The Survival of Coho Salmon (Oncorhynchus kisutch) Eggs in Two Wisconsin Tributaries of Lake Michigan

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Reprinted from

THE AMERICAN MIDLAND NATURALIST

Vol. 96, No. 2, October, 1976, pp. **451-461**

University of Notre Dame Press

Notre Dame, Indiana

The Survival of Coho Salmon (Oncorhynchus kisutch) Eggs in Two Wisconsin Tributaries of Lake Michigan[1]

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ABSTRACT: Natural reproduction of coho salmon *(Oncorhynchus kisutch)* in two Wisconsin tributaries of Lake Michigan (Little Scarboro Creek, Kewaunee Co., and Fischer Creek, Manitowoc Co.), is limited by an unusually high mortality of eggs and preemergent embryos. Of approximately 1800 coho salmon eggs planted in six study redds (spawning beds) within Fischer Creek (November 1972), none survived to hatching. The 1500 eggs planted in five study redds within Little Scarboro Creek produced 21 sac fry.

The bottom materials of both streams are comprised of at least 15% (by volume) particles smaller than 0.84 mm in diam. Streambed gravels containing this quantity of sand, silt and clay do not allow for intragravel water of sufficient dissolved oxygen concentration or velocity to meet the oxygen requirements of developing salmon eggs. Water surrounding eggs planted in Fischer Creek and Little Scarboro Creek had mean dissolved oxygen concentrations of 3.96 and 6.22 mg/liter, respectively.

The extremely low mean (2.83 C and 2.67 C) water temperatures of Fischer Creek and Little Scarboro Creek were an added cause of egg loss. In response to low temperature, planted eggs hatched after a prolonged development period of approximately 145 days. Gravel shifts caused by variable stream flow in Fischer Creek may also be responsible for killing naturally deposited eggs there.

INTRODUCTION

In the spring of 1966, the Michigan Department of Natural Resources released 850.000 yearling coho salmon (Oncorhynchus kisutch) in three Lake Michigan tributaries. The purpose of this experimental planting was to determine whether a population of coho salmon could be established in Lake Michigan to support a sport fishery and to control the exploding alewife population. The success of this initial planting has led to yearly hatchery production and release of salmonid fingerlings by the states bordering Lake Michigan, and the result has been a rapidly growing salmon and trout sport fishery. The importance of the hatchery program to the maintenance of this sport fishery in Wisconsin is emphasized by the fact that essentially all the salmonids caught in Lake Michigan are of hatchery origin (Wisconsin Department of Natural Resources, 1972). Natural reproduction of coho salmon occurs in several Wisconsin tributaries of Lake Michigan, but the number of fingerlings produced is small. Poor reproductive success due to high mortality of eggs and/or fry before emergence from

[1] Based on a thesis submitted in partial fulfillment of the requirements for the Master of Science degree, Department of Zoology, University of Wisconsin-Milwaukee.

streambed gravels is thought to be responsible foı the limited numbers of wild young fish produced, but the exact reasons for this lack of natural recruitment are unclear. This study was undertaken to determine if poor reproductive success is, in fact, a result of high embryonic mortality, and to determine those environmental factors which limit fry production in Little Scarboro Creek (Kewaunee Co.) and Pischer Creek (Manitowoc Co.).

Field studies in Alaska (McNeil, 1962a), British Columbia (Wickett, 1954, 1958), Oregon (Coble, 1961: Phillips and Campbell, 1962: Koski, 1966) and California (Gangmark and Bakkala. 1958) have demonstrated that certain physical characteristics associated with the streambed and the water surrounding salmonid eggs are of extreme importance in determining the percentage of deposited eggs which will hatch and produce healthy fry. These physical characteristics include water temperature, stream discharge, streambed gradient, silt load, stability and permeability of the spawning bed substrate, and dissolved oxygen concentration of intragravel water.

The laboratory investigations of Alderdice et *al.* (1958). Silver *et al.* (1963) and Shumway *et al.* (1964) demonstrated that the primary factor in determining the fate of developing salmonid eggs is the amount of oxygen reaching them. To determine precisely the quantity of oxygen delivered to eggs, it is necessary to measure both the apparent velocity or seepage rate of intragravel water through the redd. and the dissolved oxygen concentration of intragravel water. Water samples taken from the microenvironment of developing salmonid eggs have generally been obtained with a metal or plastic standpipe, first described by Wickett (1954), then modified by Pollard (1955). l'erhune (1958) and Gangmark and Bakkala (1958). l'he potential for water movement through a spawning bed can bc determined by estimating the permeability of the bottom materials comprising it. McNeil and Ahnell (1964) derived an empirical relationship which expresses spawning substr ate permeability as a function of the volume percentage of small partirles (less than 0.83 mm diam) constituting that substrate.

STUDY AREA

Of the 145 Lake Michigan tributaries surveyed by the Wisconsin Department of Natural Resources between 1971 and 1973, only eight were judged to have suitable spawning substrate for the natural production of salmonids (Avery, 1974). Thesc eight streams included Little Scarboro Creek, which is approximately 13 km inland from Kewaunee, and Fischer Creek, located between Manitowoc and Sheboyqan, Wis.

Little Scarboro Creek is a small spriny-fed tributary to the Kewaunce River having a surface area of 0.32 ha, gradient of 8.2 m/km and length of 2.4 km (Wisconsin Conservation Department, 1966). Its bed consists of sand and gravel: soils of the area are typically a medium sand with little organic material. This stream was judged to be the state's most suitable tributary for coho salmon production (Avery, 1974).

Fischer Creek is a direct tributary to Lake Michigan having a surface area of 2.79 ha. gradient of 5.6 m/km, and length of 10.1 km (Wisconsin Conservation Department, 1968). The heavy loam and silt-loam of its drainage area account for rapid surface runoff at times, particularly during the spring thaw. During periods of peak discharge the suspended silt load increases dramatically. The bottom of Fischer Creek consists of muck and silt near the mouth, and clay, rubble and gravel in upper sections.

Methods and Materials

The spawning run of coho salmon was well-established in both streams by the 1st week of November 1972. On 6 November five natural redds were selected for study within a 200-m stretch of Little Scarboro Creek. Six similar redds were chosen within a 400-m section of Fischer Creek on 9 November.

Estimating egg survival. Egg survival to hatching was estimated with modified Vibert boxes (Progressive Fish Culturist, 1951), which were plastic boxes (16.5 x 12.1 x 7.9 cm) having 1.6-mm holes drilled in all six sides, and spaced at 1-cm intervals. Approximately 300 fertilized, water-hardened eggs were placed in each Vibert box: one box was buried in the center of each study redd to a depth of between 20-25 cm. Extra boxes planted in each stream were periodically excavated to estimate time of hatching.

The eggs planted in Little Scarboro Creek were stripped from 35 female coho salmon and fertilized by 15 males collected on 6 November 1972; those planted in Fischer Creek were from a similar sample taken on 9 November. Extra eggs were sent to the state fish hatchery at Wild Rose, Wis.; here, they develop at 10 C and served to measure egg viability.

Spawning gravel permeability. Gravel samples were collected with a core sampler similar to that of McNeil and Ahnell (1964). Three samples were taken from each study redd immediately after placement of Vibert boxes, and again during the estimated period of fry emergence. Size composition was determined by passing dried gravel samples through a series of U.S. Standard sieves having square mesh of 25.4, 12.7, 9.51, 3.76, 2.00, 0.84, 0.42 and 0.177 mm. The material retained in each sieve was measured volumetrically by water displacement.

Intragravel dissolved oxygen concentration. The standpipe used to sample intragravel water was essentially the same as that described by McNeil (1962b). It consisted of a 1-m length of PVC pipe (inside diam 1.9 cm) in which the bottom 7.6 cm were perforated with 1.6-mm holes. The bottom of each standpipe was driven 25 cm below the streambed with a stainless steel driving rod. In this position, water entered the standpipe from approximately the same depth at which eggs were planted. In each study redd, three or four standpipes were placed approximately 30 cm from the previously buried Vibert box. Water was taken from standpipes by oral suction (McNeil, 1962b) and held in stoppered 30-ml glass vials; samples were fixed immediately with Winkles reagents as described by Harper (1953). Dissolved oxygen levels were determined in the laboratory by titrating a 25-ml aliquot of each sample with 0.0125 N sodium thiosulfate.

Temperature and *discharge.* Water temperature was monitored continuously with Ryan 8-day thermographs; theft of the thermograph in Little Scarboro Creek necessitated the use of a max-min thermometer during part of the study. Mean weekly temperatures were estimated as the average of dally median temperatures. Discharge was measured with a pygmy Gurley meter placed at 45-cm intervals across the width of each stream.

RESULTS

Egg *survival.*—Vibert boxes were rcmovcd approximately 2 weeks after the first appearance of sac fry on 14 April 1973 in Little Scarboro Creek and 17 April in Fischer Creek. Of approximately 1800 eggs planted in Fischer Creek, none survived to hatching. Each of the five Vibert boxes planted in Little Scarboro Creek contained from 1-8 live sac fry (Table 1). Visual inspection of the eggs indicated that death occurred during a relatively early embryonic stage; no dead sac fry were found.

Sixty-five percent of the eggs sent to the state fish hatchery survived to hatching, compared with no survival in Fischer Creek, and 1.4% survival in Little Scarboro Creek.

Spawning substrate composition. Size composition of spawning substrate was remarkably similar in both streams (Figs. 1, 2). Con-

TABLE 1.—-Summary of the success of hatch (number of fry hatching from approximately 300 eggs), mean intragravel dissolved oxygen concentration, and the gravel composition analysis from each study redd

Stream	Redd	Number of fry hatched from 300 eggs	Mean D.O. concentration (mg/liter)	Percent of gravel sample smaller than 0.84 mm November	April
Little Scarboro Creek	A	4	4.91	11.22	14.19
	B	8	6.46	16.61	16.02
	C	6	7.28	11.23	14.58
	D	1	7.38	16.00	22.72
	E	2	6.52	16.11	16.88
	Mean	4.2	6.22	14.23	16.88
Fischer Creek	A	0	4.45	14.43	18.21
	B	0	3.14	36.07	20.25
	C	0	6.30	8.07	19.27
	D	0	4.78	9.43	15.77
	E	0	0.96	12.33	18.65
	F	0	0.15	9.02	17.10
	Mean	0.0	3.96	14.90	18.21

tingency table analysis (Mendenhall, 1971) did not demonstrate significant ($p = 0.05$) differences in gravel size composition between the two streams, either in the November or the April samples.

Size composition of redd substrate changed in both streams during the period of egg development (Table 1). The average volume percentage of fine sediments in Little Scarboro Creek increased from an initial 14.23% in November to 16.88% in April. Fischer Creek experienced a similar increase in mean relative quantity of sands and silt, from 14.90% in November to 18.71% in April. Nine of the 11 study redds experienced an increase in the percentage of particles

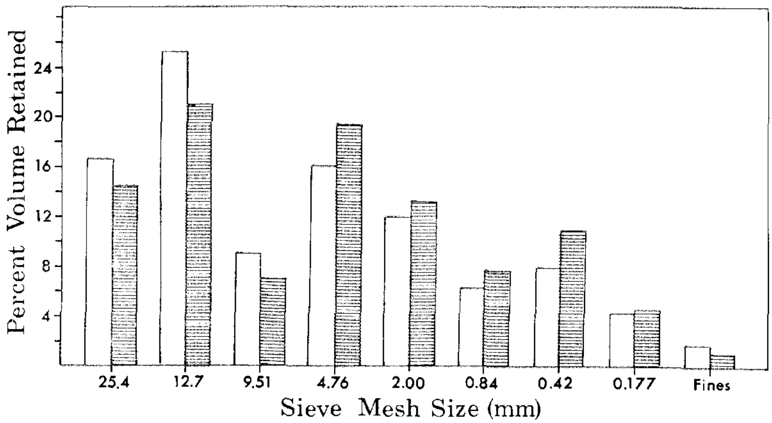

Fig. 1.—Size composition of spawning gravel samples taken from Little Scarboro Creek on 6 November 1972 (open bars) and on 14 April 1973 (stippled bars)

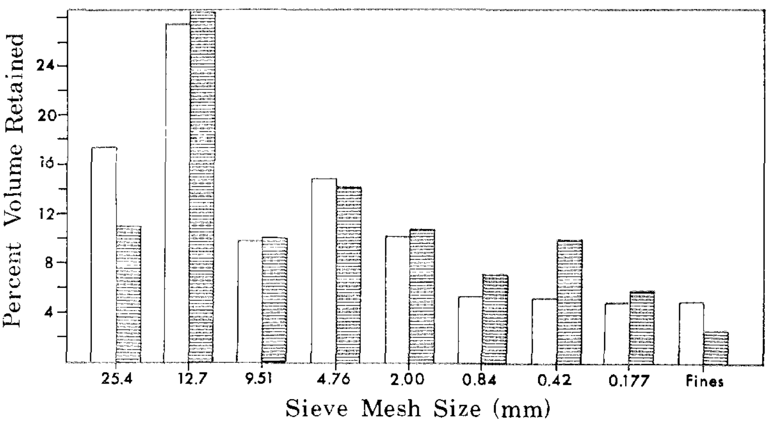

Fig. 2.—Size composition of spawning gravel samples taken from Fischer Creek on 9 November 1972 (open bars) and on 17 April 1973 (stippled bars)

smaller than 0.84 mm; this deposition of fine particles was particularly evident in Fischer Creek.

Dissolved oxygen.—Weekly water samples were taken from both streams, except during January and February when water in the standpipes was frozen. The mean dissolved oxygen concentration of intragravel water in Little Scarboro Creek (6.22 mg/liter) was significantly greater than the mean level (3.96 mg/liter) found in Fischer Creek (Table 1). Linear regression models relating dissolved oxygen to time (Fig. 3) had slopes which were significantly less than 0, thus indicating a decrease in available oxygen as the eggs developed. The rate of decline in dissolved oxygen level (i.e., slope of the regression line) was significantly greater in Fischer Creek.

Temperature and discharge.—The continuous record of mean weekly water temperatures (Fig. 4) demonstrated a similar pattern of temperature fluctuation in both streams. Between the time of egg deposition and hatching, the mean water temperature of Little Scarboro Creek was 2.67 C, compared to 2.83 C in Fischer Creek. The mean discharge rate and water velocity in Fischer Creek (0.39 m^3/s; 0.89 m/s) were both significantly greater than in Little Scarboro Creek (0.13 m^3/s; 0.28 m/s). Discharge in Fischer Creek fluctuated dramatically, while Little Scarboro Creek remained stable between November and April (Fig. 5).

DISCUSSION

Success of hatch.—The 1.4% survival of coho salmon eggs planted in Little Scarboro Creek, and the lack of survival of planted eggs in

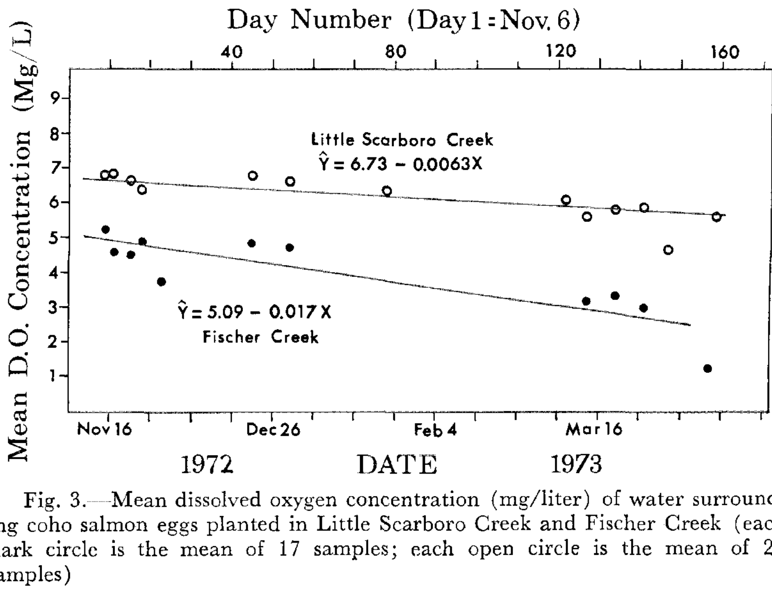

Fig. 3.—Mean dissolved oxygen concentration (mg/liter) of water surrounding coho salmon eggs planted in Little Scarboro Creek and Fischer Creek (each dark circle is the mean of 17 samples; each open circle is the mean of 20 samples)

Fischer Creek, compare very unfavorably with survival rates of coho salmon in their native streams. Shapovalov and Taft (1954) predicted that the survival to hatching of coho salmon eggs in California streams can be as high as 65 to 85%. Koski (1966) measured the survival of coho salmon embryos (to emergence from gravel) in three Oregon coastal streams; he found the mean survival to be 27.1%, with a minimum survival of 13.6% in the poorest stream, and a maximum 54.4% survival in the most productive stream. Phillips and Campbell (1962) found that survival (to hatching) of coho salmon eggs averaged 35% in another Oregon stream, and they reported a sur-

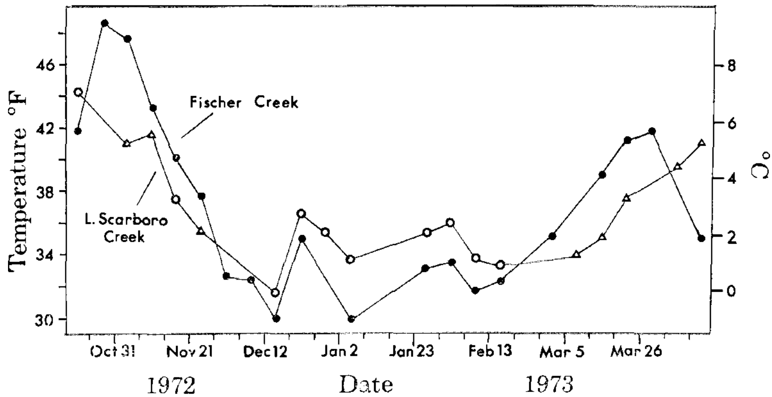

Fig. 4. Mean weekly water temperature of Little Scarboro Creek and Fischer Creek during the development period of coho salmon eggs (triangles are weekly median temperatures from a maximum-minimum thermometer; circles are the mean of seven daily median temperatures)

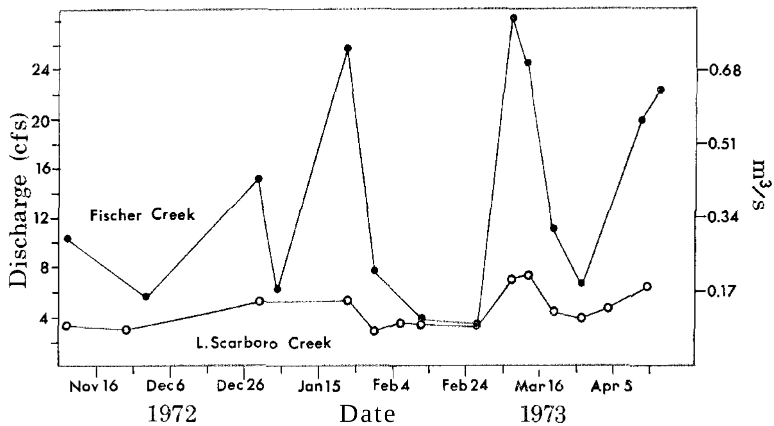

Fig. 5.—Discharge of Little Scarboro Creek and Fischer Creek during the development period of planted coho salmon eggs

vival rate of over 80% in several study redds. It is then evident that natural reproduction of coho salmon in Little Scarboro Creek and Fischer Creek is limited by an unusually high death rate of eggs and pre-emergent embryos within streambed gravels.

Those eggs used to estimate survival were not inherently weak or nonviable since 65% of the eggs in the hatchery produced healthy sac fry. It is assumed that the planting technique and handling of eggs were not significant causes of egg mortality; Phillips and Campbell (1962) used a similar method of planting coho salmon eggs and found survival rates as high as 87%. Therefore, egg mortality in Little Scarboro Creek and Fischer Creek must be attributed to the poor quality of their intragravel environments.

Size composition and *permeability of spawning* subrtrate. -The survival of deposited salmonid eggs is dependent upon an adequate intragravel water flow to allow for the delivery of oxygen, and to carry away metabolic wastes. Bottom materials having large quantities of sand and silt are generally impermeable. and are uncharacteristic of productive salmon streams (McNeil, 1962a). McNeil and Ahnell (1964) found relatively high permeabilities in bottom materials containing. less than 5% sand and silt passing through a 0.833-mm sieve. Gravel samples containing 15% sand, silt and clay had low permeabilities.

Each of the 11 study redds contained more than 15% fine sediments in April; this quantity of fines allows for a maximum permeability of 25 cm/min (McNeil and Ahnell, 1964). From Wickett's (1958) results, spawning substrate having a permeability as low as 25 cm/min allows only for a 2-3% hatch of chum salmon (Oncorhynchus keta) eggs. This value is consistent with the less than 2% survival reported here.

It is probable that impeded water flow resulting from impermeable bottom substrate is a limiting factor to the survival of coho salmon eggs deposited in Little Scarboro Creek and Fischer Creek.

Dissolved oxygen. -The production of healthy salmon fry is related to the quantity of oxygen dissolved in the water surrounding developing eggs. Attempts to derive a definitive critical level of dissolved oxygen for coho salmon embryos have been of limited success, but rarely have investigators found embryonic survival at dissolved oxygen concentrations lower than 2 mg/liter. In Koski's (1966) study, thosr coho salmon redds having intragravel water with a minimum dissolved oxygen level of 6 mg/liter averaged only 4% survival to hatching. Phillips and Campbell (1962) found good egg survival (greater than 30%) only when the mean concentration of oxygen exceeded 8 mg/liter, and they believed this to be a minimal value for the production of viable coho fry. Since the mean concentration of dissolved oxygen in water samples taken from Fischer Creek was only 3.96 mg/liter, heavy egg losses in this stream were not surprising. The mean level of dissolved oxygen in water samples from Little Scarboro Creek (6.22

mg/liter) was apparently marginal for embryonic survival and resulted in the marginal success of hatch there.

'I'he fact that groundwater dissolved oxygen levels of both streams deteriorated with time is significant, because the oxygen demand of developing eggs increases with time. Garside (1959) showed that salmonid eggs are most susceptible to oxygen deprivation near the time of hatching. Alderdice *et al.* (1958) found that oxygen consumption of chum salmon eggs increased from the time of fertilization to the time of hatching, and that the critical level of dissolved oxygen ranged from 1 ppm in the early stages of development to over 7 ppm shortly before hatching. Oxygen deprivation piobably became increasingly important in Little Scarboro Creek since the amount of available oxygen decreased as the embryos' demand for oxygen increased.

Water temperature. Because the development time of salmonid eggs is inversely related to temperature (Garside, 1959), it is possible that extremely low water temperatures can limit coho salmon egg survival by prolonging the development period and, hence, the time that embryos are forced to remain within streambed gravels. 'The mean water temperatures of Fischer Creek (2.83 C) and Little Scarboro Creek (2.67 C) were lower than winter water temperatures normally found in Pacific coast streams. During the development period of coho eggs planted in Deer Creek, Oregon, water trmperature averaged 7.78 C, and never fell below 6.67 C (Phillips and Campbell, 1962). Shapovalov and Taft (1954) reported a mean water temperature of 8.89 C while coho salmon eggs developed in the Sacramento River area of California. In this temperature range, salmon eggs will hatch and start emerging from gravel after a period of from 35 days (Shapovalov and Taft, 1954) to 70 days (Phillips and Campbell, 1962). 'I'he eggs planted in Little Scarboro Creek took approximately 145 days to hatch. This prolonged development time apparently was a response to depressed water temperature, and may be an important factor in causing the heavy mortality of coho salmon eggs deposited in Little Scarboro Creek and Fischer Creek.

Stream pow The extremely variable discharge rate of Fischer Creek may be an added cause of natural egg mortality. Although gravel movements were not quantified, it was evident from visual observation after periods of high discharge that bottom materials were unstable, and that natural redds were either partially scoured out or covered with silt, sand, and gravel.

Acknowledgment. I wish to express my thanks to Mr. Eddie L. Avery of the Wisconsin Department of Natural Resources for his invaluable advice in planning this study, and for his help in the field. The Vibert boxes, core sampler, standpipes and fertilized eggs were supplied by the Wisconsin Department of Natural Resources.

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SUBMITTED 8 MAY 1975 ACCEPTED 25 AUGUST 1975