The Library
Queen's University

Sawdust and Fish Life

BY

A. P. KNIGHT, M.A., M.D.

Professor of Animal Biology, Queen's University, Kingston.

Reprinted from Transactions of the Canadian Institute.

Vol. VII., 1903.

TORONTO:
MURRAY PRINTING COMPANY, 11-13 JORDAN ST.
1903.

SAWDUST AND FISH LIFE.

By A. P. Knight, M.A., M.D., Professor of Animal Biology, Queen's University, Kingston.

(Read 14th February, 1903.)

CONTENTS.

Part I.—Historical 2
Part II.—Experimental 9
Sinking of Sawdust 10
Aqueous Extracts from Sawdust 12
Aeration of Water Containing Extracts 13
Source of Extracts 13
Wood Cells and Cell Contents 14
Pulp Industry 15
Beet Sugar Industry 15
Solid Matter in Aqueous Solution Pine 16
Solids from Cedar 16
Effects of Cedar Sawdust Solution on Perch 17
" " " Leech, Snail, Vorticella 18
" " " Worms, Tadpole 19
" " " Black Bass Fry 20
" Pine Extracts on Fish Eggs 21
" " " Minnows, Perch, Worms, Tadpole 21
" " " Crustaceans, Hydra, Vorticella, Bass. 22
" Maple Extracts 24
" Hemlock Extracts 24
" British Columbia Cedar Extracts 24
" Red Pine, Oak, Elm 25
Rapidity of Solution 25
Fish at Mill Ends 26
A Stagnant Artificial Pool 27
Comparative Effects of Pine, Cedar. 28
" " Hemlock Bark, Cedar Bark 29
" " Hard Wood Sawdust 30
" " Conclusions Based on 32
Experiments with White Pine Bark 33
" " Hemlock and Cedar Bark 33
Decaying Sawdust 34
Bacteria in Wood Extracts 34
Aromatic Compounds 35
Nutritive Relations 37
Saw Mill on the Bonnechere River 38
Conclusions. 41
Acknowledgments 41
Dr. Connell's Bacteriological Examination 42

NOTE.—The trees mentioned in the following report are: White Pine (Pinus Strobus, L.), Red Pine (Pinus Resinosus, Ait.), British Columbia Cedar (Thuya Gigantea, Nuttall), Ontario Cedar (Thuya Occidentalis, Linn.), Hemlock (Thuya Canadensis, Carr.), Maple (Acer Saccharinum, Wang.), Elm (Ulmus Americana Linn.), Ash (Fraxinus Sambucifolia, Lam.), Oak (Quercus Rubra, Linn), Spruce (Picea Alba, Linn).

71 a.

PART I.—HISTORICAL.

THE following is a continuation of my preliminary report upon the effects of polluted waters on fish life. The work was first begun at the Dominion Biological Station, St. Andrews, N.B., in 1900, and has been continued since then at the biological laboratory of Queen's University, Kingston, and along the saw dust beds of the Bonnechere River in the county of Renfrew, Ontario.

The investigation was begun at the suggestion of Professor Prince, the fish commissioner for the Dominion of Canada, and has been carried on largely through the encouragement which he has given from season to season.

The question, "Is sawdust injurious to fish life?" has been before the Canadian public for over forty years. The *Fishery Act* of 1858 for the two Canadas provided that fish ways should be erected upon dams that obstructed the passage of anadromous fish to their spawning grounds in the shallow head waters of rivers; and it forbade also throwing lime, chemicals, and other poisonous material into such rivers. It did not mention sawdust or mill rubbish, but it provided for the making of regulations by the executive, and in the exercise of this power we find that on May 16th, 1860, a by-law was passed making it illegal to throw "slabs, edgings, and mill rubbish into any river or stream which may have been leased or reserved by the Crown for propagation, or where fish ways have been erected."

This by-law was embodied in the amended Act of 1865, the clause relating to sawdust reading as follows:—

"Lime, chemical substances, or drugs, poisonous matter (liquid or solid), dead or decaying fish, or any other deleterious substance shall not be thrown into, or allowed to pass into, be left, or remain in any water frequented by any of the kinds of fish mentioned in this Act, and sawdust and mill rubbish shall not be drifted or thrown into any stream frequented by salmon, trout, pickerel, or bass under a penalty not exceeding a hundred dollars."

Immediately after confederation the Act was further amended, and a very important proviso was attached to the foregoing clause, viz.:—

"Provided always that the Minister shall have power to exempt from the operation of this sub-section, wholly, or from any portion of the same, any stream or streams in which he considers that its enforcement is not requisite for the public interests."

Evidently the promoters of this legislation either did not feel sure that sawdust was poisonous, or they thought it just, in the interests of the lumber industry, to exempt from the operations of the Act certain large rivers in the maritime provinces, Quebec and Ontario. Exemptions were continued by the minister from year to year down to 1894, when they ceased by Act of Parliament. Parliament itself, however, extended these exemptions down to 1899.

In 1873 an Act was passed making it illegal to throw mill refuse into navigable rivers, on the ground that in some parts of the Dominion rivers once navigable had ceased to be so on account of the accumulation of mill rubbish. The Otonabee River in Ontario, and the La Have in N.S., were two rivers which were obstructed in this way.

Most of the Eastern United States have legislated against throwing sawdust into streams containing protected fish; but so far as I have been able to discover, the promoters of the legislation have never been able to prove conclusively the poisonous action of sawdust. At any rate, the scientists of the United States Fish Commission have not been unanimous in their opinions regarding the matter.

For example, in the Fish Commissioner's report for 1872-3, part i., "Inquiry into the Decrease of Food Fishes," Mr. Milner, one of the investigators, says (page 49): "In a number of rivers entering into Green Bay, the white fish was formerly taken in abundance in the spawning season. Saw mills are numerous on all these streams at the present day, and the great quantity of sawdust in the streams is offensive to the fish, and has caused them to abandon them. In one or two rivers of the north shore (Michigan) they are still found in autumn."

In this same report another scientist, Mr. Atkins, referring to the Penobscot River, says (page 303): "The extensive deposits (of sawdust) have in some instances so altered the configuration of the bottom as to interfere with the success of certain *fishing stations;* but beyond that I see no evidence that the discharge of the mill refuse into the river has had any injurious effect on the salmon. It does not appear to deter them from ascending, and being thrown in below all the spawning grounds it cannot affect the latter."

In the Fish Commissioner's report for 1872-3 and 1873-4, vol. I., we meet with another confident statement, but no proof. Mr. Watson, in an article on "The Salmon of Lake Champlain and its Tributaries" (page 536), says: "The sawdust stained and polluted the water, and the sediment and debris of the mills settled largely on the gravelly bottoms, which had been so alluring to the salmon, changed their character, and revolted the cleanly habits of the fish."

Four years after this the Commissioner inserts in his report (1878) a translation of an article by Professor Rasch, of Norway, on "The Propagation of Food Fishes": "That the rivers on which there is considerable cutting of timber gradually become more and more destitute of salmon is an undeniable fact; but while it is asserted that the sawdust introduced into the river from the saw mills causes the salmon coming from the sea either to forsake the foster stream because of meeting the sawdust, to seek another river not polluted, or else when the fish attempts to pass through the areas quite filled with sawdust then this by fixing itself in the gill openings, or between the gills causes its death, yet later experience seems to entitle us to the assumption that sawdust neither causes the salmon to forsake its native stream, nor produces any great mortality among the ascending fishes. The hurtfulness of the sawdust to the reproduction of the salmon is not so direct, but is exceedingly great in this, that it partly limits and partly destroys the spawning grounds of the river."

In his report for 1879, the Commissioner gives a translation from another Norse writer, W. Landmark, on "The Propagation of Food Fishes." This scientist mentions four objections to sawdust:—

1. "Sawdust gradually sinks to the bottom, and thus fills the very place where the fish eggs are to develop, with impure and injurious matter."

2. "When eggs are brought into contact with sawdust or any other rotting wooden matter for any length of time, the eggs are overgrown with a species of fungus, which invariably kills the germ."

3. "When the water rises and causes the masses of sawdust which have gathered in the river to move, a large number of young fish are carried away with it, and are gradually buried in the newly-formed piles of sawdust." In a foot-note he says: "It has been said that sawdust will drive the salmon entirely away from a river, but I think that

this is very improbable, and could only be possible in cases where a river has been completely filled with it."

4. "The refuse from the saw mills, in many places, interferes with the fisheries."

For the next eight years we find little or nothing in the reports of the United States Fish Commissioner regarding the ill-effects of sawdust. In an appendix to his report for 1887, entitled "Fisheries of the Great Lakes in 1885," we find the following expression of opinion from Hugh M. Smith and Merwin Marie Snell: "The fishermen appear to be considerably hampered in their operations by the presence of great quantities of drift wood and sawdust from the mills. At times this debris covers the lake (Michigan) for miles around, and very seriously interferes with the seining and netting. The most disastrous effects, however, are seen on the fish themselves, especially during the spawning season. Spawning grounds formerly existed in this vicinity, but they have been deserted for some years owing to the deposit of sawdust thereon."

On November 29th, 1888, there was started in *Forest and Stream* a very remarkable correspondence, which lasted nearly a year. The general topic was the effect of sawdust upon trout. The writers lived in Canada, the New England States, and some in the west as far as California. Both sides of the question were presented with great vigor. Most of the correspondents were evidently keen sportsmen and close observers of nature, and the only regret one feels in reading through these letters is that some of the men did not test their observations and conclusions by experimenting with sawdust. The following is a typical letter:—

A CENTURY OF SAWDUST.

Editor FOREST AND STREAM.

I was delighted with the intelligent way in which your correspondent "Piscator" handled the sawdust question in your issue of December 27th. It is a comfort to listen when a well-informed person speaks, but in these days of callow pretension experience is usually elbowed back from the front.

In my opinion the famous Mill Brook, of Plainfield, Mass., which has a record of a century as the finest trout water in the Hampshire hills, supplies those very conditions and corroborative data which "Piscator" declares are essential to determine what pernicious effect the presence of sawdust has upon the denizens of mill streams. Here is a water power which carried no less than thirteen manufactories fifty years ago. These included a tannery, a sawmill and factories for making brush and broom handles, whipstocks and cheese and butter boxes, all of which discharged, more or less, sawdust and shavings into the streams, to say nothing of three satinet factories and a felt hat factory, whose waste must have been deleterious to fish life.

Most of the buildings have since been destroyed by fire or tumbled into pieces by decay, but the old foundation, walls, and dams remain, and untold tons of tanbark and sawdust still cover the beds of the abandoned mill ponds knee deep, all of it in a perfect state of preservation, as I happen to know from wading the stream last summer. Nevertheless, the brook continues fairly stocked with small trout, despite the supplementary fact that it has been unmercifully fished ever since the memorial days of the "Mountain Miller," fifty fingerlings per rod being not unusual now for a days' catch. Besides, at no time within my recollection have there been less than three sawdust-producing mills on this stream at once, so that it may be asserted that its waters have not been normally clear for a century. Where the current is rapid and the water broken by ledges and boulders, the presence of the sawdust is scarcely perceptible, but at mill-tails, and in the basins above the dams, it accumulates in quantity and remains, becoming water soaked and sinking to the bottom.

Obviously, in localities where the entire bottom is imbedded by sawdust, fish can neither spawn nor feed ; but it happens that such deposits do not form on their breeding places, nor is the area of their foraging ground appreciably diminished by their presence. Even in the half-emptied and now useless ponds, the current constantly scours out a central channel through the sawdust, leaving the bottom clear and pebbly ; so that, in fact, these local beds are of no more detriment to the fish than so many submerged logs. The trout can range far and wide without encountering them at all. Yet, strange to say—that is, it must seem strange to those persons who take it for granted that sawdust kills fish—the most likely places for the larger trout are these self-same pebbly channels in the old ponds, along whose edges, despite a hundred freshets and ice-shoves, the persistent sawdust and tanbark lie in wind-rows so deep that the wader feels as if he were going to sink out of sight whenever he puts his foot into the yielding mass, every movement of which stirs up a broadening efflorescence which spreads for rods away, distributing itself throughout the stream.

From these sawdust beds I can always fish out three or four good trout with a cautious fly, and at certain times the surface is fairly dimpled with breaking fish, which presumably are after larvæ and insects which the sawdust has harboured, though careful investigation might discover other inducements for their congregating there.

In passing I would remark that this Mill Brook is fed by seven lateral brooklets, which tumble into it from the adjacent hillsides at intervals between dams, and are so effectually protected by overgrowth that they must always serve as prolific breeding places, secure from predatory birds and small boys, as well as places of refuge to trout which wish to escape the sawdust of the main stream. I have seen trout streams, especially in the pine barrens of Northern Wisconsin and Michigan, which were by no means as favoured as this Mill Brook, the current being comparatively sluggish, and not so capable of purging itself of sawdust ; yet I know ot few trout streams in any lumber region where its denizens cannot avoid the sawdust if they will, by withdrawing to the headquarters or lateral tributaries, provided fishways are supplied to enable them to surmount the dams where the accumulations chiefly occur. What I remark as most singular in the Mill Brook is, that the trout gather most where the sawdust is thickest, both on old mill sites and on sites where mills are running now. I take my best trout right from under the flume of a whipstock factory and sawmill, where the refuse is dumped as fast as it forms.

But I recall to mind a still more striking example of the innocuousness of sawdust. There are in Hampshire county, Massachusetts, a series of three large natural reservoirs, varying from half a mile to two miles in length, which for fifty years have abounded in pickerel, perch, eels, and bullheads.

It is said that they originally contained trout, but the water is dark and discolored by the drainage of spruce and cedar swamps. At the outlet of the lowest pond once stood a village called Hallockville, which operated a grist mill, sundry sawmills, and what was then the largest tannery in Massachusetts. It was burned in 1846 and never rebuilt, and the dams and foundation walls are now almost destroyed and buried by a new growth of forest. But the sluice and flood stream below are still clogged with the sawdust and tan bark deposited a half century ago, and the water is black and forbidding, though much broken into swirls and rapids by boulders and ledges. But for the colour of the water, it is a most likely-looking place for trout, though it has been tested time and time again without successful results. It has always been maintained, from the date of the building of the tannery, that there were no trout in it. I used to fish it myself when I was a boy. Last summer I took therefrom five small trout with a worm. They had doubtless worked their way up from the Buckland streams below, for they never came through the dam from the pickerel ponds above. Nevertheless, the lower streams are occupied by many sawmills, and carry their proportion of sawdust, that substance which some of your correspondents maintain is fatal to fish life. I leave your readers to draw their inferences, and trust that Mr. Fred. Mather will feel himself sustained by this testimony of the streams. That gentleman is not apt to make mistakes. He is grey with the experience of years, and that is better than guess work.

WASHINGTON, *December 29th.* CHARLES HALLOCK.

In this same year (1889) a very remarkable report on this subject was sent to the Hon. C. H. Tupper, the Minister of Marine and Fisheries, Ottawa, by W. H. Rogers, late Inspector of Fisheries for Nova Scotia. The report did not appear among the State papers, and it was consequently published in Halifax under the title of "*The Suppressed Sawdust Report.*" No one can read this pamphlet without being staggered with the mass of information which is supplied to prove the harmlessness of sawdust, and the marvel is that the Minister did not order a thorough investigation to be made into the whole subject.

Of course, diametrically opposite views were expressed by other fishery officers, in whose judgment, no doubt, the Minister had perfect confidence. For example, Mr. S. Wilmot, the Superintendent of the Dominion Fish Hatcheries, wrote a very vigorous report denouncing the deadly effects of sawdust, and his opinions were certainly entitled to some weight. But there was this marked difference between the reports of the two officers: Mr. Rogers' was bristling with facts and observations based evidently upon first hand knowledge of the subject, whereas Mr. Wilmots' report showed no close acquaintance with it.

Turning again to the reports of the United States Fish Commissioner, we do not find any further reference to sawdust until 1892, when Mr. Hugh M. Smith again reports upon "The fisheries of the Great Lakes." At page 404 he says:—"At first white fish and trout were both abundant. . . . Since 1881 or 1882 they have been comparatively scarce. . . . The gill-net fishermen lay the blame on the small meshed pound-nets. The pound-net fishermen, on the other hand threw the responsibility on the saw mills and the gill-net men. The saw mills, they say, pollute the waters with sawdust and vegetable refuse, and the gill-net men lose a great many nets, which with the fish in them soon decay and become a putrid mass, which contaminates the fishing grounds, and causes the fish to leave for other places."

Comparing this with his report for 1887 it will be seen that Mr. Smith refrains from asserting any ill effects from sawdust, and places the responsibility for such statements upon the fishermen. A similar remark applies to the International Fish Commissioner's report for 1893, and to the report of Mr. Richard Rathbun in 1899 on the "Fisheries in the Contiguous Waters of the State of Washington and British Columbia." "Attention," he says, "has been especially called to the Skagit river, on whose banks there are numerous shingle mills, from which a very large amount of refuse is allowed to enter the water. According to the statements of the fishermen in that region this practice has caused a great deal of damage to the spawning grounds of the salmon and has affected the fishery in other ways."

Coming to 1899 we find a very important report from the Dominion Fish Commissioner, Professor Prince, and one from the Deputy Commissioner for the Province of Ontario, Mr. Bastedo. Both reports command attention from the fact that they take opposite sides upon the sawdust question. Professor Prince says: "So far as our present knowledge goes, sawdust pollution, if it does not affect the upper waters, the shallow spawning and hatching grounds, appears to do little harm to the adult fish in their passage up from the sea." . . . "There is no case on record of salmon, or shad, or any other healthy adult fish being found choked with sawdust or in any way fatally injured by the floating particles."

Again, in summing up his conclusions upon all forms of pollutions: "In the first place it is evident that circumstances modify the effects of all forms of pollutions, so that waste matters which would be deadly in one river will pass away and prove of little harm in another, where the conditions are different. In the second place it shows how varied are the effects of various waste products under the same conditions upon different species of fish. Salmon will survive unharmed where shad and gasperaux would be killed off. Further, these notes indicate how little is actually known of the effects upon fish life of these various pollutions from accurate and thoroughly scientific experiments."

Contrast with this Mr. Bastedo's opinion as published in his report for the same year: "There can be nothing more destructive of fish life than the depositing of sawdust in the rivers and lakes. It is said to absolutely kill all vegetation, and it is well known that in waters where there is no vegetation fish life is noticeably absent. Minute crustacea of various kinds feed upon the juices of the plants which are to be found at the bottom. These afford food for the smaller fish, and again these furnish food for others of larger size."

Such was the state of our knowledge in 1900, when at the suggestion of Professor Prince, I undertook some experiments at St. Andrews, N.B., for the purpose of ascertaining whether or not sawdust was injurious to fish life.

PART II.—EXPERIMENTAL.

The results of these experiments were published in the report of the Minister of Marine and Fisheries, Ottawa, in 1901, and went to show that brook trout were not injured by living for two weeks in a water tank largely filled with sawdust, so long as a copious supply of water was allowed to run into and out of the tank. These results were abundantly corroborated this summer (1902) in a series of experiments carried on for several weeks in the biological laboratory of Queen's University, Kingston. Perch, rock bass and black bass fry were all used. In fact, the tests this season were, if anything, more exacting than they were in 1900. The volume of pine and of cedar sawdust used was 20 per cent. of the whole volume of the tank, and both adult fish and black bass fry (these latter only about six weeks old and an inch long) were kept for four or five days in the mixture, without any apparent injury.

When, however, sawdust was allowed to lie in still water, or in very slowly running water, entirely different results were obtained. Then, the most disastrous effects followed the immersion of different animals in the poisonous mixture. Not merely did adult fish die in it, but fish eggs, fry, aquatic worms, small arthropods, animalcules and water plants. Nor was the cause of death due to suffocation from lack of oxygen, because when air was made to bubble rapidly through the solution the final results were the same, the only difference being that death was somewhat delayed. No one could paint too vividly the deadly effects of strong solutions of pine or cedar sawdust when soaked in standing water. Adult fish died in two or three minutes; fish eggs in a few hours; fry and minnows in from ten to fifteen minutes; aquatic worms and insects, eight to twenty-four hours; aquatic plants, a few days. Every living thing died in it, and if one were to judge of its effects by laboratory experiments alone, then the prohibitory legislation needs no better defence.

Without anticipating further the results of these experiments, I shall proceed to describe them, so that the reader may be in a position to draw his own conclusions, if he differs from mine.

THE SINKING OF SAWDUST.

As regards the sinking of sawdust, the following experiment was typical of a large number which were carried out, in order to determine how much and how quickly sawdust sank after being thrown into the water at the tail end of a mill.

A litre measure was filled up to 900 c.c. with tap water, and then 100 c.c. of moderately packed pine sawdust was poured upon the water. The moment the sawdust touched the surface, particles began falling to the bottom, and continued to fall for nearly twenty minutes. During this time the water had penetrated 100 c.c. of the floating sawdust, and this volume of it began to sink very slowly *en masse*. Figure 1 represents the conditions in the experiment at the end of the 20 minutes. No less than 70 c.c. of the sawdust lay at the bottom; 100 c.c. were between the 700 and 800 marks, and about 20 c.c. only were floating. The 100 c.c. of sawdust at the beginning of the experiment had swollen to nearly 200 c.c. On giving the vessel a slight tap, the 100 c.c. of water-logged sawdust, lying between the 700 and 800 c.c. marks, suddenly upset and most of it sank to the bottom. The large particles, however, rose again to the top, so that in less than three minutes more, only 30 c.c. were floating, and the rest, swollen to 170 c.c., were lying at the bottom.

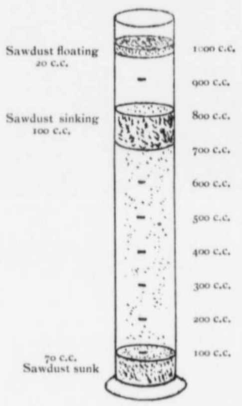

FIG. 1.

Litre measure at end of 20 minutes.

The following conclusions are based upon the results of many similar experiments: From 50 per cent. to 80 per cent. of white pine sawdust sinks in standing water, in from two to three minutes. The variations in quantity and time depend upon, (1) the size of the particles (2) upon the manner in which they are made, (3) upon whether the water is perfectly still or agitated, and (4) upon whether the particles are dry or moist.

Large particles sink much more slowly than small ones, because the latter are more easily penetrated through and through by the water.

Dust made with a hand-saw sinks more slowly than sawdust made with a large mill saw. The difference seems to be due to the difference in the force with which each is made. A large upright or circular lumber saw strikes the log with great force, squeezes out the imprisoned air from the wood fibres, renders them denser, and as a consequence they sink more quickly than particles of a similar or smaller kind which have been made by a hand-saw.

When water is slightly agitated, sawdust thrown upon it sinks more quickly than when the water is perfectly still. Consequently, in the swells of a steamer, in the waves made by wind, and in the ripple of a slight rapids, all the sawdust excepting the largest particles would sink to the bottom in a few minutes.

If thrown into a rapidly flowing stream, sawdust is carried downwards until it reaches comparatively still water, and then the finer particles sink ; the coarser may be carried for miles and miles down a river and out into the bays of a lake or sea.

In laboratory experiments the coarser particles would float for days, because the water is unable to penetrate the fibre and displace the imprisoned air, which gives to wood its buoyancy. Wood fibre is, of course, heavier than water, and therefore sinks ; and pine logs would sink much more quickly than they do only that the water cannot penetrate their interstices and drive out the air. Yet they do sink in considerable numbers, as every lumberman knows.

Hardwood logs cannot be floated to market at all, because the water of the cell-sap permeates them, rendering them heavier than water and they sink. A very simple experiment illustrates how pine logs sink after being in the water some time. Throw a piece of blackboard crayon into a dish of water. At first it floats, but soon bubbles of air escape from the chalk, and in a few moments it sinks to the bottom. So is it with sawdust and logs.

Sawdust from cedar takes a longer time to sink than that from pine. In fifteen minutes 66 per cent. only had sunk, probably because it contains more resin and consequently water-logs more slowly. Maple sawdust ranged half way between pine and cedar—66 per cent. sinking in eight minutes. Elm sawdust differed from pine, maple, or cedar in that only about 30 per cent. sank in twenty minutes; 75 per cent. of oak sawdust sank in six minutes. So that as far as my experiments went the different kinds ranged as follows: oak sank most quickly, then white pine, maple, cedar, elm. But it must be remembered that the particles in my experiments differed from each other in size and in the moisture they contained, and consequently different results might easily be obtained. The important point is that all kinds sink in a few minutes, especially in agitated water, but not, of course, in a stream with anything like a rapid current.

EXTRACTS FROM SAWDUST.

The first experiments of the season were performed for the purpose of determining the effects of sawdust upon fish eggs. The St. Andrew's experiment had shown that adult trout were not injured by sawdust in rapidly running water; but two other points remained to be determined: (1) Whether sawdust killed fish eggs, and (2) whether it destroyed the food of young, or full grown fish.

Perch eggs were collected along the shallows of Collins Bay, just west of Kingston, and brought to the laboratory on May 12th. They were placed in a clean aquarium with a stream of tap water (from Lake Ontario) running into and out of the vessel. On the same day a bag made of bleached cheese cloth, and filled with a peck of white pine sawdust was placed in an aquarium, 40½in. x 15in. x 16½in. It was weighted with stones to keep it on the bottom. Water entered the aquarium very slowly, so that the conditions of the experiment approximated somewhat to those in the pools of a sluggish stream.

Next morning it was noted that as a result of the bag of sawdust being in the aquarium all night, the water had dissolved out a sufficient amount of material from the sawdust to turn the bottom layer of water a yellowish brown color. This layer measured 1¾in. in a total depth of 16½ inches. Above the yellowish brown layer, and separated from it by a well-defined surface, the water was as clear as that of Lake Ontario. Only about ⅘ths of the bottom of the aquarium

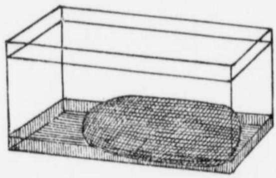

FIG. 2.

was covered by the bag; its upper surface stood about half an inch above the brownish liquid. These conditions are represented in figure 2. Four batches of eggs were placed in the aquarium at 10 a.m. of the 13th of May, viz.: two batches on the very bottom of the aquarium in the brownish water, and two on the surface of the bag of sawdust, well within the clear water.

Next morning at 9.00 a.m. every egg in the yellowish brown water was dead; and every egg in the clear water was alive.

Assuming that the brownish water was a saturated solution of material extracted from sawdust, two other solutions were made from it, —one of 25 per cent., and one of 50 per cent. strength, in tap water. Fresh batches of eggs were placed in each of them. In twenty-four hours the eggs in the 25 per cent. solution were all alive; half of those in the 50 per cent. solution were dead. In twenty-four hours more some of the fry had hatched out, but eggs and fry in both solutions were all dead.

In order to ascertain whether the death of both larvæ and fry was not due to lack of oxygen, rather than to poisonous extracts dissolved from the wood, air was made to bubble rapidly through some of the brown water. This experiment was begun at 12.30 p.m., and 800 c.c. of air per minute were passed through 230 c.c. of the discoloured water. At 5.30 p.m. of the same day, a batch of 60 eggs was placed in this aërated water, and air was passed continuously through it all night at the rate of 400 c.c. per minute. Next morning at 10 a.m. every egg in the batch was dead. The conclusion, therefore, is quite clear. The eggs were killed, not by lack of oxygen in the water, but by the poison contained in the water and evidently dissolved out of the sawdust.

The water had changed during the night to a much darker shade of brown. This marked change in colour will be discussed in a subsequent report.

SOURCE OF POISON.

The source of the poison given off by sawdust is undoubtedly to be found in the contents of the wood cells. Sugar, starch, oil, resin, gum, jelly, alkaloids, and acids are all examples of material stored in different parts of plants.

In the older parts of trees the protoplasm and sap disappear completely from the cells, and they may then contain nothing but the stored material. In the pine family there is stored in the wood and bark cells an abundance of crude turpentine and resin. The Norway spruce of Europe furnishes in this way turpentine and Burgundy pitch. The yellow pine of the Southern United States yields spirits of turpentine by distillation of the crude turpentine which runs away from the tree by cutting into it. The residue after the distillation is resin.

Now the poisonous material in sawdust must be either the cell wall or the stored material. It cannot be the cell wall, for this is just the wood fibre or material used in making paper, and pure paper is certainly not harmful to fish life. The poison can scarcely be anything else than the turpentine and other substances stored in the cells.

Different trees, such as tamarack, pine, cedar, spruce, etc., generate and store different kinds of reserve material. When a log from one of these trees is cut into boards, the sawdust gives off proportionately much more poisonous matter than the slabs, edgings and bark. The reason of this is easily understood. As each cell or vessel is microscopic, and contains only a very small quantity of poison, and as the cell wall must be broken open in order to let out the contents, it follows that the greater the number of cells that are opened, the greater will be the quantity of turpentine, resin, etc., poured out. Hence, a saw log converted into sawdust, or ground into shreds, as in a pulp mill, gives out the maximum of poison; whereas a similar log sawn into boards, edgings and slabs, will give out a much less quantity. The minimum will be given out by a saw log floating in the water.

The total waste in manufacturing saw logs into boards is sometimes stated as equal to the lumber obtained for market; but this is a gross exaggeration. Prominent manufacturers like the Rathbun Co., W. C. Edwards, M.P., and J. R. Booth estimate the waste as varying between 25 per cent. and 35 per cent. of the whole log. The proportion of refuse varies with the size of the logs, with the kind of lumber into which the log is cut, and with the kind of saw used in the mill. The old-fashioned gang saw and the large circular saw produce a higher percentage of waste than the more modern band saw. There is more waste in cutting a log into inch boards than into 3-inch deal, and small logs produce proportionately more waste in bark, slabs and edgings than large logs. The waste in sawdust alone varies from 10 per cent. to 20 per cent.

PULP INDUSTRY.

There are other industries in Canada, which in preparing their products for market grind up plants and trees, and thus let out their cell contents. One of these is the pulp industry—likely to become very extensive in the near future. Two processes are in vogue in this industry. In one, the logs are macerated with chemicals, the mills being known as sulphite mills. In the other process, the logs are ground into shreds in what are known as mechanical mills. Both processes liberate the greatest possible quantity of stored material from the wood cells, and if this material is equally poisonous with that liberated from sawdust, then the waste water discharged from a pulp mill should be much more poisonous than from a sawmill. The St. Andrew's experiments determined the percentage of poison from a sulphite mill which is fatal to fish life, but, so far as I know, the percentage of poison from a mechanical mill has never been determined. A provisional conclusion, however, may be based upon some of the experiments to be described later in this paper.

BEET SUGAR INDUSTRY.

The manufacture of sugar from the maple and from the beet depends upon the fact that sugar is one of the reserve materials stored in the cells of these plants. In order to liberate the sugar from the beet roots they must be thoroughly ground into a mash, so as to rupture the cell walls. The more effectively this is done, the higher is the percentage of sugar obtained from the beet. It is easily conceivable that the water that escapes from beet sugar factories may contain matter that is poisonous to fish life.

Professor Prince called attention to both these sources of pollution in his report for 1899, and they are referred to now merely for the purpose of emphasizing the fact that other industries may pollute the streams of Canada to even a greater extent than lumbering. In all three industries the source of pollution is the contents of the wood or plant cell.

There is a similar action going on in nature all the time. Leaves, branches, and trunks of dead trees are decomposing continuously; their cell contents are being dissolved in rain and melting snow, and are in part carried away in streams and rivers. The only difference is that in this latter case the poisons come away so slowly that air (oxygen), sunlight, and bacteria have ample time in which to change their poisonous character ; whereas in the saw mill, the pulp mill, and the beet sugar factory, the poisons are quickly discharged into running water, and tend at once to produce their effects upon fish and other life.

STRENGTH OF SAWDUST EXTRACTS.

As already explained, the first experiments were made with solutions obtained by soaking white pine sawdust for at least twenty-four hours in tap water from Lake Ontario. When the sawdust was soaked for four days in tap water, 1,000 c.c. of the yellowish-brown solution already described as oozing out from the bag of sawdust, and lying at the bottom of the aquarium, yielded 1,240 milligrams of solid matter after evaporation in a platinum crucible. The ash from this weighed 80 m.gs., which was found to be exactly the same as that from tap water. Deducting this from 1,240, leaves 1,160 m.gs. as the weight of the material stored in the pine cells of the sawdust, and dissolved out in 1,000 c.c. of water in four days.

After filtering off the first water, and adding fresh water to the same sawdust, and allowing the mixture to stand five days longer, it was found that 1,000 c.c. of this second solution yielded a total of 360 m.gs. of solid, or allowing for the ash in tap water, a net residue of 260 m.gs. of reserve material was dissolved out the second time.

The corresponding figures for cedar (Ontario) sawdust were as follows :—

1. Solid from 1,000 c.c. soaking four days...............	1,300 m.gs.
2. Same sawdust with first water filtered off, fresh water added and allowed to stand five days	=550 m.gs.
3. Same operations repeated, soaking five days	=350 m.gs.

No allowance is made in these figures for the ash from tap water, viz., 80 m.gs.

These figures indicate clearly enough that the reserve material stored in the wood cells comes away in diminishing quantities every time fresh water is added to the sawdust.

The next point sought to be determined was the number of times that fresh water could be added to a fixed weight of sawdust and continue to produce solutions which would be poisonous to fish life. For the purpose of getting information on this point two series of experiments were carried on, one with cedar sawdust and one with white pine.

EXTRACTS FROM CEDAR (ONTARIO).

On the second of June 400 grams of cedar sawdust were placed in a cheese-cloth bag and sunk to the bottom of a small glass aquarium (12 in. x 8 in. x 6 in.) containing 7,000 c.c. of tap water. Next day there had formed at the bottom, to a depth of two inches, a dark yellowish brown solution. The uppermost four inches were tinged a light yellow by diffusion, but there was a perfectly distinct surface of a greyish colour separating the upper from the underlying dark water. These characters became still more marked during the week, at the end of which time 1,400 c.c. of the lower liquid were siphoned off into a shallow circular dish and a perch weighing seventy grams immersed in the solution. In thirteen minutes it was lying on its back moribund, but revived when returned to fresh water. The control animal was kept twenty-four hours in 1,400 c.c. tap water in a similar vessel and then returned to the aquarium.

A perch weighing twenty-five grams was placed in 400 c.c. of this extract and air bubbled rapidly through it all the time. In twenty-eight minutes it was dead. The control animal in tap water under similar conditions was alive at the end of seventy hours.

Three *Daphniæ* in this extract died within two hours.

Fresh water Hydra died almost instantly in it. Paramœcia were unaffected by either cedar or pine extracts. These scavengers were often observed apparently feeding upon the dead bodies of Hydra that had died in the poisonous extracts.

On the 13th, all the water was poured off and fresh water added. On the 14th, a perch weighing seventy grams was placed in 1,400 c.c. of the solution formed during the preceding twenty-four hours. It was moribund in six minutes. With air bubbling rapidly through some more of this solution, another perch placed in it was moribund in seven minutes.

Pond silk appeared to be unaffected by an immersion of four days in this water.

June 15th. A perch moribund in fourteen minutes in a third solution—all the water being poured off and fresh added.

June 16th. A perch moribund in eight minutes in a fourth solution from the same sawdust.

June 16th. A perch moribund in ten minutes in a fifth solution formed by soaking this same sawdust in fresh water for seven hours.

June 17th. A perch moribund in ten minutes in a sixth solution. With air bubbling through more of this solution, another perch moribund in twenty-one minutes.

June 18th. A perch moribund in twelve minutes in a seventh solution. The water was poured off twice to-day, making an eighth solution.

June 19th. A perch moribund in eight minutes in a ninth solution. At 11 a.m. a pond leech was placed in this solution. It had eighteen young ones, five large and thirteen small, attached to its back. Three of these young at once detached themselves from the mother's back. The adult showed every symptom of discomfort by swimming rapidly round the vessel, then pausing and rolling itself up into a wheel as if to escape the effects of the water. It tried to leave the vessel, but was put back again. Gradually the smaller young detached themselves from the mother until only two or three of the smallest (about ¼ inch in length) remained on her back. The larger young ones were about an inch long, but when extended they were an inch and a half. Finally the smallest dropped off and wriggled about with the others on the bottom. The mother came to rest in about three-quarters of an hour. The young were all dead at 4.30 p.m.; the mother was moribund at 6 p.m., and died during the evening.

Two pond snails lived just twenty-four hours in this solution. The larva of an aquatic insect lived five and a half hours in it.

At 11.30 a.m. three bunches of vorticellæ were placed in the solution. Their cilia at once stopped moving in all the individuals, and they assumed the spherical form. By 5 p.m. most of these animals had dropped from their stalks and lay quite motionless at the bottom of the glass. Apparently they were dead. Returned them to fresh water, but found them all apparently dead next morning.

A bunch of embryos of the pond snail placed in this extract at 5.30 p.m. to-day were all found dead the next morning.

June 20th. Placed a perch weighing seventy grams in 600 c.c. cedar water drawn off for the eleventh time; air bubbling through it very rapidly. Moribund in ten minutes.

Placed in this extract about a dozen worms gathered from the mud in water about three feet deep. These animals were massed together and lying among the roots of aquatic plants. The moment the solution touched them they separated all over the bottom of the watch glass, wriggling in all directions and voiding their faeces. In three hours they were all dead. So were two small phyllapod crustaceans which happened to be along with the worms.

June 24th. Placed a batch of about fifty aquatic worms in cedar extract drawn off for the twelfth time. At first great wriggling ensues with evacuation of faeces; then constrictions occur in each segment of the body, making the animal look somewhat like a string of beads; then the hinder end appears to disintigrate but leaves the front end living and moving; finally the head dies. In two hours most of them were dead, but in a few the head was still alive.

June 25th. At 9.15 a.m. placed a tadpole one inch long in cedar extract drawn off for the twelfth time. Apparentty dead in fifteen minutes, but revived in about an hour when returned to fresh water.

Up to this time all experiments with cedar extract had been conducted with what might be considered as saturated solutions; that is, the solution used was siphoned off from the bottom of the aquarium where the sawdust was lying and where the dark colour showed the extract to be the strongest. From this date the experiment was varied by throwing out all the water, filling up the aquarium with fresh water and allowing the bag of sawdust to float at the top of the water. In this way the solution was uniform in colour and strength throughout the aquarium. The animals were then as a rule placed in the aquarium and usually swam about below the floating sawdust bag.

June 27th. Mr. Halkett, an officer of the Department of Marine and Fisheries, arrived to-day from Belleville, bringing with him about 100 black bass fry. The weight of one of these of medium size was found to be 135 milligrams; its length one inch.

Placed two of these fry in cedar extract drawn off fourteen times. Both appeared to be dead in two minutes. Placed in fresh water they did not revive.

June 28th. Two black bass fry in cedar extract drawn off sixteen times from the same sawdust, died in two hours.

June 30th. Changed all the water on the cedar sawdust to-day no less than five times. Immediately after adding the fresh water black bass fry were placed each time in the aquarium, and in each case the animal was dead in from half an hour to forty minutes.

July 7th. The last experiment with this sawdust was performed to-day. The water was changed this morning at 9 a.m. for the thirty-first time, and immediately afterwards a black bass fry was immersed in it. It swam about below the floating bag which contained the sawdust. The odour of the cedar was scarcely perceptible in the water. The strength of the solution was, of course, increasing all the time. At 11 a.m. the fry was dead.

Some of the water that was drained off from the sawdust at 9 a.m. was found to contain 235 m.gs of solid matter per 1,000 c.c. Allowing for the residue after ignition, there would still remain 155 parts per million of poisonous extract dissolved out of the cedar cells in the thirtieth withdrawal. This is quite remarkable when it is remembered that the sawdust had been soaking continuously for five weeks, and the water on it changed thirty times.

Comparing the solid in this solution with that in a saturated solution already given, viz., 1,240 per 1,000 c.c., we conclude that there has been a continuous withdrawal of poisonous extracts from the cedar. The question, therefore, of whether a river is polluted with sawdust or not, simply becomes a question of determining the quantity of sawdust poured into a known volume and flow of water, and the further question of determining whether the resulting solution is poisonous enough to kill fish eggs, fry, adult fish or fish food.

Warm water was found to extract the poison from wood cells much more quickly than cold water.

EXTRACTS FROM WHITE PINE.

The general effect of pine extracts upon fish eggs has already been described. It only remains to point out some special effects under varying conditions. One of these is that eggs live longer in aërated sawdust water than in unaërated. This is quite clear from the following experiment: At 9.45 a.m. of May 18th, two batches of eggs were placed in pine water at the bottom of the aquarium. At 5.30 p.m. every egg but two was dead.

At 11.15 a.m. of May 17th two batches were placed in pine water through which air was bubbling at the rate of 400 c.c. per minute. At

9.45 a.m. of the 18th, twenty out of one batch of thirty-three were dead; and in the other, thirteen out of seventy-three were dead. At 5.30 p.m. of the same day all of the first batch of thirty-three were dead, and only seven were alive in the other.

The effect of aërating the pine water was made apparent in another way. At 10.25 a.m. of the 18th, 120 eggs were placed in pine water in a shallow dish so that the water was only three-eighths of an inch deep. At 5.20 p.m. only a few were dead; all the rest were very quiet. At 9 a.m. the next morning forty-seven were dead; at 6 p.m. all were dead except five. At 10.30 a.m. of the 20th four of these five had hatched out and were quite lively. This experiment shows that the large surface exposed to the air absorbs oxygen, and therefore tends to prolong the life of both larvæ and fry. In contrast with this it is interesting to note that the same quantity of poisonous water put into a tall jar at 6 p.m. of the 19th had killed every egg in a batch of nineteen by 10.30 a.m. the next morning. In this case, the depth of the water and the small surface exposed to the air prevented the diffusion of the oxygen downwards to the eggs, lying at the bottom of the vessel.

There can be no doubt that fish instantly perceive the poisonous character of pine or cedar extracts. A minnow was placed in the large marble aquarium already described, and being driven to one end of the vessel, it sank through the clear water and into the yellowish brown extract lying at the bottom. The moment his head touched it he started towards the surface. I drove him back several times, and each time he sank into the coloured water he made frantic efforts to escape from it. He refused finally to be driven into it. Immersed in the pine extract in a separate vessel the minnow was moribund in three minutes and could not be resuscitated in fresh water.

A perch placed in 900 c.c. of pine water, in a shallow dish, was moribund in three minutes.

Another perch in pine water with air bubbling rapidly through it lived three and a half hours.

Two limicolous worms died in thirty minutes; two rotifers lived only ten minutes.

One tadpole half an inch long lived two hours. Another tadpole of the same size died in half an hour in a weak solution. A similar animal in strong cedar extract lived only six minutes.

A copepod placed in it at 11 a.m. was alive at 3.30 p.m., but died during the early evening.

Daphnia and the larva of an aquatic insect lived three days.

One hydra immersed at 10.40 a.m. was dead at 5 p.m. Its body was partly disintegrated and many paramœcia appeared to be feeding on it. Another hydra on being placed in the extract contracted its tentacles, detached itself from its support, contracted the lower half of its body, voided the intestinal contents, and appeared to be dead in two hours. It revived in fresh water.

A colony of vorticellæ at first showed no signs of discomfort; the cilia kept on moving, and the stalks contracting spirally. Soon the stalks ceased their movements; a little later the cilia stopped; the animals took the spherical form and within one and a half hours all were apparently dead.

A rock bass weighing seventy grams when placed in 1,300 c.c. of the extract became moribund in twelve minutes. All of the fish revived in from five to twenty minutes when returned to fresh water.

A perch weighing thirty grams when placed in a jar containing 400 c.c. of the pine water with air bubbling rapidly through it was moribund in ten minutes.

June 16th. Up to this time my experiments with this extract had been made with strong solutions. To-day a series of experiments were begun for the purpose of ascertaining, if possible, how long the same sawdust would continue to give off poisonous solutions when the saturated water was drained off and fresh water added from time to time.

With this end in view 360 grams of white pine sawdust were placed in a cheese cloth bag at 9 a.m. and sunk to the bottom of a small glass aquarium, 12 in. x 8 in. x 6 in., containing 7,000 c.c. of tap water. Two hours after, 800 c.c. were siphoned off from the extract at the bottom of the vessel. This was found to be very slightly poisonous to adult fish. Next morning at 10 a.m. 800 c.c. more were siphoned off. A rock bass lived in this one hour and twenty minutes. Another fish lived six hours in it when air was made to bubble rapidly through it. The third and fourth withdrawals of 800 c.c. each were thrown away.

June 21st. The larva of an aquatic insect lived twelve hours in the extract drawn off for the fifth time: vorticellae lived twenty hours, limicolous worms twenty hours, a pond snail seventy hours. The sixth and seventh withdrawals were thrown away.

June 27th. The eighth withdrawal of 800 c.c. made by soaking the pine eighteen hours, killed a perch in three hours, and three black bass fry in half an hour.

June 30th. A slight modification was made in this experiment. In place of siphoning off the strong extract at the bottom of the aquarium, the whole 7,000 c.c. of water were drained off, and the aquarium was filled up with fresh water. The weights were removed from the bag, which at once rose to the top of the water. Consequently the extract coming off from the sawdust, being heavier than the fresh water, fell towards the bottom and became uniformly diffused throughout the vessel. This was the twelfth withdrawal. Black bass fry lived five hours in this water, which was, of course, becoming more poisonous all the time.

July 7th. The last experiment with this sawdust was made to-day. The bag is still floating. The water was changed for the twentieth time at 9 p.m. last evening. At 9 a.m. to-day a black bass fry was immersed in this solution. In two hours it was dead. Some of this solution was evaporated and was found to contain 160 m.gs., or, allowing for the residue after ignition, eighty parts per litre. That is, pine sawdust soaking continuously since June 16th, with the water on it changed twenty times furnished in twelve hours eighty parts per million of poisonous extracts from its wood cells.

Comparing these figures with those for a saturated solution already given, viz., 1,160 parts for 1,000 c.c., we see that there has been a continuous withdrawal of poisonous material from the sawdust. The question, therefore, of determining whether any stream is polluted with pine sawdust or not is largely the question of determining the minimum amount of sawdust extracts which will kill fish eggs, fry, adult fish, and fish food. Needless to say, such determinations would have to be made for every sawmill stream in Canada, and for each separate kind of fish.

OTHER WOOD EXTRACTS.

A number of experiments were made with extracts from other woods besides pine and cedar. Norway, or red pine, British Columbia cedar, maple, hemlock, oak, ash, elm were all used, but it was soon discovered that the most poisonous extracts were obtained from the pines and cedars. Consequently experiments with the hard woods were soon discontinued.

From all hard woods, however, the saturated yellowish-brown extract was found to be very poisonous to both adult fish and fish eggs.

The following experiments give typical results in the case of each of these woods.

MAPLE SAWDUST.

A dark orange liquid oozed out from maple, and lay at the bottom of the aquarium. This was separated from the clear liquid above by a perfectly well-defined greyish surface. At the top of the water (16½ inches deep) intake and outflow pipes allowed tap water to flow into and out of the aquarium at the rate of 600 c.c. per minute. A perch having sunk into this extract once or twice could not afterwards be driven into it. The animal soon found where the fresh water inlet was, and when driven to other parts of the aquarium would always come back to the fresh water.

Aquatic plants in maple extract lost their chlorophyl in three days. Returned to fresh water they regained their colour, but the tips of their leaves had died.

HEMLOCK SAWDUST.

Hemlock has always had a bad reputation, but does not deserve it.

On July 27th, six black bass fry were placed in a mixture of five volumes of water to one volume of hemlock sawdust. The vessel was covered with four layers of cheese cloth, and a copious stream of water was made to fall upon it from a tap about a foot above it. The fry were all alive and well at the end of three days, when they were returned to the aquarium.

As a control experiment, five black bass fry were kept for the same length of time in the same volume of water, viz., 600 c.c., with air bubbling through it all the time. These animals also were quite lively and well at the end of the experiment.

BRITISH COLUMBIA CEDAR SAWDUST.

This sawdust sank rapidly, 75 per cent. falling to the bottom of perfectly still water in two minutes. It gave off a very poisonous extract. Two black bass fry lived only one minute in a solution made by standing five and a-half hours. The colour was a beautiful amber with a strong smell of cedar. A solution made by one gram of sawdust standing in 500 c.c. water for three hours rendered a black bass fry moribund in two hours. A solution from one gram in 750 c.c. water for twenty-seven hours, killed another fry in two and a-half hours. Even as homeopathic a solution as one gram in 1,500 c.c. killed fry in less than eighteen hours.

If much of this sawdust is poured into British Columbia streams, the stockholders of British Columbia Fish Canning Co's will need to look closely into the future prospects of their industry.

NORWAY, OR RED PINE.

Within three minutes, 90 per cent. of the sawdust from this wood had sunk. A strong solution made in eighteen hours rendered a black bass fry moribund in one hour. This water when aërated, but not filtered, rendered another fry moribund in exactly the same time. In both cases the gills of the animals seemed to be affected by fine particles of the wood fibre clinging to the filaments and preventing respiration. This was not observed to be the case with any other kind of sawdust.

A solution made by soaking one gram of this sawdust for nine hours in 250 c.c. of water killed a fry in less than an hour.

Another fry lived fifteen hours in a solution made by soaking one gram in 850 c.c. water for six hours.

OAK.

Contrary to expectations, oak sawdust was not so poisonous as pine and cedar. It communicated an orange colour to the water just as other woods did. A tadpole lived three days in a strong solution, and was quite lively at the end of that time.

ELM.

A few experiments were made with elm sawdust. Here again a dense yellowish-brown layer forms at the bottom of the aquarium. This kills adult fish in from half an hour to two hours. A tadpole lived over an hour in it. When this water was thoroughly aërated a perch lived twenty hours in it, and was then active and apparently well.

EXTRACTS QUICKLY SOLUBLE.

The experiments hitherto described would seem to indicate that some considerable time was required for the water to dissolve out the poisonous extracts from white pine sawdust, but such is certainly not the case. This was clearly shown in the following experiment, Fig. 3. Two minnows were confined in a bottle containing 600 c.c. water and eighteen grams of white pine sawdust. Fresh water was made to enter and leave at the rate of 100 c.c. per minute. The inlet tube passed straight to the bottom of the vessel, and its lower end was therefore buried in about an inch of sawdust. One animal lived forty minutes, the other fifty. When the incoming water was reduced to 80 c.c. per minute three

FIG. 3.

minnows lived only from three to five minutes. When the fresh water entered at the rate of 125 c.c. per minute, minnows lived from twenty to ninety minutes. The control animals were kept for a week in a similar bottle, without sawdust, of course, and with water coming in at the rate of 110 c.c. per minute. In these experiments the poisonous extracts must have been coming away all the time. The moment the bottle was full of water the minnows were slipped into it. Consequently, when the fish were killed in five minutes, the 600 c.c. at first in the bottle, and 400 c.c. additional water were poisoned. When they were killed in ninety minutes, no less than 11,250 c.c. were poisoned. That is, the percentage weight of sawdust to poisoned water was .16 per cent. This determination is important, as we shall see later, when we come to compare it with the percentage of sawdust thrown into the Bonnechere River.

FISH AT MILL-ENDS.

Millmen and anglers alike testify that many kinds of fish are taken by hook and line at mill-ends, no matter how excessive the sawdust may be. The sawdust does not kill the fish so long as there is a rapid and abundant flow of water. Why do fish thus congregate at mill-ends? To answer this question we must remember two things: first, rapidly running water is better aërated than sluggish water; and secondly, some fish, such as trout and salmon, ascend streams until they reach suitable spawning grounds, or are stopped in their ascent by high falls or mill-dams. In ascending a river these fish are but obeying a law of their nature; in congregating at mill-ends they are equally obeying a law of their nature, and are instinctively seeking water which furnishes their blood with a plentiful supply of oxygen. This instinct is well illustrated in the experiment just described in Fig. 3. The experiment was repeated a number of times, and in every instance the fish discovered where the fresh water came in. In one instance, in order to get close to the incoming water, a minnow stood on its head for fifteen minutes with more than half of its body buried beneath the sawdust. It was thus acting under the impulse of two fundamental instincts, viz., the instinct to avoid poisoned water on the one hand, and to seek fresh water on the other. The experiment seems to throw light upon the experience of anglers who have found that trout desert the main stream when saw mills are running, and betake themselves to the unpolluted branch streams lower down.

A STAGNANT ARTIFICIAL POOL.

Reference has already been made to the fact that black bass fry, minnows and perch, when placed in an aquarium, invariably avoided the poisonous sawdust water at the bottom. Having sunk into it once or twice, it was found almost impossible to drive them into it again. Here was a conflict between two fundamental instincts. On the one hand was the natural instinct to hide in deep water ; on the other hand, the equally natural instinct to avoid the poisonous solution at the bottom. Which instinct would the fish obey if compelled to make a choice ?

The following experiment was designed for the purpose of seeing which instinct was the more powerful, and for the further purpose of imitating what might possibly occur in a stagnant pool along the course of a sawdust polluted stream.

A glass aquarium 12 in. x 8 in. x 6 in. was placed in a much larger vessel and a mixture of ice and salt packed in the latter so as to surround the aquarium. The aquarium was then half-filled with white pine extract which had been forming for three weeks, and which killed adult fish in from one to three minutes. After the extract had been cooled down to 8° c., tap water at the temperature of 13° c. was slowly admitted to the aquarium so as not to disturb the underlying poisonous water. The tap water, being warmer, floated clear and transparent on the dark purplish extract below. The clear water entered and left the aquarium at the rate of 150 c.c. per minute. The arrangement of apparatus is represented in Fig. 4.

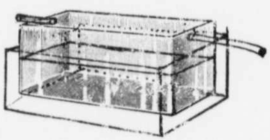

Fig. 4.

At first two minnows were placed in the aquarium. They at once dove to the bottom, encountered the poisonous water, immediately came up again, repeated the operation a few times, and finally remained swimming about in the clear water. Three black bass fry, liberated one after the other, went to the bottom and never came up—suffocated and poisoned in the dark stagnant water at the bottom. Of two other minnows dropped into the aquarium, one large one never came to the surface ; the other joined its fellows in the clear water above. All three soon found the end at which the fresh water was entering and remained there facing the stream.

This experiment shows what might possibly happen in pools partially filled with sawdust. Wood extracts would form, and being cooler and heavier than the clear water, would lie at the bottom of the pool. Of course, fish already in the pool would be driven away, but those coming up or down stream through shallow stretches, and trying to hide in the deeper waters of the pool, might be suffocated or poisoned.

COMPARATIVE RESULTS.

After obtaining the general results detailed in the preceding part of this paper, it seemed desirable to plan a series of experiments that would show comparative results at a glance. With this end in view, two grams each of different kinds of sawdust were placed in shallow circular dishes containing respectively, 300, 400, 500, 600, 700, 800, 900, 1,000, 1,200, 1,500, and 1,700 c.c. of fresh water. After soaking for about five hours in each case, a minnow was placed in each of the dishes. The length of time each animal lived was carefully noted, except in those cases where death occurred during the night. The results are given in the following tables:—

WHITE PINE SAWDUST.

Weight of Sawdust.	Volume Water c.c.	Time Soaking.	Time at which minnow was immersed.	Results.
2 grams.	300	From 10 a.m.	2.43 p.m.	Lived about 9 minutes.
"	400	"	"	" "
"	500	"	"	" "
"	600	"	"	" "
"	700	"	"	" "
"	800	"	"	" 10 minutes.
"	900	"	"	" 13 "
"	1000	"	"	" 15 "
"	1200	"	"	" 20 "
"	1500	"	"	" 29 "
"	1700	"	"	" 29 "

ONTARIO RED PINE.

2 grams.	300	10 a.m.	2.47 p.m.	Lived 47 minutes.
"	400	"	"	" 50 "
"	500	"	"	" 50 "
"	600	"	"	" 1 hour and 28 minutes.
"	700	"	"	" 1 " 14 "
"	800	"	"	" 1 " 14 "
"	900	"	"	" 1 " 53 "
"	1000	"	"	" 2 hours and 20 "
"	1200	"	"	" 2 " 50 "
"	1500	"	"	" 3 " 45 "
"	1700	"	"	" 3 " 45 "

ONTARIO CEDAR.

Weight of Sawdust.	Volume Water c.c.	Time Soaking.	Time at which minnow was immersed.	Results.
2 grams.	300	From 10 a.m.	2.33 p.m.	Lived 8 minutes.
"	400	"	"	" 9 "
"	500	"	"	" 19 "
"	600	"	"	" 20 "
"	700	"	"	" 21 "
"	800	"	"	" 22 "
"	900	"	"	" 27 "
"	1000	"	"	" 27 "
"	1200	"	"	" 1 hour.
"	1500	"	"	" 1 " and 48 minutes.
"	1700	"	"	" 1 " " 55 "

BRITISH COLUMBIA CEDAR.

2 grams.	300	10.15 a.m.	2.51 p.m.	Lived 6 minutes.
"	400	"	"	" 6 "
"	500	"	"	" 15 "
"	600	"	"	" 53 "
"	700	"	"	" 43 "
"	800	"	"	" 1 hour and 9 minutes.
"	900	"	"	Jumped out of dish unnoticed.
"	1000	"	"	Lived 1 hour and 32 minutes.
"	1200	"	"	" 1 " 36 "
"	1500	"	"	" 3 " 50 "
"	1700	"	"	" 3 " 29 "

HEMLOCK BARK.

Bark. 2 grams.	300	10.10 a.m.	2.36 p.m.	Lived 55 minutes.
"	400	"	"	" 1 hour and 32 minutes.
"	500	"	"	" 1 " 43 "
"	600	"	"	" 1 " 49 "
"	700	"	"	" 2 hours.
"	800	"	"	" 1 hour and 32 minutes.
"	900	"	"	Jumped out of dish unnoticed.
"	1000	"	"	Lived 2 hours and 18 minutes.
"	1200	"	"	" 3 " 24 "
"	1500	"	"	" 4 "
"	1700	"	"	" 4 " 15 "

HARD MAPLE SAWDUST.

Weight of Sawdust.	Volume Water c.c.	Time Soaking.	Time at which minnow was immersed.	Results.
2 grams.	300	From 10.38 a.m. July 15th.	July 15th. 3.30 p.m.	Lived 2 hours and twenty minutes.
"	400	"	"	July 21st, 10 a.m. Still alive.
"	500	"	"	" 16th. Died last night.
"	600	"	"	" 21st, 10 a.m. Still alive.
"	700	"	"	" 16th. Died last night.
"	800	"	"	" 21st, 10 a.m. Still alive.
"	900	"	"	Lived only 2 hours.
"	1000	"	"	July 18th. Died between 4 p.m. and 8 p.m.
"	1200	"	"	Lived 3 hours and 30 minutes.
"	1500	"	"	July 18th. Died between 4 p.m. and 8 p.m.
"	1700	"	"	" 20th. Died 3 p.m.

This experiment was discontinued July 21st, 10 a.m.

ONTARIO CEDAR BARK.

2 grams.	300	10.20 a.m.	2.41 p.m.	Lived 37 minutes.
"	400	"	"	" 1 hour and 20 minutes.
"	500	"	"	" 50 minutes.
"	600	"	"	" 50 minutes.
"	700	"	"	" 1 hour and 20 minutes.
"	800	"	"	" 1 " 31 "
"	900	"	"	" 1 " 40 "
"	1000	"	"	" 1 " 57 "
"	1200	"	"	" 2 hours 10 "
"	1500	"	"	" 4 "
"	1700	"	"	" 4 " 20 "

ELM SAWDUST.

2 grams.	300	10.44 a.m. July 15th.	3.30 p.m.	Lived 4 hours and 30 minutes.
"	400	"	"	Died 10 a.m. July 16th.
"	500	"	"	Lived 1 hour and 30 minutes.
"	600	"	"	" 2 hours and 30 "
"	700	"	"	" 1 hour and 30 "
"	800	"	"	July 21st, 10 a.m. Still alive.
"	900	"	"	" 18th. Died last night.
"	1000	"	"	" 21st. Died last night.
"	1200	"	"	Lived 1 hour and 30 minutes.
"	1500	"	"	" 4 hours and 30 "
"	1700	"	"	" 1 hour and 30 "

This experiment was discontinued July 21st, 10 a.m.

OAK SAWDUST.

Weight of Sawdust.	Volume Water c.c.	Time Soaking.	Time at which minnow was immersed.	Results.
2 grams.	300	Since 10.15 a.m. of 23rd.	July 23rd. 2.30 p.m.	Lived 2 hours and 30 minutes.
"	400	"	"	" 2 " 30 "
"	500	"	"	" 3 " 30 "
"	600	"	"	" 7 " 30 "
"	700	"	"	" 2 " 20 "
"	800	"	2 animals	One lived 2 hours and 20 minutes. July 24th. Died last night.
"	900	"	2 animals	One lived 7 hours and 30 minutes. July 24th. Died last night.
"	1000	"	"	July 25th. Jumped out unnoticed.
"	1200	"	"	" 30th, 9 p.m. Still alive. Released.
"	1500	"	"	Lived 3 hours and 30 minutes.
"	1700	"	"	July 25th, 3 p.m. Dead.

ASH SAWDUST.

2 grams.	300	10.48 a.m. of July 15.	3.30 p.m. July 15th.	July 21st, 10 a.m. Still alive.
"	400	"	"	Lived 1 hour and 30 minutes.
"	500	"	"	July 21st, 10 a.m. Still alive.
"	600	"	"	Lived 1 hour and 40 minutes.
"	700	"	"	" 2 hours and 10 "
"	800	"	"	July 21st. Died last night.
"	900	"	"	Lived 1 hour.
"	1000	"	"	July 21st, 10 a.m. Still alive.
"	1200	"	"	" 21st. Died last night.
"	1500	"	"	" 21st, 10 a.m. Still alive.
"	1700	"	"	" 19th. Died to-day.

This experiment was discontinued July 21st, 10 a.m.

HEMLOCK SAWDUST.

2 grams.	300	10.15 a.m. of 23rd.	2.30 p.m. July 23rd.	July 26th, 9.30 a.m. Dead.
"	400	"	"	" " "
"	500	"	"	July 30th, 9 a.m. Released.
"	600	"	"	" " "
"	700	"	"	" " "
"	800	"	"	July 26th. 9.30 a.m. Found dead.
"	900	"	"	Lived 45 minutes.
"	1000	"	"	July 26th, 11 a.m. Dying.
"	1200	"	"	" 28th, 3.00. Dead.
"	1500	"	"	Lived 1 hour and 45 minutes.
"	1700	"	"	July 26th, 9.30 a.m. Dead.

SPRUCE SAWDUST.

Weight of Sawdust.	Volume Water c.c.	Time Soaking.	Time at which minnow was immersed.	Results.
2 grams.	300	10.30 a.m. of 23rd.	2.40 p.m. July 23rd.	Lived 3 hours and 30 minutes.
"	400	"	"	July 24th, 9.30 a.m. Found dead.
"	500	"	"	" " "
"	600	"	"	" 26th, " "
"	700	"	"	" 24th, " "
"	800	"	2 animals	July 24th, 9.00. Dying. " 25th, " Found dead.
"	900	"	"	July 26th, 9.30 a.m. Found dead.
"	1000	"	"	" 30th, 9.00 a.m. Released.
"	1200	"	"	" " " Dying.
"	1500	"	"	" 27th, 7.30 p.m. Dying.
"	1700	"	"	" 26th, 9.30 a.m. Found dead.

The reader will, of course, understand that in all experiments due. allowance must be made for constitutional differences in individual fish. Some men survive the effects of cold, hunger or poisonous drugs longer than others. In the same way some species of fish, and some individuals in each species, are naturally more hardy than others, and can survive in poisoned water a longer time. Some are more delicately organized and are, therefore, more easily killed. For example, black bass fry lived longer than minnows in some of my experiments. Consequently too much importance must not be attached to the exact number of minutes or hours that a fish will live in any given strength of sawdust solution. When we are dealing with vital phenomena, all we can consider is the general average of a number of experiments. Keeping this in view, some conclusions may fairly be drawn from the foregoing results.

1. White pine sawdust is by all odds the most poisonous substance.

2. Next comes Ontario cedar.

3. Then British Columbia cedar.

4. Red pine, cedar bark and hemlock bark are moderately poisonous.

5. Maple, oak, ash, elm, hemlock and spruce may all be grouped together as only slightly poisonous.

EXPERIMENTS WITH BARK.

From the frequent references to the pernicious effects of bark which may be found in the literature of sawdust pollution, one would naturally expect to find that bark solutions were very destructive to fish life and fish food. The very opposite was found to be the case. Compared with the wood extracts, the bark solutions were comparatively harmless. Even tan bark, much execrated by fishermen and anglers alike, was not so poisonous as one might expect, but the experiments must speak for themselves.

WHITE PINE BARK.

Only 11 per cent. of sawdust from this bark sank in ten minutes. A black bass fry seemed perfectly unharmed after being three hours in a solution of this bark that had been forming for twenty-two hours (one gram in seventy-five c.c. tap water). The animal was then returned to the fresh water aquarium.

This same bark, after soaking two weeks, gave a solution that killed solely by suffocation. This was quite apparent from the fact that two minnows when placed in this water (freely aërated) lived for fwenty-four hours and were then liberated. When the solution was unaërated the minnows died in an hour or two. Pouring the solution several times from one vessel to another arëated it sufficiently to enable two minnows to live three days in it without apparent harm.

After standing six weeks a scum formed on the surface. This was removed and the solution aërated by pouring it several times from one vessel to another. A minnow now lived in it for two days and was liberated, apparently as well as ever.

HEMLOCK BARK.

A solution made by soaking one gram of this sawdust bark for fifteen hours in 100 c.c. of tap water killed a minnow in six minutes. After soaking for two weeks this water killed a minnow in one hour, even when thoroughly aërated. But these were very strong solutions compared with the ones obtained from wood.

CEDAR BARK.

Only 5 per cent. sank in fifteen hours. In two days it had all sunk excepting about 1 per cent. A 1 per cent. solution (one gram in 100 c.c.) made in fifteen hours, rendered a minnow moribund in fourteen minutes. Here again the solution was a very strong one compared with those obtained from wood sawdust and used in the experiments previously described.

As bark extracts, therefore, are not more poisonous than those from pine and cedar woods, it seemed useless to conduct separate experiments upon their effects.

DECAYING SAWDUST.

One objection frequently urged against the practice of throwing sawdust into streams and rivers is that the decaying sawdust imparts such a disagreeable odour to the water that sensitive fish are driven away to other waters not so polluted. It seemed to me, therefore, that some progress might be made towards a definite conclusion in this matter, if sawdust were allowed to stand for several weeks in an aquarium and tested from time to time as to the changes going on in it, and the influence of these upon fish.

With this end in view about 1,000 grams of white pine sawdust were placed in an aquarium three feet four inches long, fifteen inches wide, and filled up to sixteen and a half inches deep with fresh water. This was done June 24th. No water was allowed to enter or leave the vessel. No direct sunlight fell upon it.

The usual results followed, viz., a well defined layer of pale, yellow water one and three-quarter inches deep formed in a few hours and lay at the bottom. On top of this was the perfectly clear layer about fifteen inches deep.

After soaking for two days, bubbles of gas began to rise to the surface of the water, but no attempt was made to analyze it. The bottom yellowish layer had become so dense that no object could be seen across it—a thickness of fifteen inches. Its upper surface was sharply marked off from the overlying transparent water by a thin greyish layer. Microscopic examination of this layer showed it to be swarming with bacteria.

At the end of a week, only about an inch at the bottom had retained the original yellow colour; the next inch had changed to a yellowish brown; then came a greyish layer about one-sixteenth of an inch thick; above this, what had at first been fourteen inches of perfectly clear water had turned to a dark grey, though still quite transparent. Black bass fry placed in the aquarium at this time at first sank to the bottom, but after meeting the poisonous extract once or twice could not subsequently be driven into it. On the contrary they swam along the top with their nose just touching the surface of the water, and behaved as if suffering from lack of air. They lived only about two hours.

Four days after this, black bass fry placed in the upper fourteen inches lived only about one hour. They also swam along the surface and appeared to be gasping for air. That they were suffocating in both cases was proved by the fact that when fry were placed in a wash bottle of this water with air bubbling through it, they lived on for twenty-four hours, and were then apparently well and exceedingly active. On being transferred from the wash bottle to the aquarium the animals at first plunged downwards to the bottom, paused there a moment, but soon came towards the surface breathing very rapidly. Evidently they were suffering from lack of oxygen. They swim along the top with noses upwards and body inclined at an angle of about thirty degrees with the surface. Gradually they tire; sink towards the bottom; rise again; swim convulsively towards the surface; jump clear out of the water with gaping mouth; become exhausted by their convulsive efforts and finally sink to rise no more. Of all the fish killed in this extract not one ever rose to the surface after death.

It would be difficult to say whether this experiment throws any light upon a point much discussed in the literature of sawdust. The point is this: if sawdust kills fish, why are they not found dead in considerable numbers along the course of the stream? In my experiments the dead bodies of the fish never rose out of the poisonous liquid.

AROMATIC COMPOUND.

The foregoing experiments show that the oxygen naturally dissolved in the upper fourteen inches of water had, at the end of a week, all disappeared. It was used up either in supporting the life of the bacteria, or in oxidizing the wood extracts through the agency of the bacteria. Bacteria were abundant in every part of the aquarium, but especially in the underlying solution. Moreover, either by their action on the pine extracts, or by the chemical decomposition of these extracts, an aromatic compound of a sweetish pleasant smell had begun to form. At the surface the smell was faint; but in the water siphoned off from the bottom the perfume was strong and agreeable. The production of this compound is possibly due to micro-organisms, and if the special bacterium could only be isolated and used upon the extracts without admixture with other forms, it might be possible to manufacture a perfume from pine which many people would find agreeable. Alcohol, lactic acid, acetic acid, etc., are all formed by the action of bacteria upon vegetable substances in solution; the quality, too, of butter and cheese is determined by the action of bacteria on the constituents of milk; and it would, therefore, be only in accordance with well known facts to find that aromatic compounds, some pleasant, some unpleasant, could be formed from pine extracts by the action of different kinds of micro-organisms.

Some of the bottom water was distilled for the purpose of seeing whether this aromatic compound could be thus separated from the water, but the attempt failed. The distillate had the aromatic odour of the original water, but mixed with it was a disagreeable burnt smell. This distilled water killed minnows in half an hour, both when aërated or unaërated.

At the end of three weeks the uppermost fourteen inches of water had gradually become a steel grey or slaty colour and was quite opaque. The outlines of a window sash ten feet away could not be seen through it. The extract at the bottom still killed by its vegetable poison ; the slate coloured water above still killed by suffocation.

At the end of five weeks these conditions were but slightly changed. In place, however, of the pleasant aromatic odour previously arising from the surface, a musty, disagreeable smell had taken its place. As the laboratory windows were always open, mosquito larvæ became numerous and appeared to be feeding upon the bacteria. These larvæ died in sawdust solutions only when prevented from coming to the surface to breathe.

The water at the very bottom was still of a yellowish tinge ; the uppermost was smoky or slate coloured, as already explained. About 6,000 c.c. of this slate coloured water was siphoned off from the middle, on July 31st, and placed outside of the laboratory in direct sunlight. The object of this was to compare changes taking place in the slaty water placed in sunlight and breeze, with changes taking place in the slaty water which remained in the aquarium.

Dr. W. T. Connell, Professor of Bacteriology, made cultures from these two waters and compared them on three different occasions. His report which will be found in the appendix to this paper, shows that while the number of colonies from water in the shade increased from 3,435 per cubic centimetre to 7,870 per cubic centimetre ; the number of colonies from water in sunshine increased from 3,435 per cubic centimetre to 37,070 per cubic centimetre. These latter were different bacteria from the former. Sunlight and air had killed off those kinds of bacteria which flourish in shade and in absence of oxygen, and had stimulated the growth of other kinds of bacteria which flourish in sunshine and moving water. As a result of sunlight, warmth and breeze, what had been exceedingly disgusting water was changed in a fortnight to water brownish in colour, without any odour, and perfectly transparent. A heavy precipitate lay at the bottom. Minnows were able to live in it, and soon made havoc with the mosquito larvæ. In short the water had, within the fortnight, changed to normal water, while that in the shade still retained all its disagreeable and poisonous characters. The decaying mass of sawdust and water was kept for three months, and up to the very last showed no improvement. Slimy, a dark slate colour, foul smelling, teeming with anaerobic bacteria and mosquito larvæ, it was utterly unfit to support any kind of fish life.

NUTRITIVE RELATIONS.

However, the connection between a few links in the chain of animal life was apparent enough, viz., wood extracts supported bacteria, bacteria supported mosquito larvæ, and these again (after aëration of the water such as would occur in running water) supported fish life. These observations dispose to some extent of the oft repeated charge against sawdust that it destroys the food of young or newly hatched fish. When minnows relished mosquito larvæ as food, and I frequently saw them eating the larvæ, it requires no great stretch of the scientific imagination to understand how fish fry of different kinds, such as trout and salmon, might subsist upon the larvæ of mosquitoes and other aquatic insects, these latter in turn subsisting upon bacteria, and the bacteria subsisting upon the organic matter derived from the decaying vegetation of the forest.

Another thought comes up in connection with the presence of organic matter in streams and rivers. The organic matter which passed into a river when Canada was covered with forest must have been quite different in character from that which this same stream receives to-day from the vegetation of the farms along its valley. The surface drainage from a forest must differ in kind from the surface drainage of a farm, and the bacterial life in each must differ also. Moreover, the waters of our smaller streams were, years ago, shaded by trees, and the varieties of their bacterial life must thus have been quite different from the bacterial life in sunlit streams of to-day. Consequently, it may fairly be argued that the insect life, in and along the streams of an agricultural district, differs both in kind and number from what characterized these same streams 100 or 200 years ago. And if larval and adult insect life has dwindled or disappeared, so must the fish life which subsisted upon it.

The Anglo-Saxon has always been a disturbing factor in the balance of life. Forests, game and fish all disappear with his arrival. To get good fishing or good hunting now-a-days one must travel back to unsettled districts. No one expects game to be plentiful along the shores of Lake Ontario, but many people are amazed that fish are not abundant in it. They still hug the pleasing delusion that if brooks have been overfished, the fish hatchery can restock them. But with the disappearance of our forests it is exceedingly doubtful whether we can ever again, by all the help of hatchery, overseers and fish commissioners, re-people the streams which have been depleted by man through overfishing and deforestation. He has upset the balance of life ; it can only be fully restored by a return to primitive conditions. When game, therefore, becomes plentiful on the streets of Ottawa city, fish will be equally abundant below the saw mills of the Chaudiere Falls.

Such, at least, is the conclusion to which my experiments point, notwithstanding the indisputably poisonous effects of strong solutions from sawdust near the source of pollution. As I have already pointed out the question of whether any particular stream is sufficiently polluted with sawdust to kill fish life is simply the question of determining whether enough sawdust is passed into the stream to poison its waters. The forestry engineer will soon be trained to determine the strength of sawdust solutions, and will then be able to settle this question of pollution beyond the possibility of doubt.

ON THE BONNECHERE RIVER.

At present, however, a final judgment cannot be pronounced upon the poisonous effects of sawdust. These effects must be studied near the mills and along the sawdust beds of our rivers. A three weeks' study of the Bonnechere river, a tributary of the Ottawa much polluted with mill rubbish, led me to modify very considerably the conclusions which I had based upon my laboratory experiments. I visited the mill represented in two of the illustrations of this report fully expecting that not one fish could survive in such surroundings. But pike were abundant for miles below the mill, and fish (chub) could be caught any day along the side of the submerged driftwood. Stranger still, the fish so caught lived for three hours in a pailful of sawdust water drawn from the very centre of a sawdust bed. A few brook trout had been caught earlier in the season just below the mill when it was running. At the date of my visit, August 20th, 1902, the mill had been closed for seven weeks and no sawdust was then passing into the river.

The owner of the mill furnished the following information: The water passing over the dam is a stream nineteen and a half feet wide, by one and one-half feet deep, and moving two feet per second. This would mean that about sixty cubic feet of water were passing over the falls every second. Add to this, leakage through the dam, mill, and timber slide, estimated as equal to what passes over the dam, or sixty cubic feet more, a total of 120 cubic feet per second. The total water, therefore, passing down the river in July, August and September, would average 10,368,000 cubic feet per day, and weigh 642,816,000 pounds.

The mill cut an average of 375 logs per day. The logs averaged twelve inches in diameter and were chiefly sixteen feet long, but many

Sawmill on the Bonnechere river, a branch of the Ottawa. Sawdust and edgings pass into the river from the end of the mill.

were thirteen feet. Taking the specific weight of wet pine as .75, each log would weigh about 560 pounds. Of this weight about 13 per cent. would pass into the river as sawdust. This 13 per cent. was obtained as the average of five estimates furnished by such lumbermen as E. W. Rathburn, Esq., J. R. Booth, Esq., and W. C. Edwards, Esq. Consequently about seventy-two pounds of sawdust would pass into the river from every log cut into inch boards, or a total of 27,000 pounds of sawdust per day. Expressing this as percentage of water (642,816,000 pounds) we get .004 as the percentage strength of sawdust in this water.

During the high water of April, May and June the strength of the solution would be considerably less than .004 per cent., and as chub and brook trout were caught on and off all summer below the mill, this strength of sawdust solution was certainly not strong enough to kill off all the fish, though it is quite conceivable that it might drive fish down the river into tributary streams where there could be no sawdust pollution.

Comparing this percentage with that in two of the laboratory experiments described on pages 26 and 28 we find that in one case two grams of white pine sawdust in 1,700 c.c. of fresh water, *i.e.*, .12 per cent. strength, soaking for five hours, killed a minnow in twenty-nine minutes; and in the other case a percentage of .16 killed in ninety minutes.

Slabs, edgings and sawdust, half-a-mile below the mill.

Of course, these figures are mere approximations, but they point unmistakably to the conclusion that the sawdust poured into the Bonnechere river is not destroying its fish life. Moreover, in Golden Lake, an expansion of this same river, and ten miles above any saw mill, lake trout used to be very abundant. Every October large numbers were caught in nets along their spawning beds. Now these spawning grounds are reported to be deserted by the fish, and certainly sawdust cannot be blamed for their disappearance. Higher up the river, in Round Lake, the October fishing is still good, solely because there are fewer settlers and less fishing.

CONCLUSIONS.

1. Strong sawdust solutions, such as occur at the bottom of an aquarium, poison adult fish and fish fry, through the agency of compounds dissolved out of the wood cells.

2. The overlying water in such an aquarium does not at first kill fish. After about a week it does kill, but solely through suffocation, the dissolved oxygen having all been used up.

3. Bacteria multiply enormously throughout all parts of such an aquarium, and through oxidation change the poisonous extracts to harmless compounds. Mosquito larvæ live on the bacteria. No doubt, in natural pools, other aquatic insect larvæ live on bacteria also.

4. Subsequent aëration and sedimentation of sawdust water purify it, so that fish can live in it without injury.

5. Since adult fish and black bass fry both refused to be driven into pine extracts in the bottom of an aquarium after they had experienced its poisonous effects, we may infer that fish would desert a river much polluted with sawdust, going down stream and into tributaries to escape from the disagreeable influence of sawdust extracts.

6. No stream can be pronounced off hand as poisoned by sawdust. Each stream must be studied by itself and the varying conditions must be thoroughly understood before a judgment can be pronounced. The chief things to be considered are (1) the quantity of sawdust, and (2) the volume of water into which the sawdust is discharged. Subordinate conditions are the rapidity or sluggishness of the stream, the amount of sunlight or shade, and the character of the water, whether from agricultural lands or from primitive forests.

7. Further observations and studies along sawdust polluted streams and rivers of Canada are urgently needed before more definite conclusions can be reached.

ACKNOWLEDGMENTS.

Acknowledgment is due to Toronto University. the Public Library, Toronto, and the Canadian Institute, for the privilege of consulting their libraries in order to write the historical part of this report.

I am under special obligations to my colleague, Prof. J. C. Connell, M.A., M.D., for the large number of minnows which he procured for me, and which were so indispensable for the laboratory experiments.

Dr. John Waddell and Mr. C. W. Dickson, M.A., both of the School of Mining, Kingston, rendered valuable aid in determining the amount of solid matter in sawdust water.

The Ontario Fisheries Department facilitated my task on the Bonnechere by instructing their overseers to assist me in every way possible.

APPENDIX TO DR. KNIGHT'S REPORT ON SAWDUST AND FISH LIFE.

BACTERIOLOGICAL EXAMINATION OF SAWDUST WATER IN SHADE AND IN SUNSHINE.

Examination of sawdust water in aquarium made July 31st, 1902.

Two agar plates made. The *first* averaged 3,300 colonies of bacteria per cubic centimetre. None of the colonies were spirilla which were present in large numbers in direct microscopic examination of the water. The chief colonies were those of a spore bearing bacillus, a variety evidently of B. Subtilis; also a few sarcinae, particularly one like Sarcina Lutea. The second plate averaged 3,570 colonies per cubic centimetre. In general characters they were the same as in the first plate.

AUGUST 4TH, 1902. *Water in aquarium.* Agar plates averaged 3,570 colonies per cubic centimetre. These were in all respects like those of July 31st.

Same water in sunlight since July 31st. Agar plates average 4,200 colonies per cubic centimetre. These colonies contain the same bacteria as in the aquarium water, but in fewer numbers. Further, there is present a fluorescent bacillus, making up half the number of colonies present.

AUGUST 8TH, 1902. *Water in aquarium.* Agar plates develop 7,870 colonies per cubic centimetre. These colonies are of the same type as those found on previous plates with the addition of about 1,000 colonies of B. Mesentericus Vulgatus per cubic centimetre.

Water in sunlight. Agar plates develop 37,070 colonies per cubic centimetre. These consist mainly of B. Fluorescens Liquescens; also of Sarcina Lutea, and an occasional colony of B. Subtilis.

W. T. CONNELL,
Prof. of Bacteriology.