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POSSIBLE IMPACT OF SEDIMENT FROM DREDGING AND SPOIL DISPOSAL ON THE MIRAMICHI BAY HERRING FISHERY

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CONTENTS

ABSTRACT

Messieh, S. N., D. Wildish, and R. H. Peterson. 1981. Possible impact of sediment from dredging and spoil disposal on the Miramichi Bay herring fishery. Can. Tech. Rep. Fish. Aquat. Sci. 1008, iv + 33 p.

A field survey of the herring fishery in Miramichi Bay, N.B., Canada is presented, inclusive of catch statistics and fishing effort in the gillnet fishery. A spawning bed survey is described in relation to hydrographic conditions of the Bay. Data from plankton surveys designed to plot concentrations of larval fish in the Miramichi estuary are presented.

Results of experiments with herring eggs and larval fish show that sediment deposited onto spawn will increase egg mortality. Suspended sediments resulting from dredge disposal could result in earlier hatching and shorter hatching lengths and could inhibit feeding of herring larvae at levels down to a few parts per million. Juvenile herring avoid suspended sediments in the parts per million range and thus dumping could result in low catches for individual gillnets near the dump site. Suggestions are presented to minimize the potential effects of dredging and dumping on the herring fishery in Miramichi Bay.

Key words: Dredging, herring, suspended sediment, settled sediments, egg development, larval feeding, commercial herring fishery, Miramichi Bay.

RÉSUMÉ

Messieh, S. N., D. Wildish, and R. H. Peterson. 1981. Possible impact of sediment from dredging and spoil disposal on the Miramichi Bay herring fishery. Can. Tech. Rep. Fish. Aquat. Sci. 1008, iv + 33 p.

Une étude de la pêche du hareng réalisée dans la baie Miramichi (N.-B.) au Canada est présentée, ainsi que des statistiques sur les prises et l'effort de pêche au filet maillant. On décrit une frayère en relation avec les conditions hydrographiques de la baie. Par ailleurs, on présente des données sur le plancton en vue de représenter graphiquement les concentrations de larves de poisson dans l'estuaire de la Miramichi.

Les résultats d'expériences menées avec des oeufs et des larves de hareng montrent que les sédiments se déposant sur les oeufs augmentent leur mortalité. Les sédiments en suspension provenant du rejet de matières de dragage pourraient entraîner une éclosion précoce et des larves plus petites et ils pourraient empêcher dans une large mesure les larves de hareng de se nourrir à des concentrations aussi faibles que quelques parties par million. Le hareng juvénile évite les eaux qui ne contiennent que quelques parties par million de sédiments en suspension, ce qui pourrait se traduire par des prises moins élevées dans les filets maillants mouillés à proximité du lieu du rejet des sédiments. On propose des solutions pour minimiser les effets potentiels du dragage et du rejet des matières sur la pêche du hareng dans la baie Miramichi.

INTRODUCTION

Estuaries are known to be important feeding and nursery grounds for commercially valuable marine fish stocks. The Miramichi Estuary and outer Bay make up such a system of major importance in the southern Gulf of St. Lawrence. In 1979 total landed value of fish from this area amounted to more than $3 million, of which herring were valued at $0.7 million, second in value only to lobsters (Table 1). Landings of herring by weight are by far the largest of all species, amounting to 53.6% of total landings during the period 1969-78

The Miramichi Channelization Project, if it proceeds, will be one of the largest single dredging projects in the Maritimes. This project will provide a channel (8 m deep) 35 naut. mi. long extending from Newcastle, New Brunswick, to the Gulf of St. Lawrence, and will require dredging of about 5×10^6 m^3 of sediment spoil. Three dredged spoil disposal sites have been proposed of which sites B and C (Fig. 1) will receive 96% of the total volume of dredged sediment.

The impact of dredge spoils on local fisheries, particularly on herring populations in the outer Bay, has been identified as a potential area of concern. Herring return annually early in spring to spawn in shallow waters in the Bay, near site C. Although direct physical damage to spawning beds can be avoided by proper choice of disposal sites, the effects of the increased suspended sediment load in water on eggs, larval and juvenile herring remain unknown.

A collaborative research project was proposed to enable these questions to be answered and thus contribute to future decisions regarding resource conflicts of this nature, particularly as they apply to herring and to habitat alteration caused by dredging and dumping. Information on the herring fishery in this area is lacking or badly fragmented. Thus, a documentation of the characteristics of the fishery and fishing activities, prior to interruption by any dredging, was felt necessary to serve as background information for future reference.

THE HERRING FISHERY, HERRING EGG AND LARVAL SURVEYS IN THE MIRAMICHI BAY

HERRING CATCH STATISTICS

Monthly herring landings in Miramichi Bay (Statistical Districts 70, 71 and 73) for the years 1947-79 are presented in Tables 2-4. No herring are caught in Statistical District 72. Herring catches in District 71 were insignificant except for 1978 when landings amounted to 96.0 metric tons (MT) (Table 3).

The bulk of the herring catch is taken from the Escuminac area (Statistical District 73). In the past two decades, landings have fluctuated between 1000 and 5000 MT (Table 4). Three-year running means of herring landings since 1948 are shown in Fig. 2. The herring fishery in the Miramichi Bay is seasonal, largely a spring fishery (Fig. 3), based on adult fish coming to the area to spawn. Regularity of herring spawning time has been demonstrated in the fisheries in the Gulf of St. Lawrence (Messieh 1977) and is obviously shown in this fishery as well. Analysis of herring purchase slips shows that more than 50% of the catches are taken during the first 2 wk of May each year (Table 5).

Catch-per-unit-effort for the 4 yr of observations (Table 5) increased slightly from 2.14-2.23 MT/fisherman in 1976 and 1977, respectively. In 1978 it showed a further increase to 2.80 MT/fisherman. In 1979, however, catch-per-unit effort dropped to 2.09 MT/fisherman. Available data showed that catch per fisherman differed from one buyer to another (Table 6). From records obtained from four major buyers in 1979, catch per fisherman ranged from 0.92-2.09 MT.

FISHING EFFORT

No data on herring fishing effort in Miramichi Bay are available. Hence, interviews with a number of fishermen were held to get an estimate of the number of nets fished. Forty-four fishermen were interviewed, and results are shown in Table 7. Many of these fishermen reported that the number of nets used changed from year to year. Obviously, the number of nets/fisherman depend on the size of the fishery, the size of the boat and crew, and engagement with other fishing activities, e.g. lobster fishing. To make a comparison for the changes in fishing effort, nets were adjusted to a standard size of 15 fathoms long and 40 meshes deep. Results showed that average number of standard nets/fisherman increased from 66.5 to 91.1 nets/fishermen in 1976-79 (Table 7).

To estimate the total number of nets fished in Miramichi Bay, and to examine their distribution, a series of aerial photos were taken from a light, single-engine aircraft with a camera port in the floor. Plans were to carry out the survey at peak times of the fishery, i.e. first week of May. However, due to reasons beyond our control, the aerial survey was not possible until the last week of May.

Two flights were made on May 24 and 28, 1979, from altitudes of 457 and 914 m. The latter altitude was found to be adequate for photographing the fishing nets, with a scale of approximately 1:6000. Pictures were taken in sequence along three transects near the southern shore from Baie du Vin to Point Escuminac (Fig. 4). Identification of herring fishing nets was made easy by their characteristic appearance on the photographs: a series of dots in a straight line or gentle curve.

Accurate counts of fishing nets, their size and distribution were made from the aerial photographs and projected on maps as shown in Fig. 5 and 6. It was estimated that 3,000 standard nets were operating during the period in a narrow stretch of water between Escuminac wharf and Fox Island. About 2 wk before the time of photography, i.e. May 7-9 when peak herring catches were taken, it was estimated that as many as 10 times this number were engaged in the herring fixed gillnet fishery.

SPAWNING BED SURVEY

In preparation for SCUBA diving to survey the spawning bed, interviews with local fishermen were held. The locations of the fishing nets were of much help, since fishing grounds are known to coincide with spawning grounds. Fishermen were asked to report on any spawn adhering to their nets, including the time and locality of the observed spawn. A grab sampler was used to collect samples of substratum. Samples were examined on the spot for herring eggs deposited on the gravel and seaweed, and the number of eggs were recorded.

The spawning bed, as seen by SCUBA divers, was characterized by a rocky bottom. The substrate was mainly of small stones on masses of sandstone and covered with weeds, mostly Irish moss (*Chondrus crispus*) and rockweed (*Fucus* sp.). The spawning bed occupied a long narrow area parallel to the shore in depths of 2-8 m. The largest concentrations of eggs, however, were found in depths of 3-4 m (Table 8). In areas where egg deposition was found, water temperatures ranged from 6.8-12.3°C at the surface, and 3.7-9.7°C at the bottom.

Samples of herring eggs collected from the spawning bed were examined for stage of development. A scale of egg developmental stages similar to that reported by Baxter (1971) was adopted. Results are presented in Table 9. Most of the eggs were in stages 4 and 5; stage 4, embryo highly developed with eyes slightly pigmented; and stage 5, prehatching, from which larvae could hatch in a matter of hours. On May 18, 1979, a sample of 262 eggs was in stage 3, one developmental stage earlier than samples taken on May 16 and 17. This indicates that spawning probably does not occur totally synchronously. A synchronous spawning implies that either different herring populations are spawning in the same area, or that different components of the same population do not reach maturation stages at the same time.

Natural egg mortality ranged from 1.6-6.8%. This does not include mortality due to predation, which, at present, remains unknown (Table 9). Percentage mortality did not follow any particular pattern with time. Samples collected on May 22 and 23, 1979, showed that few eggs were hatching. On May 30, 1979, several attempts to collect eggs with a grab sampler from the spawning bed were made, but only six eggs were found, four of which were dead. By that time most hatching was over.

The herring egg deposition in each station was classified according to its density into four categories:

A - Few = 1-9 herring eggs per sample,
B - Common = 10-99 herring eggs per sample,
C - Abundant = 100-999 herring eggs per sample,
D - Dominant = 1000 herring eggs or more per sample.

Density of egg deposition and spawn location are presented in Table 8 and Fig. 7. It is shown that the major concentrations of egg deposition are between Escuminac wharf and eastern Fox Island. No spawn was located in the inner Bay.

Results of this survey showed that the proposed dredge site "C" does not overlap the spawning bed. The dredge channel, however, lies in close proximity to the spawning bed along its northeastern boundary. While a direct contact of the spawning bed with the dredge material could be avoided, the drift of the dispersed and suspended material over the spawning bed is inevitable.

SURFACE AND BOTTOM DRIFT

In order to study the pattern of water drift in Miramichi Bay, arrangements were made with Mr. D. Bezanson, Coastal Oceanography, Bedford Institute of Oceanography, to release surface and sea bottom drifters near the spawning bed.

In June 1979, 100 surface drifters and 100 seabed drifters were released. In August 1979, 450 releases of each type of drifters were made. Number and date of recoveries are presented in Table 10. Pattern of surface and bottom drift is shown in Fig. 8-11.

Of the surface drifters released in June, six recoveries were taken near P.E.I., Magdalen Islands, and Cape Breton Island; the farthest was found near Cape North, Cape Breton Island. Of those released in August, 39 recoveries were made in Northumberland Strait, Prince Edward Island, Magdalen Islands, and Newfoundland; the farthest was recovered in Fortune Bay, Newfoundland.

Of the sea bottom drifters released in June, 85 recoveries were made, all of which were in the Miramichi inner Bay and Estuary. Of those released in August, 130 recoveries were made. Except for three recoveries made in the outer Bay, all recoveries were in the inner Bay, the Estuary, and the Miramichi River. Some of these drifters were recovered near head of tide at Millbank. The drift pattern, as inferred from drifter recoveries, indicates a two-layer system typical of estuarine circulation: a sea-going surface drift in a southeastward direction, and an upriver bottom drift in a westward direction.

PLANKTON SURVEY

A plankton survey to collect fish larvae from Miramichi Bay was carried out between May 31 and June 22, 1979. Data on depth, temperature, and time of towing are presented in Table 11. Forty-seven plankton stations were sampled in Miramichi Bay and in northern Northumberland Strait as far as Richibucto (Fig. 12). The M/V *JEROME RII*, an 11-m fishing boat, was used for this survey. Bongo nets of 0.333 and 0.505 mm mesh and 60 cm diameter, equipped with a TSK model flowmeter, were used for sampling. Tows were step oblique at a boat speed of 2 knots for about 10 min duration.

A total of 25 species of fish larvae were identified in the plankton collecton (Table 12) of which five species are of commercial value in the Miramichi area. These are smelt, winter flounder, herring, cod and mackerel. Smelt larvae were the largest in number of larvae collected (34,818) followed by winter flounder (8,051) and herring (2,630). Obviously, the relative abundance of species represented in the plankton collection depends on the timing of the survey. All these species (Table 12) are spring spawners, and there are more species in the area which are known to spawn in summer and fall.

Numbers of larvae under an area 10 m^2 were calculated for each station, and isometric lines showing larval concentrations were drawn for each of the well represented species in the collection.

Figures 13-16 show larval abundance of four species which have maximum concentrations inside Miramichi Bay. These are herring, smelt, winter flounder and sand lance. Two more species of commercial value, cod and mackerel, showed maximal larval concentrations outside the Bay, indicating that spawning of these species occurs outside Miramichi Bay. Larval cod were concentrated a few miles off east Escuminac. Larval mackerel were concentrated in Kouchibouquac Bay.

The distribution patterns of herring larvae and winter flounder larvae were very similar and their concentration maxima were overlapping (Fig. 13, 15). The center of larval concentration coincided with the center of herring spawning as delineated by the survey. During diving, a few winter flounder were observed feeding on herring eggs. Examination of winter flounders showed that their stomachs were full of herring eggs.

The distribution pattern of smelt larvae (Fig. 14) shows two epicenters, one in the inner Bay towards the Miramichi Estuary, the other near Baie du Vin where Eel River discharges its waters. Both the Miramichi and Eel Rivers are known to support good fisheries for smelt.

Dispersal pattern of all larval fish found during this survey indicated a southeastward direction of larvae off Point Escuminac in a counter-clockwise movement. This pattern agrees with the surface drift as shown by drifters.

INFLUENCE OF SUSPENDED SEDIMENTS ON HERRING EGG AND LARVAL DEVELOPMENT

Although the deleterious effects of increased infiltration of fine sediments into salmonid spawning gravels have been well documented (Hausle and Coble 1976; Cordone and Kelley 1961; Wickett 1958), the effects of high suspended sediment concentrations and of siltation on spawning habitats of marine fish have not been investigated so thoroughly. Auld and Schubel (1978) determined the effects of various suspended sediment concentrations on embryonic development of the eggs of several freshwater and estuarine species. Hatching success of the eggs of most species studied began to be reduced at concentrations of 500-1000 mg/L. Similarly, Davis (1960) reported that larval clam development began to be affected at 1000 mg/L.

In view of the paucity of data on the influence of suspended sediments on marine fish egg development and because the proposed dredging operation in Miramichi Bay is close to an important herring nursery area, the effects of various suspended sediment concentrations and settled sediments on herring egg development and hatching were investigated.

COLLECTION OF EGGS

For the first series of experiments eggs were collected from two females and fertilized with milt from three males taken near the Escuminac wharf on May 11, 1979. The eggs were stripped into a 1-L plastic container. The milt was then added and the contents swirled for a few seconds. A 100-mL aliquot of seawater was added and the mixture again swirled for 1 min. The container was then filled with seawater, swirled and decanted. The eggs were washed and decanted once more; then nine glass microscope slides were coated with the adhesive eggs for a 2.5-cm length at one end by dipping the slides into the egg mass at the bottom of the container. The slides with attached eggs were suspended in aerated seawater in plastic containers which were in turn packed in cooled ice chests at 8-10°C for transportation to the laboratory (trip required 5 h). Due to high winds and rough seas, it was impossible to collect live fish from a boat. Fish which had been dead about 1 h prior to stripping were taken from the commercial vessels. As air temperatures were low (ca. 3°C), the eggs and sperm were viable.

For the second series of experiments one female and two male herring were collected live on Sept. 17, 1979, from a weir located near Duck Island, off the coast of Grand Manan, at a surface water temperature of 12°C. Eggs were stripped into a clean, dry, 10-L plastic bucket after which the milt from the males was added. A few hundred milliliters of seawater were added to permit mixing and the bucket swirled gently for 1 min. Another two aliquots of 500 mL of seawater were added and the bucket swirled 1 min after addition of each aliquot. The bucket was then half-filled with seawater and swirled to allow the eggs, which had now become adhesive, to coat the sides and bottom of the bucket in a single layer. The water was drained from the bucket, which was then filled with fresh seawater. The bucket of eggs was aerated and kept at 5°C for 19 h during transportation to the laboratory. At the laboratory, the eggs were allowed to come to 12°C under aeration in a constant temperature room at which time the water was replaced with fresh 12°C seawater.

EXPERIMENTAL

For the first series (May 1979) two types of experiments were performed. Some slides with attached eggs were covered with layers of fine sediment (median particle size of 4.0-4.5 μ for all experiments) to varying depths. Two slides, which served as controls, were placed in a light-tight plexiglass container (described in Peterson et al. 1977) through which seawater flowed at about 200 mL/min at 9.3°C with no layer of sediment in the boxes. Two slides were placed in plexiglass boxes under similar conditions to the controls, but were covered with a very thin film of sediment so that the outlines of the eggs could be seen, resulting in a "cobbled" appearance on the surface of the sediment. Some of the eggs remained partially exposed above the sediment surface. A third pair of slides with eggs were covered with sediment to a depth of 1 cm under otherwise similar conditions.

Another series of slides with attached eggs were suspended in four 500-mL separatory funnels. The concentrations of suspended sediment in the separatory funnels are overestimated by about 100 ppm (amount in control funnels) due to retention of some sea salt on the filtered aliquots.

Concentrations of suspended sediment in each funnel were determined by taking 50-mL aliquots from the level at which the eggs were suspended and filtering them through pre-dried Whatman #2 filter papers, then drying at 105°C (Table 13). Concentrations were measured, and suspension media changed every second day. The solutions in the funnels were aerated vigorously to keep the sediment in suspension.

In the second series of experiments, eggs were again suspended in water containing various concentrations of suspended sediment (Table 14). For this series plastic, 1-L settling cones were used instead of 500-mL separatory funnels. Strips of plastic (2.5 x 20 cm) cut from the bucket in which the eggs were fertilized, with an adherent single layer of eggs, were suspended in the various concentrations of suspended sediment. The number of eggs on each strip was counted from photographs. Solutions were changed daily. Again the suspended sediment recorded in the control cones (C-1, C-2 in Table 2) is sea salt retained on the filter papers.

Once the embryos had developed eye pigmentation, solutions were checked (every second day in the first series, daily in the second series) for hatched larvae by passing the solutions through a fine netting. Retained larvae were transferred to a petri dish of seawater and counted. Live, undamaged larvae were anaesthetized with tert-amyl alcohol and measured under magnification with a micrometer disc.

Larvae were not collected from the slides covered with sediment and their controls, but the numbers of living eggs were counted after the embryos had developed eye pigmentation. The number of living embryos and total number of eggs were counted in two microscopic fields selected randomly on the slides.

RESULTS

Series I - eggs covered with sediment deposits

The survival of eggs on the control slides was variable, depending upon whether the eggs had adhered to the glass slide in a single layer or in multiple layers. In the latter case, only those eggs in the surface layer survived. Of 31 eggs inspected, 17 (55%) were living, all those dead being covered by more superficial layers of eggs. For the 33 slides of eggs covered with a thin film of sediment, 15% were living at the eyed stage. Those surviving were probably ones that projected above the sediment as they were the most superficially located and had no sediment attached. All eggs covered with 1 cm of sediment had died and many were in an advanced state of decomposition when they were investigated. The layer of sediment had probably largely occluded any circulation of water around the eggs.

Series I - eggs incubated in varying concentrations of suspended sediment

Most of the larvae hatched in 12-14 d from fertilization at 9.3°C. Since the funnels were checked for hatched larvae every second day, possible differences in median hatching times among the various sediment concentrations could not be determined. The mean size of larvae was inversely dependent on the suspended sediment concentration for both days when hatched larvae were removed from the containers (Table 15). Since the funnels were checked only every second day, it is unknown whether the larvae were smaller due to premature hatching and lack of subsequent larval growth at high suspended sediment concentrations, or whether they hatched at the same time but were not as large due to poor *in ova* growth at high sediment concentrations. Larger larvae were obtained on May 25 than on May 23, 1979, showing less difference in mean lengths among the various concentrations.

The total number hatched is a function of number of eggs on the slides (which were not counted) rather than suspended sediment concentration. The slide suspended in the low sediment concentration had far fewer adherent eggs, which were distributed in a single layer, and all hatched. The other three slides had many more eggs with much of the egg mass being more than one layer thick. An inspection of the slides after completion of hatching showed that only the eggs in the superficial layer hatched, with those in the deeper layers dying, often in the more advanced stages of development.

Series II

Time from fertilization to hatching appeared to be primarily a function of egg packing density (Table 16). Cones containing greater numbers of eggs (hence higher densities, since the size of the plastic strips was the same) hatched earlier. This is most obvious for the C-1 and C-2 treatments where the difference in egg number is greatest. Median hatching occurred at 10 d of incubation in C-2 (1390 eggs), and at 12 d in C-1 (559 eggs). It is also apparent to a lesser extent in the other treatments. High suspended sediment concentration may also induce earlier hatching, as the H-2 treatment had the earliest median hatching time (9 d). Linear multiple regression indicated that both sediment concentration and egg density significantly influenced median hatching time with each factor having equal weight. There was no apparent effect of either egg density or sediment concentration on total percent hatch or percent live hatch (Table 16).

Sediment concentration and egg packing density both had an effect on larval size at hatching (Table 17, 18; Appendix I). Larval size at hatching was lower at higher egg densities for any given sediment concentration, and size at hatching tended to be higher at lower sediment concentrations (Table 17, 18).

For low egg densities (Fig. 17), hatching at the two higher sediment concentrations was characterized by 2-5 d of larvae hatching at submaximal size, followed by maximal mean length hatching. Larvae hatching even later were again smaller. Incubation in the highest sediment concentration resulted in the hatching of larvae of maximal mean length 2 d earlier than at lower sediment concentrations. At the two lowest sediment concentrations (L-1 and C-1) the hatching period was more compressed into the last 4 d of the hatch, with most larvae near maximal mean length.

High egg density resulted in early hatched larvae (at days 9, 10, and 11), with lower mean lengths for the lower suspended sediment concentrations as well (Fig. 18). For any given time from fertilization, hatched larvae were longer at the two lower suspended sediment concentrations. It should be realized that the densities used were not constant among the treatments.

Settled sediment, of the particle size used in these experiments, is lethal to herring eggs if the eggs are blanketed. To survive, at least a portion of the egg must project above the sediment layer. Egg mortality is probably due to a smothering effect with the sediment layer preventing circulation of water around the eggs. Similarly, we found that if eggs are deposited on incubation media more than one egg layer in thickness, the deeper layers of eggs die before hatching.

We were unable to detect any deleterious effect of suspended sediment on hatching success, up to concentrations in excess of 7000 mg/L. This suggests that herring eggs are more resistant to suspended sediment concentrations than were the eggs of those species studied by Auld and Schubel (1978). Alternatively, the differences might be due to differences in culturing procedures (Auld and Schubel retained the eggs in mesh cages in their study). Sediment particle sizes were similar in the two investigations.

Suspended sediment concentration, egg density, larval size at hatching, and time from fertilization to hatching were all interrelated. Both high suspended sediment concentration and high egg densities resulted in earlier hatching of many of the larvae. This may be in response to change in microhabitat in the vicinity of the egg (possibly higher CO_2 or lower O_2 levels). At high suspended sediment concentrations, some silt settled into the interstices between eggs, possibly creating conditions similar to that of increasing egg density. The effect of high egg density appeared to be primarily on hatching time. At equal times from fertilization to hatch, larval lengths were similar. At high and medium suspended sediment concentrations, however, larval length tended to be shorter even at equal incubation times. The relationship among these various parameters is obviously complex and merits more thorough study.

The preliminary results of experiment 1 indicate that hatched larvae may be more sensitive to suspended sediment than are eggs, since no living larvae were observed after 48 h at 19,000 mg/L. Again, these results should be investigated more thoroughly in further experiments.

THE EFFECT OF SUSPENDED SEDIMENTS ON LARVAL FEEDING AND JUVENILE BEHAVIOR OF HERRING

Background concentrations of suspended sediments in the Miramichi Estuary during calm weather should rarely exceed 20 mg/L. However, during dredging and dumping activity, concentrations up to 2,000 mg/L may be expected (MacLaren Atlantic 1978). Because herring are known to be visual feeders (Blaxter 1965), an obvious result of increased suspended solids may be to decrease feeding success. This possibility has been examined in laboratory experiments with newly hatched herring larvae. A second possibility is that suspended solids resulting from dredge spoil may result in avoidance responses by juvenile and adult herring which take them away from the fixed gillnets used in the outer Miramichi Bay fishery and thus reduce catches of individual gillnets. Previous work (Wildish et al. 1977a) with Passamaquoddy Bay sediments has suggested that juvenile herring avoid suspended sediments at concentrations down to 19 ± 5 mg/L. Consequently, these experiments have been repeated in the same apparatus with juvenile herring and Miramichi Estuary sediment from the area to be dredged.

HERRING LARVAL EXPERIMENTS

Herring larvae were obtained and hatched as described on p. 3 from Grand Manan stock. After hatching, the larvae were reared in 100-L conical tanks aerated from the bottom and supplied with locally caught zooplankton collected daily in a 64-μm mesh net. The larvae were reared in a 10°C constant temperature room with a 16 h light/8 h dark photoperiod and as soon as possible encouraged to take newly hatched *Artemia* nauplii. Fluorescent light intensity near the water surface of the cultures was 30 Lux.

Larvae which had begun feeding on *Artemia* were transferred from the rearing tanks to smaller 3-L conical tanks for a feeding experiment. Ten larvae were added to the filtered seawater in each tank and left to acclimate, without feeding, for an 18-h period. The experiment was begun by adding four *Artemia*/mL to each tank. Treatment tanks received a measured wet weight of sediment, whilst controls received no sediment. Observations were continued for a standard 2-h period after which larvae were placed in 40% buffered formalin to prevent defecation or regurgitation which could be a problem when lower formalin concentrations are used (Werner and Blaxter 1979). The experimental larvae were dissected to determine the numbers of *Artemia* consumed and the total length of each herring larva was measured with a binocular microscope and micrometer.

Treatment concentrations of suspended sediment used ranged from 1.0-6.0 mg/L, and the source of the sediment was an undefined silty sediment obtained from the intertidal region near the Biological Station, St. Andrews. Concentrations were determined by use of matched weight filters (Millipore AAWP0470M) of nominal pore size 0.45 μm, and filtering a known volume of treatment water. This technique avoided the problem of sea salts drying on the filters since the weight of the lower filter was subtracted from the weight of the upper filter.

The data were analyzed by the Student t-test to determine if the differences in the proportion of fish feeding in the control and treatment tests were significantly different and by regressing the number of *Artemia* consumed per larvae on larval length.

JUVENILE AVOIDANCE/PREFERENCE EXPERIMENTS

Avoidance/preference experiments were conducted in a figure-of-eight maze described previously (Wildish et al. 1977b). The maze walls were 30 cm apart and each half of the apparatus was joined by a 10 x 10 cm aperture to allow fish passage to all parts of the maze but to minimize water mixing. Water flowing into each half, A or B, of the maze was adjusted to 3-7 L/min and followed ambient laboratory seawater temperatures (3-13°C) during the experiments.

Herring of 17.3 cm mean length and 24.6 g mean weight were acclimated for at least 1 mo in large holding tanks and fed on dry food before being used in the experiments. Ten herring were placed in the maze and observations made to determine the number of fish in side A or B initially and at 5-min intervals for 1 h. In the treatment period, an initial injection by syringe of 90 mL of seawater containing a known quantity of Miramichi Estuary sediment from the dredging area (near Grand Dune Flats, channel buoy #5) followed by 33.8 mL aliquots at 5-min intervals was made to one or other side of the maze. The sediment additions were made to the side of the apparatus preferred by the herring in the initial control period of the experiment. Sham treatments involving injection of filtered seawater were also made to determine the effect of this operation on behavior.

Concentrations were determined by matched weight filters as previously on a bulk sample made up of aliquots taken at 5-min intervals throughout the treatment period.

Analysis by Student t-test was made to determine whether the proportion of fish in A or B in the control period was significantly different from that in the treatment period of the experiment.

RESULTS

Herring larval experiments

Feeding success may be defined as the percentage of larval fish feeding in a given experiment on one or more *Artemia* per larva or the number of food organisms consumed per larva in a given unit of time.

The results, as percentage of larval fish feeding, are shown in Table 19. For the mean values shown, the control and treatment A values are not significantly different ($t = 0.69$) whereas the control and treatment B values are significantly different at $p = 97.5\%$ ($t = 2.70$). Low values for some control experiments, e.g. on Dec. 11, 1979 (Table 19), suggest problems either in the culture conditions or age of larvae used in these experiments. A threshold of around 3 mg sediment/L is suggested.

The mechanism of the reduced feeding effect in higher concentrations of suspended solids may involve a decrease in the visibility of prey organsims. Blaxter (1966) found that the minimum amount of white light necessary for larval herring to feed on *Artemia* was 0.3 Lux, whereas, for faster moving *Balanus* nauplii it was 13.0 Lux.

Another factor affecting the number of prey organisms consumed by a herring larva is its size (Blaxter and Staines 1971). Thus larval length can be shown to be an important determinant of the number of food organisms consumed (Fig. 19). The data presented are the same as those given in Table 1 and again show that only treatment B has a significantly lower level of consumption of *Artemia* nauplii.

Only limited numbers of larvae were reared due to logistic difficulties in obtaining larvae and/or availability of natural zooplankton as food. Because of this, these experiments should be regarded as preliminary and be repeated with larger numbers of test individuals, a wider suspended sediment concentration range and under varied light conditions.

Difficulties in culturing herring larvae in the laboratory were experienced and eggs are only available for a short period in the spring and fall. A successful culture method requires feeding newly hatched larvae with suitably sized (60-100 μ) natural zooplankton which does not appear to be available in Passamaquoddy Bay in spring. Presumably suitable zooplankton food is available in Miramichi Bay in spring and it would be of interest to know which species of zooplankter are involved. Future cultures should be made following the fall spawning when suitable natural zooplankters are available. As the larvae grow (at around 6 wk of age), the natural food can be replaced by more easily cultured *Artemia* nauplii.

JUVENILE AVOIDANCE/PREFERENCE EXPERIMENTS

Results of experiments with Miramichi Estuary sediment are shown in Table 20. Since in sham experiments (Johnston and Wildish, unpubl.) no significant differences between control and treatment periods at $p = 99\%$ were noted, the significant avoidance responses in the top half of Table 2 greater than 12 ppm have an overall mean percentage avoidance of 23.8 and standard deviation (SD) of 10.0. For values less than 12 ppm, the mean percentage avoidance is 6.2 ± 15.8. The threshold for the response lies between 9.5 and 12 ppm, although some avoidances were shown at 2.5 mg/L, $p = 95\%$. This compares with a previously tested sediment (Wildish et al. 1977a) from the Digdeguash Estuary (I in Table 21) which juvenile herring avoided at 19 ± 5 mg/L and a more sandy sediment (II) at 35 ± 5 mg/L. In the latter case, the larger sand particles do not appear to be so repellant as the smaller silt/clay ones. The similarity in avoidance threshold for sediments I and III (Table 21) may be due to the physical/chemical similarities of these sediments.

It is believed that the avoidance responses shown by juvenile herring are learned (Johnston and Wildish, unpubl.) and that one conditioning stimulus involves vision. Because of this, the threshold determined in these experiments is probably apparatus-specific since it depends on the degree of lighting supplied as well as on the geometry of the apparatus used and, hence, the visual cues available to assist learning. Another factor influencing the determination of the threshold is the treatment period used since learning is a time-dependent process. Of the unconditioned stimuli in the herring avoidance response, both tactile and chemical factors could be involved (Johnston and Wildish, unpubl.).

Juvenile herring have been shown to avoid Miramichi estuary sediments at concentrations in the parts per million range. Caution is advised in extrapolating these results to the field because of the apparatus-specific nature of the results.

CONCLUSIONS

The Miramichi Estuary and outer Bay are the sites of an important commercial fishery for herring. The basis for the fishery is that the adult herring return each year to the same spawning ground and are caught in fixed gillnets erected for a month-long fishery season. The gillnets are set in May near the mouth of Eel River at the Baie-Ste-Anne and Escuminac wharves and are concentrated in the area of highest herring spawning density.

The Miramichi Channel, which will be dredged to a depth of 8 m at low water, runs parallel to Fox Island and about 2 km away from it. In addition, dredge spoil disposal site C is close to the mouth of Eel River. Most of the seabed drifters released at disposal site C move inland towards Eel River.

This suggests that any sediment disturbed during dredging in this area or from spoil disposal reaching the bottom at site C will move across the area of highest spawning and gillnet density. We have no means of predicting what suspended solid concentrations or sediment deposition rates will result from the dredging activity, although we suspect that concentrations and rates of deposition will be high when dredging is in progress. Strong bottom currents probably flow over the spawning area and may protect it to some degree.

Laboratory experiments have shown that sediment deposited onto developing herring eggs causes increased egg mortality. It is of interest to note that field mortality ranged from 1.6-6.8%, presumably some of which was caused by smothering due to multiple layers of eggs. Egg mortality in the laboratory experiments was due to a smothering effect preventing circulation of clean, oxygenated water around the eggs and could be caused either by buildup of a sediment layer or one or more additional layers of eggs.

Hatching success does not seem to be influenced by very high concentrations of suspended solids although this factor resulted in earlier hatching and shorter hatching lengths. Suspended solid concentrations of a few parts per million were shown to affect deleteriously the feeding success of herring larvae, and this could result in stunted growth and subsequent increased mortalities. Although year-class strengths are controlled by a complex of factors, two important ones are the success and amount of spawn and the availability of zooplankton in the first few weeks after absorption of the yolk sac. Blaxter (1965) has suggested the importance of this stage in determining subsequent strength of the year-class. Thus, the potential impact of sediment deposition and high suspended solids might be of sufficient magnitude to affect year-class strength of this local fishery.

The demonstrated ability of juvenile herring to avoid suspended sediments suggests that they, and possibly adult fish, may avoid high concentrations in the field. Thus, individual fixed gillnets subject to high suspended solids may face reduced catches because herring avoid such areas.

One obvious suggestion to minimize the potential effects of dredging on the herring fishery is to curtail the dredging activity whilst adult and larval fish are in the area. This would involve a dredging stoppage in May-June, particularly in the Fox Island-Point Escuminac area, and closure of site C for spoil disposal purposes.

The ability to predict effects of dredging on the herring fishery would be much enhanced by knowledge of sediment deposition rates and suspended sediment concentrations in the spawning area, and these parameters should be monitored during dredging and dumping. A number of factors, including light intensity and larval size, affect larval feeding success and these factors, in addition to suspended sediment concentration, should be investigated further before a satisfactory threshold for this effect can be established. We also recommend that herring year-class strength be monitored if dredging takes place. This could be done by determining larval density and/or by determining catch-per-unit effort of adult fish.

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Table 1. Landings (round weight, metric tons) and values ($',000) of the main commercial species of the Miramichi Bay (Statistical Districts 70-73).

Species	Average 1969-78		1979	
	Landings	Value	Landings	Value
Groundfish				
Cod	140.0	19.8	114.9	37.2
Plaice	80.9	9.2	89.7	20.3
Hake	46.0	6.1	122.0	27.0
Total	372.4	44.2	419.6	99.3
Pelagic & estuarial				
Herring	3051.4	253.3	3619.3	705.6
Mackerel	160.1	15.5	128.2	29.5
Alewife	844.8	37.7	3622.0	323.8
Eel	41.4	25.2	17.0	25.3
Salmon	50.3	107.9	18.5	83.9
Smelt	356.7	100.4	445.5	197.2
Total	4519.6	546.8	7862.9	1372.4
Molluscs & Crustacea				
Soft-shell clam	212.4	45.7	101.4	36.6
Oyster	44.8	24.1	100.2	91.6
Scallop	118.9	34.6	19.3	15.0
Lobster	359.7	723.8	451.4	1554.8
Total	802.3	830.9	686.8	1700.0
Marine plants				
Irish moss	110.0	11.8	12.7	2.0

Table 2. Inshore herring landings (MT) in Miramichi Bay, Fisheries Statistical District No. 70 for 1947-1979.

Year	Apr.	May	June	July	Aug.	Sept.	Oct.	Annual[a] total
1947	-	563.0	-	-	-	-	-	563.0
1948	-	355.2	-	-	-	-	-	355.2
1949	-	191.4	7.7	-	-	-	-	200.5
1950	-	260.6	-	-	-	-	-	260.6
1951	75.3	399.3	-	-	-	-	-	454.6
1952	-	282.7	-	-	-	-	-	282.7
1953	50.8	39.2	-	-	-	-	-	90.0
1954	-	339.3	-	-	17.1	-	-	356.5
1955	4.5	1.8	11.3	-	-	-	-	17.7
1956	1.4	79.1	14.1	-	2.9	-	-	115.4
1957	-	27.7	13.6	-	1.1	-	-	42.4
1958	83.0	17.2	-	-	-	-	-	100.2
1959	-	38.3	-	-	-	-	-	38.3
1960	-	163.3	-	-	-	-	-	163.3
1961	-	17.2	-	4.5	-	-	-	21.7
1962	-	186.8	5.6	-	-	-	-	192.4
1963	-	72.6	-	-	-	2.9	-	75.5
1964	-	109.1	-	-	0.3	0.7	-	110.1
1965	-	102.2	18.2	-	-	2.9	-	123.3
1966	27.8	140.6	-	-	-	-	-	168.4
1967	-	-	-	-	-	-	-	-
1968	-	80.0	-	-	-	-	-	80.0
1969	-	161.7	-	-	-	-	-	161.7
1970	-	13.6	-	-	-	-	-	13.6
1971	-	121.0	-	-	-	-	-	121.0
1972	-	143.3	-	-	-	182.8	-	326.2
1973	-	227.1	-	0.1	210.4	180.5	-	618.1
1974	-	149.7	0.5	-	-	-	-	149.7
1975	-	93.6	-	-	2.6	25.9	3.0	125.7
1976	-	83.9	-	-	-	-	-	83.9
1977	-	5.4	-	-	-	-	-	5.4
1978	-	36.3	-	-	-	-	-	36.3
1979	-	85.1	17.1	-	-	-	-	102.2

[a]Annual total may not add up because of small catches taken in other months.

Table 3. Inshore herring landings (MT) in Miramichi Bay, Statistical District No. 71 for 1947-79.

Year	Apr.	May	June	July	Aug.	Sept.	Oct.	Annual total
1947	-	-	-	-	-	-	-	-
1948	-	-	-	-	-	-	-	-
1949	-	-	-	-	-	-	-	-
1950	-	-	-	-	-	-	-	-
1951	-	-	-	-	-	-	-	-
1952	-	-	-	-	-	-	-	-
1953	-	-	-	-	-	-	-	-
1954	-	-	-	-	-	-	-	-
1955	-	-	-	-	-	-	-	-
1956	-	-	-	-	-	-	-	-
1957	-	-	1.8	-	-	-	-	1.8
1958	-	-	4.4	-	-	-	-	4.4
1959	-	3.6	-	-	-	-	-	3.6
1960	-	-	-	-	-	-	-	-
1961	-	-	-	-	-	-	-	-
1962	-	-	-	-	-	-	-	-
1963	-	-	-	-	-	-	-	-
1964	-	-	-	-	-	-	-	-
1965	-	-	3.8	-	-	-	-	3.8
1966	-	-	-	-	-	-	-	-
1967	-	2.3	-	-	-	-	-	2.3
1968	-	-	-	-	-	-	-	-
1969	-	-	-	-	-	-	-	-
1970	-	-	-	-	-	-	-	-
1971	-	-	-	-	-	-	-	-
1972	-	-	-	-	-	-	-	-
1973	-	42.1	-	-	-	-	-	42.1
1974	-	-	-	-	-	-	-	-
1975	-	-	-	-	-	-	-	-
1976	-	-	-	-	-	-	-	-
1977	-	-	-	-	-	-	-	-
1978	-	96.0	-	-	-	-	-	96.0
1979	-	-	-	-	-	-	-	-

Table 4. Inshore herring landings (MT) in Miramichi Bay, Fisheries Statistical District No. 73 for 1947-79.

Year	Apr.	May	June	July	Aug.	Sept.	Oct.	Annual[a] total
1947	-	323.9	-	-	-	-	-	323.9
1948	-	719.4	90.9	-	-	-	-	810.3
1949	-	835.8	-	-	-	-	-	835.8
1950	-	980.2	-	-	-	-	-	980.2
1951	333.4	286.4	-	-	5.0	10.5	-	635.3
1952	-	1539.1	-	-	6.1	-	-	1545.3
1953	154.2	548.8	-	-	16.1	-	-	719.1
1954	13.9	504.4	-	-	29.1	10.7	-	558.0
1955	27.2	865.6	-	-	4.5	30.1	-	927.5
1956	36.7	512.9	-	-	6.4	5.7	-	561.7
1957	14.0	530.3	44.3	45.9	62.2	57.1	-	807.5
1958	99.8	187.4	213.0	3.5	254.5	15.1	84.5	857.8
1959	0.1	535.0	279.7	-	15.2	110.4	4.6	945.0
1960	-	1060.7	1.8	633.0	-	26.9	39.4	1761.8
1961	-	575.0	833.3	192.3	-	10.0	1.5	1612.1
1962	22.8	3927.6	354.6	284.2	13.1	333.3	-	4935.6
1963	-	1191.0	176.9	0.4	6.6	12.2	-	1387.1
1964	25.7	1000.3	-	1.0	5.7	10.7	2.3	1045.7
1965	37.1	1565.7	76.9	80.2	13.5	34.6	0.7	1808.7
1966	119.8	1213.5	365.1	654.1	69.3	68.7	5.7	2496.2
1967	-	3579.9	978.7	-	31.8	19.7	-	4670.2
1968	31.3	3109.3	192.8	-	297.6	113.8	-	3744.8
1969	91.4	3097.8	45.6	0.1	130.4	317.3	21.9	3704.5
1970	187.6	1926.1	0.9	2.2	33.1	341.3	8.2	2499.4
1971	12.0	1072.0	35.4	0.5	110.3	356.2	-	1586.4
1972	-	1151.3	309.5	2.4	425.6	491.5	36.1	2416.3
1973	7.9	2863.3	73.0	3.2	1026.1	1063.0	-	5036.5
1974	-	1988.8	244.0	0.3	203.8	472.7	-	2909.6
1975	-	1263.2	332.3	-	241.3	720.9	-	2557.7
1976	8.0	2404.1	49.5	-	16.4	529.2	-	3007.3
1977	2.0	1122.6	114.8	-	56.9	173.4	-	1469.7
1978	0.9	2974.9	211.4	1.4	41.0	212.6	1.4	3443.5
1979	0.9	2616.1	165.8	6.3	113.4	305.0	-	3219.8

[a]Annual totals may not add up because of small catches taken in other months.

Table 5. Four-year record of daily herring catches (MT) bought by one of the largest buyers in Miramichi Bay.

Date	1976		1977		1978		1979	
	Fishermen	Catch	Fishermen	Catch	Fishermen	Catch	Fishermen	Catch
May 1							8	2.53
2			1	2.21			21	9.25
3	3	5.79	1	3.63			20	4.94
4	6	5.09			1	1.29	26	49.78
5	14	15.85			1	0.82	28	29.11
6	11	32.46			3	1.15		
7	13	65.34					32	172.02
8	9	20.82	3	9.39	22	110.77	42	241.61
9	2	5.53	12	12.08	13	37.15	40	140.32
10	6	12.61	2	0.57	5	3.72	41	71.06
11	7	11.51			15	62.62		
12	7	3.22	1	0.64	27	240.11	31	55.77
13	7	39.38	26	115.17	29	136.71	28	40.44
14	11	25.42	21	46.18	4	7.37	34	48.33
15	6	19.49	17	69.33	32	151.77	31	48.24
16			23	69.39	25	31.21	32	23.31
17	6	12.92	25	75.20	21	65.66	25	23.09
18	9	11.97	22	61.95	22	44.51	24	32.43
19	4	2.99	14	28.31	13	13.63	26	40.71
20	5	3.63	10	9.76	10	3.92		
21	4	3.70	6	6.30	11	6.28		
22	2	0.65	9	21.78	2	0.12		
23			13	9.33	12	20.36		
24			15	26.85	15	19.69		
25			16	17.26	11	15.69		
26	2	3.73	1	0.05	10	13.88		
27	3	3.63			13	19.57		
28			1	0.09	8	9.84		
29	1	0.61	6	15.01	8	8.10	2	1.38
30			8	15.11	6	1.72	12	16.75
31			10	24.15	4	0.88		
June 1			8	16.65	5	1.93		
2			4	7.62	5	12.63		
3			4	2.00	9	19.96		
4			3	8.50	7	11.79		
5					8	11.48		
6			1	0.51	8	3.45		
7					3	0.57		
8								
9			1	0.18				
10			2	1.32				
11-20			22	25.09				
21-30					2	0.41		
Unknown	7	4.60	13	14.74				
Total	145	310.94	321	716.35	390	1090.76	503	1051.12
Catch/ fisherman		2.14		2.23		2.80		2.09

Table 6. Daily herring catches (MT) and catch/fisherman in the Miramichi Bay spring fishery, May 1979, based on amount of fish bought by four major buyers.

Buyer[a]	#1		#2		#3		#4		Total	
Date	Fishermen	Catch	Fishermen	Catch	Fishermen	Catch	Fishermen	Catch	Fishermen	Catch
May 1	8	2.58			2	3.99			10	6.57
2	21	9.25			4	2.41	3	0.52	28	12.18
3	20	4.94			5	5.72			25	10.66
4	26	49.78			4	5.62			30	55.40
5	28	29.11			8	8.53			36	37.64
6			2	5.49	78	117.70			80	123.19
7	32	172.02	6	15.06	4	6.44	2	0.66	44	194.18
8	42	241.61	25	47.08	64	144.02	12	25.98	143	458.69
9	40	140.32	27	44.90	67	114.49			134	299.71
10	41	71.06	8	7.08	47	51.77			96	130.91
11					25	24.09			25	24.09
12	31	55.77			44	47.65			75	103.42
13	28	40.44			21	21.78			49	62.22
14	34	48.33	18	19.05	49	49.96			101	117.34
15	31	48.24	13	12.06	55	68.74			99	129.04
16	32	23.31	11	6.82	50	39.92			93	70.05
17	25	23.09	8	4.04	33	21.02			66	48.15
18	24	32.43	10	7.66	41	40.69			75	80.78
19	26	40.71	14	17.08	41	36.74			81	94.53
20			4	2.52	14	13.45			18	15.97
21			19	18.23	45	39.87			64	58.10
22			7	2.41	17	20.26			24	22.67
23					18	10.00			18	10.00
24							4	1.17	4	1.17
25					4	3.10	4	1.10	8	4.20
26										
27					2	0.77			2	0.77
28					2	2.20	2	1.27	4	3.47
29	2	1.38			1	0.66	3	0.70	6	2.74
30	12	16.75					3	0.31	15	17.06
31							3	1.30	3	1.30
Total	503	1051.12	172	209.51	745	902.59	36	33.01	1456	2196.23
Catch/ fisherman	2.09		1.22		1.21		0.92		1.51	

[a]For confidentiality, names of fish buyers are not included.

Table 7. Number of gillnets of 40 meshes deep/ fisherman (adjusted to a standard size of 15 fath long) in Escuminac inshore spring herring fishery (Statistical District 73) as reported in interviews with 44 fishermen.

Interview	Number of gillnets 1976	1977	1978	1979
1	44	44	44	56
2	187	187	187	233
3	-	-	-	100
4	10	10	10	12
5	30	30	30	30
6	124	124	133	133
7	36	36	36	36
8	94	113	150	188
9	10	14	4	19
10	31	31	31	31
11	18	18	18	18
12	135	146	156	167
13	-	-	20	20
14	43	46	46	48
15	98	98	98	98
16	-	-	100	100
17	15	15	15	15
18	62	62	62	62
19	28	28	28	37
20	106	106	106	125
21	7	7	13	24
22	67	67	89	89
23	72	72	93	112
24	28	28	28	33
25	14	14	14	14
26	208	417	417	417
27	104	104	104	112
28	16	16	16	16
29	-	109	136	136
30	25	25	25	25
31	156	156	222	222
32	120	120	120	120
33	33	33	33	17
34	50	56	63	81
35	11	11	11	11
36	11	11	11	13
37	7	7	7	7
38	40	40	40	200
39	9	7	7	7
40	36	36	36	45
41	133	133	133	133
42	75	75	75	250
43	207	207	207	207
44	160	189	189	189
Average effort/ fisherman	66.5	75.0	78.2	91.1

Table 8. Results of herring spawning survey in Miramichi Bay, spring 1979.

Station	Date	Depth (m)	Temperature °C Surface	Bottom	Bottom type[a]	Spawning density[b]	Observations
1	May 9	2	6.0	5.0	RO	0	Mussels
2		5	-	-	RO	0	
3		6	-	-	RO	0	
4		5	6.8	6.0	RO	A	Irish moss, sea urchins
5		4	-	-	RO	0	
6		3	4.5	4.0	RO	0	Mussels
7		2	7.0	-	RO	0	Mussels, weed
8		4	7.0	7.0	RO	A	
9		6	-	-	RO	0	Sea urchins
10	May 16	5	7.2	5.6	RO	B	Rockweed
11		4	7.2	6.6	RO	D	Rockweed
12		3	6.8	5.6	RO	C	Rockweed
13		3	7.3	-	RO	B	
14		2	7.3	6.2	RO	A	Small rocks
15		6	7.2	3.7	RO	B	
16		8	7.3	3.5	RO	0	
17		8	8.0	3.5	RO	0	
18	May 17	3	10.0	9.5	RO	0	Irish moss
19		6	9.7	6.1	RO	0	
20		8	9.2	3.6	RO	0	Lobster
21		8	9.8	3.8	SA	0	
22		4	10.7	6.7	RO	D	Irish moss
23		3	11.0	8.9	RO	C	Rockweed
24		5	11.2	5.1	RO	A	Rockweed
25		8	12.5	3.9	SA	0	
26		8	11.5	4.3	SA	0	
27		8	8.0	7.2	RO	0	
28		11	9.6	6.0	RO	0	
29		8	13.5	4.9	RO	0	Small mussels
30		8	12.3	3.9	RO, SA	B	
31		4	11.3	5.6	RO, SA	0	
32		6	11.0	4.1	RO	0	Mussels
33		3	11.5	6.1	RO	D	Weeds, mussels
34	May 22	6	9.8	7.9	RO	0	
35		4	10.5	9.1	RO	0	Irish moss
36		3	10.5	9.5	RO	0	Irish moss, rockweed
37		3	10.2	9.3	RO	0	Irish moss, rockweed
38		6	11.6	9.3	RO	0	Irish moss
39		5	10.8	8.5	RO	A	
40		2	10.5	9.7	RO, SA	B	
41		2	10.2	9.7	RO	A	Irish moss, rockweed
42		2	10.7	9.8	RO	0	Irish moss, rockweed
43		3	10.7	10.5	RO	0	Irish moss, rockweed
44		5	9.9	9.6	RO	0	Irish moss, rockweed
45		6	9.9	9.2	RO	0	Irish moss, rockweed
46		4	10.2	10.1	RO	0	Irish moss, rockweed
47		3	11.1	10.8	RO	0	
48		2	10.7	10.7	RO	0	
49	May 23	6	9.9	5.0	RO	0	Mussels, lobster
50		4	10.9	9.1	RO	0	Mussels
51		3	11.0	10.0	RO	0	Mussels
52		2	12.1	10.5	RO	0	Rockweed
53		1	11.4	11.1	RO	0	Rockweed
54		2	11.4	11.0	RO	0	Rockweed
55		1	12.0	12.0	RO	0	
56		2	11.4	11.4	RO	0	Rockweed, periwinkles
57		4	10.4	9.6	RO	0	
58		3	11.8	9.6	SA	0	
59		8	12.2	4.2	SA	0	
60		8	12.0	7.0	SA	0	
61		6	11.4	6.0	SA	0	
62	May 25	2	11.8	11.8	RO, MU	0	Eelgrass
63		3	12.2	11.5	MU	0	
64		2	12.0	12.0	MU	0	Oysters
65		3	12.3	7.3	SA	0	
66		4	12.2	10.2	RO, MU	0	Rockweed, mussels
67		5	12.3	7.3	MU	0	

Table 8. (cont'd.)

Station	Date	Depth (m)	Temperature °C Surface	Bottom	Bottom type[a]	Spawning density[b]	Observations
68	May 30	2	12.2	11.9	SA	0	Eelgrass
69		8	12.2	9.8	SI, MU	0	
70		8	12.1	9.8	SI, MU	0	
71		6	12.7	9.8	SI, MU	0	
72		5	13.0	10.5	SI, MU	0	
73		5	12.0	12.0	SI, RO	0	Mussels
74		2	13.0	12.5	SA	0	Eelgrass
75		5	12.8	12.2	SI, RO	0	
76		4	13.0	12.4	RO	0	Irish moss, mussels
77		3	13.0	12.6	RO	0	Irish moss, oysters

[a]RO = rock, SA = sand, MU = mud; SI = silt.
[b]O = no herring eggs, A = 1-9, B = 10-99, C = 100-999, D = >1000 eggs.

Table 9. Examination of herring eggs collected from the spawning bed near Escuminac, May 1979.

Date	Stage of development	Number	% dead	Temperature °C Surface	Bottom	Remarks
May 16	4	246	5.7	7.2	6.0	4 m deep
17	4	285	1.7	10.7	6.7	Eggs in heavy deposit
18	3	262	4.2			Eggs in a mat 4-6 layers
19	4	241	2.9			Small clumps
20	4	292	6.8			" "
21	5	185	2.2			" "
22	5	173	1.7	11.0	9.8	Eggs hatching
23	5	183	1.6			" "
30[a]	5	6	67.0	12.5	11.8	Most hatching is over

[a]Several attempts to collect eggs with a grab sampler were made, but only 6 eggs were found, including 4 dead.

Table 10. Recoveries (as of February 1980) from surface drifters and seabed drifters released in Miramichi Bay in 1979.

No. and date of release	Date of recovery	No. of recoveries	(%) recoveries	Farthest point of recoveries
Surface drifters	June 1979	1		
June 1979	July 1979	4		
(100 releases)	August 1979	1		
	Total	6	6.0	Cape North, Cape Breton Is.
Surface drifters	August 1979	13		
August 1979	September 1979	16		
(450 releases)	October 1979	4		
	November 1979	6		
	Total	37	8.7	Fortune Bay, Nfld.
Seabed drifters	June 1979	66		
June 1979	July 1979	18		
(100 releases)	August 1979	1		
	Total	85	85.0	Oak Point, Miramichi
Seabed drifters	August 1979	3		
August 1979	September 1979	46		
(450 releases)	October 1979	49		
	November 1979	22		
	December 1979	5		
	January 1980	1		
	February 1980	4		
	Total	130	28.9	Millbank, Miramichi River

Table 11. Miramichi plankton data.

Station no.	Date	Type of gear	Temperature °C Surface	Temperature °C Bottom	Flowmeter reading	Minimum fishing depth (m)	Time Start-finish
1	31/05/79	Bongo .333 & .505	11.9	8.3	4915	11	1005-1016
2	31/05/79	" " " "	12.5	6.8	5390	5	1124-1135
3	05/06/79	" " " "	15.8	10.8	3910	5	0940-0950
4	05/06/79	" " " "	14.8	11.8	4890	5	1032-1042
5	05/06/79	" " " "	14.8	10.6	5590	5	1117-1127
6	05/06/79	" " " "	15.8	11.4	4710	2	1227-1237
7	05/06/79	" " " "	14.7	6.3	3315	4	1313-1323
8	05/06/79	" " " "	10.4	4.6	7661	8	1400-1410
9	06/06/79	" " " "	10.1	8.7	4345	4	0935-0945
10	06/06/79	" " " "	10.3	8.6	5298	3	1014-1024
11	06/06/79	" " " "	10.0	5.0	6909	14	1055-1111
12	06/06/79	" " " "	11.7	6.3	5505	12	1205-1218
13	06/06/79	" " " "	12.0	6.0	6200	12	1300-1313
14	06/06/79	" " " "	15.0	13.2	5612	4	1600-1610
15	07/06/79	" " " "	13.3	2.0	8372	20	1148-1218
16	07/06/79	-	14.0	2.0	-	-	-
17	08/06/79	Bongo .333 & .505	12.0	3.3	4990	17	0825-0840
18	08/06/79	" " " "	12.5	3.0	5083	12	0910-0920
19	08/06/79	" " " "	12.9	2.4	5444	14	0955-1010
20	08/06/79	" " " "	13.6	6.4	5871	14	1025-1040
21	08/06/79	" " " "	14.0	2.5	5387	18	1110-1125
22	08/06/79	" " " "	14.8	3.1	5170	12	1205-1220
23	08/06/79	" " " "	14.8	3.1	7140	12	1235-1250
24	12/06/79	" " " "	15.0	14.1	4820	12	1001-1011
25	12/06/79	" " " "	13.7	12.5	5435	4	1041-1051
26	12/06/79	" " " "	14.5	8.7	9643	2	1115-1125
27	12/06/79	" " " "	15.0	7.3	5796	3	1155-1205
28	13/06/79	" " " "	4.0	3.3	5200	5	0901-0911
29	13/06/79	" " " "	4.2	3.1	8960	2	0945-1005
30	13/06/79	" " " "	11.0	6.0	4685	5	1035-1050
31	14/06/79	" " " "	10.0	3.4	10820	3	1000-1020
32	14/06/79	" " " "	10.3	5.9	13679	2	1048-1118
33	15/06/79	" " " "	9.0	3.1	5555	11	1005-1017
34	15/06/79	" " " "	9.3	2.7	5570	12	1050-1102
35	15/06/79	" " " "	9.0	4.1	5015	12	1140-1152
36	15/06/79	" " " "	9.1	3.1	5557	12	1214-1226
37	20/06/79	" " " "	14.9	10.4	6560	6	1045-1100
38	20/06/79	" " " "	15.2	10.9	7289	10	1135-1150
39	20/06/79	" " " "	13.8	8.0	6865	11	1213-1228
40	20/06/79	" " " "	17.0	12.8	6030	4	1255-1305
41	20/06/79	" " " "	14.8	10.8	5340	6	1320-1330
42	20/06/79	Bongo .333	13.0	11.7	3542	9	1352-1402
43	20/06/79	-	12.6	7.7	3841	14	1440-1450
44	20/06/79	-	12.3	7.7	6938	14	1520-1530
45	21/06/79	Bongo .333	14.0	11.8	4180	2	0945-0955
46	22/06/79	Bongo .333 & .505	12.7	11.7	6200	1	0735-0745
47	22/06/79	" " " "	14.0	12.8	4490	3	0814-0824

Table 12. Species of larval fish found in the plankton collection, Miramichi Bay, May-June 1979.

Species listing and code for Miramichi Project

Species	Common name	No. caught
Ammodytes spp.	Sand lance	1410
Aspidophoroides monopterygius	Alligatorfish	31
Clupea harengus	Herring[a]	2630
Cottidae	Sculpin	p[b]
Enchelyopus cimbrius	Fourbeard rockling	9
Gadus morhua	Cod[a]	1276
Gasterosteus aculeatus	Threespine stickleback	p[b]
Gasterosteus wheatlandi	Blackspotted stickleback	p[b]
Glyptocephalus cynoglossus	Greysole flounder	p[b]
Hippoglossoides platessoides	American plaice	100
Limanda ferruginea	Yellowtail flounder[a]	258
Liparis spp.	Seasnail	1031
Mallotus villosus	Capelin	107
Menidia menidia	Atlantic silverside	6
Merluccius billinearis	Silver hake	3
Myoxocephalus aenaeus	Grubby sculpin	116
Osmerus mordax	Smelt[a]	34818
Pholis gunnellus	Rock gunnel	13
Pseudopleuronectes americanus	Winter flounder[a]	8051
Scomber scombrus	Mackerel[a]	766
Scophthalmus aquosus	Windowpane flounder	2
Stichaeus punctatus	Arctic shanny	3
Tautogolabrus adspersus	Cunner	1
Ulvaria subbifurcata	Radiated shanny	2276

[a]Of commercial value in Miramichi Bay.
p[b] = present but numbers unknown.

Table 13. Suspended sediment concentrations (mg/L) used in experiment 1. The 111 mg/L for the control levels is due mainly to salt which had not been washed out of the filtered samples.

Date 1979	Control	Low	Medium	High
May 15	0	518	8406	23062
17	0	582	7160	23668
21	220	942	5756	14882
23	162	796	4960	22044
25	174	798	3606	10508
Mean	111	747	5978	18833

Table 14. Suspended sediment concentrations (mg/L) in experiment 2. The high levels in C-1 and C-2 may be explained as for controls in Table 13.

Date 1979	Treatments							
	C-1	C-2	L-1	L-2	M-1	M-2	H-1	H-2
Sept. 19	136	46	180	486	2444	1582	11540	7620
20	496	510	540	410	1548	1652	10438	7632
21	0	529	174	89	1108	-	7840	8261
23	22	49	15	76	974	1147	7856	8663
24	97	0	153	86	988	873	7771	6948
25	197	157	197	133	1298	1034	6604	6888
26	81	131	23	196	771	795	5896	6038
27	114	0	2	44	529	869	5742	5449
28	74	164	71	168	728	874	5044	5306
Oct. 1	185	49	61	30	1611	1113	6727	8413
2	0	116	89	119	1280	831	7487	9512
$\overline{X}$	128	159	137	167	1207	1077	7540	7339
SD	140	187	152	149	1269	1137	3403	3148

Table 15. Mean lengths of hatched larvae in the various treatments in experiment 1. No live larvae were obtained from the high concentration.

Date 1979		Sediment concentration			
		Control	Low	Medium	High
May 23	Mean length	7.64	7.11	6.87	-
	n	11	28	23	-
	S.D.	0.32	0.53	0.48	-
May 25	Mean length	8.00	7.33	7.80	-
	n	13	3	10	-
	S.D.	0.41	-	0.35	-
Total hatch (live hatch)		58(57)	56(56)	174(88)	75(0)

Table 16. Numbers hatched, percent hatched, hatching times, and percent live hatched larvae for the various suspended sediment concentrations in experiment 2.

Date 1979	Days post-fertilization	C-1 # eggs=559 live	dead	C-2 # eggs=1390 live	dead	L-1 # eggs=429 live	dead	L-2 # eggs=1076 live	dead	M-1 # eggs=471 live	dead	M-2 # eggs=791 live	dead	H-1 # eggs=768 live	dead	H-2 # eggs=864 live	dead
Sept. 24	7			1													
25	8			13						2		17		2		3	
26	9			342				344		4		206		7		513	
27	10	3		197		4		45		5	2	8	4	315		58	
28	11	12		159		136		108	1	49		53		100		36	1
29	12	316		55		111		305		202	2	220	4	3	1	9	
30	13	16		8		6	2	42	5	12	6	12	7	1	2		4
Oct. 1	14	3			57	2	1	3	8	1	4	1	13				
2	15				5			1	1				12				
Totals		350		775	62	259	3	848	15	275	14	517	40	428	3	619	5
% hatched		62.6		60.2		61.1		80.2		61.4		70.4		56.1		72.2	
% live		100.0		92.6		98.9		98.3		95.2		92.8		99.3		99.2	
% dead		0		7.4		1.1		1.7		4.8		7.2		.7		.8	
Median hatching times (d)		12		10		11		11		12		11		10		9	

Table 17. Comparison of mean lengths of newly hatched larvae and number of eggs originally placed in cones among the various treatments in experiment 2.

Sediment concentration	Duplicate A		Duplicate B		Significant* Not signif. (NS)
	Mean length(mm)	# eggs	Mean length(mm)	# eggs	
Control	7.50	559	7.07	1390	*
Low	7.72	429	7.29	1076	*
Medium	7.07	471	6.78	791	*
High	6.91	768	6.67	864	NS

Table 18. Results of multiple range test on larval length data. Any two means not underscored by the same line are significantly different ($p < 0.05$).

Treatments ranked in order from smallest to largest mean larval length

Treatment	H-2	M-2	H-1	C-2	M-1	L-2	C-1	L-1
Mean length (mm)	6.669	6.777	6.906	7.068	7.069	7.285	7.498	7.718

Table 19. Percentage of herring larvae (n = 6 to 10) feeding in control and treatment experiments.

Date 1979	Control	Treatment A < 3.0 mg/L	Treatment B ≥ 3.0 mg/L
Nov. 25	100	37.5	20.0
Dec. 4	66.7	33.3	-
5	57.7	100.0	12.5
6	80.0	73.6	-
11	40.0	72.7	63.6
14	100.0	-	0
14	-	-	60.0
Mean SD	73.9 ± 9.8	63.4 ± 12.5	31.2 ± 12.9

Table 20. Avoidance/preference responses of juvenile Atlantic herring to various concentrations of Miramichi Estuary sediment.

Sediment concentration mg/L	Proportion of time in A or B Control ± SE	Treatment ± SE	Significance (%)	% Avoid. − Pref. +
55.3	.54 ± .033	.43 ± .057	90	-8.6
48.6	.56 ± .054	.30 ± .054	97.5	-26.1
46.3	.53 ± .035	.16 ± .031	99	-36.1
33.8	.54 ± .034	.45 ± .043	90	-7.7
29.1	.69 ± .035	.35 ± .05	99	-30.7
24.6	.53 ± .026	.27 ± .041	99	-25.5
21.9	.60 ± .04	.35 ± .035	99	-25.4
12.0	.52 ± .056	.31 ± .047	97.5	-20.7
12.0	.63 ± .051	.31 ± .04	99	-33.0
9.56	.88 ± .03	.87 ± .02	NS	-0.8
9.5	.46 ± .04	.45 ± .06	NS	-0.8
9.5	.77 ± .03	.52 ± .025	99	-24.6
7.16	.54 ± .035	.65 ± .029	97.5	+11.6
5.06	.5 ± .054	.51 ± .047	NS	+0.8
4.98	.5 ± .054	.17 ± .052	99	-33.1
4.5	.67 ± .026	.60 ± .034	90	-6.9
3.9	.58 ± .05	.48 ± .06	NS	-10.0
2.5	.5 ± .036	.56 ± .04	95	+6.0
2.5	.53 ± .04	.36 ± .07	95	-17.0
2.5	.61 ± .04	.50 ± .04	95	-10.8

NS = not significant

Table 21. Sediment sorting characteristics and Walkley-Black organic carbon as percentage dry weight of the sediment.

Number	Source	Md Ø (μ)	QDØ	SkqØ	% carbon
I	Digdeguash Estuary	7.94 (4.5)	0.79	-0.13	3.11
II	Pottery Creek	6.68 (10.0)	2.57	-0.69	1.30
III	Miramichi Estuary	7.40 (6.0)	1.51	-0.27	3.33

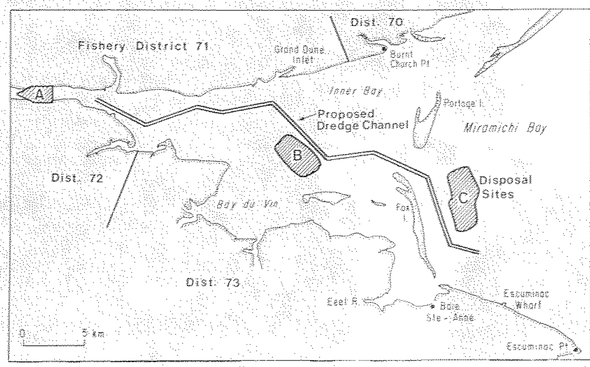

Fig. 1. Map of Miramichi Bay showing proposed dredge channel and disposal sites.

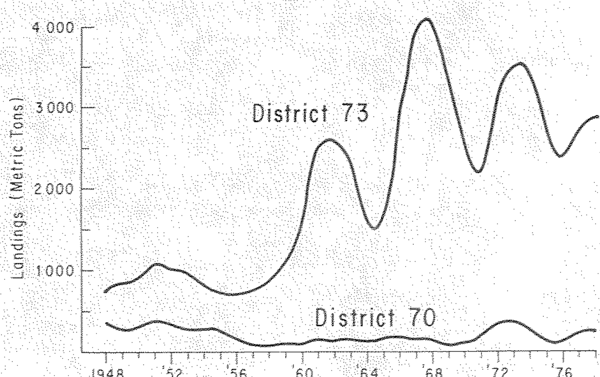

Fig. 2. Herring landings (MT) in Miramichi Bay area (Statistical Districts 70 and 73) from 1948-78; three-year running means centered.

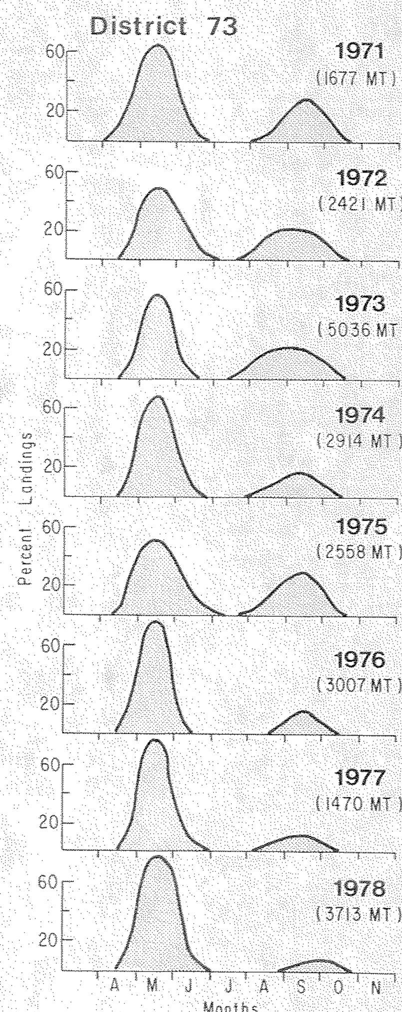

Fig. 3. Seasonal pattern of herring landings in Statistical District 73, Miramichi Bay, 1971-78.

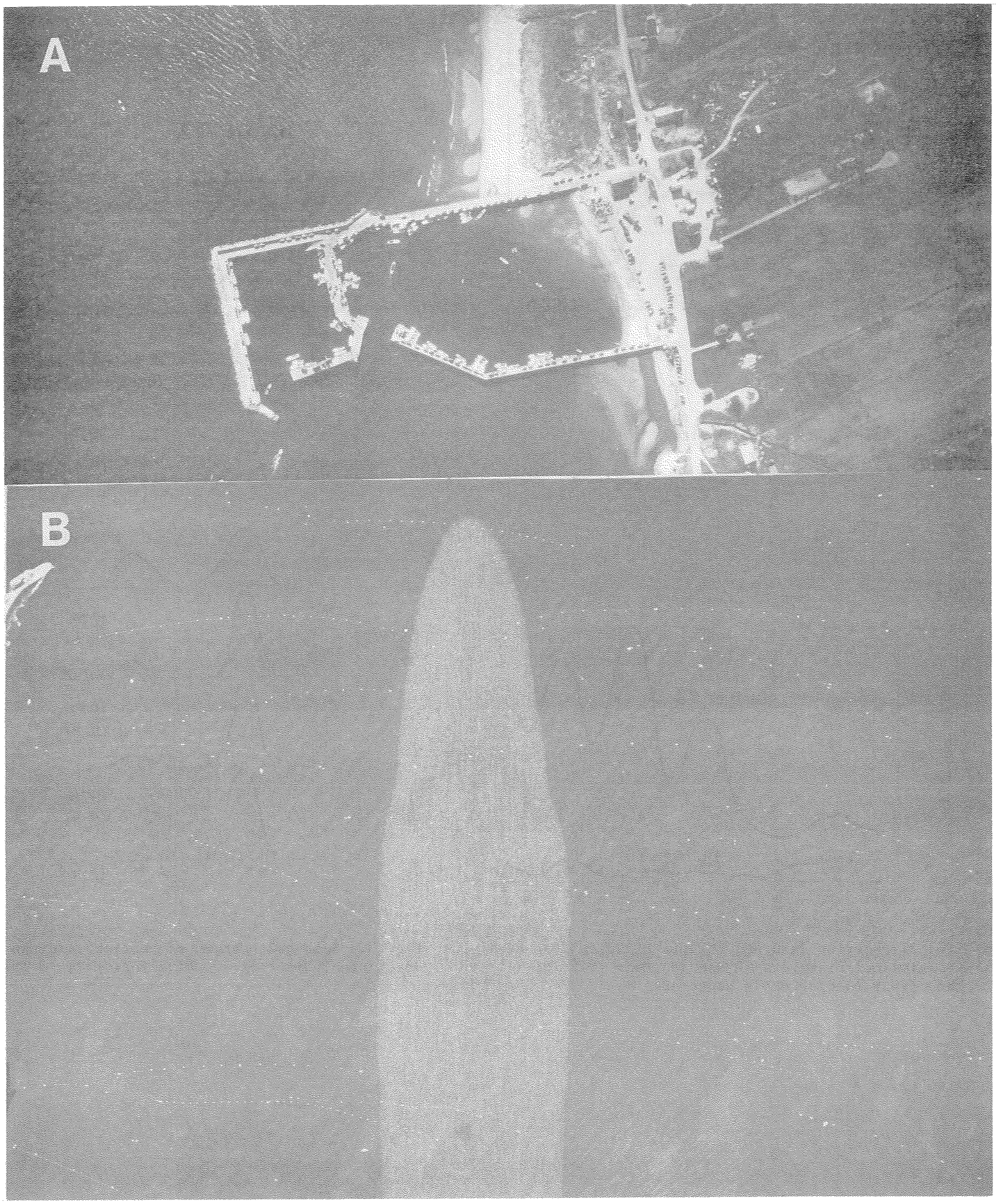

Fig. 4. Aerial photos showing Escuminac wharf in Miramichi Bay (A) and herring gillnets (B).

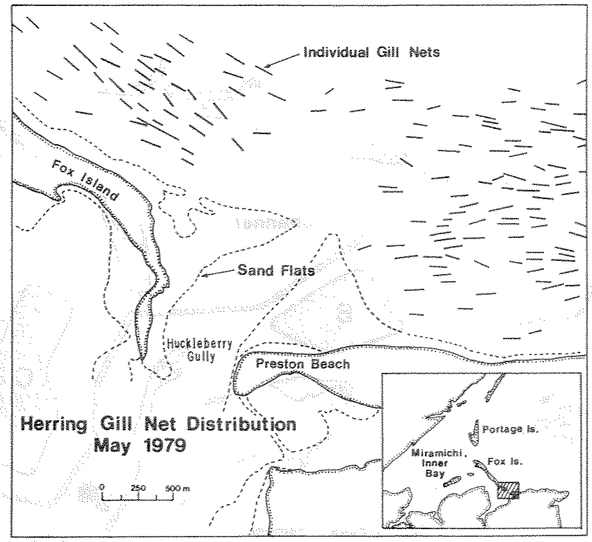

Fig. 5. Herring gillnet distribution on a spawning bed near Fox Island, Miramichi Bay.

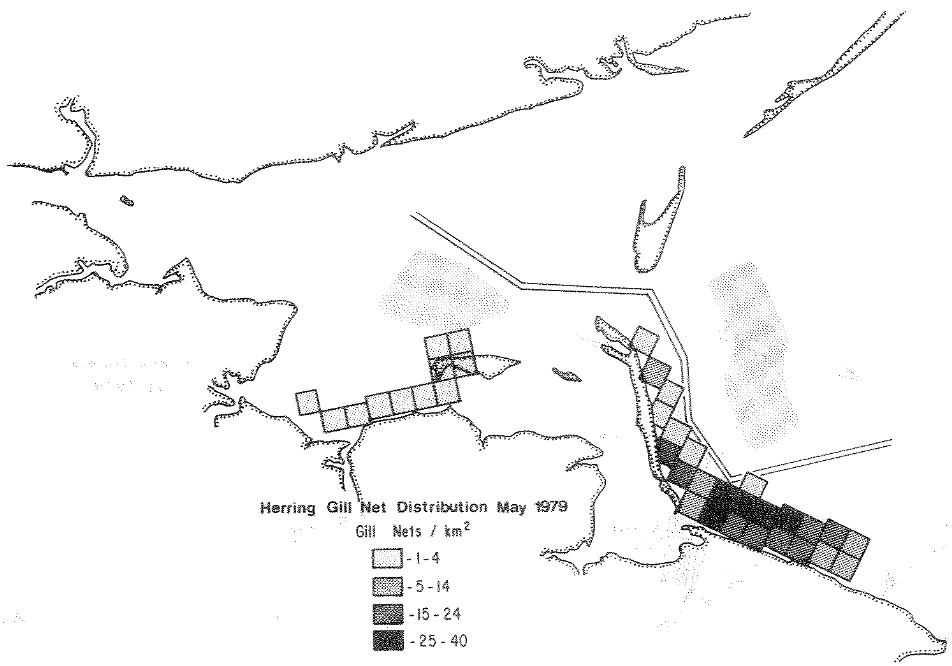

Fig. 6. Herring gillnet distribution (number of nets/km^2) in southern Miramichi Bay, based on an aerial survey, May 14, 1979. Each gillnet represents eight standard nets (27 m long and 40 meshes deep).

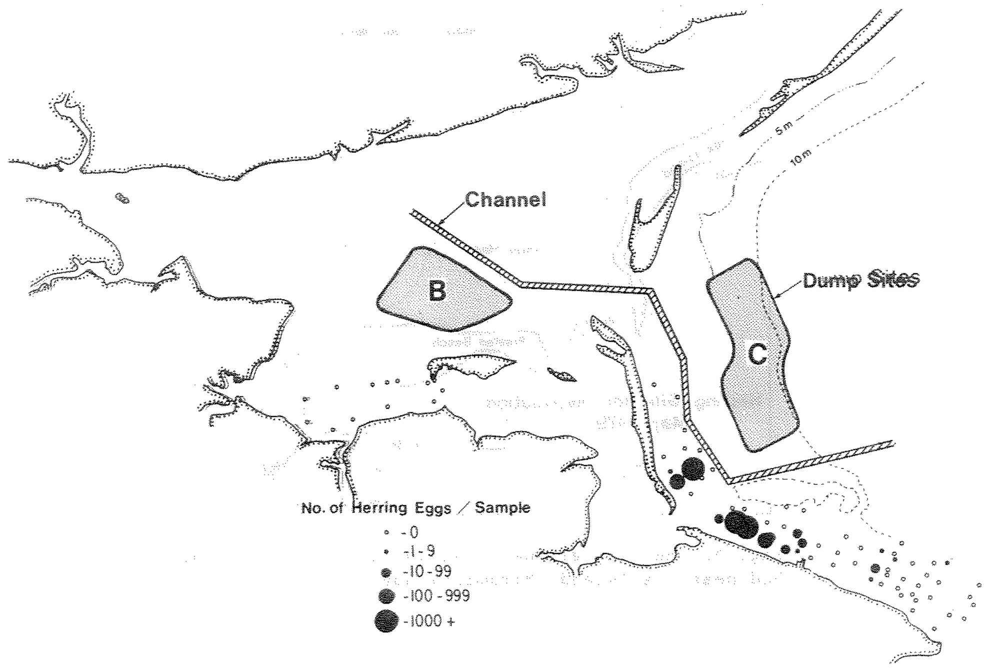

Fig. 7. Results of herring spawning bed survey in Miramichi Bay area, showing number of herring eggs per sample. Proposed dump sites, B and C, and dredge channel are also shown.

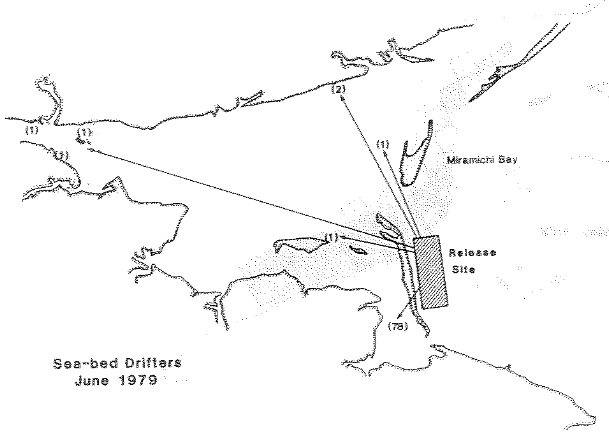

Fig. 8. Map of the Gulf of St. Lawrence showing location of recoveries (number in brackets) from 100 surface drifters released in June 1979.

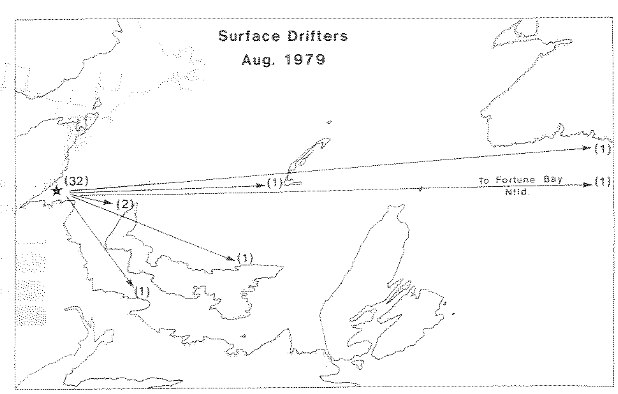

Fig. 9. Map of the Gulf of St. Lawrence showing locations of recoveries (number in brackets) from 450 surface drifters released in August 1979.

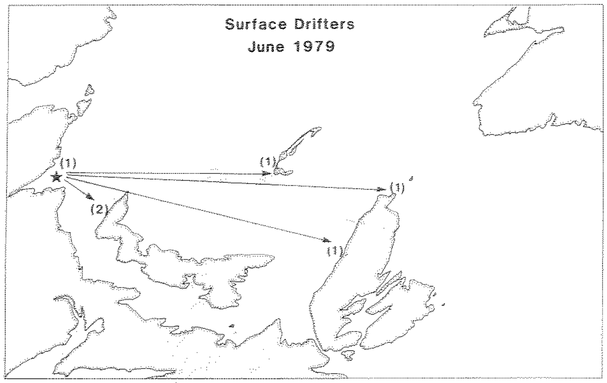

Fig. 10. Map of Miramichi Bay showing locations of recoveries (number in brackets) from 100 seabed drifters released in June 1979.

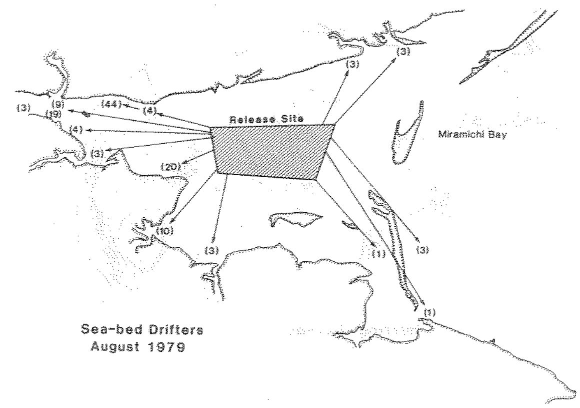

Fig. 11. Map of Miramichi Bay showing location of recoveries (number in brackets) from 450 seabed drifters released in August 1979.

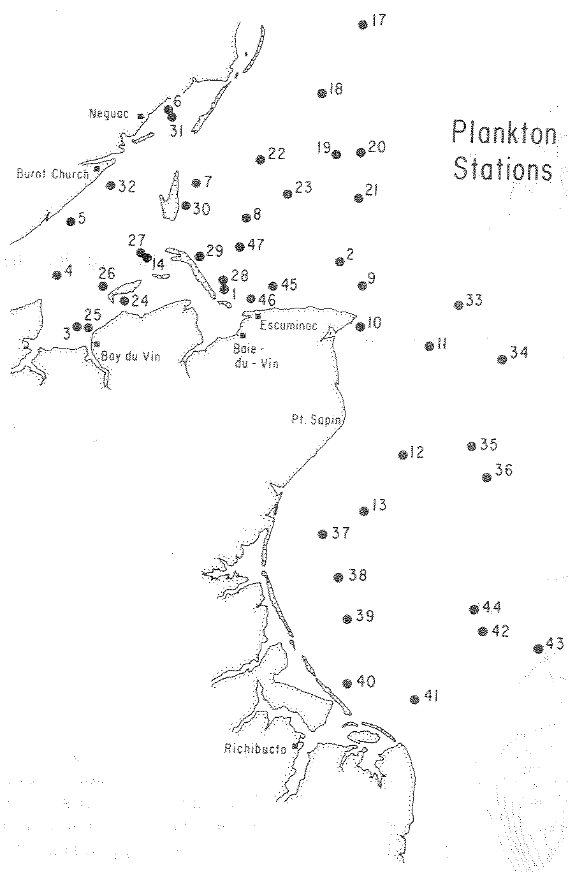

Fig. 12. Map of Miramichi Bay and northern Northumberland Strait showing plankton stations sampled.

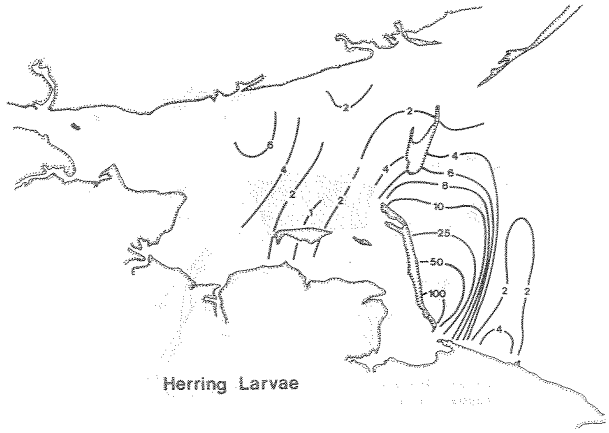

Fig. 13. Abundance of herring larvae (number under an area 10 m^2), based on plankton survey in Miramichi Bay, May 1979.

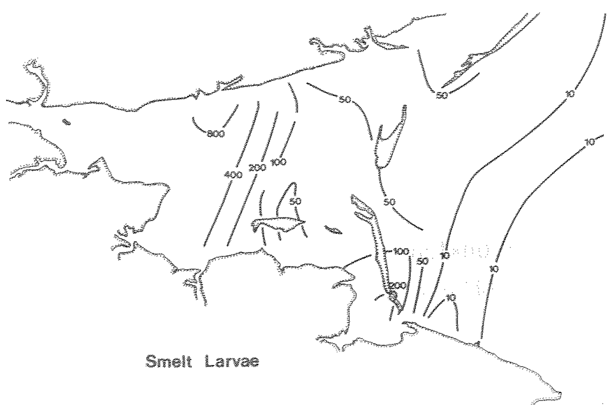

Fig. 14. Abundance of smelt larvae (number under an area 10 m^2), based on plankton survey in Miramichi Bay, May 1979.

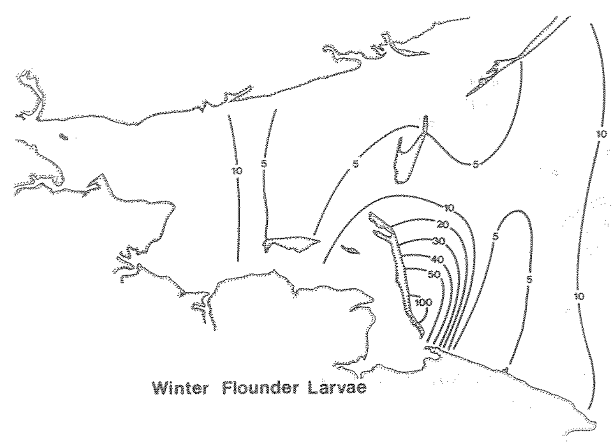

Fig. 15. Abundance of winter flounder larvae (number under an area 10 m^2), based on plankton survey in Miramichi Bay, May 1979.

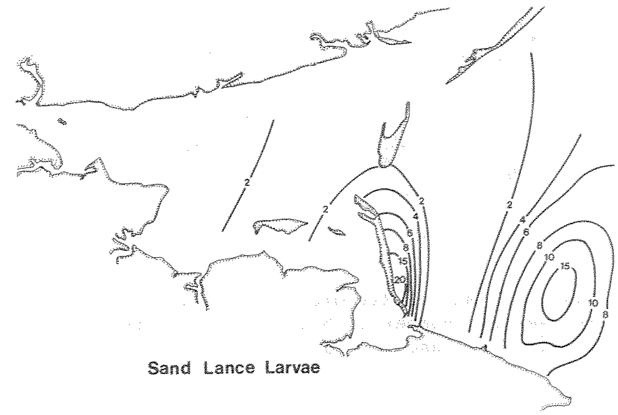

Fig. 16. Abundance of sand lance larvae (number under an area 10 m^2), based on plankton survey in Miramichi Bay, May 1979.

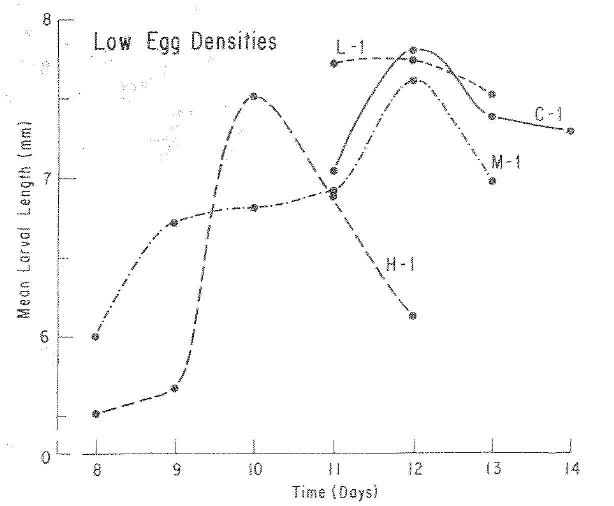

Fig. 17. Mean larval length vs time for the various suspended sediment concentrations in experiment 2 (low egg densities). For details on number of larvae from various sediment concentrations and times, see Appendix II.

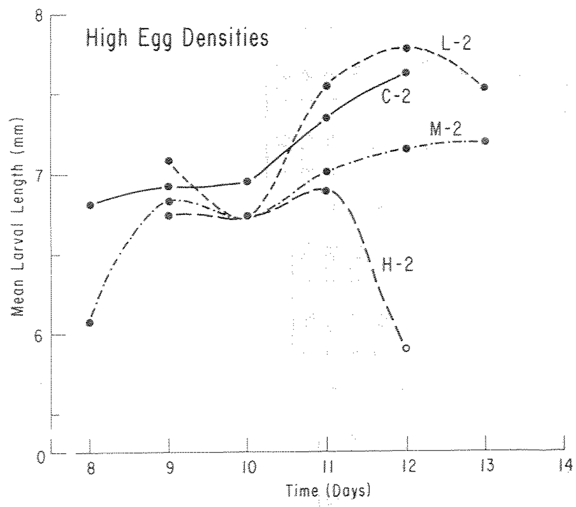

Fig. 18. Mean larval length vs time for the various suspended sediment concentrations in experiment 2 (high egg densities). For details on number of larvae from various sediment concentrations and times, see Appendix II.

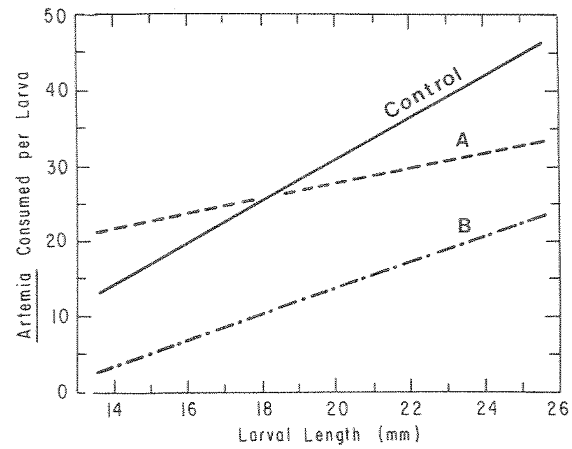

Fig. 19. The number of *Artemia* nauplii consumed per larval herring per 2 h against herring larval length in millimeters.

APPENDIX I

Detailed statistical analysis of larval length data.

A. ANOVA:

Source	d.f.	SS	MS	F value
Treatments	7	40.3047	5.7578	$\frac{MST}{MSE} = 19.2216$
Error	390	116.8242	.2995	
Total	397	157.1289		

$F^{m}_{I} = .05^{7,390} = 2.29$ 19.2216 > 2.29, hence conclude means are unequal.

B. Comparison of all possible pairs of means, following the method of Kramer (1956)

Treatment comparisons

	Range factor	B-10 Critical value	Significance*	B-10 R'p	B-10 C.V.	*	A-10 R'p	A-10 C.V.	*	B-0 R'p	B-0 C.V.	*	A-10 R'p	A-10 C.V.	*	B-10 R'p	B-10 C.V.	*	A-0 R'p	A-0 C.V.	*	A-10 R'p	A-10 C.V.	*
B-10^4				.77	1.52		1.56	1.60		2.82	1.65	*	3.79	1.69	*	4.45	1.72	*	4.98	1.75	*	6.91	1.77	*
B-10^3							.93	1.52		2.28	1.60	*	2.14	1.65	*	4.08	1.69	*	4.65	1.72	*	6.77	1.75	*
A-10^4										1.15	1.52		1.10	1.60		2.75	1.65	*	3.57	1.69	*	5.39	1.72	*
B-0													.01	1.52		1.72	1.60	*	2.75	1.65	*	4.63	1.70	*
A-10^3																1.60	1.51	*	2.62	1.60	*	4.38	1.65	*
B-10^2																			1.38	1.52		3.15	1.60	*
A-0																						1.33	1.52	
A-10^2																								

APPENDIX II

Number of larvae measured and mean length in millimeters for each treatment and day.

Treatment	Days post-fertilization 7	8	9	10	11	12	13	14	Treatment mean and total n
A-0				x=7.70mm n=1	7.03 10	7.80 15	7.38 2	7.54 3	7.50 31
B-0	6.35 1	6.80 12	6.92 15	6.95 15	7.35 7	7.64 10			7.07 60
A-10					7.71 20	7.76 20	7.54 3	7.61 1	7.72 44
B-10			7.08 15	6.73 15	7.56 15	7.78 10	7.53 10	7.15 1	7.29 66
A-10		6.00 2	6.71 3	6.82 4	6.91 14	7.61 15	6.97 8	6.15 1	7.07 47
B-10		6.07 14	6.83 15	6.73 7	7.01 11	7.15 10	7.20 5	7.69 1	6.78 63
A-10		5.52 2	5.67 6	7.50 20	6.89 14	6.12 2			6.91 44
B-10			6.74 15	6.73 15	6.79 9	5.90 4			6.67 43