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Avoidance of Suspended Sediments by Smelt as Determined by a New "Single Fish" Behavioral Bioassay

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The behavioral work with smelt, Osmerus mordax, reported here and previous work with herring, Clupea harengus harengus (Johnston and Wildish 1981) were stimulated by the implementation in 1981-83 of a large dredging project in the Miramichi estuary, New Brunswick, Canada. During this project, it was planned to dredge 4.3 million m^3 of sediment and dispose of it at three designated sites within the Miramichi estuary (Messieh et al. 1981). The most landward of these was close to a fixed net fishery for smelt and fears were expressed by smelt fishermen that spoil disposal would reduce their catches.

In the period 1969-1978, the smelt fishery was the fourth largest in landed value in the Miramichi estuary after lobster, herring, and salmon, with an average value of $100,000 and average landings of 357 metric tons (Messieh et al. 1981). Smelt are captured in fixed bag nets during fall as they ascend the estuary to spawn and in winter in box nets which are fished under the ice (McKenzie 1964).

The purpose of this work was to test the hypothesis that smelt are capable of avoiding suspended sediments and hence may avoid fixed nets in the estuary where high levels of suspended sediment are present as a result of dredging and dumping. During this work, individual fish have been tested whereas in earlier tests a group or "schooling fish" bioassay was used (Johnston and Wildish 1981). The "single fish" approach overcomes the difficulty present in the schooling fish test that each individual fish is not an independent data point (see Mathur and Silver 1980).

MATERIALS AND METHODS

The sediment used throughout the experiments was collected from Grand Dune Flats channel, near buoy #5, Miramichi estuary, and consisted of a silty clay sediment high in organic carbon content (3.3% carbon on a dry weight basis) similar to that previously reported (Johnston and Wildish 1981).

The experimental apparatus consisted of two interconnecting arenas, A and B, forming a figure-of-eight maze. The connection between the two halves of the maze was a 10 x 10 cm door which allowed fish passage but limited water exchange between sides A and B. The arena walls were 30 cm apart and A and B each supplied with a seawater flow of 7 L/min from a common temperature-regulated head tank. The experiments took place in winter 1982/83, and it was necessary to maintain the sea water at 10 $\pm$ 1°C to ensure sufficient swimming activity to complete the behavioral tests.

Two white strip lights were mounted 1 m above the maze and provided 300 lux just above the water surface. In some experiments, these were replaced by a single red 100-W bulb.

Smelt were obtained by trawling in Passamaquoddy Bay in November 1982 and acclimated in large holding tanks with sea water near 10°C until they were feeding satisfactorily on brine shrimp. Smelt were of 16.7 cm average length and 27.1 g average weight.

A smelt was randomly selected from the holding tank, placed in the figure-of-eight maze and allowed to acclimate for a 15-min period. Direct continuous observation of the individual fish was then started without disturbance to the subject. Record was kept of the number of times the fish passed through the gate and the accumulated time it spent in A and B. The temporal criterion used during the experiments was the time taken to traverse the gate either 10 or 30 times. This method tends to reduce individual variability between fish in background swimming activity.

The control period of the test is defined as the total time spent by the fish in A and B which it requires to traverse the gate for a specified number of times and sets the equal observation time required for the treatment period. The treated side A or B was chosen from a table of random numbers and 1 min before the test began 90 mL of sediment slurry was injected by syringe into the selected arena. At the beginning of the test, a further 34 mL of slurry was added and this was repeated at 5-min intervals throughout the treatment period to maintain a constant suspended sediment concentration. Seawater samples (20 mL) were taken at 5-min intervals from the maze throughout the test period and concentrations of suspended sediments determined on the stirred, bulk sample for each fish or each concentration by spectrophotometric measurements at 500 nm and reference to a standard curve prepared from known dry weights of sediment. Flow rates and water temperatures were also recorded during the experiments.

Ten individual smelt were used for each run of an experiment and the test variable was the time, in seconds, spent in one side of the arena during the control period compared by analyses of variance to the time spent in the same, treated side during the treatment period.

RESULTS AND DISCUSSIONS

In the first experiment, the same fish was observed for ten consecutive control periods (Table 1), involving approximately 8 hr of

Table 1. Time (s) spent by a single smelt at 10°C in each side of the maze for 30 passages of the door

Replicate	1	2	3	4	5	6	7	8	9	10	X Y	$\bar{S}_x$ $\bar{S}_y$
Side A	629	691	338	533	850	824	502	492	597	350	581	166
Side B	627	1187	1486	575	556	628	361	410	590	691	711	333

observations. Because there should be no conditioning stimulii present during the control period, we have assumed that the times recorded in A and B are independent data points and a _t_-test shows that there is no significant difference between time spent in A or B ($t = 0.96$, d.f. = 9). Although 30 passages of the door were used to present the data in Table 1, similar results were obtained if 10 passages of the door were used as the temporal criterion.

For the next experiment, the criterion used to establish the length of the test period was the time required to complete ten passages through the door. When suspended sediments are added to the maze at the concentrations shown in Table 2, there appears to be a threshold effect between 18.8 and 21.8 mg/L suspended sediment. At the two concentrations at/or below 18.8 mg/L, the _t_-test shows no significant difference between the mean times in control and treatment periods. At 21.8 mg/L and above, however, the t-values indicate that significantly less time is spent in the sediment-treated side during the test period ($p < 0.05$).

To test whether naive smelt, which had not previously been in the maze, relied on vision for swimming, they were first exposed to normal white light conditions in the maze, and the time to make 30 passages through the gate was recorded. In a second control period, the only change made was to replace white with red light. The smelt were observed for the period established in the white light control period. The results (Table 3) clearly show that red light inhibited swimming movements, with the smelt tending to remain in whatever side they were present in when the lights were changed.

The apparent threshold of ~20 mg of suspended sediment/L for the smelt avoidance response is higher than that found for herring (~10 mg/L) but with a different species, protocol and analytical methods (Johnston and Wildish 1981). If a learning process is involved in these experiments as we suspect, then suspended sediments represent the unconditioned stimulus. Visual cues, as suggested by the red-light experiments in which vision is blocked (Johnston and Wildish 1981), as well as other possible sensory cues, are the conditioning stimulii. Because learning is a temporal process, the arbitrary choice of a time period as used in these experiments may bias the results obtained and help yield an apparatus-specific threshold avoidance result.

Table 2. Time (in seconds) spent by smelt in a white lighted maze containing sea water at 10 ± 1°C. Test time is set by the time in A and B required to complete ten door passages in the control period

Fish no.	Concentration suspended sediment, mg/L, (95% confidence interval)									
	14.3 (12.7–15.9)		18.8*		21.8*		24.0*		39.9 (36.0–43.8)	
	Control	Test	Control	Test	Control	Test	Control	Test	Control	Test
1	250	35	152	0	576	217	283	119	287	126
2	405	263	703	648	394	287	120	282	541	264
3	188	204	65	54	650	188	410	198	552	362
4	84	19	268	260	182	143	277	52	200	142
5	122	204	507	451	180	195	170	47	116	117
6	197	283	122	63	365	266	277	5	165	153
7	123	153	137	177	502	526	161	59	264	102
8	266	915	414	441	192	144	260	271	210	187
9	143	84	73	105	242	274	148	93	488	253
10	345	617	571	673	768	447	542	201	133	286
$\bar{X}$, $\bar{Y}$	212	278	301	287	405	269	234	125	296	199
S_x, S_y	99	267	219	237	201	120	87	96	168	83
t value	−0.84		0.63		2.42**		2.85**		2.32**	

*Determined on bulk sample for all experiments at this concentration.
**Significant at $p < 0.05$.

Table 3. Effect of lighting conditions on the number of passages through the door

Fish	Lighting conditions	Control time in A + B (s)	No. of times through door
1	White Red	1450	30 1
2	White Red	2936	30 0
3	White Red	3153	30 1
4	White Red	1034	30 1

Our laboratory experiments do provide indirect evidence that smelt could avoid areas high in suspended solids. Because of the apparatus-specific nature of the results and the multiplicity of environmental and innate behavioral factors operating in field conditions, extrapolation from laboratory results directly to the field is problematical. The results indicate the need for field studies of smelt behavior where other behavioral drives such as migration and escape movements may overide the avoidance movements observed in our laboratory tests.

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