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INFLUENCE OF TURBIDITY ON SURVIVAL, GROWTH  
AND DISTRIBUTION OF LARVAL LAKE HERRING

Coregonus artedii<sup>1</sup>  
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*"Nature is Often Hidden: Sometimes Overcome, Seldom Distinguished"*

*Essays: Of Nature In Men  
by Frances Bacon  
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INFLUENCE OF TURBIDITY ON SURVIVAL, GROWTH  
AND DISTRIBUTION OF LARVAL LAKE HERRING  
Coregonus artedii<sup>1</sup>

by

William A. Swenson and Melvin L. Matson  
Department of Biology and  
Center for Lake Superior Environmental Studies  
University of Wisconsin, Superior  
Superior, Wisconsin 54880

Abstract

Influence of red-clay turbidity on survival, growth and distribution of larval lake herring, Coregonus artedii, was measured by holding post hatch larvae for 62 days at 9 levels of suspended solids varying from 2 to 50 FTU (1 to 29 ppm). The concentrations included the normal range in the red clay area of western Lake Superior. The bioassay was conducted in a continuous flow system with chambers designed to promote normal behavior and influence light levels between the surface and bottom.

Growth and survival were not influenced by the range of concentrations studied however, larvae in the higher suspensions concentrated closer to the surface of the test chambers, a condition which may indirectly influence survival in Lake Superior through increased interaction with rainbow smelt, Osmerus mordax.

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<sup>1</sup>  
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Abundance of lake herring, Coregonus artedii, has declined in Lake Superior since the early 1950's with the earliest and most extensive declines occurring in the extreme western end of the lake, near Superior, Wisconsin. This area is characterized by usually high suspended solid levels during some years with concentration and duration being dependent on climatic conditions and water levels. Storm related turbidity results from erosion of red clay deposits and extends along approximately 30-50 miles of shoreline and from a few hundred meters to several kilometers into the lake with concentrations reaching 125 ppm but rarely exceeding 50 ppm (Swenson unpublished data).

The major spawning ground for the western Lake Superior stock occurred north of Superior and the zone of high turbidity (Anderson and Smith 1971a). Location of spawning and current patterns (Beeton et.al. 1959) suggest herring larvae would be carried into the turbid water zone. Previous investigations have suggested decline of herring is associated with over fishing (Great Lakes Herring Subcommittee Rept. 1973) and competition with rainbow smelt, Osmerus mordax, (Anderson and Smith 1971a). This investigation was undertaken to evaluate the direct effects of red clay turbidity on larval herring survival, growth and distribution.

Because larval fish lack the ability to shed solids from their gills by mucus secretions, they are more susceptible to adverse effects of suspended solids (Everhart and Duchow 1970). However, there is presently no literature available defining the effects of naturally occurring turbidity levels on larval fish. Investigations on the feeding behavior of larval whitefish, Coregonus wartmanni demonstrate they are sight feeders with feeding success limited by attack success, swimming ability and visual field (Braun 1967). By altering light intensities and quality, red clay turbidity

may alter the feeding success of larval Lake Superior herring and thereby influence growth, survival and abundance of the stock.

### Materials and Methods

The study was conducted using a continuous flow clay-turbidity delivery system. Turbid water was produced in two 200 l head tanks. Constant turbidity was maintained at 50 FTU (29.4 ppm  $\pm$  10%) in the head tanks through a sensor which reacted to change in light intensity from a source by activating a pump through a relay which circulates water over a clay source (Figure 1; L, R,P,CS). Head tank volume was maintained at 200 l by maintaining inflow in excess of outflow with some loss occurring through an overflow (Figure 1; I,D).

From the two turbid water head tanks water flowed to a 185 l constant-head holding tank which directed the water into a single-chambered 70.4 l manifold. The manifold and a similar structure connected to a clear water source tank distributed water to test chambers through calibrated standpipes and funnels to provide proportional dilutions of clear and turbid water (Figure 1). Each funnel received water from one clear water and one turbid water standpipe totaling 400 ml/min (Table 1). Flows were directed to twenty 70.5 l (61 x 20.3 x 61 cm) test chambers at 9 concentrations (Table 1).

Two 15 watt incandescent bulbs were located at a height of 10.2 cm over the chambers. Translucent fiberglass covers served to reduce glare and disperse light over water surface of each chamber. Light intensities obtained using a Photovolt Model 200 photometer with the photocell placed against the outside chamber wall at 10.2, 30.5, and 5.8 cm from the top are reported in Table 2. Throughout the bioassay a constant thirteen hour

photoperiod was maintained. The light timing device described by Drummond and Dawson (1970) increased light intensity over a thirty minute "morning period" and reduced intensity in the "evening" at the same rate.

Turbidity was measured morning and afternoon in Formazin Turbidity Units (FTU) using an Ecologic Instrument Model 104 Nephelometer. Gravimetric analysis (American Public Health Association 1971) was performed on 33 samples to define relationship between FTU and ppm suspended solids. Temperatures were recorded daily. Oxygen, conductivity and pH were measured weekly. Means and ranges of turbidity, pH, temperature, oxygen, and conductivity are reported in Table 3.

Lake herring utilized in the bioassay were hatched from eggs obtained on December 2, 1974, from the Apostle Islands region of Lake Superior. The eggs were incubated at 2°C and 3.5-4.5°C in a hatchery consisting of two rows of 10 inverted 1-liter plastic jars. The selected temperatures are within the range reported for normal development (Colby and Brooke, 1970). Water was supplied at 1-l/min through a nylon screen upon which the eggs were placed before passing out through an overflow tube. The water and hatched fry were collected from the overflow in two 58 l chambers.

The bioassay began on April 4, 1975 using approximately sixty 3-day-old sac-fry/chamber and was terminated 62 days later. On May 22 the number of fry/chamber were reduced to 30.

During the bioassay the fish were fed brine shrimp Artemia salina obtained as eggs from Salt Lake City, Utah. A constant but intermittent feeding system (Anderson and Smith 1971b, Figure 1) was used in distributing approximately 400 shrimp/hr to each chamber for 12 hrs. Concentrations averaged 720/m<sup>3</sup> in the test chambers. The concentrations were lower than the average concentration of copepoda nauplii found in Lake Superior reported

by Anderson (1969) to be  $2,900/m^3$ . The concentrations were chosen because brine shrimp were estimated to be approximately 4x heavier than copepoda nauphii shown by Anderson and Smith (1971a) to be the dominant natural food of herring larvae in Lake Superior.

Each week larvae were transferred to a 180 x 250 x 8 mm chamber by siphoning. Dead fish were removed and percentage of larvae containing food or <sup>with</sup> signs of disease was estimated. Growth and survival counts were determined from photographs taken of living larvae over a  $mm^2$  grid (Martin 1967).

Behavior was observed in levels 1 through 7 (control - 29 FTU's) from May 10 to June 4. Location of larvae in test chambers was determined by placing a frame partitioned into nine grids measuring 20.3 x 16.9 cm in front of the chamber and recording larvae within each area. Grids 1-3 4-6 and 7-9 included top, middle and bottom areas of the chambers respectively with grids 1, 4 and 7 being located nearest the inflows for water and food. At turbidity levels exceeding 12 FTU it was necessary to place a bright light next to the chamber wall to observe fry to the opposite wall.

### Results

Weekly observations showed red clay turbidity has no effect on survival of larval lake herring at the levels occurring in western Lake Superior. Weekly survival varied from a low of 49% to a high of 100%. No differences in survival were suggested between replicates or between periods prior to and after thinning. No trend in survival was suggested when average weekly survival was plotted against turbidity (Figure 2). Signs of disease were rare and unrelated to turbidity.

Growth of larval herring over the 62 day period averaged 9.2 mm. Growth increments indicated a slight improvement in growth with increasing turbidity (Figure 3). The positive slopes of a line fitted by regressions was not significant ( $P=0.1$ ).

Distribution was reported as a percentage of the total number of larvae observed within a chamber in 9 grids. Observations were made before feeding (approximately 9:00 A.M.) and several hours after feeding had commenced (approximately 15:00 P.M.). Herring larvae demonstrated a clear preference for areas near the surface at all concentrations (2-29 FTU) before and after feeding ( $P=0.5$  Figure 4). Movement away from the surface after feeding was suggested by differences in slopes of regression calculated for observations made prior to and after feeding. The analysis suggested a greater movement away from the surface at lower turbidity levels (Figure 4). Analysis of covariance applied to the data in order to reduce variability between laterally adjoining grids showed significant increase in abundance at the bottom of the test chamber under low turbidity ( $P=0.05$ ). A significantly increase in abundance in the middle depth of the test chamber was seen at the higher levels (24-29 FTU;  $P=0.05$ ).

### Discussion

Controlled laboratory studies conducted on a number of warm and cold water fish indicate turbidity is not a lethal condition in the life of juvenile or adult fishes at concentrations normally found in nature (Wallen 1951; Herbert and Merkens 1961). Excessively high turbidities over long time periods can produce clogged gill cavities resulting in suffocation (Everhart and Duchrow 1970) or may cause slowly healing wounds and abrasions which <sup>become</sup> infected with bacterial diseases (Herbert and Merkens 1961).

No change in survival, disease occurrence or growth was evident in tests on larval lake herring. Growth under the food regime was similar to that reported by Anderson and Smith (1971a) for Lake Superior herring larvae. Larval herring did show a tendency to concentrate closer to the surface under higher turbidity. This effect may be attributed to reduced light condition occurring near the bottom of turbid water chambers.

Concentration at the surface may influence survival through effects on feeding, predation or current induced movement. Because the historic spawning grounds of an important western Lake Superior herring population was located just north of the red-clay zone (Anderson and Smith, 1971a), surface currents and storm activity in this area would result in accelerated movement of larval near the surface into the near-shore turbid water zone (Beeton et al. 1959). Field studies in progress demonstrate occurrence of rich food supply and large population of smelt in this area. Prior to increased abundance of smelt concentration of larval herring in this region may have enhanced survival as a result of increased food availability. Additional study will be required to determine if the concentrating effect of turbidity on distribution of herring larvae has resulted in increased interaction with rainbow smelt.

#### Acknowledgements

The work was conducted at the U. S. Environmental Protection Agency, National Water Quality Laboratory, Duluth, Minnesota. In addition to space we gratefully acknowledge the valuable technical assistance provided by several members of the laboratory staff. Graduate Assistant, Mr. James Jonasen, was responsible for performing much of the laboratory work. His exceptional performance deserves special mention.

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Table 2. Light intensity in test chambers at depths of 10.2, 30.5, and 50.8 cm, for average turbidity levels.

Test Chamber	Foot Candles at Depth (cm)			Turbidity (FTU)
	10.2 cm	30.5 cm	50.8 cm	
A-1	1.63	1.78	1.73	1.4
A-2	.87	.87	.95	1.8
A-3	1.18	1.30	1.03	6
A-4	1.05	1.05	.82	13
A-5	1.43	1.33	.92	20
A-6	1.43	1.47	1.00	25
A-7	.67	.48	.28	32
A-8	1.63	1.42	.83	36
A-9	1.13	.78	.43	38
A-10	1.19	.92	.47	42
B-1	1.13	1.13	.93	1.9
B-2	1.70	.92	.47	2.2
B-3	1.37	.63	.47	10
B-4	1.75	1.63	1.22	12
B-5	1.43	1.30	.85	14
B-6	1.35	1.28	.60	24
B-7	1.07	1.00	.78	4.1
B-8	1.85	1.42	.87	30
B-9	1.95	1.57	.85	32
B-10	1.45	.98	.48	40

Table 3. Means and ranges of turbidity, pH, temperature, oxygen concentration, and conductivity in 62 day larval herring growth bioassay. Standard deviations are given in parentheses.

Test Chamber	Turbidity (FTU)	pH	Temperature °C	O <sub>2</sub> (mg/l)	Conductivity (Kohms)
A-1					
mean	2.0 ( $\pm 0.8$ )	7.53	6.2	12.4	15.86
range	--	7.38-7.69	3.0-7.8	11.8-13.1	15.25-16.47
A-2					
mean	2.1 ( $\pm 1.0$ )	7.56	6.1	--	14.31
range	--	7.52-7.65	3.2-7.8	--	13.15-15.46
A-3					
mean	6 ( $\pm 1.6$ )	7.64	6.1	--	15.31
range	--	7.55-7.73	3.9-7.5	--	14.20-16.41
A-4					
mean	13 ( $\pm 2.7$ )	7.69	6.2	--	14.16
range	--	7.57-7.78	4.2-8.0	--	12.87-15.40
A-5					
mean	19 ( $\pm 3.8$ )	7.71	6.1	--	16.09
range	--	7.59-7.84	4.0-7.9	--	15.73-16.46
A-6					
mean	24 ( $\pm 5.3$ )	7.81	6.3	12.0	15.24
range	--	7.72-7.90	4.0-8.0	11.6-12.4	14.02-16.47
A-7					
mean	29 ( $\pm 4.9$ )	7.81	6.1	--	15.99
range	--	7.73-7.91	4.2-7.8	--	15.55-16.43
A-8					
mean	35 ( $\pm 5.9$ )	7.87	6.2	--	15.78
range	--	7.80-7.98	4.5-7.7	--	15.53-16.04
A-9					
mean	40 ( $\pm 6.3$ )	7.88	6.4	--	15.56
range	--	7.80-8.02	4.4-8.1	--	15.11-16.01
A-10 <sup>1</sup>					
mean	45 ( $\pm 7.1$ )	7.84	5.7	12.2	--
range	--	7.83-7.89	4.4-7.0	11.5-12.4	--
A-10 <sup>2</sup>					
mean	50 ( $\pm 7.5$ )	8.00	7.0	11.8	15.54
range	--	7.98-8.05	6.2-8.3	11.7-12.0	15.32-15.76

<sup>1</sup>Test fish were lost after 33 days (May 8).

<sup>2</sup>New fish added on May 8.

Table 3. (continued)

Test Chamber	Turbidity (FTU)	pH	Temperature °C	O <sub>2</sub> (mg/l)	Conductivity (Kohms)
B-1					
mean	2.2 ( $\pm 1.0$ )	7.69	5.9	--	16.45
range	--	7.40-7.84	3.0-7.6	--	15.84-17.06
B-2					
mean	2.3 ( $\pm 1.0$ )	7.67	6.0	--	15.61
range	--	7.40-7.86	3.2-7.9	--	14.50-16.72
B-3					
mean	8 ( $\pm 2.0$ )	7.69	6.0	--	16.64
range	--	7.49-7.88	3.2-8.0	--	16.11-17.17
B-4					
mean	12 ( $\pm 1.8$ )	7.72	6.1	--	15.57
range	--	7.55-7.89	3.9-7.7	--	14.70-16.45
B-5					
mean	17 ( $\pm 3.4$ )	7.74	6.0	--	16.15
range	--	7.53-7.91	3.5-7.7	--	15.75-16.55
B-6					
mean	28 ( $\pm 4.6$ )	7.81	6.62	--	15.04
range	--	7.61-7.92	4.5-7.8	--	14.09-16.17
B-7 <sup>3</sup>					
mean	26 ( $\pm 4.7$ )	7.67	5.6	--	--
range	--	7.60-7.80	4.1-6.8	--	--
B-7 <sup>4</sup>					
mean	26 ( $\pm 0.5$ )	7.81	6.9	--	16.65
range	--	7.78-7.84	6.0-8.0	--	16.05-16.66
B-8					
mean	34 ( $\pm 5.3$ )	7.82	6.2	--	16.13
range	--	7.65-7.96	4.8-7.8	--	15.72-16.55
B-9					
mean	39 ( $\pm 5.9$ )	7.88	6.4	--	15.68
range	--	7.72-8.05	4.2-8.0	--	15.23-16.12
B-10					
mean	47 ( $\pm 7.3$ )	7.91	6.4	--	15.70
range	--	7.83-8.06	4.8-8.0	--	15.39-16.01

<sup>3</sup>Test fish were lost after 33 days (May 8).

<sup>4</sup>New fish added on May 8.

Figure 1: Continuous flow turbidity system. Dashed lines signify transfer of light or electrical energy. Solid lines with arrows symbolize water flow. The clay source tank maintains turbidity levels utilizing the following:

CS = Red clay source

L = AC Model 4516, 6 V. spotlight

S = Precision, Model T-15 photocontrol sensor

R = Relay

P = Model IP 681 Teal Pump

I = Inflow

D = Overflow

A = Aeration

Figure 2: Average weekly survival of larval herring held in clay suspensions.

Figure 3: Growth of herring larvae held in clay suspensions.

Figure 4: Percentage of total larval herring observed at the surface mid-depth and bottom of 61 cm deep chamber at 24 and 29 FTU prior to (solid line) and after feeding (dashed line). Surface is represented by grids 1-3, mid-depth by grids 4-6 and bottom by grids 7-9.



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February 26, 1976

Dr. William A. Swenson  
Center for Lake Superior Environmental  
Studies  
University of Wisconsin, Superior  
Superior, Wisconsin 54880

MS 75-113: "Influence of Turbidity on Survival, Growth, and  
Behavior of Larval Lake Herring, Coregonus artedii"

Dear Dr. Swenson:

This paper was judged to be a valuable contribution to the field of larval fish ecology, as well as to an understanding of Lake Superior herrings. Minor editorial revisions, as suggested on the enclosed manuscript copies (my notes are in red), and the addition of some data on growth and mortality, as indicated on the review sheet, are the only changes that we request.

Please send two copies of your revision at your early convenience.

Sincerely,

Robert L. Kendall  
Editor

RIK/twb

Enclosures

