INTERNATIONAL PACIFIC SALMON
FISHERIES COMMISSION

PROGRESS REPORT

No. 24

EFFECTS OF DECAYING BARK ON INCUBATING SALMON EGGS

BY

J. A. SERVIZI, D. W. MARTENS
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NEW WESTMINSTER, B. C.
CANADA
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ABSTRACT

The effect of bark contamination on salmon spawning grounds was assessed in laboratory tests on sockeye salmon (Oncorhynchus nerka) eggs and alevins. Bioassays showed that chemical toxicity of materials leached from bark of Douglas fir, Lodgepole pine, Engelmann spruce and Alpine fir was not a factor influencing survival under the conditions tested. However, abundant growths of Sphaerotilus occurred on bark during initial stages of decay, causing severe mortalities among sockeye eggs and alevins owing to suffocation. In gravel-filled incubation boxes, contamination of gravel with bark caused significant reductions in survival from egg to fry at bark concentrations of 10% by volume, but 1% bark concentrations did not influence survival. Mortalities were attributed to blockage of intragravel water flow by bark particles. The oxygen demand of decaying bark was found to be relatively constant with time during the 683-day study. Calculations based on oxygen demand of bark indicated the amount of oxygen which would remain for egg incubation in natural redds at various temperatures and levels of bark contamination. Possible effects of various oxygen concentrations on size and emergence timing of fry were discussed and limiting amounts of bark recommended.

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EFFECTS OF DECAYING BARK ON INCUBATING SALMON EGGS[1]

INTRODUCTION

Logging practices which include waterborne transport and storage of logs have resulted in deposition of bark in streams and lakes which support salmon fisheries (Bond and DeRoche, 1950; McCrimmon, 1954; Vladykov, 1959). Although declines in quality of the aquatic environment have apparently been related to logging practices, the specific effects of bark deposits on fisheries resources have not been measured. One survey has shown that spawning sockeye salmon (Oncorhynchus nerka) avoided historic spawning areas blanketed by bark but eggs were deposited in locations where bark was mixed with the gravel (Internat. Pacific Salmon Fish. Comm., 1966; B.C. Research Council, MS, 1967). However, the amount of bark contamination which might interfere with normal development from egg deposition to fry emergence was not determined, consequently the laboratory study described herein was undertaken to evaluate the effects of bark on the incubation phase of the freshwater life of sockeye salmon.

Bark undergoes a decay process as the result of microbial activity, exerting an oxygen demand on the water percolating through the stream bed. Furthermore, bark and its associated wood tissues are known to contain substances such as tannins and resins which in sufficient concentrations are toxic to fish. Thus there is the possibility that organic compounds harmful to fish life may be leached from the bark, or formed as the result of microbial activity. Since the process of natural bark decay is believed lengthy, bark deposited in a stream bed from a single event may influence normal uses of the stream bed by salmon populations for an extended time.

The stream-bed environment is vital to salmon survival since it controls the only link between successive generations of sockeye. Adult sockeye die after spawning, and the eggs deposited in autumn in gravel redds hatch into

[1] This study was financed by the Governments of Canada and the United States with a part of the United States contribution originating from the Federal Water Pollution Control Administration of the U.S. Department of the Interior.

alevins in winter and emerge from the gravel in spring as free-swimming fry. During the gravel incubation period, eggs and alevins depend on percolation of stream water through the gravel for their oxygen supply and removal of metabolic waste products. Phenomena which disturb normal flow of this intragravel water or reduce the oxygen supply can kill the eggs or alevins directly, or so alter the rate of development that emergence of fry may be delayed, thus preventing fry from entering their new environment at the normal time.

The purpose of this study was to determine, in the laboratory, the oxygen demand of old and new deposits of bark during the decay process, the toxicity of materials leached from bark, and the influence of bark deposits on survival, development rate and ultimate size of sockeye fry incubated in gravel redds. Results of these experiments were used to calculate the effect of bark deposits on oxygen levels in typical salmon redds to indicate limiting levels of bark contamination.

METHODS AND MATERIALS

Two concurrent experiments, denoted A and B, were conducted in the laboratory. Experiment A was designed to measure the oxygen demand of bark and to detect the presence of toxicants in the leachate. Experiment B was designed primarily to assess the effect of intragravel bark on survival, emergence timing and size of sockeye salmon fry.

Experiment A

The study of oxygen demand of decaying bark was conducted in 18 round black plastic columns (3-inch diameter by 18 inches high) packed with known amounts of bark (FIGURE 1). Both "old" and "fresh" bark were studied. The "old" bark was dug from the bed of the Stellako River, 340 miles north of Vancouver, British Columbia, where it had lain underwater for approximately 14 months. The bark had originated from winter-cut Douglas fir (Pseudotsuga taxifolia), Lodgepole pine (Pinus contorta latifolia), Engelmann spruce (Picea engelmanni) and Alpine fir (Abies lasiocarpa). The logs had been rafted in lake water for a few weeks before driving. "Fresh" bark was

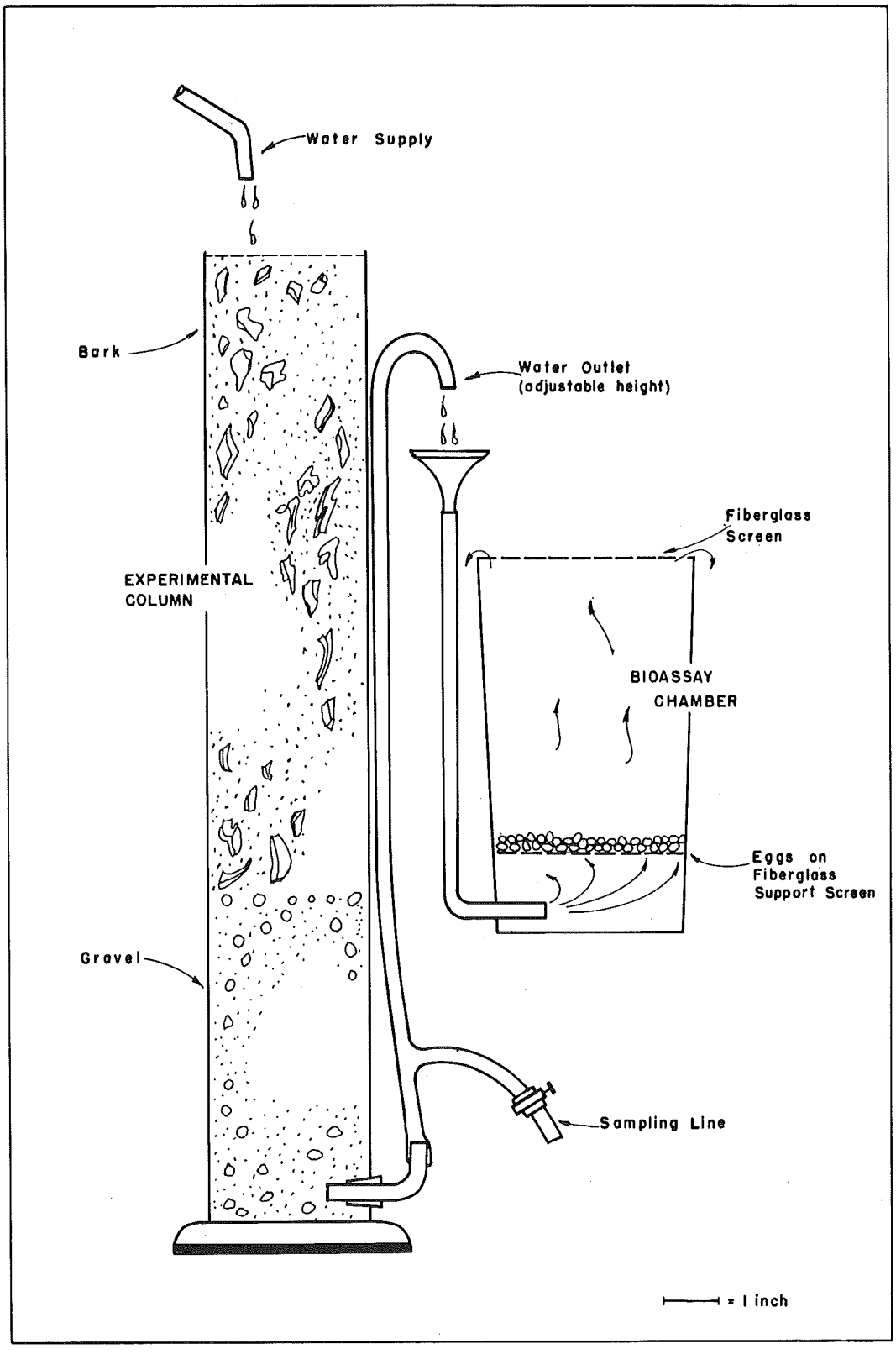


FIGURE 1 - Column and bioassay chamber used in Experiment A.

stripped in early September from Douglas fir, Lodgepole pine, Engelmann spruce and Alpine fir trees growing in the same general region.

Bark was chipped into pieces about 2 by 2 by 0.3 cm, the species mixed equally together and the 18 columns filled according to the protocol in TABLE 1. Washed gravel filled the lower section of experimental columns and formed a reservoir so that water samples drawn from the bottom would represent water which had passed at the specified velocity through the entire column of bark. A volume of 750 ml of wet bark equivalent to 221 gm of dry "old" bark or 182 gm of dry "fresh" bark was added to the experimental columns, while control columns contained only a 6-inch depth of gravel. Two water velocities and three constant temperatures were used for the tests. Effluent from each column was passed through a plastic bioassay chamber (FIGURE 1) containing 400 Cultus Lake sockeye eggs stocked within 24 hr of fertilization. Bioassays were maintained until the fry stage was reached. Bioassay chambers were checked twice weekly and dead eggs or alevins were removed and recorded.

TABLE 1 - Number of experimental columns at each temperature (°F) and water velocity (cm/hr) in tests of bark oxygen demand.

	EXPERIMENTAL CONDITIONS			
	35°F	45°F		55°F
BARK	15 cm/hr	15 cm/hr*	30 cm/hr*	15 cm/hr
Fresh bark	2	2	2	2
Old bark		2	2	
Control without bark	2	2		2

* Velocity of 15 cm/hr equal to water flow of 16 ml/min, and 30 cm/hr equal to 32 ml/min.

Dissolved oxygen content of inlet and outlet water of each column was measured 27 times throughout the 683-day study. Oxygen demand calculations were based on the amount of oxygen removed during passage of water through the column, flow rate and dry weight of bark. Corrections were applied for oxygen demand associated with control columns. The biochemical oxygen demand (BOD) of inlet and outlet water to the 55°F columns of fresh bark was

measured on the 187th and 194th days. Twice during Experiment A, analyses for hydrogen sulfide were conducted on water samples using a modification of the methylene blue colorimetric method (Standard Methods, 1965; and Von Gemerden, personal communication). Carbon dioxide and pH were also measured twice during the study. Carbon dioxide was measured by the titrimetric method (Standard Methods, 1965) and pH with a Beckman Model G pH meter.

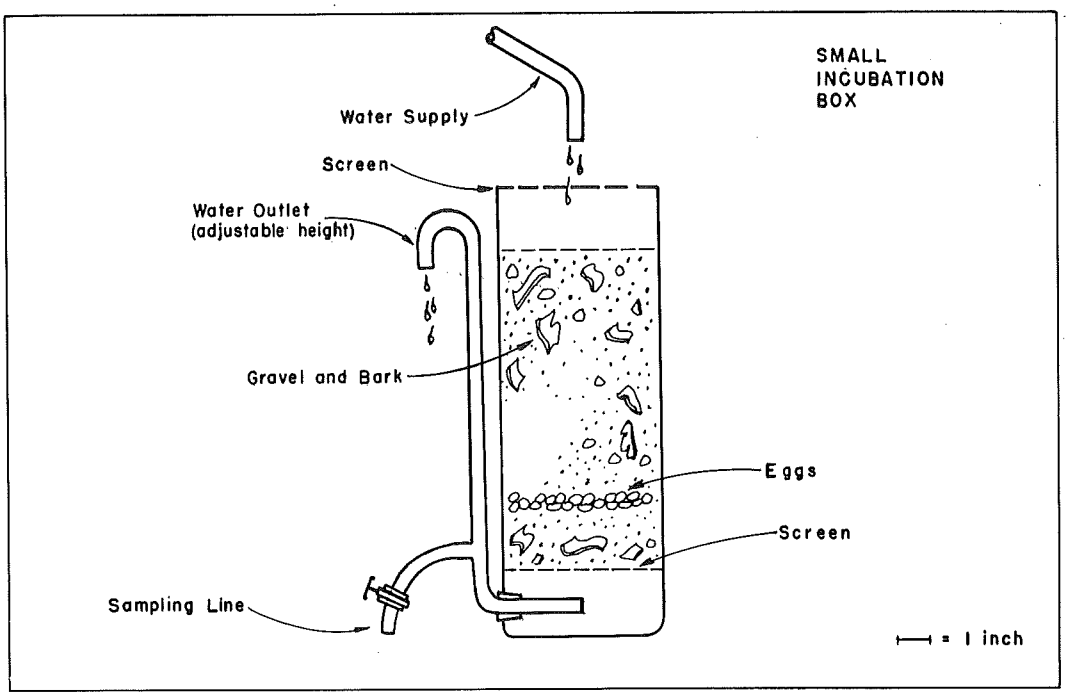
Experiment B

The effect of bark on incubating sockeye eggs was measured in large and small gravel-filled incubation boxes (FIGURE 2) at three different water velocities, two bark concentrations plus a control (TABLE 2) and one temperature schedule, to be described later. Each combination of bark concentration and water velocity was tested in four large and four small incubation boxes, giving a total of 48 tests plus 24 controls. In each case, two of the four identical boxes contained 800 eggs, while the other two were used to assess the toxicity of leachate to eggs held in a plastic bioassay chamber of the same type used in Experiment A (FIGURE 1). Thus 18 large and 18 small incubation boxes were operated without eggs but were equipped with plastic bioassay chambers containing 400 eggs through which the incubation box outlet water was directed.

TABLE 2 - Conditions of water velocity and bark concentration used in large and small gravel-filled incubation boxes of Experiment B.

WATER VELOCITY cm/hr	BARK CONCENTRATION %	NUMBER OF REPLICATES			
		Large Boxes		Small Boxes	
		800 eggs	0 eggs*	800 eggs	0 eggs*
5	0 (control)	2	2	2	2
	1	2	2	2	2
	10	2	2	2	2
15	0 (control)	2	2	2	2
	1	2	2	2	2
	10	2	2	2	2
50	0 (control)	2	2	2	2
	1	2	2	2	2
	10	2	2	2	2

* Plastic bioassay chambers containing 400 eggs receive outflow of boxes without eggs.



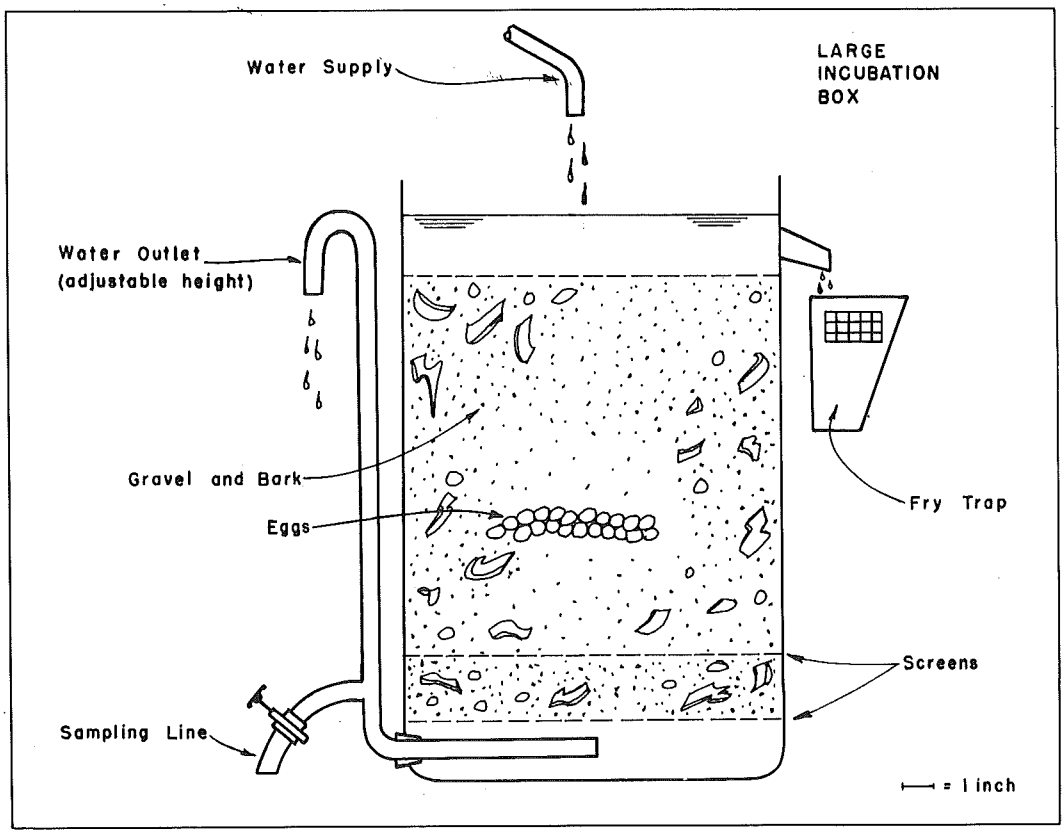


FIGURE 2 - Gravel-filled incubation boxes used in Experiment B.

The water velocities reported are apparent velocities, i.e., the discharge divided by the cross-sectional area, including both particles and voids. The velocities of 5, 15 and 50 cm/hr used in this study represented the normal range found in sockeye spawning grounds (Pyper and Vernon, MS, 1955). Discharge of incubation boxes was controlled by adjusting the height of the outlet, while the water supply was kept great enough to assure overflow, thereby maintaining the desired temperature. The water supply was drawn from Cultus Lake through a wood stave, plastic and iron plumbing system.

Gravel used in the experimental boxes was mixed from washed gravel and sand obtained from a local supplier. The mixture had a grading similar to that of typical sockeye spawning gravel for the smaller gravel sizes (TABLE 3). Gravel exceeding 1.5-inch diameter was excluded and gravel above .75 inches was reduced to decrease the likelihood of the larger pieces playing a significant role in channeling water around or away from the pocket of eggs.

TABLE 3 - Grading of gravel used in incubation boxes of Experiment B.

PARTICLE SIZE		PER CENT PASSING BY WEIGHT	
Inches	Sieve No.	Incubation Boxes	Range for Typical Spawning Grounds
1.5		100	45-84
1.0		96.4	33-72
0.75		66.7	27-60
0.525		36.3	22-49
0.263	3	14.1	12-30
0.185	4	12.4	9-24
0.093	8	10.5	6-17
0.046	16	7.4	4-10
0.023	30	3.3	2-4
0.0117	50	0.5	0.5-2
0.0059	100	0.0	0-0.5
0.0039	150		0-0.5

The bark used in the incubation boxes was "old" bark previously submerged for 14 months as described in Experiment A. The pieces of bark were passed through an industrial grinder where they were cut into particles ranging from 0.5 to 10 mm square and then added to the gravel mixture on a per cent of gravel volume (rocks plus voids) basis using water displacement to measure the volume of bark.

The experiment was conducted with sockeye salmon eggs from the Adams River race. Eggs were fertilized, water hardened and then transported to the laboratory where they were planted within less than 24 hr following fertilization. Eight hundred eggs, measured volumetrically, were planted in each box and 400 in each bioassay chamber according to the schedule in TABLE 2. A 5-inch square frame was used to confine the eggs during planting in large boxes in order to form an egg pocket. A frame was not used when planting the small boxes as they were only 5 inches square. Three of the larger stones were placed before eggs were planted in order to afford protection when the gravel covering was added. Eggs were carefully covered with an 8-inch layer of gravel, or gravel and bark, immediately following planting. The number of eggs in each pocket and the size and location of the pocket coincided with findings from studies at Weaver Creek where the mean number of sockeye eggs per pocket was 787, mean pocket size 23 square inches, and the pocket was 8 inches beneath the gravel surface (Pyper and Vernon, MS, 1955). Some alevins tend to move away from the egg pocket following hatching and the large boxes allowed for this phenomenon (Bams, 1969).

Since decay of bark is a biological process it is temperature dependent and oxygen demand would increase with temperature. Hence, in order to simulate the most severe conditions, temperatures equal to those experienced during a mild winter incubation period were selected for the incubation boxes (FIGURE 3). The same temperature schedule was used for all boxes and was adjusted daily to duplicate the desired temperature as closely as possible. Although a warm year temperature record (1962-1963) was duplicated, it was only slightly higher than the mean temperature of a typical Interior sockeye spawning stream and was similar to incubation temperatures at sockeye spawning grounds at many locations on the Fraser system.

Water samples at incubation box inlets and outlets were analyzed once each 2 weeks for dissolved oxygen by the high-DO-content modification of the Winkler method (Standard Methods, 1965). Carbon dioxide and pH were measured midway through the incubation period on inlet and outlet water of control boxes and those containing 10% bark.

Plastic bioassay chambers were checked twice weekly and dead eggs or alevins removed and recorded. The small boxes were terminated simultaneously prior to fry emergence at 1,630 degree-days (a degree-day equaled the difference between the mean daily temperature and 32°F). The contents of

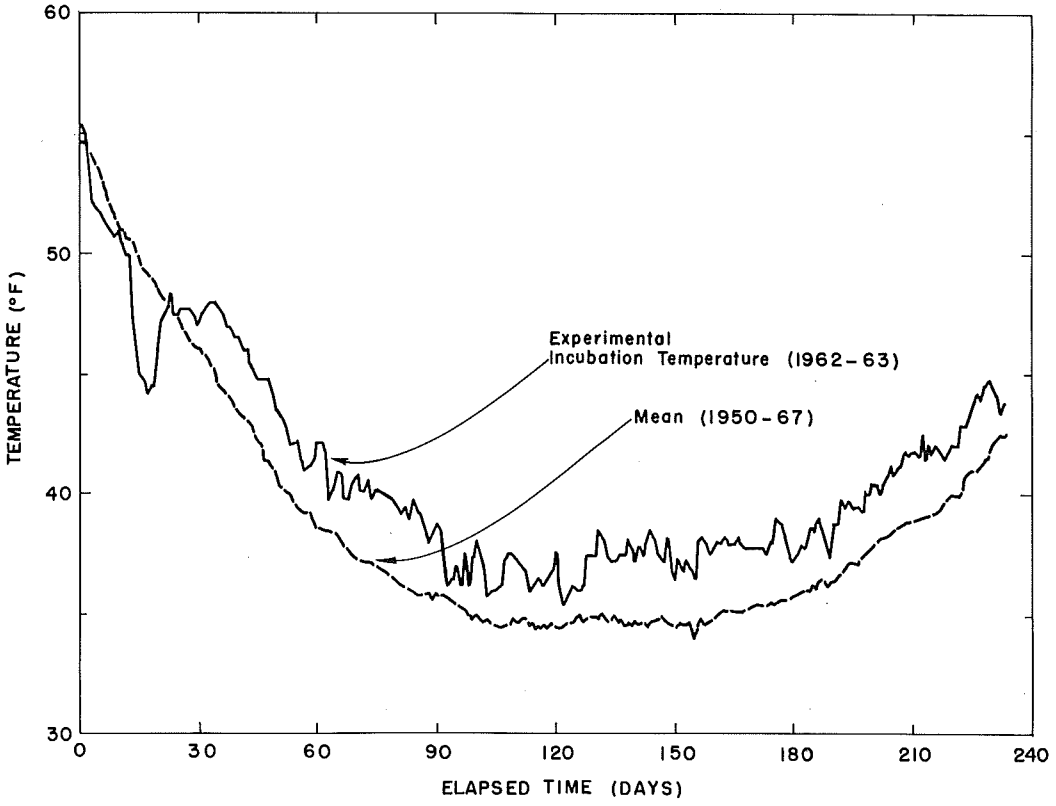


FIGURE 3 - Incubation temperatures used in Experiment B.

each small incubation box containing eggs were removed, pre-emergent fry enumerated and preserved in 10% formalin for later measurement of dry weight using 20 fry.

Fry traps on the large incubation boxes were placed in service prior to emergence and all overflow water directed to the trap via the fry outlet (FIGURE 2). Emergence was recorded daily for each box and a sample of 20 fry from the peak period was preserved in 10% formalin for measurement of dry weight. Dry weights of alevin bodies were obtained by carefully dissecting the body from the yolk, drying it for 24 hr at 98°C and weighing the body on an analytical balance. Any yolk material was separated from emergent fry before they were dried at 98°C and weighed.

RESULTS

Description of the Decay Process

Qualitative observations of the columns of old and fresh bark indicated that growth of filamentous bacteria Sphaerotilus sp. on fresh bark was the most noticeable event associated with the decay process. Sphaerotilus growth was first noted around the 28th day and appeared equal at temperatures of 45°F and 55°F, but was much less at 35°F. The latter temperature is considered by Harrison and Heukelekian (1958) to be near the limiting temperature for growth of this microorganism. Sphaerotilus growths flourished on fresh bark in the interval between the 50th and 100th day but declined gradually to a low level by the 194th day. However, the organism was still present, although in small quantity, when the experiment was concluded after 683 days.

During the period of peak abundance, growth of Sphaerotilus was great enough to almost fill the void spaces in the columns and was often discharged in the effluent where it subsequently plugged screens in bioassay chambers, and lodged in the gills of alevins, causing mortalities as will be described subsequently. Coincident with maximum growth of Sphaerotilus was the faint odor of hydrogen sulfide in discharges from columns of fresh bark. Although dissolved oxygen was 4 ppm or more in the discharges, clogging by Sphaerotilus may have created anaerobic zones where hydrogen sulfide was formed.

Sphaerotilus is known to utilize carbohydrates as a nutrient source, and the increase and subsequent decline in growth was probably associated with utilization of these components of bark.

Initially old bark was hard and did not break easily, however, it began to disintegrate after 100 days when fine particles were noted in the column discharges. Disintegration was still occurring at conclusion of the study, although the mass of bark in the columns was not noticeably decreased. Sphaerotilus was never observed on the old bark, suggesting that any carbohydrate present initially had been utilized during the previous 14-month decay period in the river.

Water Quality and Oxygen Demand of Bark

Carbon Dioxide, pH and Hydrogen Sulfide

Carbon dioxide remained at 4.5 ppm in the influent and effluent water from both the columns and the incubation boxes. Similarly, pH was unchanged by passage through columns or boxes and remained at 7.3 to 7.4 throughout the study. Hydrogen sulfide was detected only in effluents from columns containing fresh bark. Although easily detected by its characteristic odor, the highest concentration of hydrogen sulfide measured was 0.049 ppm. This concentration was approximately 10 to 16% of the level causing distress to salmonids (Haydu, Amberg and Dimick, 1952; McKee and Wolf, 1963; Servizi, Gordon and Martens, 1969).

Oxygen Demand

Approximately 2 to 6 ppm of dissolved oxygen was removed from saturated supplies by bark as water passed through the experimental columns in Experiment A, whereas depletion was only 0.1 ppm during passage through control columns. Calculations using oxygen depletion and flow rate showed the oxygen demand of bark varied with temperature, duration of decay, and whether the bark was fresh or old. At 45°F, the oxygen demand of fresh bark was about 1½ times that of old bark throughout the test period (TABLE 4). Oxygen demand of fresh bark after 2 years of testing continued to exceed the initial oxygen demand of old bark, even though the latter had decayed in the

river for only 14 months. This difference may have been related to the difference between the two categories of bark when first obtained. That is, the fresh bark had considerably more phloem attached to the cork than old bark, and this phloem may have accounted for the greater oxygen demand of the fresh bark, even after aging. In addition, much of the oxygen demand of old bark may have been exerted while in the river, owing to faster decay at summer river temperatures of 70°F.

TABLE 4 - Mean oxygen demand of bark (mg O_2/day/kg dry bark) at 100-day intervals (Experiment A).

Interval Days	No. Samples	Fresh Bark			Old Bark
		35°F	45°F	55°F	45°F
0-100	11	16.3	20.9	22.0	14.2
100-200	5	13.7	20.7	25.2	13.2
200-300	4	17.1	19.0	27.3	12.5
300-400	3	20.2	22.2	24.5	13.4
400-500	1	16.2	18.0	21.0	13.1
500-600	1	16.0	24.5	20.1	11.8
600-700	2	20.0	21.6	13.6	12.9
Mean		16.7	21.4	22.9	13.8

The oxygen demand of fresh bark was related to temperature, and averaged 140% greater at 55°F than at 35°F. The oxygen demand of both fresh and old bark varied little with time except for fresh bark at 55°F where the demand peaked at 27.3 mg/day/kg between 200 and 300 days and then declined in 600 to 700 days to a rate equivalent to that of old bark (13.6 mg/day/kg).

The possibility that organic materials capable of exerting BOD might be leached from decaying bark was checked by comparing the BOD's of inlet and effluent water of the 55°F columns on the 187th and 194th days when Sphaerotilus growth had declined. Since BOD's of the inlet and effluent water were similar and very low at less than 1.0 ppm, it was concluded that significant quantities of oxidizable organics were not leached from the bark as water passed over it. Thus oxygen demand was only of significance at the bark surface and not in the effluent water.

Judging from the foregoing results, the oxygen demand of decaying bark may be significant for more than 2 to 3 years. Thus successive depositions of bark on a stream bed would increase the oxygen demand on the intragravel water.

Toxicity of Leachates

A continuous bioassay of effluent from experimental columns in Experiment A resulted in no mortalities from old bark, but significant mortalities occurred in effluent from fresh bark at the two higher temperatures owing to suffocation of eggs and alevins by Sphaerotilus sloughed from the bark (TABLE 5). Alevins were apparently suffocated by entrapment of Sphaerotilus on their gill filaments (FIGURE 4). Sphaerotilus was not a problem at 35°F, where experimental and control mortalities were similar, although some mortality was probably caused by continuous incubation at this low temperature, which is an abnormal environment for a full incubation period.

TABLE 5 - Mortality from egg to fry stage during bioassay of effluents from columns of decaying bark (Experiment A).

Temperature °F	Bioassay Interval Days	Bark	Average Mortality %	Remarks
35	212	Fresh	11	
		Control	12	
45	147	Fresh	62	Suffocated by Sphaerotilus
		Old	1.0	
		Control	1.7	
55	64	Fresh	71	Suffocated by Sphaerotilus
		Control	5	

Dissolved oxygen concentration was not responsible for mortalities in bioassays since, in the most severe cases, dissolved oxygen registered around 4 ppm but typically ranged from 6 to 12 ppm in effluents from columns and boxes. These levels of oxygen are adequate to support development of eggs and alevins. Apparently leachates from both old and fresh bark mixtures did not

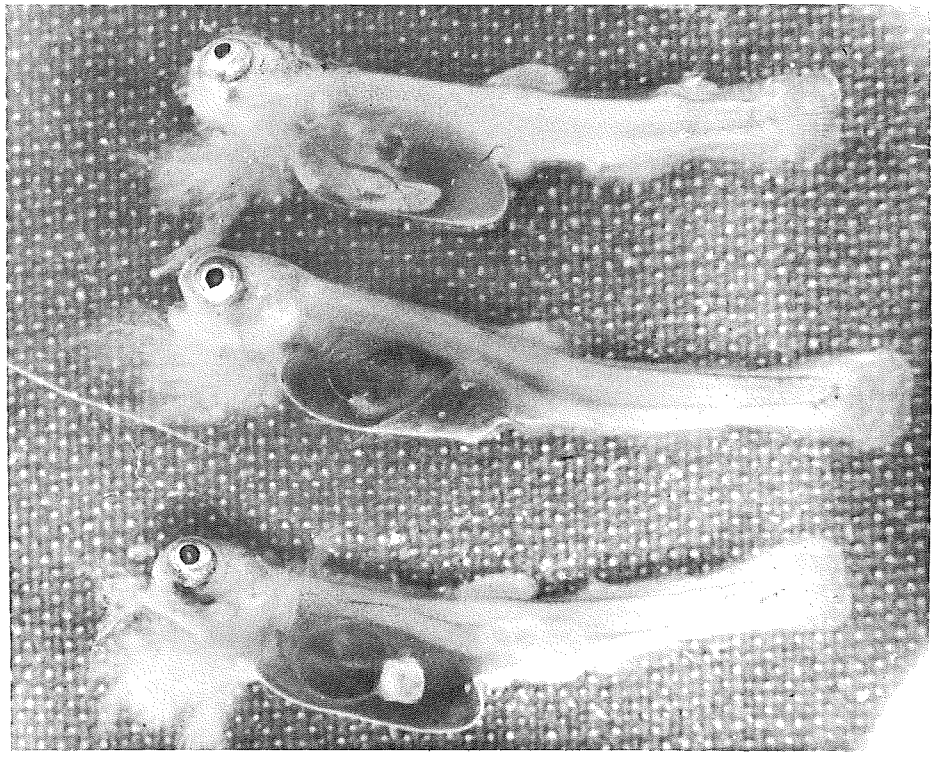


FIGURE 4 - Sphaerotilus lodged in gills of sockeye salmon alevins.

contain lethal concentrations of toxic substances when water velocities were equivalent to those occurring in natural spawning grounds.

Bioassays of effluent from incubation boxes of Experiment B indicated that acutely toxic conditions were not reached since mortality was uniformly low (TABLE 6).

TABLE 6 - Mortality from egg to fry stage during bioassay of effluents from incubation boxes (Experiment B).

INCUBATION BOX CONDITIONS		MEAN MORTALITY IN BIOASSAY CHAMBERS %
Water Velocity cm/hr	Bark Concentration %	
5	0 (control)	0.9
	1	1.1
	10	1.2
15	0 (control)	0.6
	1	1.2
	10	0.6
50	0 (control)	1.0
	1	0.4
	10	0.9

Egg-to-Fry Survival

The purpose of Experiment B was to determine whether inclusion of bark in gravel of a salmon redd altered survival, emergence timing, or size of fry. The effect of bark concentration and water velocity on survival of sockeye eggs planted in incubation boxes is summarized in FIGURE 5. In general, the presence of bark reduced survival below that of control groups. Although statistical analysis indicated survival in 1% bark was not significantly less than the control (without bark), survival in 10% bark was much reduced at all water velocities. In addition, survival at the lowest flow of 5 cm/hr was reduced in both the control and experimental groups.

Examination of data for individual boxes indicated the effect of flow and box size on survival. Survival was influenced by water velocity as well as

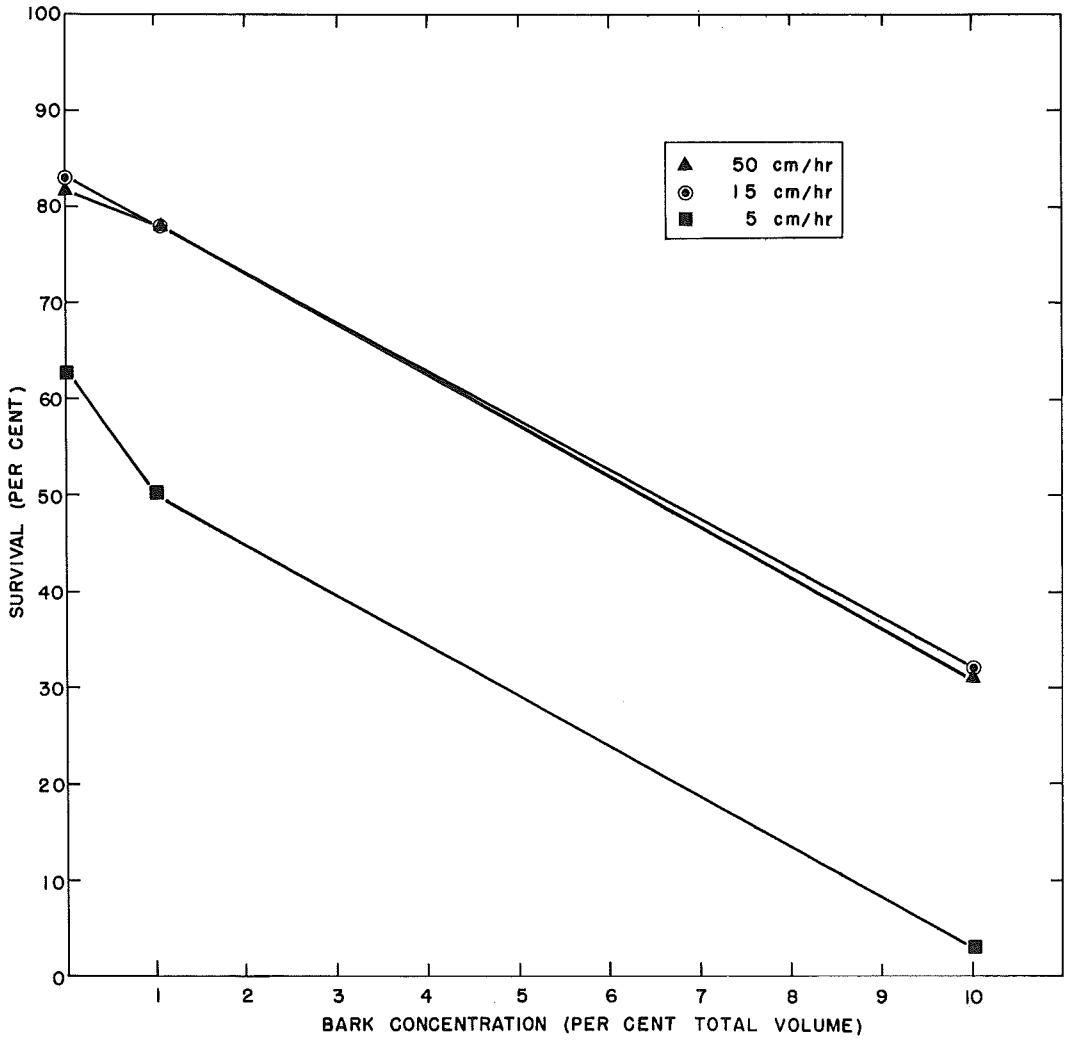


FIGURE 5 - Egg-to-fry survival of sockeye in incubation boxes.

bark concentration since at 5 cm/hr and 10% bark, survival was uniformly low in all boxes, whereas it was moderate to good in half the boxes at 15 and 50 cm/hr (TABLE 7). Survival among control and experimental groups was generally greater in the larger incubation boxes than in the small boxes with similar conditions of bark and velocity. The larger boxes provided space into which alevins could disperse if flow in their original niche was insufficient and thus may have accounted for the better survival. However, the added space of the larger boxes did not fully ameliorate the detrimental effect of bark as mean survival in these boxes was significantly reduced at 10% bark, just as in the smaller boxes.

TABLE 7 - Survival of sockeye eggs in incubation boxes (Experiment B).

WATER VELOCITY cm/hr	BARK CONCENTRATION %	% SURVIVAL				
		Large Boxes		Small Boxes		Mean
5	0 (control)	68	80	64	45	63
	1	68	61	29	43	50
	10	9.3	0	1.8	0	2.8
15	0 (control)	100	87	81	63	83
	1	78	94	57	71	78
	10	85	0	0.5	44	32
50	0 (control)	75	81	76	95	82
	1	98	74	61	81	78
	10	65	0	0.4	60	31

Examination of contents of small boxes indicated mortalities were a mixture of dead eggs, alevins and pre-emergent fry. Thus mortality occurred at all stages of development. Microscopic examination showed that bark particles had not lodged in the buccal cavities or gills of live or dead pre-emergent fry. Similarly, gills and buccal cavities of fry emerging from the large boxes were free of bark particles. Furthermore, Sphaerotilus was not observed growing on the old bark and thus could not have been a factor influencing survival.

Dissolved oxygen was lowest in effluents from incubation boxes containing 10% bark (TABLE 8), but the smallest single value of oxygen measured was 2.45 ppm. This oxygen concentration may retard rate of development but is

greater than the lethal level of 1.0 to 1.4 ppm reported for chum salmon eggs (Alderdice, Wickett and Brett, 1958). Although oxygen in the effluents was adequate for survival it was probably not representative of conditions at localized sites within the box where oxygen may have been less than that necessary to support fish life owing to clogging of gravel interstices by bark. Similar results using gravel-filled hatching boxes were found by Pyper and Vernon (MS, 1955). Finally, since bioassays of bark leachate showed that toxicity would not be a factor in survival, the foregoing results suggest that mortality was related to localized clogging of the gravel by bark particles, thereby isolating some groups of eggs and alevins from adequate flow and oxygen. Such a hypothesis is in keeping with the fact that survival in 10% bark was uniformly low at 5 cm/hr whereas moderate to good survival occurred in half the boxes at higher velocities, as would be expected if some gravel interstices were blocked by bark, preventing uniform distribution of flow through the voids. The results are also in agreement with studies showing that fine material in gravel reduced survival of incubating eggs (Cooper, 1965; McNeil and Ahnell, 1964). The oxygen demand of bark would add to the detrimental effect of clogging by causing localized depletions of oxygen, thereby creating an environment which would not support eggs or alevins.

TABLE 8 - Dissolved oxygen concentrations of effluents from large and small incubation boxes containing eggs (Experiment B).

WATER VELOCITY cm/hr	BARK CONCENTRATION %	LARGE INCUBATION BOXES Dissolved Oxygen - ppm Mean	LARGE INCUBATION BOXES Dissolved Oxygen - ppm Range	SMALL INCUBATION BOXES Dissolved Oxygen - ppm Mean	SMALL INCUBATION BOXES Dissolved Oxygen - ppm Range
5	0 (control)	10.51	12.70-8.60	8.52	11.95- 3.10
	1	10.33	12.10-7.30	8.26	11.45- 2.45
	10	6.75	9.10-3.40	5.32	10.20- 3.35
15	0 (control)	11.51	12.80-9.60	10.33	12.20- 8.15
	1	11.37	12.90-9.60	9.88	11.30- 7.05
	10	9.87	11.80-8.20	9.07	11.05- 6.20
50	0 (control)	11.90	13.40-9.90	11.61	13.00-10.10
	1	12.01	13.20-9.80	11.61	12.55-10.10
	10	10.89	12.30-9.35	10.98	11.90- 9.50

Although bark had a significant effect upon survival, it had little effect upon the size of surviving fry. The weight of peak emergent fry from the large boxes or pre-emergent fry from the small boxes was little different from that of respective control groups. A statistical comparison indicated a tendency for fry incubated in 1% bark to average about 5% larger than fry incubated in control gravel (TABLE 9). There was no significant difference between weights of fry from control gravel and 10% bark. Samples were not obtained from all incubation boxes containing 10% bark since survival was too low in some to provide an adequate sample. Weights shown in TABLE 9 also indicate the similar body size of peak emerging fry (large boxes) and pre-emergent fry (small boxes), even though the latter were sampled at an earlier stage of development and still had a mean dry yolk weight of 2 mg. Peak emerging fry had little or no yolk remaining. Presumably fry maintained a relatively constant body weight in the last stage of yolk consumption or else reached a peak weight prior to emergence.

Fry emergence timing from large incubation boxes was similar for all experimental conditions with the exception of the box containing 10% bark supplied with 5 cm/hr velocity (TABLE 10). The small numbers of fry which survived to emerge under these conditions were delayed approximately 100 degree-days, which was equivalent to 12 days at the prevailing temperature, and were also the smallest in mean body weight (TABLE 9). Late emerging fry could have a reduced survival potential since maximum survival is believed keyed to normal emergence (Brannon, 1965).

TABLE 9 – Mean dry body weights of fry from large and small incubation boxes.

WATER VELOCITY cm/hr	BARK CONCENTRATION %	LARGE INCUBATION BOXES		SMALL INCUBATION BOXES	
		Mean Dry Weight ± Std. Deviation mg	Mean mg	Mean Dry Weight ± Std. Deviation mg	Mean mg
5	0 (control)	21.58 ± 1.97 22.21 ± 1.59	21.90	21.99 ± 2.07 21.93 ± 2.74	21.96
	1	21.51 ± 2.06 22.54 ± 2.54	22.03	22.58 ± 1.90 24.22 ± 2.15	23.41
	10	* 18.32 ± 2.62	18.32	* 22.37 ± 1.88	22.37
15	0 (control)	21.82 ± 2.80 22.66 ± 2.70	22.24	22.12 ± 2.07 22.39 ± 1.75	22.26
	1	22.92 ± 1.75 23.95 ± 2.28	23.43	22.21 ± 1.94 23.01 ± 2.00	22.61
	10	* 22.84 ± 1.58	22.84	* 22.97 ± 2.05	22.97
50	0 (control)	20.24 ± 1.59 21.86 ± 1.74	21.05	21.71 ± 2.96 22.36 ± 2.29	22.04
	1	22.46 ± 1.84 24.35 ± 2.05	23.41	22.37 ± 1.66 23.81 ± 1.83	23.09
	10	* 21.69 ± 1.91	21.69	* 23.29 ± 2.50	23.29

* Insufficient emergence.

TABLE 10 -- Number of degree-days to 50% emergence from large incubation boxes.

Water Velocity cm/hr	Bark Concentration %	Degree-Days	
		Each Box	Mean
5	0 (control)	1879 1879	1879
	1	1902 1822	1865
	10	1958 *	1958
15	0 (control)	1876 1834	1855
	1	1814 1888	1856
	10	1888 *	1888
50	0 (control)	1862 1875	1868
	1	1875 1842	1859
	10	1854 *	1854

* Insufficient emergence.

Estimation of Oxygen Available in a Typical Redd

The effect which decaying bark may have upon dissolved oxygen concentrations in typical redds can be calculated using oxygen demand data from TABLE 4 and conditions reported for a typical salmon redd, including flow rates and intragravel oxygen concentrations. Interpretation of published data (Cooper, 1965) indicated the distance from the point where surface flow entered a typical redd to a point where it would contact incubating eggs was about 100 cm. Intragravel flow rates in areas used by sockeye salmon for spawning ranged from 5 to 50 cm/hr (Pyper and Vernon, MS, 1955). Dissolved oxygen concentrations of intragravel water in spawning grounds have been reported to vary considerably depending upon characteristics such as amount of surface water interchange, natural oxygen demand and intragravel flow. Wickett (1954) reported intragravel oxygen values ranging from 56 to 88% of saturation. McNeil (1962) found mean dissolved oxygen saturation values of 32.9, 62.9, 78.4 and 76.6% in a stream of Southeastern Alaska. Calculations using data of Pyper and Vernon (MS, 1955) indicated the mean dissolved oxygen in intragravel water of a typical sockeye spawning ground would be about 75% of saturation.

Taking the mean of the foregoing values at 67%, using maximum mean oxygen demand data for fresh bark from TABLE 4, and correcting dissolved oxygen for spawning at 1,000 ft elevation and a 100-cm flow path, the calculated amounts of oxygen available to eggs and alevins at 45°F and 55°F are shown in FIGURE 6. At a velocity of 5 cm/hr the dissolved oxygen available for incubation decreases rapidly as bark concentration is increased, whereas the effect of bark on available oxygen is progressively less pronounced at higher velocities. In assessing the possible effect of bark on oxygen resources of a spawning ground, the normal oxygen concentrations of intragravel water play a significant role. For example, an average value of 67% saturation was used as the normal oxygen saturation level in preparing FIGURE 6, but it is readily seen that if the value were lower the influence of added bark on available oxygen would be even more severe.

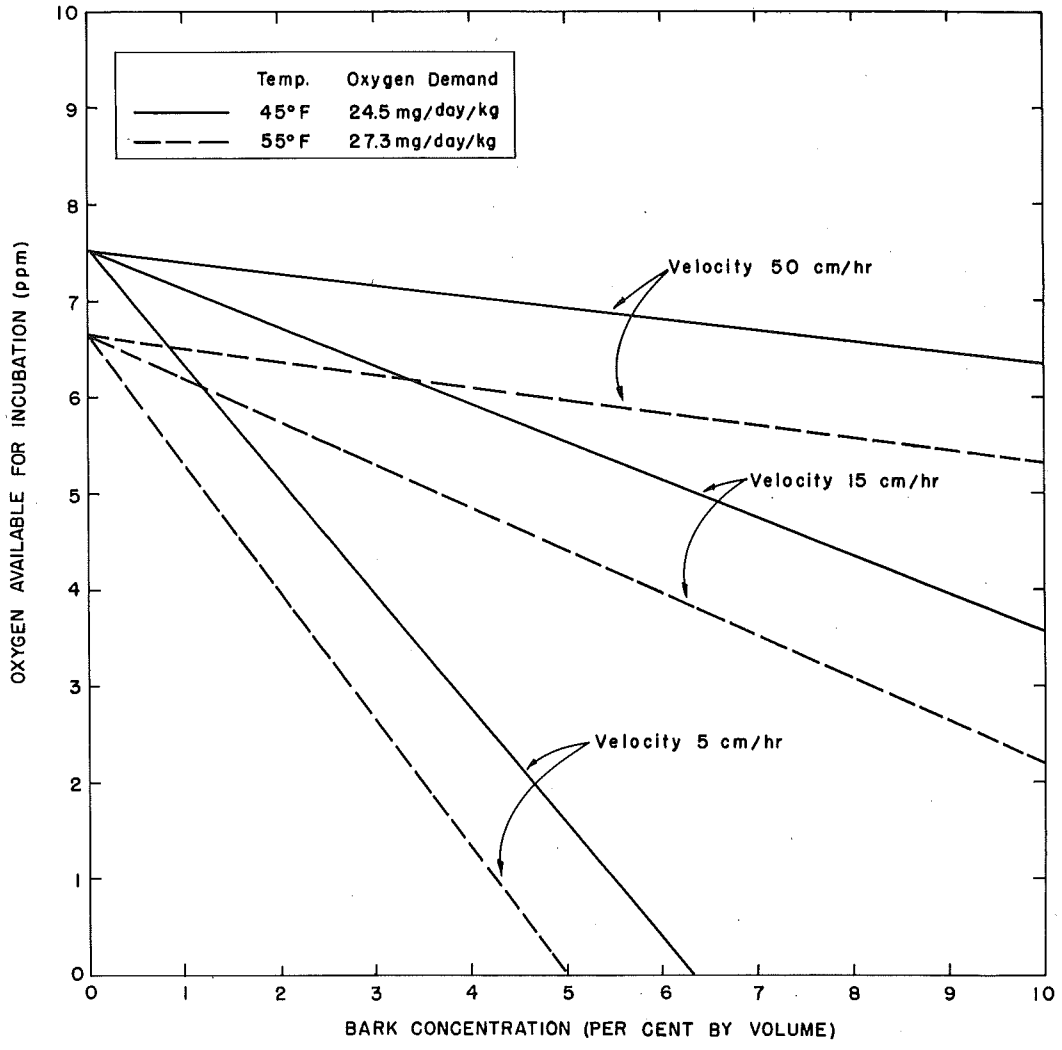


FIGURE 6 - Oxygen available for incubation at 1,000 ft elevation.

DISCUSSION

Results have shown that bark deposits in a spawning ground could be responsible for mortality of eggs and alevins and for delayed emergence of fry. Chemical toxicity was apparently not a factor which influenced survival or rate of development of sockeye alevins with the wood species used. This is not to infer that compounds of a toxic nature were not leached from bark, but rather that concentrations of harmful substances were lower than the toxic level at water velocities similar to those in natural spawning grounds. The inclusion of cedar or hemlock bark which are believed to release toxicants might create toxic conditions but should be the subject of a separate study. There were indications that Sphaerotilus growths might reduce survival if fresh bark were present in sufficient quantity, but the amount was not defined by the experimental results.

In incubation experiments, bark apparently reduced egg-to-fry survival by clogging the gravel and creating local zones of insufficient water flow. Blockage of water flow by particles is of a somewhat variable nature and not easily predicted, but experimental results indicated that 10% bark resulted in sufficient clogging to significantly lower survival at velocities of 5, 15 and 50 cm/hr. On the other hand, an apparent reduction in survival at 1% bark could not be confirmed statistically. Thus the effects of clogging by bark particles may become evident at concentrations somewhere between 1 and 10% bark.

In addition to the experimental incubation tests indicating the effect of bark, measurements of bark oxygen demand provided data for calculations showing that oxygen available to eggs and alevins would be reduced significantly by percolation of water through bark-contaminated gravel. The results of these calculations, summarized in FIGURE 6, may be used in conjunction with published reports on oxygen requirements to estimate permissible levels of bark contamination in spawning grounds. Wickett (1954) estimated 2.8 ppm as sufficient oxygen to meet the demand of pre-eyed chum salmon eggs incubating at 46°F and 5 cm/hr. Alderdice et al. (1958) reported the lethal level for chum salmon eggs just prior to hatching was 1.0 to 1.4 ppm oxygen at 50°F. Silver, Warren and Doudoroff (1963) found 2.5 ppm

dissolved oxygen adequate for survival of salmonid eggs until termination of the experiment following hatching. However, alevins were smaller at hatching at oxygen levels less than saturation. Brannon (1965) found that low oxygen levels slowed development, but alevins incubated at 3 ppm reached the same ultimate weight as did those at higher oxygen concentrations. The delay in development may play a role in survival, however, since late emerging fry may be at a considerable disadvantage. Brannon's experiments were conducted in hatchery baskets at velocities of 180 cm/hr and greater, but results might have been more pronounced or severe, had tests been carried out at the lower velocities found in natural redds.

The foregoing reports indicate that development will proceed at 2.5 to 3 ppm but excessive mortalities will result if dissolved oxygen is lower than 1.4 ppm. Hence, according to FIGURE 6, bark concentrations of 4% and greater may lead to severe losses at velocities around 5 cm/hr. To maintain sufficient oxygen in the gravel to simply prevent mortality is not sufficient protection, however, since maximum survival in later stages of life is related at least in part to normal timing of fry emergence and therefore to normal rate of development. Although oxygen influences rate of development, as cited above, the relationship of oxygen to emergence timing from a natural redd is not well defined. However, based upon mean oxygen levels, emergence timing, and fry size in Experiment B, it appears that about 5 ppm oxygen in intragravel water may allow a satisfactory rate of development. Entering FIGURE 6 with this value indicates that bark should not exceed about 1% by volume at 5 cm/hr or 4% at 15 cm/hr.

The foregoing permissible levels of bark concentration are based upon uniform distribution of water in the gravel voids at all velocities. However, results indicated that bark may block some interstitial passages causing uneven distribution of water and leading to mortalities. This effect was most pronounced at 5 cm/hr but occurred at 15 and 50 cm/hr at 10% bark. Thus, for example, although sufficient oxygen for incubation would theoretically be available at 50 cm/hr in gravel containing 10% bark, excessive mortalities could be expected owing to uneven distribution of water flow.

CONCLUSIONS

The research reported herein has demonstrated that oxygen demand of bark is great enough and of such a prolonged nature as to create hazardous conditions in spawning grounds. There were indications that fine bark particles clogged the gravel causing mortalities of eggs. Furthermore, it was noted that the bacteria, Sphaerotilus sp., could grow on bark and suffocate eggs and alevins as a result of its filamentous nature. It was estimated that bark concentrations of 4% and more were likely to increase egg-to-fry mortality owing to depletion of oxygen supplies at incubation velocities around 5 cm/hr, whereas bark concentrations of 1% and greater might retard emergence timing owing to oxygen depletion. However, calculated oxygen levels alone are insufficient criteria for estimating the effect of bark upon survival, since they fail to consider uneven distribution of water flow caused by bark contamination. Mortalities increased as bark concentration increased and as water flow decreased. These results must be applied to spawning grounds with care, taking into account normal water flow, oxygen levels and temperature as significant factors. Furthermore, hazards such as Sphaerotilus or other deleterious phenomena associated with bark but not detected in the laboratory may reduce survival. Hence in applying the results obtained herein a safety factor is recommended.

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