282

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Fish populations in the province of Newfoundland and Labrador, like those of many other areas, are being subjected to increasing adverse pressure due to water pollution caused by industrial and domestic wastes disposal programs. Freshwater areas are especially affected, though tidal areas are not immune.

Technically, pollution is the addition to natural water of any substance that changes its quality. From the point of view of fish life, it is the addition of anything that lessens its ability to support normal fish populations; and although this review is concerned only with fish, it might be pointed out that a river that is so polluted that it can no longer support its normal fish population, has implications far more serious than the fate of fish. As one author (Turing, 1952) has said "What do a few fish matter.... Actually, they matter very much, not because people who want to catch them cannot do so, but because their absence means a very sick river.... Water which is not fit for fish habitation is not fit for human needs either...." The foregoing quotation expresses the broader implications of water pollution. This review, however, is confined to pollution and fish, this being of sufficient importance to merit our sole attention.

Because of the relatively confined nature of freshwaters, and the many demands upon it, pollution problems are usually more critical in these areas than they are in tidal waters, though each situation depends on many things: including the nature of the pollutant, the fish population involved, the area in question, and a host of other factors.

For convenience sake, pollution problems in the province may be roughly grouped into a few classifications. Any one of a number of groupings could be used. That which follows is based mainly on the source of the pollutant, the most important ones in Newfoundland and Labrador being: (i) wastes from the mining industry, (ii) wastes from pulp and paper manufacture, (iii) domestic sewage disposal, and (iv) miscellaneous sources of pollution. Each is briefly discussed in the following review.

Wastes from the Mining Industry

Although some attempts at mining began in the province as early as the last quarter of the eighteenth century, the industry did not become firmly established until 1892 when exploitation began of the iron ore deposits at Bell Island and, although other deposits were brought into production in the intervening period, the years since the end of World War II have seen a marked increase in the tempo of mining activity in the province.

In the area of Labrador, two very large iron ore operations have begun, or will begin, large scale production very shortly. Each of these operations produces a "beneficiated" product from the treatment of some 15,000,000 to 20,000,000 tons of raw ore annually. This results in about 60 percent of the original ore being discarded as wastes, the higher grade materials (about 40 percent) being shipped to market.

These millions of tons of wastes (called "tailings") are largely finely divided low grade material that has been separated from the richer ores, and which must be disposed of in some way. When spilled into water areas, which is where most of them finally end up, these wastes may be carried for long distances. The heavier particles settle out quite rapidly, but the so called "fines", the more finely divided material, can travel very long distances, and are kept in suspension for long periods by the action of wind and currents. The main effects of these in excessive quantities are: (i) to destroy spawning areas by siltation, (ii) to smother plant and invertebrate growth on the bottom, (iii) by reduction of light penetration, decrease general food production, and (iv) by effects on certain tissues, especially respiratory, directly decrease the ability of fish to survive.

The problem of finding suitable areas for disposal, without harm to fish populations, of the millions of tons of tailings involved is not easily solved. In the case of one of the operations in the Labrador area, a lake of 3,000 acres in extent will be isolated from surrounding waters and used, in effect, as a large settling basin. In this case it is expected that tailings will eventually fill the lake well above its present water level. Even though this lake will be removed from the realm of fish production, the scheme will have the advantage of preventing indiscriminate spreading of tailings to connecting waters.

In the case of the second operation, a large dyked area is being enclosed within an even larger lake. This, when completed, should form "a lake within a lake" and provide some reduction of spread of tailings to adjoining waters. However, because of the time factor in constructing the dyke, and because it is being constructed of tailings themselves, it has not yet contributed appreciably to containing fines from the disposal operation in question.

On the island of Newfoundland the situation is somewhat different. Only one iron ore mine is in production, and wastes from its beneficiation plant are discharged directly to the sea. Here, except in a very limited area, it seems unlikely that substantial effect on fish populations occurs, since these wastes are rapidly diluted and dispersed. However, there have been complaints to the effect that fishing gear and equipment located many miles away are fouled, and their efficiency reduced, by fines from this operation.

The primary effects of the iron ore operations discussed are those due to their physical actions - turbidity, smothering, gill irritation, etc. This means that the wastes themselves are practically inert. That is, the physical effect is predominant, and there is little or no toxic effect due to chemicals in solution. Those to follow have a dual chemical and physical effect. These are the operations concerned with the extraction of the "heavy" metals, copper, lead, and zinc. A number of these are in production, and others will become so in the near future.

Four "heavy" metal mines are now in operation and two additional are expected to begin production in 1965. Of the six mines, five produce, or will produce, mainly copper. One (at Buchans) also produces lead and zinc. Two of these mines are located on tidewater and the other four in inland areas. Wastes from all are of concern to the Department of Fisheries because of their possible effect on fish populations if proper precautions are not taken.

Tailings spilled from ore concentrators located at each of these sites have much the same physical effects as those from the iron ore operations just described, these being mainly the result of smothering, turbidity, and mechanical irritation. Chemically, and more difficult to control, these tailings also carry lead, copper, and zinc in solution. In addition to their primary physical effects, the solid tailings are also a continuing source of supply of copper and zinc ions to the receiving waters. In most local waters lead is fairly rapidly precipitated out and is a lesser problem.

Zinc and copper in solution are toxic to fish life at very low concentrations. In similar waters elsewhere, zinc at 0.600 ppm, and copper at 0.048 ppm, has been determined to be the Incipient Lethal Level (ILL) - that level of toxicity at which the organism can no longer survive for an indefinite period of time (Sprague, 1964). With this value known, other concentrations of these substances may be expressed as multiples of the ILL. Thus it has been shown that concentrations of dissolved zinc or copper equal to four tenths (0.4) of their ILL is the level at which, under natural conditions, Atlantic salmon begin to be adversely affected. This concentration may be expressed as 0.4ILL (Sprague, et al., 1964).

In the freshwater environment, wastes from the mine at Buchans are a source of concern. This mine, which began operation in 1927, processes raw ores to produce lead, zinc, and copper concentrates. Some 360,000 tons of ore are processed each year, of which some 260,000 tons are disposed of as tailings to Buchans Brook and thence to Red Indian Lake and downstream areas of the Exploits River.

Until a few years ago when this Department began surveys, no investigation of the effect on receiving waters of this disposal operation had been carried out. Recent studies have shown three water areas to be affected. These are (i) the approximately 5 miles of Buchans Brook below effluent entry, (ii) Red Indian Lake, and (iii) the Exploits River below Red Indian Lake.

Below the point of entry of concentrator wastes into Buchans Brook, a stream draining an estimated 100 square miles of watershed, no biological life is known to survive due to (a) the physical effects of large amounts of silt in these waters, and (b) lethal levels of dissolved zinc and copper. Zinc concentrations in this brook, in terms of Incipient Lethal Level, run at least as high as 100ILL, or some 200 times that recommended as a maximum for young salmon. Within a radius of several hundred yards from where Buchans Brook enters Red Indian Lake, concentrations are still at a level of 10ILL, or 20 times the recommended level.

Combined concentrations (Sprague, 1964a) of zinc and copper in the main body of the lake, particularly its northern half, range from 0.3 ILL to 1.0ILL, and several miles downstream on the Exploits River combined zinc and copper levels ranging from 0.1 to 0.8ILL have been determined by regular sampling operations.

The situation in these waters may be briefly described by saying that (i) Buchans Brook below the point of entry of these wastes is grossly polluted by physical and chemical waste products, (ii) to a lesser degree, but still serious, the same may be said for an area of Red Indian Lake within a radius of at least one-half mile from the mouth of Buchans Brook. (iii) the lake bottom has large deposits, in the central one-third in particular, of silt that must severely inhibit the growth of bottom fauna, and (iv) dissolved zinc and copper concentrations in the lower river, though at lower levels than in the lake, are still present in amounts such as to cause concern about their effect on migratory salmon populations. Discussions with the Company involved are underway to try to find an acceptable method of waste treatment, and disposal, that will reduce metal pollution in these waters to levels tolerable by fish life.

Two copper mines in insular Newfoundland are located at tidewater. Both are on the Baie Verte Peninsula, one being located at Tilt Cove and the other at Little Bay, a few miles from Springdale.

The mine at Tilt Cove spills some 7,000 tons of liquid wastes, and about 2,000 tons of solid wastes each day. These discharge directly to tidal water from the concentrator. Because of the very large dilution available in the surrounding sea, chemicals in solution have not been traced more than a few hundred yards or so from the effluent pipe. Consequently, from this point of view, little harm is believed done to fish populations except in the immediate vicinity of the discharge. Fines from solid tailings are, however, distributed far and wide by the action of wind and tide and these, which settle out during times of low wind and tide action, are stirred up again by periodic heavy storms. In this regard, complaints are received of fines fouling fishing gear located many miles from the area of wastes discharge. Fishermen advise that these conditions occur mainly after wind storms from certain directions. Sufficiently detailed work has not been done to properly assess this problem.

At the Little Bay mine, near Springdale, about 900 tons of solid tailings, and an estimated 3,000 tons of liquid tailings are spilled daily to a small arm of the sea called Shoal Arm. This arm, which is some 50 acres in extent, formerly opened to the sea by a narrow mouth and acted as a partial settling basin. Nonetheless, turbid water was often carried by wind and tide to outside waters. Because of this, the Company was requested to construct a low dam across the mouth of Shoal Arm to confine the spread of fines to the arm itself. The dam was constructed and has since successfully reduced the spread of turbid water to the outside area.

An additional copper mine has recently begun production in the Baie Verte Peninsula area and another will become operative soon. Both of these propose to discharge concentrator wastes into freshwaters, and discussions have been held to find acceptable ways to reduce the effects of these liquid and solid tailings on fish and other aquatic life. Some success has been achieved in confining solid wastes to limited areas in both cases but the problem of chemicals in solution, especially copper and zinc, is more difficult to solve. No large runs of migratory anadromous species are involved in either of these operations but the Department takes the attitude that fish populations, even if not fully exploited at present, should not be unnecessarily destroyed.

Still another copper deposit, located near Gull Pond, a major lake on South Brook, Halls Bay, will be brought into production in 1965. A concentrator for copper ore will also be a feature of this operation. In this case it seems likely, unless very careful precautions are taken, that substantial physical and chemical pollution of the downstream areas of South Brook may result.

The stream involved, South Brook, is one of three good sea-run salmon and trout streams flowing into Halls Bay at the base of the Baie Verte Peninsula. These streams provide the best recreational fishery, and almost the only substantial sport fishery for salmon, between the Exploits and Humber Rivers situated some fifty miles on either side of Halls Bay. In addition, each river also contributes substantially to the commercial salmon fishery in the area. Discussions were initiated some time ago to attempt to find a satisfactory solution to the problem of wastes from this mining development.

The foregoing has concerned itself with wastes disposal from iron ore mines and "heavy" metal mines. Other mines are in operation in the province but these are not known to contribute significantly to the water pollution problem.

Wastes from Pulp and Paper Manufacture

Two large newsprint mills are established on the island of Newfoundland. One is situated at Corner Brook, on the West Coast, and the other at Grand Falls, on the Exploits River. Annual production at the Corner Brook mill is in the order of 320,000 tons of newsprint and 30,000 tons of sulfite pulp; at Grand Falls it is about 220,000 tons of newsprint and some 7,000 tons of sulfite pulp. In both cases the sulfite figures quoted are for export pulp and are additional to sulfite pulp used in the production of newsprint.

At both locations newsprint is produced by a groundwood-sulfite pulp combination in the approximate proportions of 80:20 respectively. Much larger quantities of sulfite pulp are produced for newsprint production, therefore, than is produced for export. Wastes from sulfite pulp production, by the calcium process used in both mills, have a very high oxygen demand and figure prominently in pollution due to such operations.

A survey of the receiving waters for the effluent from both these mills was conducted in 1942 (Vavasour and Blair, 1955). No significant pollution, such as would endanger fish populations, was reported as a result of that survey. Since that time, wastes from both mills have increased as a result of stepped-up production. At the same time, domestic wastes from adjoining towns have also increased.

Wastes from the mill at Corner Brook empty directly into Humber Arm, Bay of Islands, about two miles from the mouth of the Humber River, probably the single most productive salmon river on the island. The location of waste outfalls away from the river mouth, and the dilution effect of the waters of Humber Arm seem, so far, to have precluded serious effect by these wastes on salmon escapements to the Humber River. Because of these factors no major pollution problem is known to exist in the area. It must be emphasized, however, that the area has not been examined in detail since the 1942 survey was conducted.

The situation due to wastes disposal from the mill at Grand Falls differs in many ways from that just discussed. The most obvious difference is that this mill is located some ten miles upstream on a river. All mill (and town) wastes are discharged to this river which is also a migratory path for anadromous salmon and trout.

Because of the Department's concern for anadromous and freshwater fishes, and because the Exploits is the largest river on the island and has much potential for salmon development (less than 20 percent of its watershed being utilized by salmon due, mainly, to natural obstructions), sampling and observation was begun some years ago to measure the effect on fish populations of these wastes. As a result, it can be said that the situation in the river below Grand Falls gives cause for concern under certain river conditions; these relating mainly to the volume of flow during migration periods.

This discussion of the effects of mill wastes to the Exploits River at Grand Falls concerns itself mainly with sulfite waste liquor (SWL) because the deleterious effects of this waste predominates over those of all other wastes combined (e.g., the oxygen demand from the wastes required to produce one ton of sulfite pulp is in the order of 600 pounds, that from one ton of groundwood pulp about 10 - 20 pounds).

SWL exerts two main effects on fish populations. These are (i) a toxic effect on the fish themselves, and (ii) a reduction of dissolved oxygen in the receiving waters which may make them unsuitable for fish life. In evaluating toxicity, it must be borne in mind that in the experiments to determine critical levels of SWL to which reference is made (Holland, 1960) dissolved oxygen was artificially maintained, whereas in a natural situation the two would operate together. Considering toxicity alone, therefore, probably provides an over optimistic view of the situation prevailing.

Average flow in the Exploits River ranges from a high of about 25,000 cfs to a low of around 2,000 cfs. In the area below Grand Falls, flow is seldom less than 5,000 cfs since the requirement of the powerhouse at the falls is of that order and additional water is provided from storage during low flow periods. It is considered, therefore, that minimum flow below Grand Falls is about 5,000 cfs. These low flow periods usually occur during the months of July and August, the time of Atlantic salmon upstream migration to their spawning grounds. This flow of 5,000 cfs is the equivalent of about 135,000,000 U.S. gal. per hr. The flow of sulfite waste liquor from sulfite production is approximately 400 U.S. gal. per min., or 24,000 U.S. gal. per hr.

The SWL experiments referred to in the foregoing were based on a 10 percent total solids content. SWL spilled at Grand Falls has a total solids content of 11 - 14 percent. It is assumed in the following that it is adequately described by the average of this range, namely 12.5 percent total solids.

To compare the effect of SWL at Grand Falls, therefore, with the experimental data referred to, it is necessary to express SWL at Grand Falls in terms of 10 percent total solids. The hourly SWL discharge becomes, by this method, about 30,000 U.S. gal. per hr. of 10 percent SWL. Using this figure, the flow of SWL into 135,000,000 U.S. gal. per hr. of river water gives a concentration of about 220 ppm SWL at river flow of 5,000 cfs.

The same experiments showed that at a SWL of 500 ppm a dangerous situation for young salmon was being entered upon. In these experiments, as noted earlier, dissolved oxygen level was artificially maintained, whereas in the natural situation it would be lowered by the concomitant oxygen demand of SWL, so that the situation would be less favourable to fish.

The detailed implications for Exploits River salmon and trout populations of SWL in the concentration shown cannot be stated for the following reasons:

(a) Atlantic salmon may be slightly more or less susceptible to SWL than the Pacific species tested.

(b) Experiments were conducted on young fish. Adults may be more or less tolerant, but other work does not suggest that this would provide much greater long term resistance to the effects of SWL.

(c) SWL in the river is not uniformly distributed for several hundred yards below the outfalls. This means that in some areas concentrations are probably lethal, while in others they may be harmless.

(d) Sampling data is not sufficiently precise to accurately chart SWL concentrations in affected areas of the river.

It may be stated with confidence, however, that during the adult migration period, which usually occurs during flow periods of 5,000 cfs (perhaps less, at times, due to operations at the powerhouse) there is real cause for concern. During the period of smolt migration, river flows (May - June) are usually well above summer low flow levels, so that SWL concentrations, in most years, should not reach dangerous levels at this time. Since most smolts now originate well below Grand Falls (except those from Stony Brook) it is probable that, for most of them, the worst zones of SWL pollution do not have to be traversed. There are, however, serious implications for development (for salmon production) of the area above Grand Falls since both adults and smolts from this area would have to pass through the areas of worst SWL concentrations.

Experiments have also been conducted to determine whether migratory salmon (adult or young) would deliberately avoid areas of SWL pollution, if cleaner water were available, and thus escape the worst effects of traversing zones of serious SWL pollution. These experiments (Holland, G.A. et al., 1960) indicated that, for SWL concentrations from 300 to 1,000 ppm, no well established aversion could be demonstrated.

As noted earlier, SWL has, in addition to its direct toxic effects, a large demand for dissolved oxygen. Obviously, the less water available to satisfy this oxygen demand, the more likely that depletion will occur. It is assumed, in the following, that minimum flows in the Exploits River are 5,000 cfs, and that salmon require not less than 5 ppm dissolved oxygen to enable them to survive and carry out normal functions.

At a low flow of 5,000 cfs in the Exploits below Grand Falls, and an average dissolved oxygen level of around 8 ppm, about 100 tons of oxygen are available on a daily basis in the area of the outfalls. The oxygen demand of the waste products from one ton of sulfite pulp production is estimated to be some 600 pounds (Beak, 1962), though some authors (Eldridge, 1960) report it to be as high as 700. Based on an average production of some 250 tons of sulfite pulp per day at Grand Falls, there is an approximate oxygen demand of some 150,000 pounds, or about 75 tons, by these wastes in that area. From the point of view, therefore, of the oxygen demand of SWL at low flows, it is obvious that a good situation does not exist since these wastes require some 75 percent of the dissolved oxygen available. It seems here that "the day is saved", at least partially, by the fact that wastes are not evenly distributed in the river, so that while some areas are almost devoid of dissolved oxygen, others retain a sufficiently high level to enable fish to migrate through. Actual oxygen determinations have shown some areas of the river to be below 2 ppm at times. It has also been noted that, while upstream of the polluted area fish (resident trout) are fairly plentiful, in and below this area they are, for practical purposes, non-existent - as are juvenile salmon. This is as might be expected under such conditions.

It is also important to note that, in the Exploits River below Grand Falls, the effects of SWL due to toxicity and oxygen depletion are further compounded by the presence of zinc and copper in solution (from mine wastes disposal) and, a few hundred yards below the mill outfalls, by domestic sewage from the twin towns of Grand Falls and Windsor. Mine wastes were discussed earlier, the effect of domestic sewage is reviewed in the following paragraphs.

Domestic Sewage Disposal

There are not many large communities in the province of Newfoundland and Labrador and, with a few exceptions, they are situated near tidal waters. Thus pollution due to domestic sewage disposal has not been as widespread as elsewhere.

There is, however, a problem on the Exploits due to domestic sewage disposal from the twin towns of Grand Falls and Windsor. This probably would not be too important, from the fisheries point of view, were it not operating in conjunction with the effects of SWL from the

Grand Falls mill. On the basis of a population in the order of 10,000 people, the BOD of the sewage wastes from these towns should be in the order of about 1 ton per day. It was noted earlier that oxygen available in the river at a flow of 5,000 cfs would be about 100 tons per day. This demand should thus be easily satisfied with no hint of depletion. Conditions in the area of sewer outfalls, however, are not normal since they are located only about one-half mile below outfalls for SWL.

Measurements in 1961 showed that, a few hundred yards below the point of SWL entry (Station No. 2), dissolved oxygen was reduced to an average of 65 percent saturation (39 - 85%, 3.4 - 7.9 ppm). Just below this area (Station No. 3) there is a small rapids, and some recovery of dissolved oxygen occurs - to 75 percent saturation (3.0 - 12 ppm). This, however, is temporary, since it seems that the SWL has not been totally oxidized in the short stretch of river in question. A few hundred yards below this station (at Station No. 4), and below two town sewer outfalls, dissolved oxygen levels drop even further than at Station No. 2. This is attributed to the fact that (i) the continuing oxidation of sewage wastes, with normal oxygen supply, has over balanced the additional dissolved oxygen provided at the small rapids below Station No. 2, and (ii) nutrient salts in the sewage have accelerated the SWL oxidation rate. At the next sampling station (Station No. 5), which is below the entry of all mill wastes and domestic sewage, dissolved oxygen values drop to an average of 56 percent saturation (range 18 - 92%) or 5.6 ppm (range 1.7 - 9.7 ppm). Approximately nine miles further downstream (Station No. 6) a fair recovery of dissolved oxygen levels becomes apparent. Even at this point, however, normal values had not been fully restored.

As far as domestic sewage in the Exploits River is concerned, it can be said, therefore, that in themselves their volume is insufficient to cause any lack of dissolved oxygen. However, since they enter an area already polluted by SWL, the effect of nutrient salts in the sewage is such as to accelerate oxidation of SWL and thus worsen a situation which was marginal prior to that time.

<u>Miscellaneous Sources of Pollution</u>

In addition to the major sources of pollution outlined in the foregoing, numerous isolated instances occur regularly. These relate mainly to such things as (i) gravel washing in or near salmon and trout streams to provide railway track ballast or highway construction materials, (ii) operation of sawmills, particularly in relation to sawdust disposal, (iii) use of insecticides, usually in more northern areas, for biting insect control, and (iv) small domestic sewage disposal problems, cesspool drainage and such like. These are handled on an <u>ad hoc</u> basis, and can usually be resolved without permanent harm being done to fish populations concerned.

Summary

From the foregoing it must be concluded that the province of Newfoundland and Labrador is no longer the pollution free area that it has sometimes been considered to be. And, although fish populations and water pollution have been the theme of this report, it seems that the situation in some areas is such that unless reasonable foresight is exercised, and proper precautionary measures taken, the foreseeable future may see not only valuable fish stocks threatened, but perhaps other water resource uses also being unnecessarily jeopardized.

Acknowledgements

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