the water silty in 1938; these conditions remained the same in 1943, 1947 and 1954 and presumably will not change.

The bottom fauna has also remained constant since 1948; it is a poor fauna consisting of oligochaetes, midge larvae and sphaeriids in that order of abundance.

In 1938 the fish fauna was predominantly of common and sturgeon suckers with some Rocky Mountain whitefish, burbot, *Lota lota maculosa*, and Dolly Varden and a sparse population of cutthroat and brown trout—too sparse to provide angling.

In 1947 lake trout turned up and thereafter lake trout were stocked several times. In the last few years anglers have caught small numbers of lake trout, but the fishery is confined to a small, silt-free area in the mouth of the Ghost River.

The combination of silt and fluctuating levels render this reservoir of extremely low productivity and no improvement is likely.

GLENMORE RESERVOIR: In 1932 the city of Calgary built a dam across the Elbow River upstream from its junction with the Bow and on the edge of the city. The dam created the Glenmore Reservoir which is used as a water supply for Calgary.

The reservoir has an area of 960 acres and a mean depth, when full, of about 25 feet. There is never a great fluctuation in level; the principal drop is in late fall and in winter, below the ice cover.

The reservoir was studied by Rawson in 1938 and by Miller in 1947. Both investigations found a poor plankton, reminiscent of the Ghost Reservoir and a moderate bottom fauna. No change was noted from 1938 to 1947.

In the summer and winter of 1947 an intensive study of the fish population was undertaken by gill-net settings. The reservoir was found to contain a large population of common and sturgeon suckers, a moderate population of pike and a sparse, and evidently seasonal, population of trout and burbot. At certain times trout fishing has been fairly good.

This reservoir, while more productive than the Ghost, is limited by the constant load of suspended silt.

BARRIER RESERVOIR: Barrier Reservoir was formed by a dam in the lower Kananaskis River built in 1947. When full, it has an area of 760 acres and a mean depth of approximately 50 feet. The annual fluctuation, from April to June, is 25 feet as in the Ghost; the low water exposes an enormous area of mudflats.

The reservoir was examined by Rawson during the year it filled and by Nursall in the following year. No studies have been made since. The reservoir has failed to produce angling of significant value.

Barrier Reservoir appears to be a smaller duplicate of Ghost Reservoir; it suffers from a similar silt load, sparse plankton, and fluctuating level. It is unlikely to provide a fishery of value.

In summary of Section III, it may be said:

The main stream reservoirs might be hoped to create a fishery where none, or only a very small one, existed before. Their construction could not lead to the deterioration of an established fishery, as is the case with the headwater lakes. However, they do not provide the angling that their surface dimensions might suggest. This is apparently due largely to two factors that diminish productivity, 1) a load of silt which leads to a sparse plankton, and 2) alternate flooding and exposure of the productive littoral zone which is proportionately large in reservoirs of this type, thus leading to a bottom fauna of small size and poor in trout-food organisms.

IV. Irrigation Reservoirs

Irrigation development in Alberta involving the South Saskatchewan river system has resulted in approximately 1,371,000 acre feet of water storage. This storage is divided among 37 reservoirs supplying water to nine irrigation systems. The primary sources of most of this impounded water are the Bow and St. Mary rivers. The remaining storage involves small projects on tributary streams in the Red Deer and Oldman river watersheds and tributaries of the South Saskatchewan River proper. Waters impounded for irrigation purposes may be divided into two categories, namely, irrigation dams on streams and reservoirs created by diversion schemes.

IRRIGATION DAMS ON STREAMS: For the purpose of discussing the effect on fisheries, stream impoundments may be further divided into: (a) large primary reservoirs on main streams and (b) reservoirs on tributary streams supplying relatively small irrigation projects.

a. Primary reservoirs on main streams

BASSANO RESERVOIR: Bassano dam was built on the Bow River in the early days of settlement on the Alberta prairies. It forms water headworks of the Eastern Irrigation District. The reservoir created by the dam extends up the Bow River valley approximately five and one half miles and has a surface area of slightly more than 1,300 acres. Rather than being designed for storage the dam serves to raise the water level of the river so that it can be diverted through a system of canals to irrigable lands.

The original reservoir had a maximum depth of 60 feet but extensive silting has reduced the maximum depth to 31 feet. Over four-fifths of the reservoir is now eight feet or less in depth. Since the main purpose is not one of storage, there is little annual fluctuation in level. Water temperatures in the reservoir during the summer are about the same as those of the Bow River in this region (65° F in August). There is no thermal stratification and little oxygen depletion. Due to the heavy silt load, the water transparency is only five feet.

Plankton production in the reservoir is low and more typical of river plankton than lake plankton. The bottom fauna is rich but composed mainly of silt resistant forms such as Oligochaetes, Chironomids and a few Sphaeriids. Fresh water shrimps are absent or at best very rare.

Fish production during the early history of the reservoir is virtually unknown. The first recorded fish sampling was done by Miller in 1947. The tail waters below the dam were also sampled at that time. The reservoir was found to contain a population of common suckers and an occasional northern pike. The tail waters supported a rich fish fauna of goldeye, *Amphiodon alisoides*, yellow walleyes, *Stizostedion vitreum*, lake whitefish, Rocky Mountain whitefish, and suckers. Anglers fish these tail waters extensively but rarely fish in the reservoir. As well as goldeyes and yellow walleyes, the occasional cutthroat rainbow hybrid trout is taken in the tail waters. It would appear that Bassano reservoir produces less game fish than a comparable length of unaltered Bow River water.

ST. MARY RESERVOIR: St. Mary reservoir was formed by construction of a dam across the St. Mary River near Spring Coulee in 1951. It was examined by Miller and Paetz in 1952. The purpose of the reservoir is primarily water storage. At full supply level it has an area of 8,800 acres and a mean depth of 36 feet. The 80 foot vertical draw-down during the summer, reduces the surface area to 1,000 acres and the mean depth to 30 feet.

The water temperature, due to the influence of the incoming river, remains very uniform. It varies only six degrees (55° F to 61° F) from bottom to surface.

Plankton was abundant during the 1952 examination; Cladocerans were especially well represented. The bottom fauna was in early stages of establishment. Bottom animals are doubtless now restricted to only that portion which remains flooded at maximum draw-down.

The fish fauna in 1952 consisted chiefly of northern pike, sturgeon suckers, common suckers and cutthroat trout. These species were resident in the river prior to impoundment. Rainbow trout were stocked in 1953 and landlocked sockeye salmon were stocked in 1952, 1953 and 1955. Rainbow trout showed excellent growth in the reservoir but provided angling for only a brief period. At present, pike fishing yields considerably better returns than trout fishing. Gill net settings during the past year yielded no trout but fair numbers of pike and lake whitefish. There have been no indications that the sockeye salmon introductions were successful.

After a short period of fair trout production, St. Mary reservoir has undergone a shift in fish fauna to less desirable game species. There is little hope of a recovery of the trout fishery but there are indications that a small commercial whitefish fishery may be established.

TRAVERS RESERVOIR: Travers reservoir was formed by building a dam on the Little Bow river in 1953. An additional supply of water for the reservoir is obtained by canal from Lake McGregor which lies immediately to the north. At maximum level, Travers reservoir has a surface area of 5,600 acres and a mean depth of 46 feet. The annual vertical draw-down of 16 feet reduces the surface area to 4,600 acres. The mean depth at low level is 39 feet. Although the reservoir exhibits definite thermal stratification, the hypolimnion retains an adequate supply of dissolved oxygen.

The bottom fauna is thus far sparse, except at the upper shallow end of the reservoir. Plankton is also scanty in deep areas but much richer in shallow portions.

Fish have access to the reservoir both from the Little Bow river and Lake McGregor. Sampling with gill nets and seines has shown that northern pike, common suckers, sturgeon suckers, chub, *Couesius plumbeus*, and lake whitefish have become established. A commercial fishery for whitefish was attempted early in 1956 but with little success. In 1957 the reservoir yielded 9,000 pounds of whitefish and 2,000 pounds of pike to commercial fishermen. The whitefish fishery is expected to develop further. Lake trout have been introduced but at this time it is not known whether or not the introduction was a success.

b. Irrigation reservoirs on small tributary streams

CAVAN RESERVOIR: Cavan reservoir was formed by a dam on Gros Ventre Creek to supply water to the Ross Creek Irrigation District. It was given only a brief examination by Miller and Paetz in 1952. At full supply level the reservoir has an area of 300 acres and a mean depth of 16 feet. The summer draw-down is variable, depending on the water demand of the small irrigation project which it supplies. Due to the contours of the coulee in which the reservoir lies, the draw-down does not significantly affect the area.

The plankton is rich, especially in plant forms, which cause extensive water blooms. The bottom fauna has not been studied.

The fish fauna originally consisted of suckers and fathead minnows, *Pimephales promelas*. Rainbow trout were introduced in 1952 and additional plantings were made in 1955 and 1956. The initial planting of trout was very successful and trout growth proved to be excellent. In four summers, these fish attained weights of 10 to 14 pounds. Yields to anglers for two years after the introduction, were good but thereafter a sharp deterioration in angling success was noted. Plantings of trout subsequent to the 1952 introduction have not restored the fishery appreciably.

CAROLSIDE RESERVOIR: Carolside reservoir was formed by damming Berry Creek, tributary to the Red Deer River. The stored water is used to supply a small scale irrigation project but future development will link this reservoir with a larger irrigation scheme.

At full supply level the reservoir has an area of 1,600 acres and a mean depth of 19 feet. Maximum draw-down is not expected to exceed one-half the total storage capacity. During seven years of operation the annual draw-down has not approached the expected maximum.

Carolside reservoir is typical of prairie lakes in that no thermal stratification occurs and water temperatures reach 65° to 68° F during the summer. The yield of both plankton and bottom fauna is moderate.

The fish fauna consists of common suckers, cyprinids, sticklebacks, *Eucalia inconstans* and northern pike. The latter species was introduced as a game fish in 1951.

This introduction was a decided success and the excellent pike fishing attracts fishermen from a radius of approximately 100 miles.

Carolside reservoir has provided angling in a part of the province where practically no angling opportunities existed previously. The future of the fishery is, however, dependent largely on water demand for irrigation purposes.

Reservoirs Created by Diversions

The greatest percentage of irrigation storage in the South Saskatchewan drainage is provided by diversion reservoirs. These projects vary in usable storage capacity from 1,000 to 240,000 acre feet. They are supplied by diversion canals from rivers or from mainstream reservoirs. A number of these reservoirs function as "balancing reservoirs" and do not fluctuate noticeably in level, whereas the water supply types fluctuate rather violently.

GRASSY LAKE RESERVOIR: This reservoir lies in the St. Mary-Milk River irrigation development. It is seventh in a series of reservoirs which obtain water from the main canal leading from St. Mary dam. The surface area, at full supply level, is approximately 1,100 acres. An expected seasonal draw-down of 14 feet will reduce the surface area to 700 acres.

Although no biological surveys have been carried out on Grassy Lake, there is considerable information available on the status of the fishery. The reservoir was filled in 1953 and 250,000 rainbow trout were introduced the following spring. A second planting of trout was made in 1955; no further stocking was considered worthwhile. Trout introduction proved very successful. Fish of 12 to 16 ounces in weight were being caught by September of 1954 and during the next two summers the lake provided excellent trout fishing. Deterioration of angling success similar to that experienced on Cavan reservoir, followed, although some large trout were known to be present. Recent sampling of the fish population indicates that whitefish, northern pike, suckers and burbot are now well established. Yellow walleyes were represented by two specimens.

DRIGG'S RESERVOIR: Drigg's reservoir was formed by building two dams on a basin in the Mami Creek Valley. The reservoir obtains its water from Mami Creek and a diversion canal from the Belly River. It supplies water to the Mountain View-Leavitt Irrigation District near Cardston.

At maximum level the reservoir has an area of 832 acres and a mean depth of eight and one-half feet. The original policy regarding draw-down, was to keep the reservoir at or near full supply level during the summer, then lower the level in late fall to a maximum depth of seven feet to avoid flooding in the spring. After trout planting was undertaken in the reservoir, irrigation authorities co-operated by keeping the fall water levels high to prevent winter kill. Under this policy of water manipulation there is actually little annual fluctuation in level.

Observations by Miller (1942) revealed a rich bottom fauna and plankton. The reservoir bottom was more productive at depths of 15 feet and over since these portions had not been exposed by fall draw-down.

During early years of operation, Drigg's reservoir supported a large population of common suckers, fewer sturgeon suckers, fathead minnows and a sparse population of Dolly Varden trout. Cutthroat trout had access to the reservoir from Mami Creek but did not inhabit it in sufficient numbers to provide good angling. Rainbow trout stocking was carried out and this resulted in improved trout fishing. Trout growth averages eight to ten ounces per fish each summer. Drigg's reservoir offers opportunities for management of a trout fishery. Draining the reservoir periodically would achieve control of coarse fish populations as well as enabling removal of large trout when fishing begins to deteriorate.

McGREGOR RESERVOIR: McGregor reservoir was formed by construction of dams at the north and south ends of a large prairie coulee. Water is supplied to the reservoir by a diversion canal from the Bow River at Carseland. The maximum area of 10,700 surface acres is reduced to 6,380 acres by a 15 foot annual draw-down. The mean depths are 28 feet at full supply level and 22 feet at minimum level.

No plankton studies have been made on McGregor reservoir. Hartman (1957) took a series of bottom samples from north to south and found a low to moderate fauna present. Silting near the north-end inlet appears to restrict bottom food production in that portion of the reservoir.

McGregor reservoir supports a varied fish fauna of suckers, burbot, northern pike, lake whitefish and cyprinids. In addition to a substantial sport fishery for pike, a commercial fishery for whitefish is sustained. The average annual commercial whitefish yield over a 12-year period has been 151,800 pounds.

This impoundment has resulted in establishment of a commercial fishery comparable in importance to that of a number of small natural whitefish lakes in Alberta. No fishery existed prior to building of the reservoir.

CHIN LAKE RESERVOIR: Chin lakes originally were three natural lakes lying near the north end of a long prairie coulee. A dam was constructed between the two lower lakes in the early 1900's to provide approximately 7,700 acre feet of irrigation storage. Later, when the Chin project was included in the St. Mary-Milk River Development, a canal was built to convey water from the St. Mary reservoir to Chin lakes. This was the stage of development when the lakes were examined by Thomas in 1955.

The lower lake at this time was shallow and choked with emergent aquatic plants; it was not examined. Discussion here will be limited to the middle and upper lakes. The middle lake had a relatively constant area of 500 acres and a maximum depth of 22 feet. The upper lake comprised 1,600 surface acres with a maximum depth of 33 feet. In 1955 neither lake had been subject to draw-down during the preceding seven years.

No thermal stratification occurs; dissolved oxygen is present to near saturation at all depths during the summer.

Production of bottom fauna was low in both lakes but the plankton was moderately rich.

The fish fauna consists of cyprinids, common suckers, northern pike and lake whitefish. A commercial fishery was operated in 1947-48 with a production of 26,000 pounds of whitefish and 3,000 pounds of pike. Chin lakes were not fished commercially again until 1955. In 1955-56 the fishery yielded 3,000 pounds of whitefish; in 1956-57 the yield increased to 11,300 pounds.

The upper lake is now undergoing further development for irrigation. A dam recently completed between the upper and middle lakes will increase its area to 4,000 acres at full supply level. A rather severe annual draw-down of 54 feet will reduce the area to 2,300 acres. In view of this development and the existing low bottom food production, it is believed that fish production will show little, if any, improvement.

JENSEN RESERVOIR: Jensen reservoir was formed by damming Pothole Creek coulee, a tributary of the St. Mary River. Prior to completion of the St. Mary dam in 1950, Jensen reservoir was used as an irrigation water supply but since that time it has been used only as a "balancing reservoir" and is no longer subject to draw-down. It now receives water from St. Mary reservoir and delivers water to Ridge reservoir to the north east.

At full supply level the reservoir has an area of 525 acres and a mean depth of 34 feet. Thermal stratification occurs in August, resulting in depletion of oxygen below the 35 foot level.

Miller and Ward in 1950, found that the reservoir was poor in bottom fauna but rich in plankton with zooplankton predominating.

The fish fauna consisted of a large population of common suckers and small numbers of northern pike. Burbot have since been reported present in considerable numbers. Rainbow trout were stocked for three successive years beginning in 1950 and a fourth planting was made in 1955. Trout of the first two plantings grew rapidly and provided fair angling returns. Subsequent plantings have yielded poor returns. The establishment of pike and burbot in the reservoir and continued entry of these and other undesirable species through the irrigation system suggest that there is little hope of managing these waters for trout production.

In summary of Section IV it may be said that:

(1) Excessive fluctuation in level on St. Mary reservoir and pronounced silting of Bassano reservoir prevent development of worthwhile fisheries. Travers reservoir is a contrast in these respects and is expected to provide both sport and commercial fishing.

(2) Good sport fisheries have been provided by irrigation reservoirs on small tributary streams but continued production is dependent on extent of draw-down and is therefore uncertain.

(3) Diversion reservoirs in some instances offer opportunities for short term trout fisheries. The majority have provided sport fishing for northern pike while the larger reservoirs contribute substantially to the commercial pike and whitefish production of the province. The total annual commercial yield from irrigation reservoirs is approximately 580,000 pounds of whitefish and 40,000 pounds of pike. An increase in commercial production is expected as recently completed projects come into production.

V. Stock Watering Reservoirs

The water shortage which developed on the Alberta prairies as a result of the severe drought of the 1930's, demonstrated the need for a water conservation programme which would assure stockmen of a constant future water supply. Many small reservoirs which store spring run off waters have since been built by the P.F.R.A. (Prairie Farm Rehabilitation Act) or by stock growers with assistance from this organization. These reservoirs are usually located on coulees, intermittent creeks or small permanent streams which drain into the larger water courses. A number of these stock watering impoundments have been found to offer suitable habitat for game fish; many, however, are too shallow to sustain fish life over winter; still others are located in such sheltered situations that shortage of dissolved oxygen renders them unsuitable for fish.

Limnological and biological data are lacking on many of these projects even though satisfactory fisheries may have become established in them. Several that have been examined and are providing angling may be used as examples.

ARMSTRONG RESERVOIR: Armstrong reservoir was formed by damming a small intermittent creek on the north slopes of the Cypress Hills. It was examined by Miller and Paetz in 1953 shortly after completion and while the level was approximately four feet below full supply.

At maximum level the reservoir is about 60 acres in area and has a maximum depth of 20 feet. There is a possibility of draw-down in dry years to supply water to the ranches below the dam. Thus far a draw-down has not been required.

No thermal stratification occurs. Water temperatures reach 65° to 70° F during the summer.

Plankton was rich in variety of forms but only moderate in quantity when compared with that of typical prairie lakes. Although quantitative estimates of bottom fauna were not made it was noted that fresh water shrimps, Chironomids, snails and leeches were becoming established.

The only species of fish occurring naturally in the reservoir was the red belly dace, *Chrosomus eos*. Rainbow trout were stocked in 1953, 1954 and 1955. The growth rate of trout was comparable to that in Cavan reservoir and a successful trout fishery has resulted. Deterioration of angling success is now taking place, suggesting a need for a trout rehabilitation programme.

NEUFELDT RESERVOIR: This reservoir was formed by a dam on Tennessee Creek, a small stream draining from the Porcupine Hills to the Oldman River. It is a very small reservoir, approximately one and one-half acres in area with a maximum depth of 14 feet. Tennessee Creek flows throughout the year at a rate of less than one cubic foot per second except during spring run-off when the flow increases considerably.

Water temperatures in the reservoir do not exceed 60° F.

A moderate plankton is produced with zooplankton being greater in quantity than phytoplankton. No bottom fauna studies have been made.

No fish were resident in the reservoir prior to introduction of 3,000 rainbow trout in 1956. Throughout the 1957 season, angling success was excellent. The trout averaged less than one pound in weight by the end of the second summer. Growth rate was therefore noticeably less rapid than in Armstrong and Cavan reservoirs.

In summary of Section V it may be said that:

Stock watering dams have added significantly to the sport fishery potential of the South Saskatchewan watershed. The small size of most of these impoundments and the absence of undesirable coarse fish species provide opportunities to establish successful trout fisheries.

VI. Discussion and Conclusions

We have been considerably hampered in our attempt to evaluate the fishery situation in these reservoirs by a shortage of factual material on physical, chemical and biological conditions before and after the developments were made. However, some firm conclusions may be drawn:

(1) Power projects on high altitude lakes and rivers have proven to be, in Alberta, uniformly deleterious to the sport fishery. Trout and char fisheries which existed in the lakes prior to the power developments have deteriorated very markedly. On the whole, physical and chemical conditions and the plankton have been little affected; the bottom fauna has usually suffered profound changes, particularly littoral forms which are eliminated by fluctuating water levels. The trout have become scarce partly because of this change in bottom food, but mainly because of the elimination of suitable spawning gravels. At present there is no promising management scheme in sight for these power lakes.

(2) Power projects on rivers and streams have not increased the productivity of sport fishes beyond the level that existed in the rivers before damming. The reservoirs are characterized by high silt loads, low plankton and bottom fauna and sparse fish faunas. The fluctuating water levels rule out any useful management scheme.

(3) Irrigation dams and diversions and stock-watering projects, all at lower altitudes than power projects, lie, therefore, in more fertile soil and are considerably warmer. This gives them an inherently greater productive potential. In addition, the majority is subject to much less draw-down than mountain developments. These advantages are reflected in the fish production. The large reservoirs have developed valuable commercial fisheries for whitefish and pike and sport fisheries for pike. Little or no success has been achieved in attempts to establish trout fisheries in them. The small reservoirs which acquired a coarse fish fauna at the time of their construction have provided good pike angling; those where coarse fish could be excluded have been stocked with rainbow trout. The trout grow extremely well and have provided some excellent angling. However, the angling degenerates as a residual population of large trout accumulates. Some of these may be managed by lowering fall water levels to create winter kills, but most of them constitute, at present, an unsolved management problem.

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The Effects on Fresh Water Fisheries of Man-Made Activities in British Columbia

by

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Introduction

The development of British Columbia has been confined to such a recent period of history that it is relatively easy to describe with some confidence the effects of man's activities on the abundance and distribution of freshwater species of fish. It is only since the turn of the century that there has been any major exploitation of the province's resources and industrial development has taken place most noticeably only in the last decade. Fisheries agencies were thus largely cognizant of the potential effects of development on fisheries and were organized to cope with them almost from the time that the problem was posed.

British Columbia has a diversified group of natural resources and thus a great variety of effects on fisheries can be observed. Logging is the province's major industry. Mining for gold, base metals, coal and other valuable minerals is another major provincial industry. In fairly restricted areas agriculture is very intensive. There are abundant sites for development of hydro-electric power, and access to the sea and the subsequent cheap transportation cost encourage secondary industry. Hence the recent and diversified resource development occurring at a time when fisheries agencies were both informed and conservation-minded has provided an excellent opportunity for study, both of the effects of man's activities on freshwater fisheries, as well as the methods of alleviating the effects when they are harmful.

Most of the material in this paper was assembled by six graduate students at the Institute of Fisheries at the University of British Columbia. These students were Messrs. G. Dibblee, J. C. MacLeod, J. D. McPhail, V. R. Pantulu, J. T. Pennell, and C. E. Stenton. Their information was gained both from reviews of the literature and extensive discussions with Messrs. C. H. Clay and W. R. Hourston of the Department of Fisheries of Canada and Mr. R. G. McMynn and Mr. F. P. Maher of the British Columbia Game Department.

It is to these latter authorities that most of the credit is due for the factual material which was assembled, most of which was available only in government files and accessible only to those who were initiated into the intricacies of finding things in government filing systems.

Effects on Fresh Water Fisheries of Forestry Practices: (J. T. Pennell)

The effects of forestry practices on freshwater fisheries can conveniently be divided into general effects, such as the effect of logging on run-off characteristics of watersheds; and particular local effects that depend on the mechanics of the logging operation and the particular local situation.

General effects

It has long been known that the characteristic pattern of flow in streams can be greatly influenced by modifying the character of the plant cover. Extensive logging of an area undoubtedly changes the pattern of run-off from that area. Although there has been no work in B.C., directly correlating these changes in run-off with change in fish productivity, Neave (1949) in a study of the game fish population of Cowichan River, cautiously ascribed a change in the abundance of fish and/or their availability to anglers to changes in run-off consequent upon extensive deforestation in the area.

Logging results in removal of the forest cover, a compaction of the soil, and an overall decrease of ground litter. Removal of the trees decreases the area of surface available for the evaporation and interception of precipitation. Compaction of the soil and reduction of litter is followed by a decreased permeability and storage capacity of the soil for water. A greater fraction of the water runs off the soil surface.

These changes are reflected in the consequent run-off pattern after deforestation. After deforestation there is:

1. An increase in the absolute amount of water flow from that area. It has been estimated that for every pound of dry wood produced by a tree, 1,000 pounds of water are transpired.
2. An increase in the flood peak discharge and a decrease in the low water flow. This is attributable to the changed storage capacity of the soil and the increased amount of direct run-off.
3. Increased run-off and flood peak flows usually mean increased erosion of the watershed area and increased turbidity and sedimentation in streams flowing from the area.
4. An increase in the temperature of streams flowing from the area. This increase in stream temperature follows the removal of streamside shade trees and possibly the increase in the proportion of direct run-off as compared to water percolating slowly down through the soil.

The importance of stream temperature in the distribution and migration of trout has often been noted. A study in the Smoky Mountains of Tennessee showed that migration upstream of brook trout followed logging of the watershed. In a comparison of stream temperatures from two watersheds—one containing a farm, the other a forest, Green (1950) records that over a period of a year the farm stream with little or no shade averaged 11.5°F higher (ranging from 9-20°) than the forest stream with its abundant shade.

The increased turbidity and sedimentation in streams after logging usually has a detrimental effect on the fish population, smothering eggs and altering the aquatic organisms, particularly the aquatic insect fauna, upon which many fish feed.

The increased flood peak flows gouge out fresh stream channels, disturb existing spawning gravel, and pile up debris impeding the water flow. The decrease in low water flow reduces the area available for spawning and feeding of fish. Eggs may be left high and dry in the gravel.

Sustained yield and patch logging with greater care in the construction and placement of logging roads mitigates deforestation effects on run-off pattern.

Concerning B.C., A. J. Whitmore of the federal Department of Fisheries, in the brief to the Sloan Commission on Forestry, 1956, has this to say, "Our department would welcome recognition in the forestry permits of the fisheries needs as associated with streams and lakes, in the terrain to be logged. The recommendation in our previous brief (to the Royal Commission of 1945) that a one-half mile wide belt of timber be left along all salmon streams was ruled to be uneconomical".

These recommendations have now in part been implemented. In the Prince Rupert area an arrangement has been made between forestry and fisheries departments whereby as soon as an application for logging is received at the district forester's office the files are consulted to see if a salmon stream is within the area to be logged—the salmon streams within forestry areas having been indicated on forestry maps by the fisheries inspectors of each sub-district. If a salmon stream or portion of a stream is involved, the district supervisor is advised and he notifies the fisheries inspector in charge of the district involved requesting that he recommend the most suitable clause of the Forest Act, Forest Management, that would provide adequate protection to the salmon stream involved. The clause is then inserted in the logging contract and once the licence is granted the fisheries inspector can carry out periodic checks to ensure that the conditions of the contract are not being violated. The forest management clauses most applicable are—

L30: "The licensee shall at all times keep all streams and stream beds free from logging debris, sawdust and slabwood, and shall cause no interference with, or obstruction to, stream flow at anytime. All trees felled within......feet of the...... stream shall be felled away from the creek."

L30A: "It is understood and agreed that it is a condition of this contract that no slash or other logging debris is to be placed in any stream channel, neither are earthfilled stream crossings to be used, nor are logs to be skidded within any stream channel whether containing water at the time or not".

L30B: "All streamside trees within......chains of any stream or stream bed on the sale area, which are required to be cut under the contract shall be felled away from the stream even though this may require special measures".

L30C: "All logging and road building debris shall be kept out of streams at all times and out of reach of high water. Such logging and road building debris as does get into the streams shall be removed by methods as directed by the forestry officer in charge".

L30D: "All tractors and logging equipment shall be kept out of stream channels and away from the banks except for the minimum number of necessary crossings which shall be carefully situated and protected as required, to ensure that they do not become sore spots in the channel."

Local Effects

In the above-mentioned brief to the Sloan Commission it is stated: "*Log driving* in shallow rivers caused considerable damage in the past and remains a constant threat. Besides the devastation from the gouging of spawning gravel bars and resultant channel erosion, the construction of so called 'river improvements' creates further hazards by disrupting the normal regime of the river." Stranded logs may divert water flow from gravel bars, resulting in drying out of deposited spawn, or diversion of normal water flows from potential spawning areas. Although log driving is now rare in B.C., the operations that do occur can do tremendous harm to the fishery. The remains of many of the old "splash dams" still exist on many rivers in B.C. Some have been removed and programmes are underway to rehabilitate the salmon runs. The Adams River is an outstanding example of what log driving can do to a stream and its fish. The Kalum and Zymoetz (Copper) tributaries of the Skeena River, and the Nass River from the North end of the Columbia Cellulose Licence area to Grease Harbour—a distance of about 75 miles—are understood to be currently under view for log driving.

Log driving and booming on larger rivers such as the Fraser appear to leave the fish unharmed.

Log jams and logging debris often cause obstructions and where they hinder up and downstream migration of fish, are undesirable. Where log jams are directly attributed to the operations of a logging company, the operators are obliged to clear the obstruction. Fisheries officers and stream clearance personnel of the Fish Culture and Development Branch of the Department of Fisheries, clear jams other than those mentioned. Unless jams are impassable or at least a decided hindrance to fish passage, they may be a stream asset; the deep holes usually associated with jams afford places of refuge for salmon prior to spawning. In addition a jam often prevents severe scouring during freshets.

Pulp mills are large water consumers; their waste products must be disposed of economically. Water intakes for pulp mills have been screened and storage facilities provided where pulp mill demand would have reduced stream flow.

Sawdust disposal from small sawmills requires constant checking by fisheries officers in order to prevent pollution. Mill Lake (personal communication from Dr. P. A. Larkin) at Abbotsford has been adversely affected by sawdust pollution and smothering the bottom fauna. The disposal of water, containing a heavy concentration of bark sediment, from the hydraulic barking process now being installed in many mills could cause increased pollution problems. No serious pollution has been reported from this specific cause as yet in B.C. Adequate screening is usually practised.

Spraying against forest insects has recently created some local problems. In 1957 there were extensive efforts on the part of federal and provincial governments and the companies whose timber was affected, to save large stands of hemlock in the Nimpkish-Port Hardy area on Vancouver Island from defoliation by the black headed budworm. Aerial spraying of D.D.T. over some 158,000 acres at a cost of over $300,000 was carried out in 1957. Timber values were estimated at $25 million.

From test pens and general observation, damage to young salmon was extensive. Every effort was made by those in the spraying operation to avoid contamination of streams and lakes but seemingly without success.

Summary

There can be no question that historically, extensive clear cut logging has had deleterious effects on populations of freshwater and anadromous fish, particularly in coastal areas. However, the recent trend to sustained yield management of forest resources together with the inclusion of practices in logging which are designed to protect fisheries resources, will no doubt greatly mitigate these effects in the future.

At the same time, other trends in modern forestry practices are causing substantial concern to fisheries agencies. The indiscriminate spraying of large areas of forest for insect control is known to have disastrous effects on fish in streams. If forest spraying is to be carried on in the future on a large scale—and there are indications that it may be—fisheries agencies will require a greatly increased knowledge in this field upon which to base sound conservation measures.

Effects on Fresh Water Fisheries of Agricultural Development in British Columbia (J. D. McPhail)

At the present time the effects of agriculture on fisheries in B.C. are relatively unimportant. Nevertheless these effects are real, and it seems likely that they will become increasingly important in future years.

The major agriculture practices affecting fisheries in B.C. are:

1. Irrigation
2. Removal of cover from a watershed
3. Crop spraying

Since many of the flood control devices which have been installed in British Columbia have been designed for protection of agricultural areas they will also be discussed here.

Irrigation

It is estimated that 150,000 acres are under irrigation and that in British Columbia another 500,000 could be brought under irrigation at a somewhat higher cost (Purcell 1955). Most of the irrigation takes place in the dry interior region of B.C. although there is considerable land under irrigation in the lower Fraser Valley. Irrigation is especially important in the Okanagan Valley and the Kamloops-Merritt district.

Irrigation can affect fish in the following ways:

1. Fish are diverted into irrigation channels
2. Water is removed from the stream
3. Water is stored for irrigation
4. Silting arising from irrigation caused erosion

The diversion of fish into irrigation channels can be a major problem. For example the Nicola River and its tributaries are important salmon producers, but there is also extensive irrigation and large numbers of young salmon are diverted each year into the irrigation channels. In many small diversions water is pumped from the stream. Unless the pumps are properly screened young fish can be sucked into the pumps and killed.

It is not expected that losses of this type will become a serious problem. Present regulations specify that all types of irrigation diversions must be properly screened. The Department of Fisheries has developed self-cleaning screens for larger diversions. These are being installed by the Government on all old diversions and by the builders on any new diversions.

The minimum flow of a stream is held to be one of the most important factors limiting productivity. The removal of water for irrigation purposes comes at a time when stream flow is naturally low. Irrigation therefore aggravates the minimum flow condition. Low water reduces nursery areas, exposes spawning beds and causes an increase in maximum temperatures. In many cases so much water is taken that the stream dries up. Clemens et al. (1939) estimated that perhaps 60 per cent of the tributary streams entering Okanagan Lake were being more or less completely utilized for irrigation purposes. Undoubtedly the percentage is much higher at the present time. The Salmon River which flows into Shuswap Lake once supported a run of sockeye salmon. So much water is being utilized for irrigation purposes that the stream goes dry over much of its length during the summer months.

Applications for water licences are now referred to the Department of Fisheries, the B.C. Game Commission and the International Pacific Salmon Fisheries Commission for comments and suggestions. These organizations attempt to reserve minimum flows in fish producing streams.

The storage of water for irrigation purposes has some important effects. Dams are built at the outlets of lakes whose outlet streams are used for irrigation. The flow through the dam can be controlled and in this way a good supply of water is assured during the irrigation season. Beaver Lake and many other mountain lakes in the Okanagan are dammed in this manner. The water level fluctuations of these lakes are increased by the storage dams, but in some instances productivity is improved by changes in lake morphometry. In many of these lakes adult trout go over the dams to spawn but neither the adults nor the fry can get back into the lake. Where possible the storage regime is modified for fish conservation purposes. The construction of fishways at storage dams and stocking programmes where indicated have greatly offset any harmful effects.

Silting caused by erosion has been minimized in recent years by increasing use of soil conservation techniques. Sprinkler irrigation (rather than furrow irrigation), the planting of cover crops, and contour plowing have all been encouraged with mutual advantage both to the agricultural and fisheries resources.

Removal of Watershed Cover

When the large trees and other cover are removed from a watershed the result is usually a very rapid run-off and often a lowering of the water table.

The physical characteristics of a stream determine to a great degree what the level of abundance of fish will be. Some of the more significant physical characteristics which can limit productivity are:

1. Minimum flow—low flows restrict the food supply, strand fish inside pools, render fish more susceptible to predation and can increase temperatures to intolerable levels.
2. Stability of bottom deposits—highly variable run-off, freshet conditions, stream silting, bottom scouring etc., destroy food organisms, prevent successful incubation of eggs and in other ways adversely affect fish populations.
3. Stability of stream banks—largely associated with natural cover. Bank erosion causes silting, absence of shade warms the water and reduces natural cover.

These three characteristics are inter-related and often occur together. All three can be caused by man's utilization of the stream's drainage area. In most parts of B.C. agriculture does not affect a very large portion of a stream's drainage area. However, the lower mainland is a notable exception. The entire drainage areas of many of the small, but heavily fished lower mainland streams are almost entirely utilized for agricultural purposes.

A good example of such a stream is the Salmon River in the Langley area. The forest cover of the Salmon River drainage area has been greatly reduced and replaced by cultivated crops and grass land. This has resulted in increased stream discharge during periods of heavy precipitation and in lower reserves of ground water during the more arid periods. Farmers with wells in this area have reported a drop in the summer water table of from 15 to 20 feet since first entering the area (McMynn and Vernon 1954).

It has been demonstrated (Neave 1949) that a simple general relationship existed between stream run-off and the commercial catch of coho salmon two years later. It is also known that minimum flow of any stream is an important limiting factor in the number of fish produced by that stream. Utilization of the Salmon River drainage basin for agricultural purposes has resulted in greater variability in stream flow, restriction of cover and erosion of stream banks. The low flow condition is further aggravated by irrigation. There are 30 licensed water users in the area. They utilize nearly 400 acre feet of river water annually. The greater portion of the water used for irrigation is used during the minimum flow period. It seems very likely that in the case of the Salmon River minimum flow is a main limiting factor in fish production. There can be little doubt that the low minimum flow is largely a result of the utilization of the drainage basin for agricultural purposes.

Flood Control

Because flood control is intimately connected with the problem of run-off it is included here. It is not, however, strictly an agricultural problem.

Two of the major flood control projects in B.C. have affected fisheries. These are the Okanagan River flood control project and the flood control programme on the lower Fraser River.

With the construction of the Grand Coulee Dam the upper Columbia River salmon populations were relocated. Large numbers of sockeye were planted in Osoyoos Lake. As a result the Okanagan River above Osoyoos Lake is now one of the major salmon producers of the Columbia system. In 1950 a flood control project was proposed on the Okanagan River. The project plans included the construction of a new stream channel between Osoyoos Lake and the Southern Okanagan Lands Project Dam. Part of the new stream bed was to be paved with heavy boulders. This would eliminate a major portion of the sockeye spawning beds. Because the new river bed would be much shorter than the original, the channel gradient would be much increased. In order to compensate for this it was proposed that thirteen vertical drop structures be built between Osoyoos Lake and 1½ miles north of the town of Oliver. These drop structures would constitute a series of obstructions which would cause the delay of the migrating salmon. Because the salmon ascending the river from Osoyoos Lake are fast approaching maturity this delay would be of serious consequence.

A report on these fisheries problems associated with the project was prepared in 1954 by the U.S. Fish and Wildlife Service, the Washington State Department of Fisheries, and the Department of Fisheries of Canada. In this report modifications of the proposed project were suggested in order to preserve the salmon runs. The following pertinent modifications were suggested:

1. Instead of paving, parts of the channel should use dyking or some other means of channel protection.
2. That the vertical drop structures be built in such a manner as to assure unobstructed movement of the salmon, i.e., the installation of weirs in the drop structure stilling basin.
3. That provision be made for a minimum flow in the summer months.

These recommendations were followed to a large extent by the flood control authorities and salmon still spawn successfully in this portion of the Okanagan River.

Following the flood of 1948 the Fraser Valley Dyking Board was set up to carry out a flood control programme. This programme consisted primarily in the construction of dykes on the low-lying regions contiguous to the Fraser River. Flood gates were constructed on several lower mainland tributary streams entering the Fraser. These flood gates are automatic and close when the Fraser starts to back up into the tributary streams. When the gates are closed water is pumped out of the stream, over the dyke and into the Fraser.

The 15-year average duration of freshet on the Fraser extends from May 1st to July 31st (Hourston 1950). The months of April and May are the period during which the greater part of the seaward migration of young salmon takes place. This means that during a large portion of the migration period the only route to the Fraser is through the pumps. It was observed that some degree of mortality was resulting from this passage through the pumps. Experiments were carried out and it was established that the mortality varied directly with the length of the fish. The rivers involved are utilized by coho, chum and pinks. Chums and pinks migrate seaward very soon after hatching and as a result they are very small, and so is the mortality through the pumps. Coho, however, usually spend up to a year in fresh water and are of such a length when they migrate that a high mortality could occur when they go through the pumps. For this reason it has been recommended that bladeless pumps be used.

Crop Spraying

It is well established that many of the insecticides used agriculturally are toxic to fish in the concentrations used. It has been reported (G. Dibblee, personal communication) that there have been several cases of minor fish kills in the lower Fraser Valley due to crop spraying. However none of these instances have been investigated.

In Alabama, Young and Nicholson (1951) report that a combination of heavy rainfall and repeated applications of insecticide resulted in the washing of sufficient toxic material into streams to cause major fish kills. These conditions are often duplicated on the lower mainland and it seems likely that there is some fish mortality from crop spraying.

Summary

In general, the effects of agriculture on fisheries in British Columbia can be regarded as relatively unimportant at the present time. Losses of fish in irrigation diversions have been reduced by screening. Reduction of flow in streams and storage dams on small lakes have had harmful effects but every effort has been made to minimize losses. Soil conservation practices have lessened the harmful effects of silt in streams. Flood control programmes have been studied from the fisheries viewpoint and have incorporated fish protection measures.

With complete inspection of all water licence applications an established routine there is every reason to believe that the present situation can be maintained.

Effects of the Mining Industry on Fresh Water Fisheries of British Columbia (G. Dibblee)

Generally speaking, the mining industry of British Columbia poses a potential threat chiefly to the sport fishery of the province. Damage to the sport fishery can arise mainly from two phases of mining activity which may be described as mining and processing. In placer gold mining it is the actual mining operation that adversely affects the sport fishery while in the case of other minerals it is the waste products of the processing operation which can cause harm. Since the extraction of minerals from their ores and the disposal of the resulting waste products requires a large amount of water it is not surprising to find that processing plants are almost invariably located near a lake or stream. If any lake or stream on which a plant is located is used to carry away the waste product of the processing operation, serious harm to any sport fish present will result.

The most intensive mining area is the southeastern portion of the province. In terms of the number of mining centres and value of minerals produced, it represents well over 50 per cent of the provincial total. This area also presents more mining pollution problems than all the other areas combined.

Placer mining is particularly detrimental to the sport fishery. Because the mining operation itself takes place in the stream and utilizes the gravel of the stream, there is little that can be done to avoid the harmful effects of this operation. Placer mining by dredging involves scooping up the gravel of the stream bed, screening out the larger stones, and running the rest through sluice boxes where the gold particles settle out and are reclaimed. Hydraulicing is also used in placer operations. This consists of directing water through high pressure hoses at the banks of the stream bed and at other gravel areas that cannot be reached by dredging. Mr. F. P. Maher (personal communication) summarizes the effects of placer mining on a river as follows:

1. The removal, screening, and final replacing of the gravel in the stream bed greatly increases its porosity since only clean stones are replaced. This may result in the stream disappearing and flowing underground.
2. Stacker belts of the dredges replace the gravel in the stream in an unnatural way with the fine gravel on the bottom and the coarse gravel on top. This reduces the bottom fauna and prevents or reduces spawning.

3. The gravel might be replaced by piling which creates pools and back-waters which become dry at lower water levels.
4. The operation of sluice boxes and hydraulicing produce large volumes of silty water which affect the stream as mentioned below in the case of tailings.
5. Large scale placer mining operations often remove plant cover and top soil from large areas along the stream banks. This causes higher stream temperatures due to lack of cover, reduction of surface insects available as food, and erosion—which can cause excessive siltiness.

The majority of *mining pollutions* in southeastern British Columbia are caused by the wastes or tailings of the processing operation which extracts the minerals from their ores. Most commonly the minerals are lead, zinc and tungsten. The ore from the mines is conveyed to the mill, ground up, mixed with water and various re-agents, put through a flotation process and the metal extracted. Since the mineral recovered forms a small part of the ore, the waste product amounts to a sizeable output. Small mills put out up to 150 tons of tailings a day, while larger mills produce up to 2,000 tons a day. Tailings appear as a sludge made up of water, chemicals and ground-up rock of various sizes. If the tailings are allowed to enter a stream the effects are highly deleterious to the sport fishery:

(*a*) The turbidity caused by the tailings inhibits angling, reduces photosynthesis which in turn reduces productivity. Algal growth disappears.

(*b*) The coarser sand particles of the tailings are usually quite clean and apparently have a scrubbing effect on the rocks and gravel of the stream. This tends to remove algal growth as well as bottom organisms.

(*c*) Coarser rock particles plug up the interspaces in the gravel and hence reduce the habitat of bottom fauna.

(*d*) Spawning of trout is affected since observations by Maher on the Lardeau River indicate that trout avoid highly turbid water and will crowd into clear areas to spawn. If the clear area of the stream suitable for spawning is insufficient a reduction in the number of offspring would result.

(*e*) If eggs are already in the gravel when pollution occurs, the compacting of the gravel with tailings will reduce circulation of water through the redd and cause the eggs to suffocate.

Maher found that no aquatic life is present in the area of a stream affected by a tailings pollution.

Although small concentrations of metallic salts are known to be lethal to fish, Maher reports that they are not present in the tailings in sufficient concentrations to cause harm.

Although mining pollutions by chemical wastes are rare, in certain instances potassium cyanide used in processing gold ore has caused serious harm to sport fish. This reagent is used to reclaim gold in either the leeching or flotation process. In the former case, any potassium cyanide which enters the stream is purely accidental since it may contain gold. On occasion this has been known to occur in the Kootenay region, resulting in high mortality to fish. Maher reports that concentrations as low as 0.27 p.p.m. of potassium cyanide have killed trout in ten minutes. When potassium cyanide is used in the flotation process it is included in the effluent from the mill and therefore presents a serious pollution if it is allowed to enter water containing fish. A pollution of this type exists in Jack of Clubs Lake near Wells, where the outlet stream is used to carry away plant wastes. In this instance the part of the lake adjacent to the outlet and the outlet itself are toxic to fish, while the remainder of the lake is unpolluted. Test cages containing one hundred rainbow trout fingerlings were put in the outlet and inlet streams. After twenty-four hours all of the fish in the outlet cage were dead while complete survival of the inlet fish resulted.

As already mentioned, the area with the greatest mining pollution problem is the southeastern part of the province, commonly referred to as the Kootenay region. An examination of the pollution files of the B.C. Game Commission showed that in 1952 there were at least 16 mining pollutions in this area. Four of these were caused by gold processing operations, two by placer mining, and the remainder by tailings mostly from base metal concentrators. At the present time two known pollutions exist and they are in the process of being remedied. This excellent "clean-up campaign" is due to the co-operative efforts of personnel of the B.C. Game Commission, particularly Mr. F. P. Maher and the various mining concerns. In the remainder of the province only a few isolated mining pollutions still exist but it is expected that these will be overcome in the near future. On a province-wide basis, more than 85 per cent of the mining pollutions existing in 1950 have been corrected.

Three methods of preventing tailings from entering lakes and streams are employed in British Columbia. Most commonly an impoundment of tailings is accomplished by erecting a barrier around the area into which tailings are dumped. The impoundment may be made of wood, stone or concrete, etc., or may utilize the local terrain, i.e., damming a ravine. Since the quantity of tailings produced is large, impoundments often reach a considerable size. For example, the impoundment area for the H. B. concentrator (Pb, Zn) is three-quarters of a mile long and one-half mile wide. The lead, zinc concentrator of the Reeves-MacDonald Mines Ltd. on the Pend d'Oreille River discharges 1,200 tons of tailings a day; 200,000 tons a year; and 900 cubic feet of tailings an hour. Another method of dealing with the tailings problem is by backfill. In this case the waste material is pumped into the worked-out sections of the mine. The Bluebell Mine (Pb, Zn, Ag) on Kootenay Lake uses this method in conjunction with an impoundment. A centrifuge pump separates the solid waste from the water, whereupon the solid waste material is conveyed into the worked-out chambers of the mine. In one instance at least, the spring high water period is used to convey excess waste from an impoundment. The waste, calcium sulphate, is retained in an impoundment until the spring freshet occurs, whereupon it is pumped into the river. Release of the effluent at this time does not interfere with the sport fishery since the river is unfishable due to natural turbidity.

The correction of a tailings pollution in most cases is costly and drawn out. This is often due to difficulties involved in enlarging existing disposal facilities and securing land for additional impoundment areas. In precipitous terrain particularly, this presents a real problem. In pollution, as with illness, an ounce of prevention is worth a pound of cure. This is especially true in mining pollutions where a programme of abatement is simplified by the inclusion of adequate disposal facilities with initial construction plans.

Effects of Hydroelectric Development on the Fresh Water Fisheries of British Columbia (V. R. Pantulu)

By the end of 1956 there was an installed hydroelectric turbine capacity of slightly over 2½ million horse power in British Columbia. Estimates by competent authorities suggest that a total of about 9½ million horse power may be required by 1975, to meet the growing demands of various agencies. Past experience elsewhere, has shown that the effect of power dams on salmon producing streams and rivers could prove disastrous to the existing and potential salmon fisheries. While on this score alone "it would be unrealistic to adopt an attitude that fish production and power development are completely incompatible resource uses" (Larkin 1956), it certainly highlights the necessity of closely examining every project with a view to analyzing its probable effects on fisheries and planning in advance, fish protection facilities, to ensure judicious exploitation of resources.

There have been many recent accounts of the various effects of hydroelectric developments on fisheries (Hoar 1956, Larkin 1956, Brett 1957, Hourston 1958). Table I briefly sketches the nature of many of the problems and indicates both the types of solution at present and the lines on which current research is progressing. (From Larkin 1956). Figure 1 is from Hourston (1958) and indicates the types of problems which occur in diversion projects.

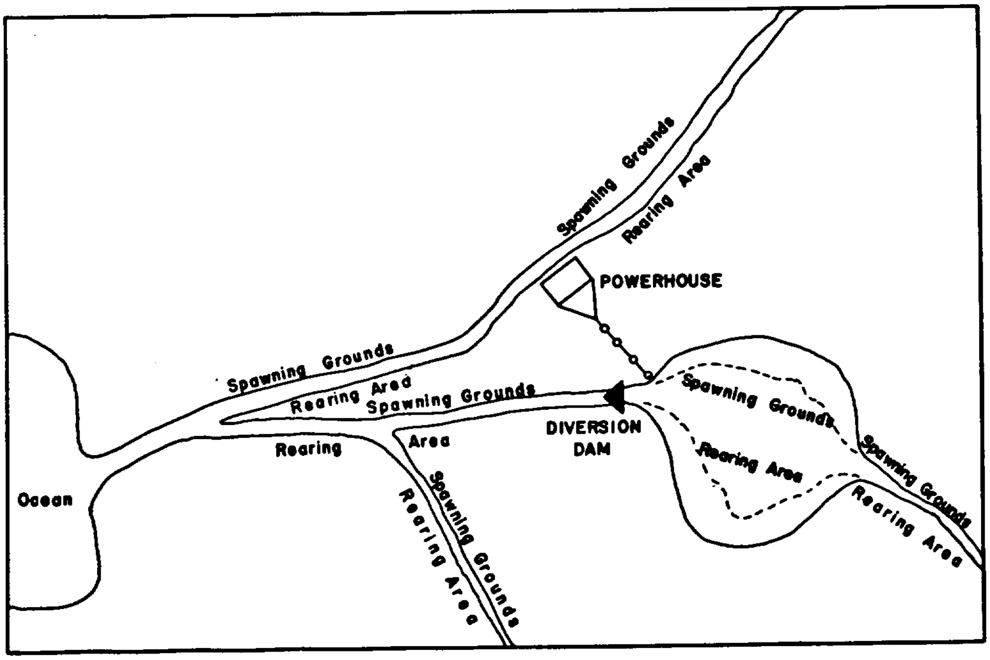

FIGURE 1. *Plan of a typical diversion type hydroelectric project. Areas utilized by anadromous fish are shown. (From Hourston 1958).*

Table I

Types of effects on fisheries of hydroelectric developments in British Columbia

Structure or Phenomenon	Example	Effects	Possible solution	Type of Research or investigation needed or in progress
Diversion of stream to new drainage system.	Babine from Skeena to Fraser.	Portion of young Babine fish diverted to Stuart would probably return as adults to Babine via Fraser; thus portion of Babine run lost.	Prevent migrants from going down diversion.	Screening or guiding.
Diversion of most of stream through pipe or tunnel to power house.	Seton lake power project; any typical diversion type project.	Adult fish congregate at power house; do not take simple passage through lesser flows.	Shut off power house for short period when necessary; guide fish to lesser flow.	Could be a guiding or attracting problem.
Change in temperature regime of streams.	Depth of water release from impoundments can alter temperature characteristics.	Alters rate of dissipation of energy reserves of fish, ability to swim and negotiate obstacles and fatigue; may alter behavior; end results can be failure of fish to reach destination, or reduced reproduction. Under some circumstances this factor could alleviate harmful effect of mechanical obstructions.	Manipulation of level of water release to obtain desired temperature. Basic research on physiology much needed to gauge effects and suggest solutions.	1. Basic research on physiology. 2. Prediction of temperature structure of reservoir. 3. Investigation of mechanical methods of drawing water for turbines or spills from various depths.
Change in volume of flow and chemical characteristics.	Diversion or impoundment of water.	Possible physiological effects largely unknown.	Manipulation of water release levels. Research needed to gauge effects and suggest solutions.	Basic research on physiology.

TABLE I (*Continued*)

Types of effects on fisheries of hydroelectric developments in British Columbia—*Continued*

Structure or Phenomenon	Example	Effects	Possible solution	Type of Research or investigation needed or in progress
Obstruction by dam.	Any large dam in which only small proportion of flow can be economically spared for fishpasses.	1. Fish die or are at least delayed because they do not locate fishpass entrance. 2. Fish are delayed or injured because fishpasses will not accommodate sufficiently large number of fish. 3. Fish are exhausted or injured in fishpass because of faulty design.	1. Proper design of fishpasses and attraction devices based on— 2. Knowledge of behavior and performance of fish.	1. Hydraulics research on fishpass design. 2. Basic research on physiology and behavior.
		4. Fish swept back over dam after negotiating bypass.	1. Guiding or steering fish away from spillway. 2. Transport of fish above forebay of dam.	1. Guiding of fish. 2. Physiology in transport of fish.
Transport by tank truck.	Capilano; any high dam where elevator structures uneconomical.	Fish injured or die from effects of handling and trucking.	1. Fish swim into truck. 2. Drugs used to quiet fish. 3. Application of research on physiology of transport.	1. Research on improved trucking techniques. 2. Research on physiology in transport.
Delay in reservoir.	Any large impoundment on a migration route.	Fish not adapted to going through still water, delay from temperature stratification in lakes? Seriousness of problem needs evaluation.	1. Transport of fish past reservoir. 2. Attract or guide adults through reservoir.	1. Research on possibility of this being a problem needs study

Accumulation of small delays at many dams and reservoirs.	Any series of dams and/or reservoirs.	Fish attain maturity before reaching spawning grounds; or reach spawning grounds but reproductive ability impaired.	1. Transport of fish past series of dams. 2. Improve fish passes ana speed up passage in reservoir.	See above.
Flooding of spawning grounds.	Lake storage flooding out spawning streams; river dams flooding out pink, spring salmon or steelhead spawning.	Prevents successful spawning or crowds too many fish on remainder of grounds or forces spawning on inferior grounds.	1. Build artificial spawning channels. 2. Create storage by lowering rather than raising lake levels (in some cases).	1. Research on making artificial spawning grounds. 2. Engineering surveys.
Rate of flow from storage area to spawning grounds.	Storage dam located on lake above outlet spawning grounds.	Can reduce spawning area, in some cases can improve on natural conditions.	1. Build artificial spawning channels. 2. Regulate flow to be high and uniform from spawning to fry emergence.	1. Research on artificial spawning grounds. 2. Engineering surveys.
Temperature of water from storage area higher than natural.	Storage dams upstream of spawning grounds.	Can influence growth and survival of eggs and young.	Modify storage regime, siphons for outlet works.	1. Survey local site to gauge effects.
Obstruction of young fish by storage dam.	Storage dams upstream of spawning grounds.	Young salmon cannot *ascend* from spawning grounds to lake.	Fishpass through storage dam for young salmon.	1. Research on ability of young fish to perform. 2. Hydraulics research on fishways.
Productivity of lake changed by storage use.	Any alteration in lake levels.	May reduce capacity of lake to produce fish, may be compensatory effects.	Modify storage regime; artificial culture of fish.	Survey lake before and after project to assess effects.
Productivity of lake changed by diversion of water into it.	Many diversion type projects.	May affect productivity by changing transparency, temperature and mineral content.	Modify storage regime; artificial culture of fish.	Survey lake before and after project to assess effects.
Flooding out stream habitat areas.	Capilano. Coho and steelhead rearing areas.	Substitute lake environment for stream fish, may affect production of young fish.	Artificial culture of fish.	Survey lake before and after project to assess effects.

TABLE I (*Concluded*)

Types of effects on fisheries of hydroelectric developments in British Columbia—*Concluded*

Structure or Phenomenon	Example	Effects	Possible solution	Type of Research or investigation needed or in progress
One or more reservoirs on stream.	Any large integrated basin development scheme.	Pink and coho salmon and steelhead not adapted to migrating through lakes. Spring and sockeye naturally migrate through one or at most two lakes. Passage through several reservoirs probably would cause high percentage of death or "residualism".	Devising methods of flushing young salmon through reservoir areas; guiding migrants, diverting migrants, catching migrants above reservoirs and trucking them downstream.	1. Research on steering or guiding migrants. 2. Research on catching and trucking migrants.
Spillway of dam.	Any dam.	Young fish killed in spillway by abrasion, concussion, and various other kinds of mechanical factors.	1. Design spillways so fish not killed. 2. Guide migrants away from spillway and into bypass.	1. Research on spillway design. 2. Guiding migrants.
Turbines.	Any dam where power turbines water intake within 100 ft. (?) of surface.	Fish killed in passage through turbines by turbine blades or pressure change.	1. Screen turbine intake. 2. Change design of turbine. 3. Guide migrants away from intake and into bypass.	1. Research on turbine design. 2. Guiding migrants.
Changed ecological conditions in stream.	Below reservoirs.	Accumulation of predators causes high loss of migrants.	Seasonal eradication of predators?	Survey to assess after dam built.

Table II

Developed hydroelectric projects in British Columbia

Name of Project	Location	Species of fish involved	Problems	Solutions
1. Alouette River Project.	Alouette Lake.	Sockeye, spring, coho and chum salmon, steelhead and cutthroat trout.	Barrier of migration. Flooding of spawning grounds above dam. Reduction in flow of residual river reduced runs and destroyed spawning grounds.	No fish protection or passage facilities exist. Facilities at this stage not likely to be helpful unless other provisions, indicated below, made. Arrangements needed for release of minimum flow and construction of artificial spawning channels. If these provisions cannot be made at this stage main Alouette may be fenced off to divert the migrants to Pitt River spawning grounds.
2. Ruskin dam.	Ruskin.	Coho salmon Steelhead.	Reduction of flow in the river below the dam—results, spawning areas destroyed, no attraction flow for adults.	No fish protection facilities exist. Arrangements needed for releasing adequate quantities of water from the reservoir.
3. Alcan project.	Nechako River.	Sockeye, pink, spring salmon.	Reduced water flow in residual river. Increase in water temperature. Unsuitable to migrants. Creation of points of difficult passage. No clearing of reservoir.	Facilities exist: Dam constructed on Cheslatta tributary to provide sufficient water during periods of migration. Suggested release of cold water at a depth of 200 ft. from reservoir. Channel improvements where necessary. (Int'l. Salmon Comm. 1953).
4. Seton Creek Project.	Seton Lake.	Sockeye and pink salmon, steelhead trout.	Obstruction to migration. Reduction of water level in Seton Creek spawning areas. Turbine-mortality of downstream migrants.	Vertical-slot fishway constructed. Provision for releasing water from reservoir. (Andrew and Geen 1958).

TABLE II (*Concluded*)

Developed hydroelectric projects in British Columbia—*Concluded*

Name of Project	Location	Species of fish involved	Problems	Solutions
5. Puntledge River Project.	Comox Lake.	Pink, chum, coho and spring salmon, steelhead trout.	Obstruction to migration. Reduction of water level in spawning areas. Turbine mortality of downstream migrants.	Fishway constructed. Provision for releasing water from reservoir. Experimental screens and louvres installed for keeping migrants out of penstocks (Brett and Alderdice, 1958).
6. Wahleach River Project.	Wahleach Lake and Jones Creek.	Pink and chum salmon.	Reduced water flow in residual river.	Artificial spawning ground provided. (Hourston and MacKinnon 1957).
7. Cheakamus River.	Cheakamus.	Chum, pink, sockeye and coho salmon, steelhead trout.	Reduction of flow below diversion dam will impede migrations of adults. Creation of points of difficult passage. Attraction of migrants to power house on Squamish River. Loss of spawning areas.	Provision for minimum flow of 200-350 c.f.s. through a low level outlet. Channelization work. Collection and trucking of adults so attracted. Provision of artificial spawning areas. (Dept. of Fisheries 1957).
8. Bridge River.	Bridge River.	Spring salmon.	Blockage of migration.	Relocate spawning grounds.
9. Campbell River Project. (i) Dam at Irene pool. (ii) Lower Campbell. (iii) Upper Campbell. (iv) Buttle Lake.	Campbell River.	Rainbow trout............ Cutthroat trout........... Dolly Varden.............	No appreciable effects on commercial fishes. Flooding shoreline destroys sport fishing. Sport fish spawning areas reduced.	Clearing of lake margins done. Artificial propagation (McMynn and Larkin 1953).

10. Waneta				
11. Buntzen				
12. Southslocan				
13. Cora Linn				
14. Lois River				
15. Jordan River		No appreciable effects on commercial fishes. Minor effects on sport fisheries.		Clearing of lake margins done. Artificial propagation.
16. Whatshan				
17. Powell River				
18. Ocean Falls				
19. Britannia				
20. Big Falls River				
21. Spillimacheen				
22. Clowhom River				
23. Wood Fibre				
24. Victoria Lake				

Table III

Proposed hydroelectric projects in British Columbia

Name of Project	Location	Fish affected	Problems	Solutions
1. Atlin-Yukon-Taku	Taku Valley.			
(a) Atlin Lake dam		Lake trout	Complete loss of spawning areas following flooding.	Construction of artificial spawning grounds.
(b) Tagish Lake dam				
(c) Yukon River		All species of salmon.	Barriers to migration. Reduction of water flows in residual river. Inundation of spawning grounds.	Provision of adequate fish passes. Release of required quantities of water at appropriate period. Construction of artificial spawning channels if necessary (Withler 1956).
(d) Mary River				
(e) Taku Valley				
2. Fraser-Thompson development.				
(a) Emory Creek	Fraser 60'		Barriers to upstream migration.	Construction of suitable fishways.
(b) Spuzzum Creek	" 100'		Interference to local fry migrations, in Babine and South Thompson rivers. Alteration of ecological and limnological conditions in all storage reservoirs. Changes in temperature regime and flow conditions in all river systems. Cumulative delays to migration period might exceed the critical limit. Provision of facilities to reduce mortality of downstream migrants.	
(c) Anderson River	" 100'			
(d) Cisco	" 100'			
(e) Gladwin	Thompson 95'	All species of trout		No solution, research required.
(f) Seddel	" 50'			
(g) Basque	" 35'			Release of adequate quantities of water from the reservoirs at proper periods.
(h) Ashcroft	" 35'			
(i) McAbbee	" 35'			No solution, research required.
(j) Kamloops Lake	" 35'			
(k) Shuswap	Shuswap River			No definite solution though various types of screens and collection devices could be tried.
(l) Adams	Adams Lake			
(m) Mabel	Mabel Lake			
(n) Quesnel	Quesnel Lake			
(o) Stuart	Stuart Lake			
(p) Babine Lake	Skeena River (to be diverted to Fraser)			

3. Moran development.	Fraser River at Moran above confluence with Thompson.		Dam too high for fishways. Delay of adult migrants. Reducing mortalities of downstream migrants.	No solution—research required on quick gathering and transport facilities for adults. Research required on collecting and transporting downstream migrants.
4. Peace River Diversion.	Peace River.	Salmon and trout.	Invasion of Fraser system by northern pike which might affect adversely salmon and trout.	
5. Somass River Project.	Somass River.	Sockeye, spring, coho and chum salmon, steelhead trout.	Spawning areas either completely eliminated or greatly reduced. Reduced rearing capacity of Ash and Stamp rivers. Diversion of spawners bound for Ash and Stamp rivers to tail races in Sproat system.	Artificial propagation. Provision for adequate water releases from dams. Collection of spawners and releasing them in home streams.
6. Taseko-Chilko-Homathko.		Sockeye.	Lake productivity affected by storage. Outlet spawned fry could not ascend into lake. Reduction of water flows in residual river.	No diversion of Chilko Lake or into Chilko Lake.
7. Stikine River	....	Salmon involved.	Facilities have to be provided.	
8. Iskat River	....	"	"	
9. Chilliwack River	....	"	"	
10. Elaho River	....	"	"	
11. Dean River	....	"	"	
12. Moss River	....	"	"	
13. Bulkley River	....	"	"	
14. Nass River	....	"	"	
15. Quesnel River	....	"	"	
16. Nahatlatch River	....	"	"	
17. Nimpkish River	....	"	"	
18. Harrison River	....	"	"	
19. Upper Adams River	....	"	"	
20. Columbia River at Murphy Creek	....	Salmon not involved.	No appreciable effects.	Facilities need not be provided.
21. Murtle Lake diversion	....			
22. Bull River	....			
23. Columbia River-Mica Cr.	....	"	"	
24. Pend d'Oreille River	....	"	"	

Table II summarizes developed hydroelectric projects in British Columbia and their effects on fisheries. Details on all of the projects are available from the various government agencies responsible.

Two points might be mentioned in connection with this tabulation.

(1) It must be concluded that to date the effects on fisheries of power development in British Columbia have been relatively slight. None of the major salmon producing rivers has yet been involved. For all recent projects facilities have been provided that should ensure partial or complete protection for fish populations. Of necessity, many of the installations have been experimental, and careful study of their effectiveness will prove extremely valuable (Hourston et al, 1955).

(2) Sport fish protection poses special problems that are not brought out in the tabulation. In most instances the monetary value of the stocks affected is difficult to gauge. In addition, the effects of a project are more often concerned with "fishability" and aesthetic values than with the production and maintenance of fish stocks. Finally, there are available a large number of alternative sport fishing and recreational areas so that for the present at least the loss of a few areas does not meet with general public concern. Nevertheless, for all recent developments a substantial measure of consideration has been given to sport fish values. Clearing of lake margins prior to flooding is now an accepted practice. In some instances monies have been provided by the project builders for artificial propagation of trout.

Table III summarizes some of the major proposed hydroelectric installations in British Columbia. Many of these are such major developments that they pose problems of fish conservation that have no parallel in the past. For instance, it has been estimated that a dam in the canyon of the Fraser River would require facilities for accommodating as many as 700,000 fish per day if runs were to be passed without delay. Similarly, any scheme of artificial culture of fish would require the production of several hundreds of millions of smolts, far in excess of the largest existing hatchery installations. For many of the problems posed there are no existing solutions, and recent investigations give indications that in developments involving a series of dams many serious effects on fish may occur which to date have not been suspected. For example, Brett (1958) reports on the possibilities of mortality to young migrants caused by the accumulation of indiscriminate stress. At each dam, a fraction of the fish which survive are sufficiently affected that they more easily succumb to stress conditions downstream. Recent work of Black (summarized in 1958) and others, suggest limitations to the degree and duration of exercise of which salmon are capable, implying the need for modification of fish pass designs particularly where delay may be critical.

These and many similar findings have prompted even more intensified research both on all aspects of salmon biology, and all phases of applied biological and engineering research as they pertain to hydroelectric developments.

At present a major integrated development of the Fraser watershed for hydropower would pose problems of fish conservation for which there are at present no adequate solutions. The joint report of the various fisheries agencies (1955) estimated that fish protection facilities for a multiple dam and storage development on the Fraser and Thompson rivers would cost $306,000,000 and that they "would not be successful in maintaining the salmon and steelhead runs." The situation is undoubtedly essentially the same today, and will remain so until much more progress has been made in the technical investigations. It is certainly to be hoped that alternative sources of power will be available until adequate solutions to the fisheries problems have been indicated.

The Effects of Industrial Pollution on Fresh Water Fisheries in British Columbia (J. C. MacLeod)

Introduction

In some cases of pollution the decline of a commercial fishery may indicate the results of pollution. In other instances, for example in streams which have a fish population but no fishery, the adverse effects may be noted by evidence of dead fish in the water. However in the vast majority of cases it is not possible to measure directly the effect on the fish populations. Thus the main part of this discussion will deal with the degree of pollution in B.C. waters, keeping in mind that this affects the fish in the water.

Several factors have combined to give the present comparatively "rosy" pollution situation in B.C. These are:

(1) The concentration of industry and population on the coast and on the large waterways leading into the ocean.

(2) The comparatively small population of B.C.

(3) The present early stage of development of B.C.

Domestic Sewage

There have been no records of serious pollutions or major fish kills caused by domestic sewage in the province. This is rather startling when we consider that in 1953 only five municipalities had secondary sewage treatment and only six others had any primary treatment. In 1953 Vancouver and Victoria, with a sewered population of almost 400,000 people, had no treatment whatsoever. (Bowering 1953). This condition exists because of the situation of cities and towns close to the ocean or on large rivers such as the Fraser, Thompson, and Columbia. Most inland towns used septic tanks in the early days, and today as the towns grow in population, sewage treatment plants are set up. In the Okanagan Valley the towns of Penticton, Vernon and Kelowna all have secondary treatment facilities for sewage. At Kelowna a sewage reclamation plant has been set up.

In Vancouver harbour, Victoria harbour, Nanaimo harbour and parts of Ladysmith harbour the Department of Health has made it illegal to take oysters and other shellfish from the areas because of threatened sewage contamination. Disposal of sewage is a common use of water and in some cases organic matter may increase productivity of aquatic environments.

Pollution of the North Arm of the Fraser River

Vancouver is situated on the delta of the Fraser River. Having as yet no sewage treatment plants, the city has directed most of its main trunk sewers into the North Arm which is also a concentrated industrial area. It is estimated that five per cent of the sockeye salmon going up the Fraser pass through the North Arm.

The North Arm is one of the two main branches of the mouth of the river. It is 18.46 miles long and from 400 to 1200 feet wide. It discharges five to 10 per cent of the flow of the Fraser and is tidal, with a considerable inflow of salt water at high tide. At seasons of low water and spring tide the effect is to halt or reverse the outward flow of the river during part of each day, which periodically corresponds to the highest rate of sewage discharge into the river. (Rawn 1953). Both sides of the river have been zoned for heavy industry. In 1953 there were 30 lumber mills and ten other more specialized wood processing plants, six food processing plants, three chemical and fertilizer plants, five building material plants, one metal fabricating plant and two shipyards. (Farry et al. 1953).

In 1952 the B.C. Research Council published the results of a water quality survey from the mouth of the river to Prince George, 400 miles upstream. The data indicated that the chemical composition does not show large seasonal or chemical variations and that pollution is probably not significant except in the North Arm below New Westminster. (B.C. Research Council 1952).

Tests of the five-day, 20°C Biological Oxygen Demand in the North Arm showed an average B.O.D. of 2.1 ppm with a maximum of 3.5 ppm at Lulu Island bridge. The dissolved oxygen averaged 11.5 ppm with a minimum of 8.8 ppm at Sea Island bridge. It is generally accepted that in fresh water, at least five ppm of oxygen is necessary to support a healthy population of fresh water fishes and their necessary food organisms (Vernon 1956). Thus it can be seen that the oxygen present was, at the time of the survey, above the required level for fish survival.

Bacterial *coli-aerogenes* counts made by the B.C. Department of Health and Welfare, showed that the river was in a moderately polluted stage as far as health standards were concerned. A check on the 1951-52 survey was made by the B.C. Research Council in 1955 and it was found that the dissolved oxygen had not decreased markedly but that the *coli-aerogenes* count had increased. (B.C. Research Council 1955). At present the pollution should not affect the 50,000 sockeye salmon using the channel.

The B.C. Research Council made comparisons with the Willamette River in Oregon which "supports" a salmon run and received organic wastes equivalent to wastes from a population of 4,000,000 people—a situation similar to that which might develop in the lower Fraser in the future. The oxygen content of the river gradually decreased until in Portland harbour, the oxygen content was zero and the water had a dangerously high bacterial count. This oxygen block prevented the anadromous fishes from passing on to the headwater of the Willamette River and created a barrier to the young fish trying to reach the ocean. Quoting from the report: "With large industrial developments in prospect in British Columbia it is not impossible that similar septic ones could develop in the Fraser". Many of the food processing plants and other manufacturing companies at present utilize the city sewers, releasing wastes which first must meet a certain standard.

A Greater Vancouver District Joint Sewage Board plan for sewage disposal has been drawn up. In one plan, Vancouver sewage would be diverted to a treatment plant on Iona Island at the mouth of the South Arm. The municipality of New Westminster would release its sewage into the South Arm rather than the North Arm. (Rawn 1953).

Industrial Waste

The main consideration of the B.C. Fisheries is the preservation of the salmon runs. The major industries, excluding mining, which might produce harmful wastes are: the wood industries, the lower Fraser valley food processing plants, and the petroleum industry refineries and pipe lines. Their wastes seem to have had comparatively little effect on B.C.'s salmon fishery to date. There are however numerous individual cases of pollution which have posed problems.

Pulp and Paper

The pulp and paper industry is one of the largest of the wood product industries in B.C. The pulp and paper can be processed in the same mill or as is usually the case, the pulp can be processed in a pulp mill, and then shipped to a paper mill. Paper mills produce very little waste. However a *sulfite* pulp mill can produce an amount of waste equivalent to that of a town of 450,000 people. Pulp mill wastes can be divided into (McMynn 1953):

(1) bark and wood fibre wastes

(2) inorganic wastes from

  (*a*) liquor used to boil the woods chips

  (*b*) wash water

In the liquor sulfides, mercaptans and alkali are the most critical constituents. Experiments indicate that roughly 1/20th dilution of test solutions are "safe" for fish but that an accumulative effect may occur. Alderdice and Brett (1957) using sockeye salmon underyearlings and samples from the *sulphate* pulp mill effluent on the Somass River found that a 4.8 per cent concentration of the effluent by volume in seawater of 20 parts per thousand salinity at 17.8°C was a limiting concentration for toxicity, below which survival was complete and independent of length of exposure. An effluent concentration of 2.5 per cent for the liquor was recommended.

Alberni Inlet on Vancouver Island supports well-established runs of sockeye, coho, chum, and spring salmon and steelhead trout. (Tully 1949). A site on the Somass River was chosen for a pulp mill after consultation with the Fisheries department. The pollution effects of the pulp mill effluent would be attributed to high oxygen demand, high acidity, direct toxic effects or the presence of wood fibres. The fibre contained in the liquor consists of pure cellulose which settles to the bottom and oxidizes very slowly. The resulting matte is deleterious in the neighbourhood of spawning grounds of anadromous fish because it interferes with the adults spawning and the fry feeding. The pulp mill wastes would have been lethal only at low flow periods of the Somass River. Thus a water storage reservoir was constructed and during low flows of the river the water is released to increase the flow.

At Crofton, B.C. the Pacific Biological Station studied the problem created when a proposed pulp mill threatened to wipe out the oyster fishery. As a result of the survey, the completed mill disposed of its wastes by running a long effluent pipe far into the bay where a diffusing system released the waste so that at no point was it concentrated enough to be harmful to the oyster beds. (Waldichuck 1955).

In 1956 Dr. M. Waldichuck carried out an investigation at the Port Alice pulp mill regarding its proposed expansion. In as much as the salmon runs in the inlet were small, the expansion would have little effect on the fishery.

Pulp mills first set up in the province utilized the *sulfite* process for cooking pulp. This method wasted 100 per cent of the cooking liquor. Modern mills are usually of the *sulfate* type in which the cooking wastes are burned to recover the liquor constituents resulting in only a 10 per cent total loss of digestor liquor. This improved method has meant that the pulp industry saves on the boiling process and at the same time releases a smaller amount of waste to pollute surrounding waters.

Sulfite mills which are still in operation such as at Port Alice and Prince Rupert are close to the disposal facilities of the ocean. There, the highly concentrated wastes are easily accommodated without harm to the fishery.

Oil Wastes

Oil which escapes to surface waters floats, and the volatile fractions evaporate rapidly, leaving only heavy oils. Oils which may be trapped along the shoreline will either be worked into the shore through wave action or will become attached to vegetation and eventually sink to the bottom. There, bacteria gradually destroy the hydrocarbons through biochemical oxidation. (Department of Fisheries 1953). Thus shoreline and emergent vegetation becomes coated and dies. Aquatic organisms feeding or living at the surface become coated with oil and die. Fish may get oil on their gills from feeding at the surface and die from asphyxiation. Fish eggs and bottom larvae die when coated with bottom sludge. Oil itself can taint the flesh of the fish. Oil emulsions in the water usually break down forming free oil.

Only a few occurrences of ships dumping oil into Vancouver harbour have been recorded and no apparent fish losses were observed. An oil line break on the coast caused the pollution of several miles of beaches but no large fish mortalities were observed.

A possible break in the transmountain oil pipeline would be extremely important in the case of one or more salmon producing streams. Thus special valves have been installed at all stream crossings under Federal Department of Fisheries supervision. The oil companies also have special devices to immediately warn of any leaks and periodic inspections of stream and river crossings are made by helicopter and otherwise.

At Kamloops on the Thompson River, an oil refinery was recently built. Very large numbers of sockeye, pink, and coho salmon annually enter the Thompson River to reproduce in various parts of the watershed. The sockeye run to the Adams River has a value of as much as $12,000,000 in a year. The refinery empties none of its oil wastes directly into the river. A large settling basin has been constructed which settles out the sludges and removes the oils which might remain when the extensive recovery process is completed. (Department of Fisheries 1953). Brine separated from the crude oil is sufficiently diluted and treated to make it non-toxic. Caustic soda used to treat gasoline for removal of sulfides, mercaptans and phenols is used many times over and is finally discharged to sewers, usually in batches. The caustic soda has a high pH. and a high B.O.D. Thus it is greatly diluted and neutralized with acid. It has been the rule to keep the pH. of the river between 6.7 and 8.6 and the fish runs should not be affected to any extent. A pH. of 9 is considered lethal to fully developed fish.

Localized Industrial Pollutions

Each year the B.C. Game Commission and the federal Department of Fisheries investigate numerous pollution cases either through water license applications or public complaints.

A harbour containing approximately 700-900 tons of schooling herring was found polluted by a large quantity of alkaline waste. Dead herring were in great numbers all around the area and it was estimated that the lethal concentrations for fish could easily be reached in the harbour with the amount of alkaline waste disposed of. The actual tonnage of herring killed is not known except that it was a considerable portion.

A chemical plant has prevented pollution from its chlorine wastes by using a diffusing system along the inlet bottom which provides sufficient dilution at all areas.

A stream entering Burrard Inlet was periodically polluted by large amounts of acid wastes which were found harmful to the salmon populations; pH's below 4 are considered harmful. In Burnaby a plant using an alkaline cleaning compound, each week emptied its tanks into a small stream where it was found that the small cutthroat trout were being killed by a pH of 10.0.

Gypsum is a large byproduct of certain base ore processing plants and fertilizer plants. One company produces 4.4 tons of calcium sulfate per hour and releases the waste into a river. It was found to be almost completely soluble and there was no oxygen depletion. The river flow was large and the effluent did not seem to affect the fish. A fertilizer plant was advised to retain its $CaSO_4$ wastes in an impoundment to avoid silting of salmon spawning beds during periods of low water in the river. The calcium sulfate also caused a cloudiness in the water. During spring freshets when the river flow was at a maximum, the $CaSO_4$ was released, the cloudiness not being detected in the muddy water.

Food plants and Breweries

Along the coast there are numerous salmon canneries. On the lower mainland are many food processing plants and breweries. The salmon canneries usually dispose of their offal right into the ocean or into fast flowing rivers which carry the waste into the sea. In recent years the salmon canneries have begun to use the offal in the production of profitable byproducts such as mink food, thereby reducing the waste material in the water.

One cannery on the lower mainland was releasing vegetable wastes into a stream containing salmon fry. Fifteen hundred feet downstream the oxygen concentration was 4.4 ppm, 41 per cent of the full saturation. There was a slight increase in bottom fauna (oligochaetes and chironomids) at the effluent but a thick fungal matte covered the bottom. Salmonid fry were abundant upstream but none were found below the polluted area. This situation has been rectified.

In Vancouver, breweries are allowed to empty their wastes into the city sewers as long as they do not contain harmful substances such as acid which would damage the sewage system. One brewery situated beside a lower mainland river uses a spray pond to aerate its wastes before turning them into the river.

Milk wastes are a most serious stream pollutent demanding a large amount of oxygen from the stream. One milk plant repeatedly polluted a stream making it unfit for fish for the entire distance from the plant to a larger river. The problem was temporarily solved by running a pipe 1½ miles to the larger river.

Bakeries too have polluted lower mainland streams. Two bakeries discharged flour into a small stream. The stream became undesirable for fish and the waste contributed to oxygen deficiency.

One meat plant found that the removal of all trade waste from its effluent was beyond its financial capacity and yet seriously polluted the nearby river.

In some cases the pollutions of small industries pose difficult problems. Only when streams and rivers reach a certain level of pollution is it necessary to ask a company to treat its wastes and when they have been operating in an area for a long period of time they are reluctant to finance an elaborate treatment system. It is essentially the increasing number of industries, each contributing perhaps only a small portion of waste to a river or stream, that poses one of the more difficult pollution problems for the future. It is economically impossible for some companies to treat their wastes completely. At present each plant that requires the use of water for disposal purposes must apply for a water licence. If it is decided that the company will remain within certain standards so that it will not cause pollution to the stream, then the licence is granted. However when the load put on a river is increased by new industries the original plant may have an inadequate sewage treatment.

Discussion

The solution to these problems may not be easily forthcoming. Various courses of action have been proposed:

(1) to make new plants improve the quality of their wastes

(2) to establish zoning regulations for certain industries and to allow them to release their wastes into rivers which would be "sacrificed" for sewage disposal.

(3) the zoning of industries and a central treatment by government subsidized treatment plants.

At present, pollution effects on fisheries are relatively minor and under control in B.C. but with increasing industry and population, problems will undoubtedly multiply.

Aware of these developments, in 1956 the B.C. legislature passed a bill providing for establishment of a Pollution Control Board. The board is now constituted and co-ordinates all the provincial government agencies concerned with pollution. It has jurisdiction in the lower Fraser river basin and at present has no direct representation from the fisheries agencies.

The most satisfactory step towards eventual pollution control will undoubtedly be a long term resource zoning and planning programme carried out with the close co-operation of all concerned groups—provincial, federal, industrial and private.

The Effects on Fresh Water Fisheries of Development Construction in British Columbia (C. E. Stenton)

No description of the effects of man made activities on fisheries of British Columbia would be complete without brief mention of catastrophes occasioned by construction projects concerned with the province's development. In most instances of road or railway construction care is taken to avoid creation of obstacles to fish migration or excessive silting of streams. The classic example of an inadvertent effect on fisheries is provided by the Hell's Gate story.

The Fraser River sockeye salmon catches up to 1913 were a large industry—estimated 2,400,000 cases in 1913. After 1913 the catches dropped rapidly and in 1917 approximated 500,000 cases. From then until 1937 it rarely exceeded 200,000 cases. (Talbot, 1950). The drop in the catches following 1913 was attributed to a blockage of the Fraser River at Hell's Gate Canyon by debris from railroad construction (Talbot 1950).

Hell's Gate is a narrow gap through which the Fraser River flows with considerable speed and turbulence. Prior to 1913 the river in Hell's Gate was fast and turbulent but salmon were able to pass it. In 1913 the Canadian Northern Railway (later to be known as the Canadian National) was constructed through this area. The rock from the road-bed construction was dumped into the river, thus causing a narrowing of the channel. This added material caused an increase in the flow and turbulence, which in turn produced a barrier to fish at certain water levels. (Jackson 1950). This barrier resulted in a delay in the migration followed by a heavy mortality (Talbot 1950). In 1914 there was a rockslide resulting from the construction of a tunnel on the railroad. In late 1914 and early 1915 an excavation of the debris was done in hopes of returning the river to its former state. These excavations did not prove to be of much success. These were the last changes made at Hell's Gate for twenty-six years. Due to this barrier the sockeye runs above Hell's Gate were seriously reduced and some were completely wiped out.

In 1938 the International Pacific Salmon Fisheries Commission made a study of Hell's Gate. From the study it was concluded that fishways must be built to restore the sockeye runs. In 1942 a temporary fishway was constructed to provide information for designing a permanent fishway and to pass some salmon past the obstruction (Talbot 1950).

In 1944 work had begun on the permanent fishways and by early 1946, fishways on both sides of Hell's Gate were completed. The fishways are of the vertical slot type and are designed to operate from water levels between 23 and 54 feet (Talbot 1950). From a tagging programme initiated by the International Pacific Salmon Fisheries Commission it was found that the sockeye could negotiate Hell's Gate (Talbot 1950).

As a result of the fishway construction there has been an improvement in the number of sockeye reaching the spawning grounds, and it has been concluded that the fishways have been a success. (Royal 1953).

Similar types of problems have been posed by natural obstructions and while they were not caused by man's activities their solution has been instructive in demonstrating the types of effects which can result from man-made obstructions.

In 1951 numerous dead and injured fish were found in the Skeena and lower Babine Rivers. Reports from a counting weir just down stream from Babine Lake, showed that the fish were having difficulty getting up the river. A survey was made and it was found that a large rockslide had blocked the river (Godfrey et al. 1954). The slide was 420 feet long and consisted mainly of large rocks. From a study conducted by engineers and biologists, it was concluded that high water velocities and excessive turbulence were the main block to the salmon and that a removal of the material would be the best remedial measure (Godfrey et al. 1954).

Since the slide occurred late in 1951 no remedial measures were taken that year, but the following spring some removal of the material was done. By the spring of 1953 the channel was back to its original state.

During the period of blockage, some salmon were able to surmount the barrier but heavy losses occurred. In 1951 it was calculated that 319,000 fish out of an estimated run of 461,000 were lost and in 1952, 700,000 out of a run of 1,051,000 were lost. Of the fish that did arrive on the spawning grounds only 60-70 percent spawned, the rest died from injuries received coming over the barrier (Godfrey et al. 1954).

The effect on the future fisheries is not considered a serious problem as the slide only stopped the runs of two years. This effect will probably not be evident after two or three generations of fish (Godfrey et al. 1956).

In the management of the Pacific salmon, much concern has been given to the removal of obstacles which block or delay the spawning migration. The rivers of the mountainous coast of British Columbia have many waterfalls, which, through tagging programmes, have proven to be a factor in the delay of the migrating salmon. During such delays, there is an appreciable amount of mortality, either from injury or from Indian fisheries which are usually located at such places (Milne 1950).

The federal Department of Fisheries and the International Pacific Salmon Fisheries Commission have constructed a number of fishways which allow the salmon to pass such barriers. Fishways have been constructed on the Fraser, Chilcotin, Stamp, Stoat, Skutz, Naden, Indian, Bulkley, Nimkish, and Kajusdis rivers. Each of these fishways bypasses either a waterfall or a place of very fast and turbulent water.

The fishways on all except the Nimkish and Kajusdis rivers are of the vertical slot type. This type of fishway has been found to work best with varying water levels. There are five of these fishways in Farwell Canyon on the Chilcotin River. The fishway which bypasses Karmutsen falls on the Nimkish River is of the Denil type. The fishway on the Kajusdis River is a pool and weir type.

The efficiency of most of these fishways has not been thoroughly checked but local reports indicate much improvement over previous conditions. A tagging programme on the Moricetown fishways on the Bulkley River showed that several days were cut off the period of delay (Hourston and Stokes, 1952).

Discussion

In reviewing the effects of man-made activities on freshwater fisheries of British Columbia four generalizations are suggested:

(1) In recent years, most major effects on fisheries have been foreseen or have been quickly acted on when evident. In consequence there are few instances in which the effects on fisheries have not been avoided or largely alleviated.

(2) The present fortunate state is largely attributable to efforts of the substantial trained staffs of the various government agencies which have investigated each of the man-made projects for effects on fisheries.

(3) Future problems will require an even broader base of research in biology and engineering if effects of some of the potential projects are to be minimized.

(4) Most problems are presently being handled on an *ad hoc* basis. However, if as planned, multiple resource use becomes more and more a part of administration of resources, it will be necessary to provide better representation of fisheries interests to ensure that fisheries are not harmfully affected.

The first three statements concern quite self evident trends in events, but the fourth perhaps needs enlargment.

At the present time the Government of Canada carries most of the load for protection and regulation of stocks of fishes, both marine and anadromous. The Provincial Department of Recreation and Conservation, Fish and Game Branch, shoulders responsibility for sport fish administration but regulation of catch is still the formal responsibility of the federal Government. The provincial Department of Recreation and Conservation, Fisheries Branch, handles licensing of processing plants and freshwater domestic fishing licences. This division of federal and provincial responsibility conforms to the provisions of the British North America Act and subsequent legislation and to date has resulted in effective, harmonious action by the various agencies.

Within the last decade however resource development has proceeded at an accelerating pace in British Columbia and in all resource fields there has been growing concern about the best procedures for resolving resource conflicts. The general objective of wise use of natural resources must be to develop each resource as far as possible without harm to other resources. When conflict arises between two resource uses in a common area then the greatest public interest must be served. Great public expense can be saved if conflicts of this type are anticipated and if a plan for multiple resource use is developed for each region—usually a stream drainage area. These problems were recognized as serious and were the stimulating factor in the formation of the B.C. Natural Resources Conference. This group comprises a majority of the technical personnel employed in government, university and industry in the province. The conference has produced 11 volumes of transactions concerned with resource use problems in British Columbia as well as a splendid Atlas of Resources which summarizes current technical information on the province. It has brought together the people concerned with resource use and established a cordial spirit of understanding between various agencies. Finally it has indicated the need for planning agencies that would suggest schemes for co-ordinating resource uses and adjudicating resource conflicts.

The recent formation of a Pollution Control Board and the recent organization of a Department of Recreation and Conservation were both in large part initiated by conference discussions. Further steps to provide planning agencies will no doubt be forthcoming.

In such an atmosphere it is anomolous that the fisheries resource (excluding the sport fisheries) can only be adequately represented by a federal agency which has a limited authority in directing provincial resource use planning. Accordingly our conclusion must be that a strong provincial fisheries department would be most desirable if effects on fisheries are to be minimized by the proverbial ounce of prevention rather than by the usual pound of cure. Effects on fisheries of man-made activities in British

Columbia have fortunately been a minor factor in fisheries conservation to date, thanks to the excellent services provided by the Canadian Department of Fisheries. This happy situation can continue provided the federal agency is adequately assisted by strong representations of a provincial fisheries department.

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