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Avoidance of Dredge Spoil by Herring *(Clupea harengus harengus)*

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The proposed dredging of the Miramichi estuary in New Brunswick will be one of the largest dredging operations (4.3 million cubic metres) undertaken in the Maritime Provinces of Canada (PHILPOTT 1978). The disposal of dredge spoil in this estuary may have negative impacts on important local fisheries, particularly the herring gill net fishery of the outer Bay (MESSIEH et al. 1981). The purpose of this work was to determine the avoidance threshold of juvenile Atlantic herring to a representative sample of sediment to be dredged and dumped in the Miramichi estuary.

Also presented are some preliminary studies on the sensory cues employed by herring in avoiding suspended sediment. BLAXTER & PARRISH (1959) and BLAXTER & HOLLIDAY (1963) emphasized the importance of vision in many aspects of herring behavior, particularly in avoiding nets.

MATERIALS AND METHODS

Sediment used in the avoidance/preference experiments was collected from Grand Dune Flats Channel, Buoy #5 in the Miramichi estuary and frozen whilst in storage. The sediment was composed of 3.33% organic carbon, as determined by the Walkley-Black method (HOLME & McINTYRE 1971). The sediment had a median particle diameter of 6.2 µm and a sorting coefficient of 1.52, which indicates a poorly sorted sediment. The median particle diameter and the sorting coefficient were determined by the procedures outlined in the IBP Handbook #16 (HOLME & McINTYRE 1971).

The apparatus used in the experiments was that used previously by WILDISH et al. (1976) and consisted of two interconnecting arenas (A + B) forming a figure of eight maze. The arena walls were 30 cm apart and the aperture in the common wall, between the two halves of the apparatus, was 10 x 10 cm. Each arena had a separate water flow of 3-7 L/min from a common source. Water depth in the arena was maintained at 22 cm. Ambient water temperature ranged from 3-13°C during the experiments.

Juvenile herring were caught in Passamaquoddy Bay, New Brunswick in November and acclimated in holding tanks for 1 mo before use in experiments. An experiment consisted of a control and treatment

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test. Forty-five minutes before experimentation, herring were placed in the maze. Ten herring were used in each experiment and then discarded. The average length and weight of the herring at experimentation was 17.3 cm and 24.6 g. Control tests consisted of 13 observations at 5-min intervals and sham procedures involving an initial injection of 90 mL of seawater followed by injections of 33.8 mL of seawater at 5-min intervals in either side A or B.

Five control experiments were conducted which consisted of two consecutive sets of 13 observations but without treatment injections.

To determine avoidance (-) or preference (+) responses, experimental materials were injected in the same side as the herring preferred during the control period, and the change in the number of fish in the treatment arena was noted. Observation and injection schedules followed the same procedure as for the control. Due to the possibility of chance responses, the difference in percentage of fish in the injected side of the arena during control and treatment tests had to be 15% or greater to be considered avoidance.

During the treatment test, water samples totalling 500 mL were taken periodically from A and B sides of the arena. The water sample was filtered through a pair of Millipore® matched weight filters of 45-μm nominal size and the concentration of suspended sediment was calculated from the dry weight of the residue and known volume filtered.

Avoidance/preference experiments were conducted to determine the effect of: A. untreated sediment; B. Whatman® cellulose powder CF11 with a mean length of 263 μm; C. avoidance threshold concentrations of suspended sediment in various lighting conditions, and D. sediment after treatment in a dialysis bag with a molecular weight cut-off of 12,000 and submergence in an open, running-water system for 25 h.

The significance of differences between control and treatment tests was determined by Students t-test (OSTLE & MENSING 1975) (90% *, 95%**, 99.5% ***, 99.95% ****, confidence limits).

RESULTS AND DISCUSSION

Preference, non-significant at 99.95%, was demonstrated for all control experiments (Table 1) and showed a mean preference of 8 with a standard deviation of 5.

In experiment A the herring exposed to suspended sediment (Table 2) exhibited an avoidance threshold between 9 and 12 mg/L. Above the threshold herring demonstrated a mean avoidance of 24 and below the threshold, a mean avoidance of 6 with standard deviations of 10 and 16, respectively.

TABLE 1. Control experiments - percentage of fish present in A side of arena during control 1 and control 2 periods.

	Control 1 ± S.E.	Control 2 ± S.E.	Signif.	% Avoid. - Pref. +
Control	82 ± 3	94 ± 2	**	+12
Control	64 ± 2	66 ± 3	N.S.	+ 2
Control	80 ± 1	83 ± 1	*	+ 3
Control	72 ± 2	83 ± 3	***	+11
Control	74 ± 7	84 ± 8	*	+10

TABLE 2. Percentage of fish present in treated side of arena during experiments. Treatment with suspended sediment from Grand Dune Flats.

Concentration during treatment test (mg/L)	Control ± S.E.	Treatment ± S.E.	Signif.	% Avoid. - Pref. +
55.3	54 ± 3	43 ± 6	*	- 9
48.6	56 ± 5	30 ± 5	***	-26
46.3	53 ± 4	16 ± 3	****	-36
33.8	54 ± 3	45 ± 4	*	- 8
29.1	69 ± 4	35 ± 5	****	-31
24.6	53 ± 3	27 ± 4	****	-26
21.9	60 ± 4	35 ± 4	****	-25
12.0	52 ± 6	31 ± 5	***	-21
12.0	63 ± 5	31 ± 4	****	-33
9.6	88 ± 3	87 ± 2	N.S.	- 1
9.5	46 ± 4	45 ± 6	N.S.	- 1
9.5	77 ± 3	52 ± 3	****	-25
7.2	54 ± 4	65 ± 3	***	+12
5.1	50 ± 5	51 ± 5	N.S.	+ 1
5.0	50 ± 5	17 ± 5	****	-31
4.5	67 ± 3	60 ± 3	*	- 7
3.9	58 ± 5	48 ± 6	N.S.	-10
2.5	50 ± 4	56 ± 4	**	+ 6
2.5	53 ± 4	36 ± 7	**	-17
2.5	61 ± 4	50 ± 4	**	-11

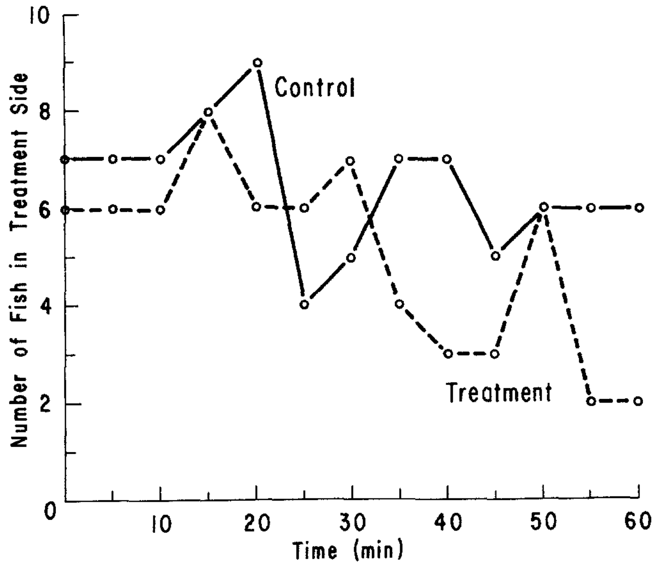

Figure 1. Time dependence of avoidance response during one experiment to a continuous stimulus applied at time zero.

The time dependency of the behavioral response to suspended sediments (Fig. 1) indicates a complex learned response by herring.

Learning is known to involve both conditioned and unconditioned stimuli to produce the appropriate response. During the 45-min acclimation period the herring become familiar with the apparatus: a process of learning the layout of the maze and involving one or more unconditioned stimuli inclusive of chemo-, tactile and/or visual sensory cues. During the control period the fish demonstrate a preference for one side of the maze. The avoidance or preference response elicited by the addition of sediment to the preferred side of the maze, which becomes the conditioning stimulus, is characteristically time-dependent, because of chance factors and differential learning speeds of individual fish. Thus, in Fig. 1, all but 2 of the 10 fish had learned the avoidance response by the end of the 60-min observation period. By altering the length of the observation period, the magnitude of the avoidance can readily be changed.

Cellulose (experiment B) consists of neutral solid particles with no dissolved component. During experiment B, the herring displayed an avoidance threshold between 14-16 mg/L. The mean avoidance for concentrations above this threshold was 26 and below it was 6 (Table 3) with standard deviations of 8 and 11, respectively. The elevated threshold of avoidance demonstrated during cellulose treatments as compared to the suspended sediment treatments (Table 2) shows that herring exposed to cellulose may be reacting to other unconditioned stimuli besides tactile ones. The avoidance by herring of dissolved substances has been shown by WILDISH et al. (1977) with sodium lignosulphate and humic acid with avoidance thresholds of 0.1-0.3 mg/L and 0.1-0.2 mg/L, respectively.

TABLE 3. Percentage of fish present in treated side of arena during experiment. Treatment with cellulose particles of 263 μm mean length.

Concentration during treatment test (mg/L)	Control ± S.E.	Treatment ± S.E.	Signif.	% Avoid. - Pref. +
41.6	72 ± 4	48 ± 6	***	-25
39.2	72 ± 3	39 ± 6	***	-33
38.3	74 ± 5	44 ± 3	****	-30
33.2	75 ± 5	41 ± 3	****	-35
24.4	94 ± 2	53 ± 8	****	-41
23.4	63 ± 4	48 ± 4	**	-15
22.4	65 ± 4	48 ± 4	***	-17
22.3	63 ± 4	47 ± 4	***	-21
16.0	72 ± 6	53 ± 4	***	-19
14.9	59 ± 5	51 ± 3	*	- 8
14.0	85 ± 3	84 ± 3	N.S.	- 2
10.4	77 ± 4	83 ± 4	**	+ 5
10.0	95 ± 2	89 ± 2	**	- 6
9.8	94 ± 3	69 ± 4	****	-25
7.3	75 ± 3	68 ± 5	N.S.	- 7
5.0	55 ± 6	43 ± 6	*	-12
4.6	55 ± 3	70 ± 4	***	+15
4.2	48 ± 5	34 ± 4	**	-15

This suggests that leachates from sediments could also be involved in avoidance responses.

BLAXTER (1964) found that 2.9×10^{-4} lux of white light was the threshold for visual perception of a barrier by herring. The herring should therefore be able to see at white light levels of 4.2×10^{-1} lux. Yet, the herring in experiment D at this light level have a decreased avoidance response with a mean of 11 and standard deviation of 3 as compared to a mean avoidance of 20 with standard deviation of 3 for light levels above 4.2×10^{-1} lux (Table 4). This suggests that decreased light causes a partial inhibition of the avoidance behavior.

Spectral sensitivity of herring declines as the wave length of ambient light increases from 500 nm (BLAXTER 1964). A masking effect is suggested by the extinction of avoidance response during all experiments with red light (mean avoidance 3, standard deviation 10 (Table 5)) confirming that visual cues are important as conditioning stimuli.

TABLE 4. Percentage of fish present in treated side of arena during experiments. Treatment with avoidance threshold concentrations of suspended sediment at various white light levels.

Lux	Concentration during treatment test (mg/L)	Control±S.E.	Treatment±S.E.	Sig.	% Avoid. - Pref. +
107.6	11.7	74 ± 2	55 ± 3	****	-19
96.8	13.1	84 ± 2	59 ± 5	****	-25
75.3	12.6	65 ± 3	42 ± 6	***	-22
64.6	12.3	55 ± 3	38 ± 6	**	-18
43.0	9.8	68 ± 4	45 ± 5	***	-22
10.5	10.1	63 ± 4	48 ± 4	**	-15
0.4	11.2	66 ± 4	48 ± 4	***	-19
0.4	12.7	65 ± 3	54 ± 4	***	-11
0.4	11.8	67 ± 2	57 ± 3	***	-11
0.4	10.7	55 ± 3	43 ± 6	**	-12
0.4	10.3	68 ± 4	52 ± 6	**	-16
0.4	9.3	75 ± 1	67 ± 2	***	- 8

TABLE 5. Percentage of fish present in treated side of arena during experiments. Treatment with avoidance threshold concentrations of suspended sediment at various red light levels.

Lux	Concentration during treatment test (mg/L)	Control±S.E.	Treatment±S.E.	Sig.	% Avoid. - Pref. +
53.8	9.2	70 ± 4	62 ± 2	*	- 8
43.0	9.5	62 ± 3	55 ± 3	**	- 6
32.3	12.7	62 ± 3	52 ± 3	***	-10
21.5	11.1	48 ± 2	60 ± 3	**	+12

The removal of dissolved substances by dialysis (experiment D) from the Miramichi estuary sediment resulted in a lower avoidance threshold (less than 4.8 mg/L with average avoidance of 15 and standard deviation of 7, Table 6) as compared to experiment A, contrary to expectation. The dissolved substances removed had a molecular weight smaller than 12,000. The low avoidance threshold with

TABLE 6. Percentage of fish present in treated side of arena during experiments. Treatment with dialyzed sediment with soluble organic compounds less than 12,000 molecular weight removed.

Concentration during treatment test (mg/L)	Control + S.E.	Treatment ± S.E.	Signif.	% Avoid. - Pref. +
13.3	71 ± 2	61 ± 2	***	-10
12.3	69 ± 2	61 ± 2	***	- 8
10.2	67 ± 4	51 ± 6	*	-16
9.8	60 ± 4	32 ± 4	****	-29
9.7	58 ± 3	49 ± 3	**	- 9
9.6	55 ± 3	38 ± 6	**	-18
9.1	68 ± 4	50 ± 6	****	-18
8.7	58 ± 3	38 ± 6	***	-21
7.9	79 ± 4	59 ± 4	***	-21
7.6	89 ± 4	88 ± 2	N.S.	- 1
7.3	58 ± 4	34 ± 5	****	-18
7.1	65 ± 2	47 ± 2	***	-18
6.4	68 ± 3	58 ± 3	**	-11
5.3	55 ± 1	42 ± 3	****	-14
4.8	57 ± 2	45 ± 3	***	-12

dialyzed sediment may be due to the removal of a chemosensory masking or buffering agent present before dialysis.

Extrapolating our laboratory results to field conditions is difficult due to the experiment-specific thresholds of avoidance determined by us. However, it is clear that juvenile herring can learn to avoid the suspended sediments which may be dumped in the Miramichi estuary.

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