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Effects of Aquaculture Outfall on Benthonic Foraminifera in Clam Bay, Nova Scotia*

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Introduction

This report describes the effect of aquaculture effluent on benthonic foraminiferal populations in Clam Bay, Nova Scotia. The study area is 45 miles east of Halifax (Fig. 1) and was first visited by the author in 1968. At that time, coastal geodynamic processes were monitored by marine geologists of the Bedford Institute and a definition of these conditions attempted. All geodynamic processes studied were in relation to sediment movement on the foreshore and regression of berm lines in the backshore area. Specifically three sets of energy indicators were monitored. These consisted of the measurement of current velocity within the bay, daily tidal fluctuation in the area and lastly the combined factors of wave frequency, height and intensity.

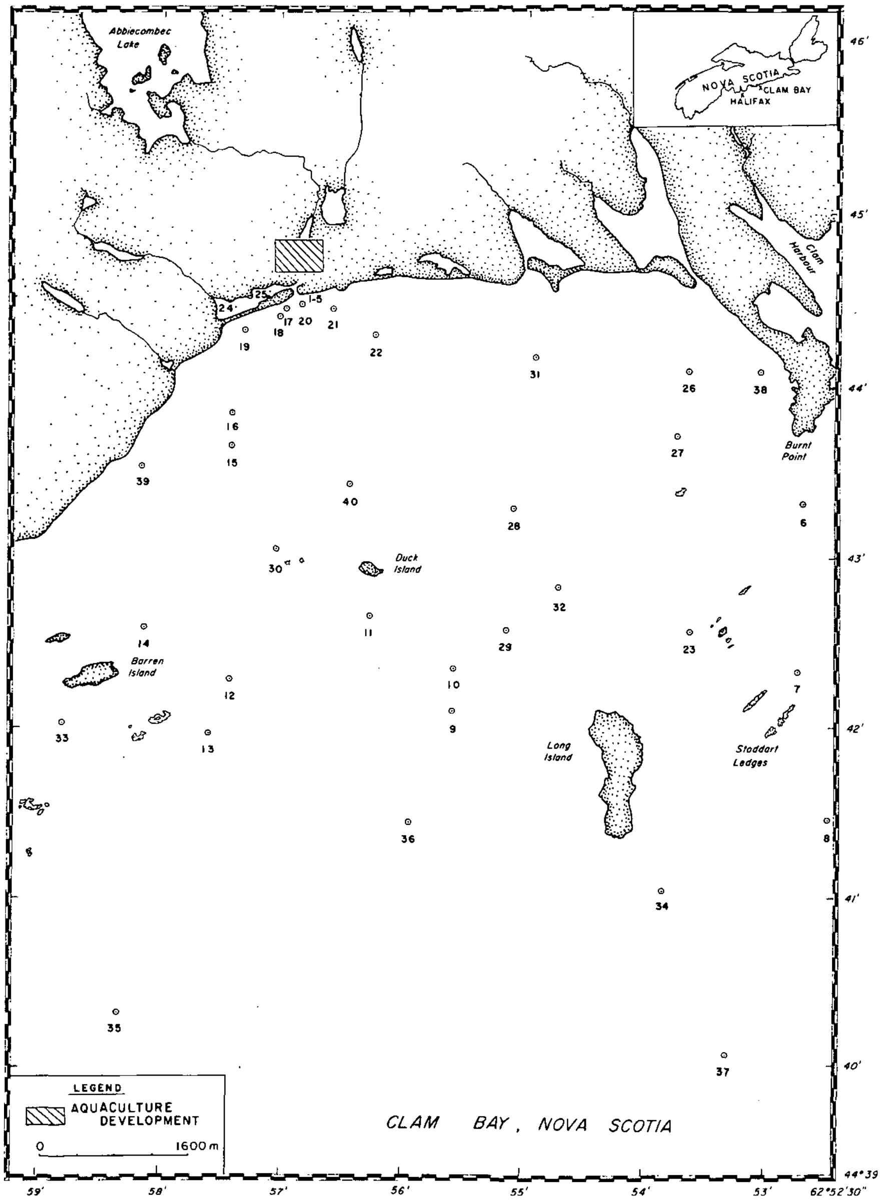

Figure 1 - Sampling locations and position of the aquaculture development.

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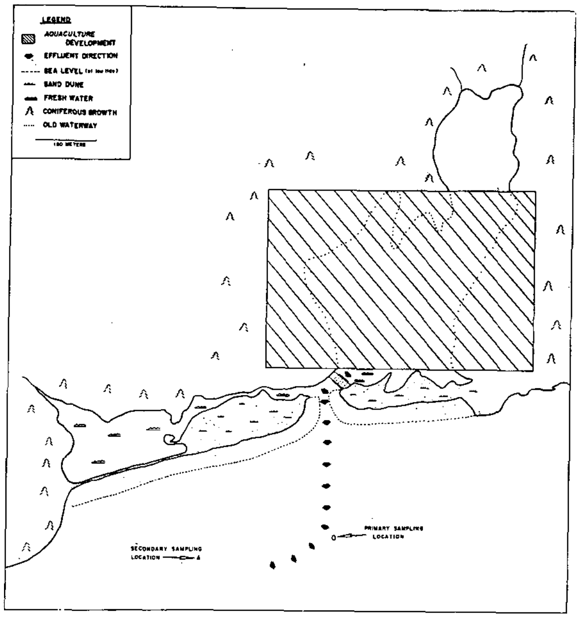

Figure 2 - Station locations and physical surroundings of the sampling program, Part II.

This latter property was measured on an arbitrary scale of zero energy to a theoretical maximum energy of seven. In 1969 reclamation operations were started on Abbiecombec salt marsh, one of the several marshes adjoining Clam Bay. A large aquaculture operation, utilizing fresh water drainage from the land and salt water from tidal flooding, was built on this site. The plant's objective is to raise young trout and salmon to a commercially saleable size. This is accomplished by means of high protein diets and warm circulated water which increases the growing rate of these fish. An opportunity to follow the ecological changes in the bay caused by a steadily increasing production level at the plant led to the present study. Monthly sampling of foraminifera was carried out at the mouth of the aquaculture outfall from November, 1969 to November, 1970.

Little chemical work has been done specifically with aquaculture effluents. Most chemical and environmental studies are concerned with the quality of water entering the system rather than the effluents (e.g. Hickling, 1968). However, production studies have been carried out by Ryther (1954, 1971) on duck-farm effluents in which he assesses the effects of nitrate ratios on the lower parts of the food chain, and by Schafer (1971) who is currently attempting to determine the effects of various types of domestic and industrial effluents on the local distribution of benthonic foraminifera in polluted areas of the Bay of Chaleur, New Brunswick.

Materials and Methods

This study involved a two-part sampling program. The objective of part one was the determination of species distribution throughout the bay. Part two consisted of monthly sampling at the mouth of the outfall to determine temporal variations within the influence of the effluent. Thirty-three grab samples of the top two centimetres of sediment were taken from the bay (Fig. 1). These samples provided the information on the distributional patterns for part one. Samples for part two were collected in a different fashion. Scuba diving techniques were employed to core the top two centimetres of sediment. Coring was performed in lieu of larger grab samples because of the increased accuracy of the method (Schafer, 1967). Fifteen cores were taken over a period of twelve months. The great increase in the amount of time needed to sample, using Scuba divers, prevented the use of these coring methods in part one of the program.

Oceanographic measurements were determined in situ. Salinity and temperature readings were made using a Beckman RS-5 Electrodeless Induction Salinometer, and were preceded by daily calibration with Copenhagen water. Current direction and speed were periodically determined with low profile drift buoys and Rhodamine β dye (Carpenter, 1960). Rhodamine β dye was emptied into the Abbiecombec outfall and distributional patterns were established for the effluent during its mixing process with the waters of the bay. The path of the dye was followed visually by divers under water and from boats on the surface. This procedure was repeated three times during the year and the results remained the same (Fig. 2).

Visual reconnaissance was maintained throughout the year to make certain that no new conditions were introduced into the ecology of the area. This reconnaissance was carried out by boat and in accessible areas, by truck. Occasional shoreline shifts were noted, due to the high transport qualities of the sand in the bay. However, no major changes, particularly man made, were introduced into the area of the bay during the period of study.

In the laboratory, samples were split; one part was examined for fauna, and the other was analyzed for sediment size. Size analyses were determined for each sample using standard sieving techniques (Krumbein and Pettijohn, 1938). Foraminiferal tests were separated using density differentiation methods. A mixture of acetone and bromoform served as the floating liquid (Sen Gupta and McMullen, 1969). In cases where total foraminiferal number would exceed three hundred individuals, populations were split using an Otto microsplitter (Otto, 1933).

Physical Environment

Clam Bay is a large crescent-shaped bay 4.26 km wide from headland to headland, and is dotted with numerous islands, the largest of which is 1500 m and the smallest 30 m long. Much of the area is isolated and totally inaccessible and was largely undisturbed by man prior to 1969 when the Abbiecombec salt marsh was reclaimed and occupied by a commercial company which began aquaculture operations. This plant uses salt water from the bay mixed with fresh water from the Abbiecombec Lake. After utilization this mixture is returned to the bay 5 per cent less saline than the original salt water. These hyposaline conditions are no longer detectable at a distance of 300 m from the mouth of the outfall.

The shoreline of Clam Bay is characterized by an alternating series of fine sandy beaches and areas covered in cobble-size boulders, with only the occasional outcrop of quartzite. Approximately 40 per cent of the shore is flanked by till cliffs and these provide most of the source material found within the confines of the bay.

Four principal fresh-water streams empty into the bay (Fig. 1). The water volume from these outlets is of moderate intensity, for example, Abbiecombec drainage amounts to 27,000,000 gal/day. Each stream derives its water from lakes situated higher in the terrain. The streams have an outfall which is constant throughout the year.

The bay floor is characterized by a gently sloping sandy bottom along the nearshore areas and reaches a maximum depth of 15 m. Well rounded cobbles occur intermittently in this area. Approximately 2.4 km from shore, the bottom changes abruptly to steep sided cliffs consisting of bedrock, which occasionally rise to the surface to form islands. Pockets of sand and pebble are interspersed between these islands at depths to 35 m.

Only small amounts of mud were found within the bay. Samples No. 6 and 7 from the far eastern portion of the bay contained medium to coarse silt, the remaining samples were sand. A more detailed sediment sampling program was conducted by V. Asthana of the Bedford Institute. Throughout the year the sediment size fell within the fine-sand range (see Wentworth, 1922) and it varied between 2.5 and 3 ϕ units (V. Asthana, personal communication). Generally, slightly coarser sand was found in the western portion of the bay. These data were used as an indicator of energy conditions occurring at the sediment-water interface and are indicative of fairly constant conditions.

Current patterns in the bay are controlled largely by wind direction and because of a prevailing easterly wind, an east to west current predominates. This east-west current together with tidal effects combine to have a total flushing effect on all water within the boundaries of the bay. For any given time salinity and temperature remain constant throughout the bay, except for areas around fresh-water outlets. Salinities for the months of January and February had a mean value of 29.98 $^{o}/oo$ at the surface and 30.15 $^{o}/oo$ at the sediment-water interface. Throughout the year salinities ranged from 29.62 $^{o}/oo$ to 33.42 $^{o}/oo$ and varied little between the surface and the bottom waters.

The aquaculture development, located on the Abbiecombec salt marsh, breeds economically useful fish such as brook trout (Salvelinus fontinalis), Atlantic salmon (Salmo salar) and Arctic char (Salvelinus alpinus) (Gustrom, 1970). All fish follow an eight-month growth schedule during which they are raised on a high protein diet in warm waters. Salinity is steadily increased during the growth period until the fish are living in a pure salt water environment at maturity. Upon maturity these fish are shipped to the larger cities of North America and sold as fresh fish. The plant consists of several large breeding ponds varying from twenty-five to fifty feet in diameter, plus dyked sea-water empoundments and small fresh-water lakes.

Ten per cent of all water from the breeding areas is lost during one complete circulation of water. This 10 per cent loss flows into Clam Bay carrying with it all the plant's waste. The daily volume averages 25 million gallons of water.

Because an increase of pollutants did not necessarily mean an easily observable change in the effluent it was decided that commercial productivity of the plant could be used as a good indicator of increases and decreases in the quality of the effluent. Commercial productivity was defined in terms of the amount of fishmeal used each month (Fig. 4). Increases and decreases in the graphical representation reflect procedural changes and seasonal plant slowdowns that occurred during the study period. As fish-feed poundage increased, plant effluent would be effected by an increase in fish wastes, excrements and unused fish-feed. Direct mathematical relationships were not determined, but it was assumed in most cases to be linearly related.

High nitrogen levels may be suspect at the fish farm. This was observed by the examination of effluents from duck farms where high nitrate levels occurred (Ryther, 1954). Excrement products and unused fish-food would make contributions to the nitrogen level in the effluent of the fish farm. Great quantities of blue-green algae in the holding tanks and drainage ducts attest to this suggestion. This effect however must be considered only within one-half mile radius of the outfall. This distance was determined from the distribution patterns of Rhodamine β dye poured into the effluent (Fig. 2). If effluent effects are considered for the whole bay then one must allow for dilution factors of 1:5000 and certainly question any calculations based on the bay as a whole.

Clam Bay Foraminifera

Thirty-five species of benthonic foraminifera were identified. Only those present to at least 5 per cent of the total sample population were reported in the faunal list (Appendix I). Station 37 is near the boundary separating bay and open ocean environments as shown by the increased species diversity. Station 24 was barren.

Bucella frigida, Cibicides lobatulus, Eggerella advena, Elphidium sp., and *Quinqueloculina seminulum* are dominant species throughout Clam Bay.

To establish dominance patterns within the bay, relative percentages of the most prevalent species were calculated (Table I).

Eggerella advena populations changed in an east-to-west direction with the greatest numbers occurring on the eastern side of the bay. This eastern portion receives water from both Ship Harbour and Clam Harbour. Subsequent depletion of nutrients in a westerly direction may be responsible for the decreasing numbers of this species in the western portion of Clam Bay. This rather rapid change in total sample percentage suggests that *Eggerella advena* is a high nutrient-demand species and substantiates the observations of Watkins (1961) who found this species in great numbers around the Orange County sewer outfall in California.

Table 1 - Percentage Dominance in Representative Sampling of Clam Bay

STATION NUMBER	TOTAL NUMBER PER GRAM OF SEDIMENT DRY WEIGHT	*BUCELLA FRIGIDA*	*CIBICIDES LOBATULUS*	*EGGERELLA ADVENA*	*ELPHIDIUM SPP*	*QUINQUELOCULINA SEMINULUM*
6	10.3	11.6	32.0	9.7	46.6	0.0
7	31.7	3.1	21.1	39.7	32.1	3.7
8	23.1	1.7	63.2	11.6	21.6	1.7
13	6.4	3.1	23.4	40.6	32.8	0.1
14	0.4	3.3	25.0	12.5	50.0	5.0
15	0.1	0.1	0.1	0.1	80.0	20.0
16	5.4	1.8	18.5	25.9	46.2	7.4
17	0.5	20.0	20.0	20.0	20.0	20.0
18	.3	0.0	33.3	0.0	33.3	33.3
19	.1	0.0	100.0	0.0	0.0	0.0
20	.2	0.0	50.0	0.0	0.0	50.0
21	.4	20.0	20.0	0.0	20.0	20.0
22	.3	0.0	33.3	33.3	33.3	0.0
23	8.3	2.4	9.6	68.6	19.2	0.1
26	2.6	3.8	11.5	46.1	34.6	3.8
27	1.0	1.0	20.0	30.0	49.0	1.0
28	7.5	9.3	13.3	30.6	44.0	2.6
29	3.6	2.0	27.7	13.8	55.5	2.7
30	6.6	7.5	10.6	1.5	60.6	6.0
31	0.8	1.2	1.2	49.0	49.0	1.2
35	53.5	1.3	38.6	26.3	33.2	0.3
37	89.6	7.8	8.2	31.4	51.0	0.1
39	0.6	1.6	33.3	33.3	32.1	0.1

Cibicides lobatulus populations change in a direction normal to the shore with higher percentages found in deeper waters. *Elphidium spp.* decrease numerically, normal to the shore, but with lower percentages in deeper water.

Bucella frigida and *Quinqueloculina seminulum* although dominant in the samples, maintain an even distributional pattern throughout the bay and appear to be unaffected by variables within the bay such as food supply bathymetry and energy conditions (Table 1).

Species dominance patterns have not clearly been established around the outfall. Relative percentages are detailed in Table 2 using data on a two-month interval basis. Favourable growing conditions in the months of February and June as shown in Figure 4, correlated with the data in Table 2 suggest that *Elphidium spp.* dominate the populations in this area of the bay only when growing conditions are good. If any ecological strain is placed on this species their numbers immediately decrease and *Cibicides lobatulus* begins to dominate the population.

Table 2 - Percentage Dominance in Effluent Control Zone

	Nov. 69	Feb. 70	June 70	Sept. 70
B. frigida	38.82	4.44	10.20	18.18
C. lobatulus	11.76	26.25	14.28	72.72
E. advena	12.94	3.08	20.40	0.00
E. spp.	29.41	64.28	51.02	9.09
Q. seminulum	7.05	1.93	4.08	0.00

Monthly sampling during the study period produced results which are shown graphically in Figures 3 and 4. Figure 3 represents monthly foraminiferal populations at the primary sampling location (Fig. 2). The number of animals are recorded as the number per cubic centimetre of sediment. Attention is drawn to the maximum peak in February which is found too early in the season to be attributable to the yearly spring bloom. If this peak is compared with the commercial productivity of the plant then an inverse correlation can be seen as shown in Figure 4. During the months of December 1969 to February 1970, productivity at the plant decreased due to operational difficulties and seasonal slowdowns. The graph shows that the foraminiferal number quickly increased when ecological pressures, that are probably related to the physical and chemical characteristics of the plant effluent, were eased. This inverse relationship was again observed during the period June to September 1970.

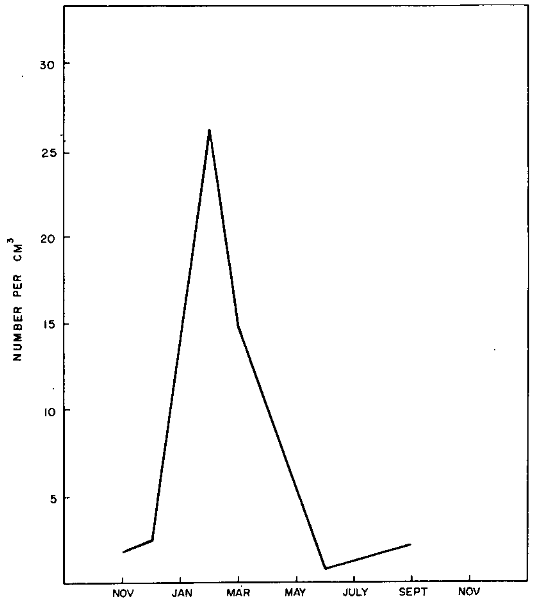

Figure 3 - Foraminiferal population changes at the primary sampling location from November 1969 to November 1970.

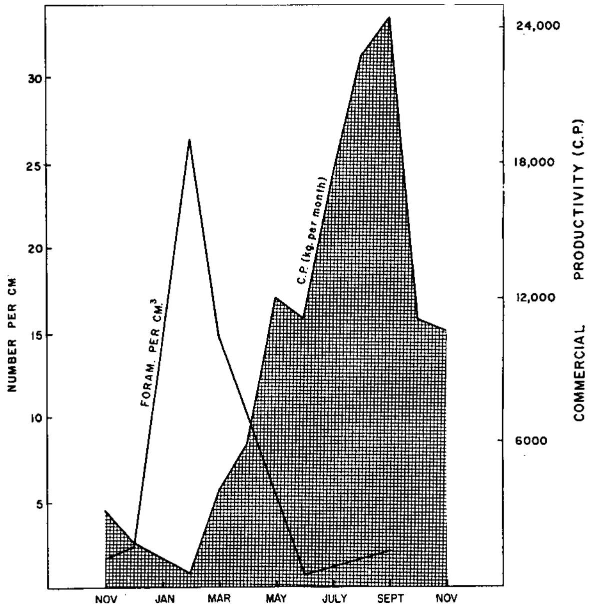

Figure 4 - Foraminiferal population values as monitored at the primary sampling station vs. the commercial productivity (C.P.) of the aquaculture development, from November 1969 to November 1970 (see text for definition of C.P.).

Conclusion

Foraminiferal fauna of Clam Bay are generally good representatives of the typical foraminiferal fauna found in the nearshore waters of the Atlantic Provinces (See Bartlett, 1964; Vilks, 1968). Oceanographic conditions are stable throughout the water mass and are the same throughout the bay at any one time. A northeast current generally prevails in the bay and causes greater depositional activity in the eastern portion. This factor seems to favour higher overall foraminiferal populations.

The area immediately adjacent to the aquaculture outfall represents a unique situation where populations vary rapidly with no discernible connection to the measured oceanographic parameters. Correlation between the quality of the outfall waters and the Foraminiferal Number provide the only apparent explanation for the variation in benthonic foraminiferal populations in this particular part of the bay.

Acknowledgements

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Appendix I - Faunal Occurrences at Sampling Stations

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Angulogerina fluens			x																			
Bolivina pseudopunctata							x															
Buccella frigida	x	x	x	x	x	x	x	x					x	x	x	x					x	
Buccella inusitata																						
Bulimina exilis							x						x									
Cibicides lobatulus	x	x	x	x	x	x	x	x					x	x	x	x	x	x	x	x	x	x
Cornuspira involens				x																		
Cribrostomoides crassimargo																						
Cribrostomoides jeffreysi							x	x							x	x						
Eggerella advena	x	x	x	x		x	x	x					x	x	x	x	x					x
Elphidium spp.	x	x	x	x	x	x	x	x					x	x	x	x	x	x			x	x
Fissurina marginata																						
Fissurina ventricosa																						
Islandiella islandica													x									
Lagena gracillima													x			x						
Lagena semilineata																						
Laryngosigma hyalascidia							x	x					x			x						
Miliolinella chukchiensis																						
Oolina costata	x					x		x					x	x	x	x				x		
Oolina lineata																						
Oolina melo							x	x								x						
Parafissurina fusuliformis								x														
Quinqueloculina seminulum	x		x	x			x	x					x	x	x	x	x	x		x		
Quinqueloculina subrotundum																					x	
Quinqueloculina stalkeri													x									
Recurvoides turbinatus													x			x						
Reophax curtus																						
Saccamina atlantica																						
Scutuloris tegminis								x														
Spiroplectammina biformis							x	x					x			x						
Textularia torquata																						
Trochammina lobata							x	x						x	x							
Trochammina rotaliformis								x					x			x					x	
Trochammina squamata																						
Trochamminella bullata																						

Appendix I (cont'd) - Faunal Occurrences at Sampling Stations

	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Angulogerina fluens		X		X		X	X	X				X		X	X	X			
Bolivina pseudopunctata							X	X		X						X			
Buccella frigida		X		X	X	X	X	X	X	X			X	X	X	X			X
Buccella inusitata						X					X								
Bulimina exilis		X		X	X	X	X	X	X	X	X								
Cibicides lobatulus	X	X		X	X	X	X	X	X	X	X	X		X	X	X	X		X
Cornuspira involens																			
Cribrostomoides crassimargo		X				X						X	X	X		X	X		
Cribrostomoides jeffreysi				X	X		X	X				X	X	X	X	X			
Eggerella advena	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Elphidium spp.	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
Fissurina marginata		X			X	X	X	X	X	X	X	X			X	X			X
Fissurina ventricosa					X	X	X		X	X	X	X			X				X
Islandiella islandica							X												
Lagena gracillima					X	X	X	X		X						X	X		X
Lagena semilineata							X						X	X		X			
Laryngosigma hyalascidia							X	X		X		X	X		X	X			
Miliolinella chukchiensis		X			X														
Oolina costata		X			X	X		X	X	X		X	X	X	X	X	X		
Oolina lineata		X									X		X	X		X		X	
Oolina melo					X	X		X	X		X	X		X		X	X	X	X
Parafissurina fusuliformis		X								X									X
Quinqueloculina seminulum				X	X	X	X	X	X	X	X	X	X	X	X	X			X
Quinqueloculina subrotundum		X																	
Quinqueloculina stalkeri							X									X		X	
Recurvoides turbinatus		X																	
Reophax curtus		X																	
Saccamina atlantica		X				X	X	X	X	X	X	X	X			X			X
Scutuloris tegminis		X																	
Spiroplectammina biformis		X		X	X	X	X	X			X		X	X	X	X		X	
Textularia torquata							X							X		X			
Trochammina lobata		X			X	X	X	X		X			X		X		X		X
Trochammina rotaliformis		X							X	X	X	X							
Trochammina squamata					X	X	X	X	X	X								X	
Trochamminella bullata					X														

Appendix II - Faunal Reference List

Angulogerina fluens Todd - Loeblich and Tappan, 1953, Smithsonian Misc. Coll., vol. 2, N. 7, Pl. 20, Fig. 10-12.

Bolivina pseudopunctata Höglund - Loeblich and Tappan, 1953, Smithsonian Misc. Coll., vol. 121, No. 7, Pl. 20, Fig. 13, 14.

Buccella frigida (Cushman) - Vilks, 1969, Micropaleo., vol. 15, No. 1, Pl. 3, Fig. 7.

Buccella inusitata Anderson - Loeblich and Tappan, 1953, Smithsonian Misc. Coll., vol. 121, No. 7, Pl. 22, Fig. 1.

Bulimina exilis Brady - Barker, 1960, Tax. Notes Species dredged by H.M.S. Challenger, Pl. 50, Fig. 5, 6.

Cassidulina norcrossi Cushman - Parker, 1952, Bull. Mus. Comp. Zool., vol. 106, No. 9, Pl. 6, Fig. 24, 25.

Cibicides lobatulus (Walker and Jacob) - Parker, 1952, Bull. Mus. Comp. Zool., vol. 106, No. 9, Pl. 6, Fig. 26a, b.

Cribrostomoides crassimargo (Norman) = *Labrospira crassimargo* (Norman) - Parker, 1952, Bull. Mus. Comp. Zool., vol. 106, No. 9, Pl. 2, Fig. 16a, b.

Cribrostomoides jeffreysi (Williamson) = *Labrospira jeffreysii* (Williamson) - Parker, 1952, Bull. Mus. Comp. Zool., vol. 106, No. 9, Pl. 2, Fig. 20.

Cornuspira involens (Reuss) - Loeblich and Tappan, 1953, Smithsonian Misc. Coll., vol. 121, No. 7, Pl. 7, Fig. 4, 5.

Eggerella advena (Cushman) - Parker, 1952, Bull. Mus. Comp. Zool., vol. 106, No. 9, Pl. 3, Fig. 12, 13.

Elphidium spp. - Parker, 1952, Bull. Mus. Comp. Zool., vol. 106, No. 10, Pl. 4, Fig. 3 - 6, 8. - Parker, 1952, Bull. Mus. Comp. Zool., vol. 106, No. 9, Pl. 5, Fig. 10, 11. - Loeblich and Tappan, 1953, Smithsonian Misc. Coll., vol. 121, No. 7, Pl. 19, Fig. 5-7.

Fissurina marginata (Montagu) - Loeblich and Tappan, 1953, Smithsonian Misc. Coll., vol. 121, No. 7, Pl. 14, Fig. 6-9.

Fissurina ventricosa (Wiesner) - Loeblich and Tappan, 1953, Smithsonian Misc. Coll., vol. 121, No. 7, Pl. 14, Fig. 15.

Lagena gracillima (Sequenza) - Loeblich and Tappan, 1953, Smithsonian Misc. Coll., vol. 121, No. 7, Pl. 11, Fig. 1-4.

Lagena semilineata Wright - Loeblich and Tappan, 1953, Smithsonian Misc. Coll., vol. 121, No. 7, Pl. 11, Fig. 14-22.

Larynogosigma hyalascidia Loeblich and Tappan, 1953, Smithsonian Misc. Coll., vol. 121, No. 7, Pl. 15, Fig. 6-8.

Miliolinella chukchiensis Loeblich and Tappan, 1953, Smithsonian Misc. Coll., vol. 121, No. 7, Pl. 6, Fig. 7.

Oolina costata (Williamson) - Parker, 1952, Bull. Mus. Comp. Zool., vol. 106, No. 9, Pl. 4, Fig. 20, 21.

Oolina lineata (Williamson) - Loeblich and Tappan, 1953, Smithsonian Misc. Coll., vol. 121, No. 7, Pl. 13, Fig. 11-13.

Oolina melo d'Orbigny - Vilks, 1969, Micropaleo., vol. 15, No. 1, Pl. 2, Fig. 29.

Parafissurina fusuliformia Loeblich and Tappan, 1953, Smithsonian Misc. Coll., vol. 121, No. 7, Pl. 14, Fig. 18, 19.

Quinqueloculina seminulum (Linné) - Parker, 1952, Bull. Mus. Comp. Zool., vol. 106, No. 10, Pl. 2, Fig. 7a, b.

Quinqueloculina subrotunda (Montagu) - Parker, 1952, Bull. Mus. Comp. Zool., vol. 106, No. 9, Pl. 4, Fig. 4a, b.

Quinqueloculina stalkeri Loeblich and Tappan, 1953, Smithsonian Misc. Coll., vol. 121, No. 7, Pl. 5, Fig. 5-9.

Recurvoides turbinatus (Brady) - Barker, 1960, Tax. Notes Species dredged by H.M.S. Challenger, Pl. 35, Fig. 9.

Reophax curtus Cushman - Parker, 1952, Bull. Mus. Comp. Zool., vol. 106, No. 9, Pl. 1, Fig. 12.

Saccammina atlantica (Cushman) - Vilks, 1969, Micropaleo., vol. 15, No. 1, Pl. 1, Fig. 13.

Scutuloris tegminis Loeblich and Tappan, 1953, Smithsonian Misc. Coll., vol. 121, No. 7, Pl. 5, Fig. 10.

Spiroplectammina biformia (Parker and Jones) - Loeblich and Tappan, 1953, Smithsonian Misc. Coll., vol. 121, No. 7, Pl. 4, Fig. 6.

Textularia torquata Parker, 1952, Bull. Mus. Comp. Zool., vol. 106, No. 9, Pl. 3, Fig, 9, 10, 11.

Trochammina nana (Brady) - Barker, 1960, Tax. Notes, Species dredged by H.M.S. Challenger, Pl. 35, Fig. 6-8.

Trochammina rotaliformis Wright - Loeblich and Tappan, 1953, Smithsonian Misc. Coll., vol. 121, No. 7, Pl. 8, Fig. 6-9.

Trochammina squamata Parker and Jones - Parker, 1952, Bull. Mus. Comp. Zool., vol. 106, No. 9, Pl. 4, Fig. 11-16.

Trochamminella bullata Höglund - Vilks, 1969, Micropaleo., vol. 15, No. 1, Pl. 2, Fig. 2a, b.