WINTERKILL OF HARD CLAMS IN GREAT SOUTH BAY, N.Y. 1976-77

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marine sciences research center
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Approved for Distribution

J.R. Schubel

J. R. Schubel, Director

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

To estimate mortality of the commercially important hard clam (*Mercenaria mercenaria*) resources of Great South Bay, New York, during the severe winter of 1976-77, clams were sampled at 31 stations in the Bay. Mortality was quite variable and ranged from 0 to 27.2 %. Mortality showed no strong relation to any of the variables measured at each station: depth, salinity, substrate particle size, substrate organic content, and clam density. High mortality (10 % and higher) was confined to one small area of the Bay and was apparently not due to winter stress alone, but to a combination of factors, perhaps including disease. With the exception of the one area, mortality of the hard clam over the winter was not extreme and averaged 1.6 %. Shelf lives of clams from each station were also determined. Shelf life, represented by the time taken for the first 10 clams from a sample of 30 to die under constant temperature and humidity, varied from 15 to 38 days and showed no strong correlation with mortality or any of the other variables observed at each station. Some clams survived 59 days out of water, the duration of the shelf life experiment.

INTRODUCTION

Great South Bay is a shallow, bar-built estuary on the south shore of Long Island, New York (Figure 1). The Bay is approximately 40 km long and covers an area of about 230 km^2. Average depth of the Bay is about 1.3 m (MLW). Hard clams (*Mercenaria mercenaria*) thrive in the Bay and support the most valuable hard clam fishery in the world. The fishery accounts for more than 50 % of the landed value of all commercial fishery resources in New York State, and the retail value of the clam catch has been estimated at one hundred million dollars (Nassau-Suffolk Regional Planning Board, 1974; U.S. Department of Commerce, 1976). The hard clam industry is very important to local communities. It employs several thousand baymen and shippers, and indirectly contributes to the income of a variety of other businesses such as marinas, fishing supply stores and restaurants. The resource also supports substantial unrecorded recreational and subsistence clam fisheries (McHugh, 1977).

The winter of 1976-77 was one of the coldest on record in the Long Island area. Based on the average temperatures for the months of December, January and February for the New York City area, the winter of 1976-77 was the coldest in 41 years and the tenth coldest on record. The mean temperatures for December, January and February were -1.2, -5.5 and 0.8° C, respectively; norms for those months were 1.9, 0.1 and 0.8° C, respectively (J. Allen, National Weather Service, personal communication). Because unusually low temperatures were persistent, ice up to 0.6 m thick covered most parts of Great South Bay for approximately 1½ months, from late December to mid-February. On February 9, 1977, a group from the Marine Sciences Research Center made an aerial reconnaissance of the Long Island area to assess the extent of ice coverage on coastal waters. Great South Bay was found to be completely covered with ice except in the immediate vicinity of Fire Island Inlet where relatively strong tidal currents prevented ice cover. Several aerial photographs are presented in this report to show the extent of ice cover in some areas sampled in this study (Figures 2, 3, 4 and 5). On February 2, 1977, several researchers from the Marine Sciences

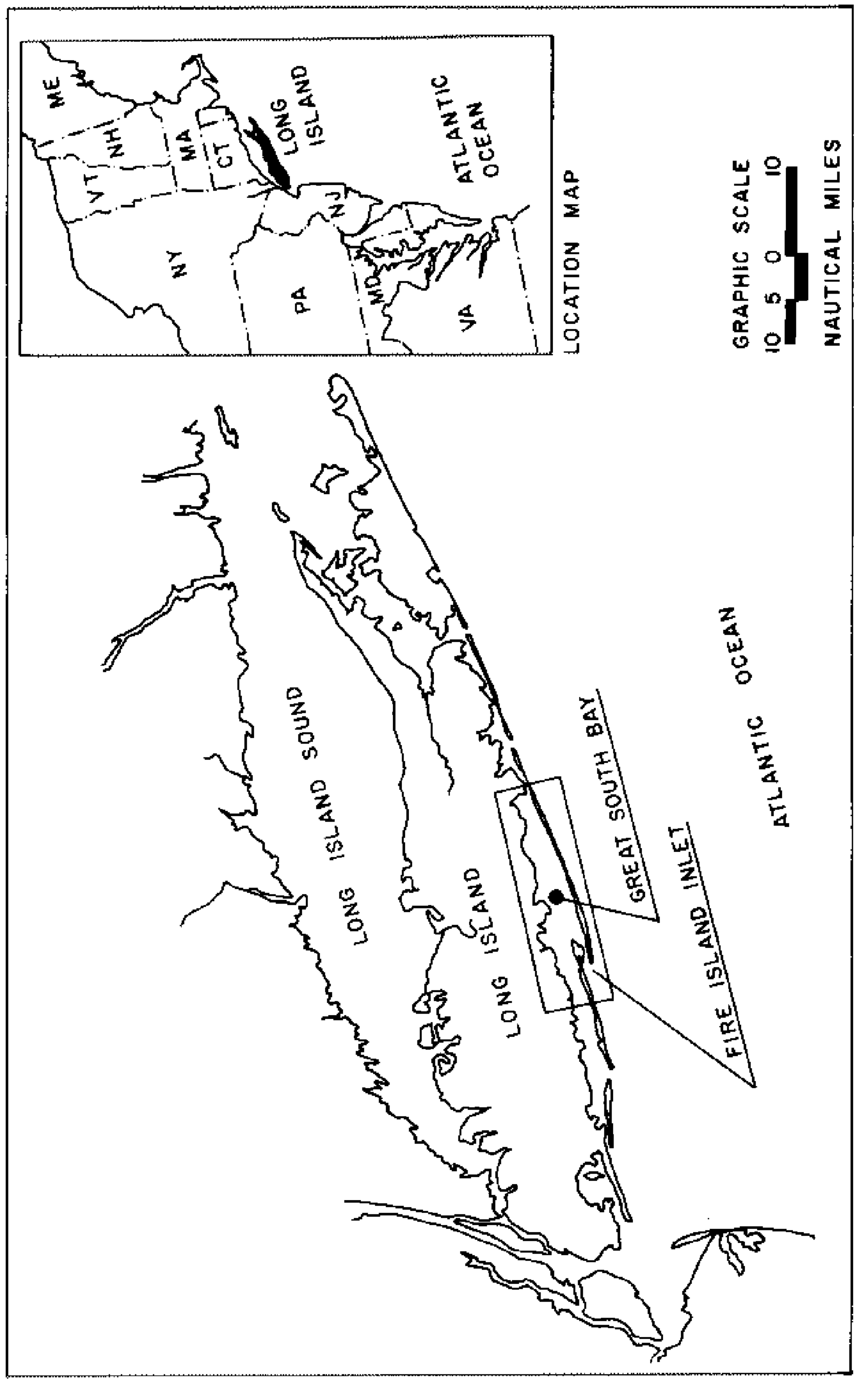

Figure 1. Location of Study Area.

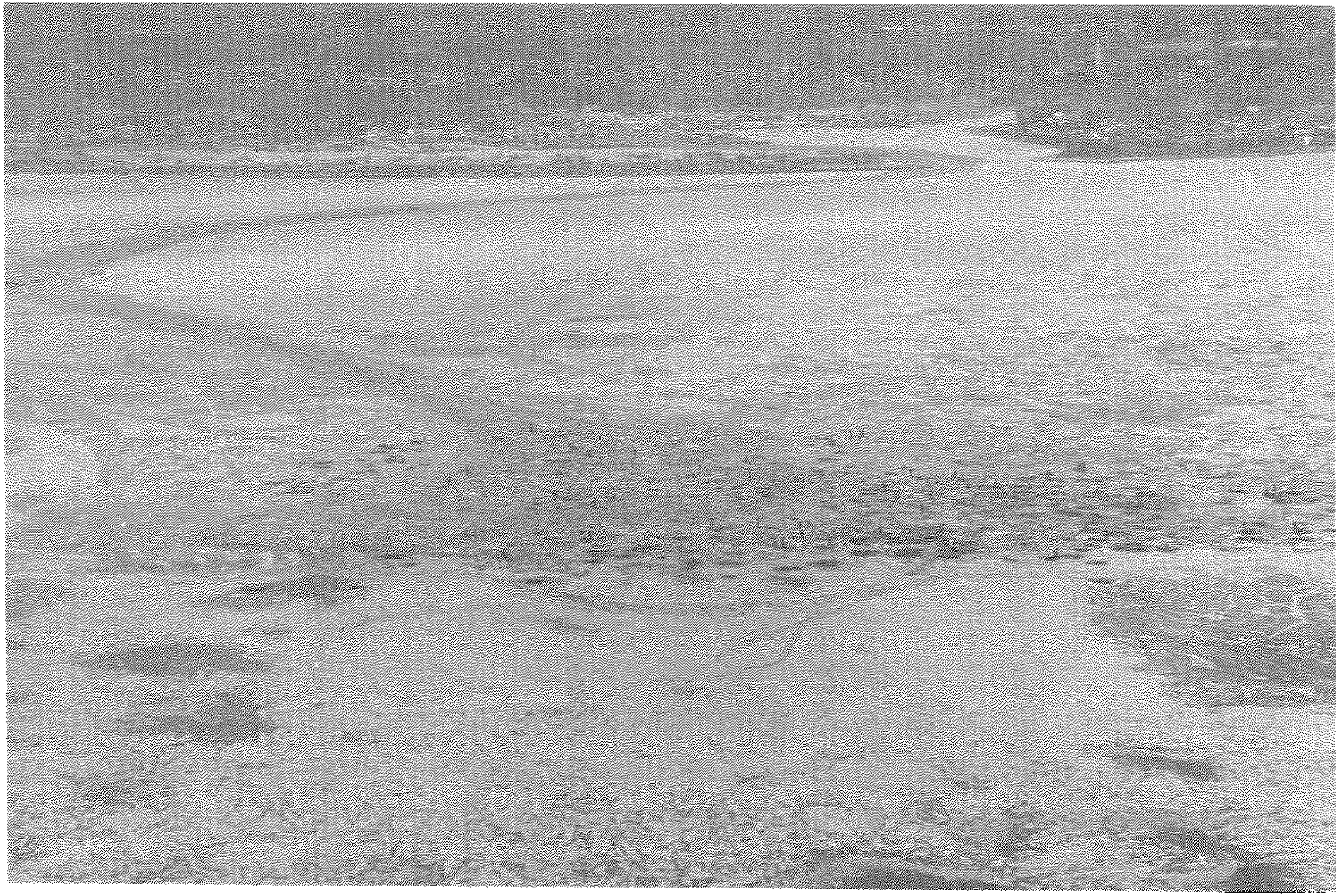

Figure 2. Great Cove.
Note baymen in foreground clamming through holes chopped in the ice.
Stations 23, 29, 30 and 31 were in this vicinity.

Figure 3. Mouth of Brown Creek.
Stations A1 and A2 were located in this vicinity.

Figure 4. Mouth of Patchogue River.
Station 27 was in this vicinity.

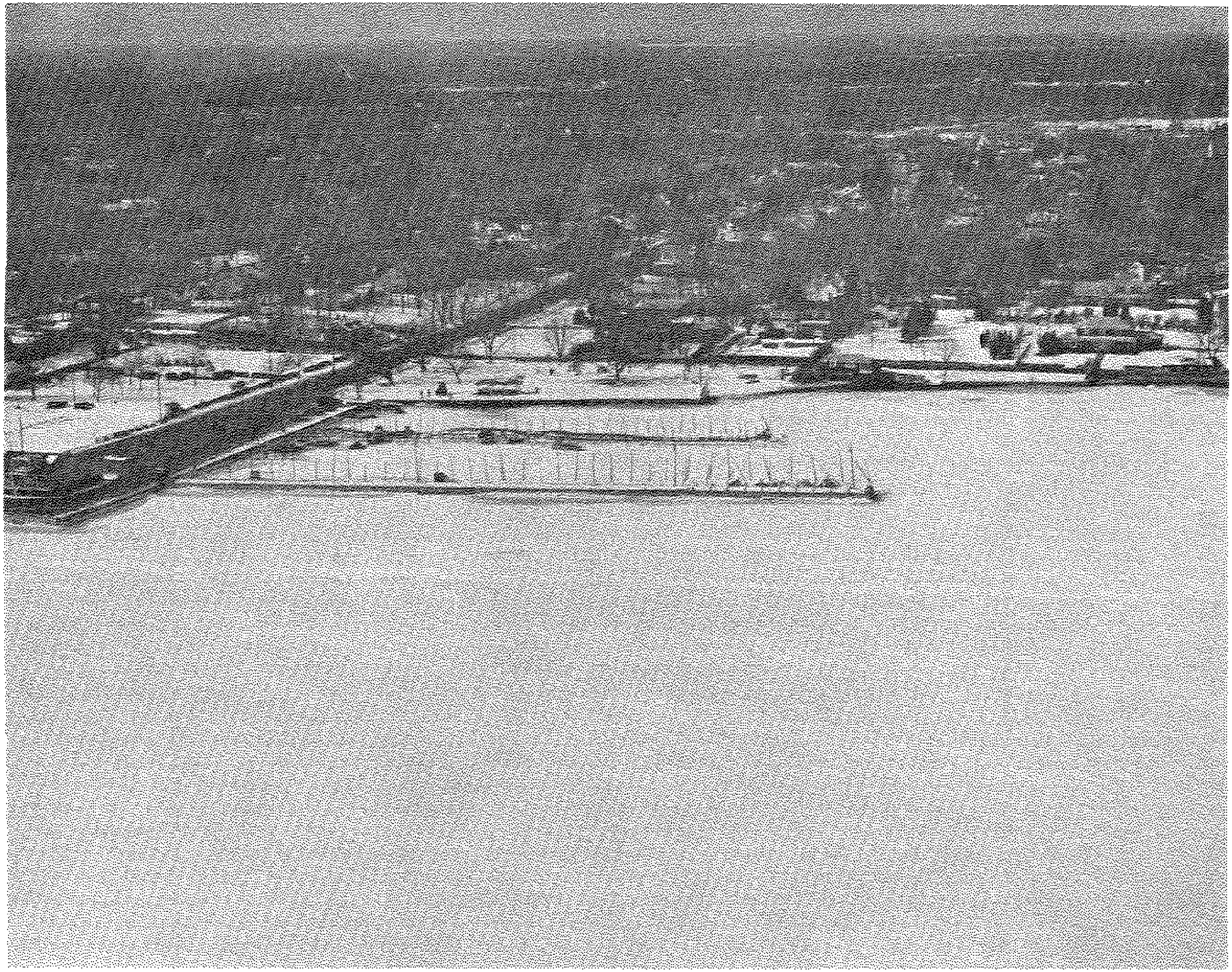

Figure 5. Bellport Town Docks.
Station 5 was in this vicinity.

Research Center visited the Bay to determine the thickness of the ice. Three holes were chopped in the ice in the vicinity of Brown Creek and the entire water column (about 0.4 m) was found to be frozen.

Because the unusual cold and ice persisted, concern arose that the hard clam resource of the Bay might be adversely affected. Following breakup of the ice cover and commencement of baywide clamming during the last week of February, many clammers reported unusually large numbers of dead clams (up to 20 %) in their catches in some areas. A winterkill of 20 % would represent a substantial loss to the hard clam resource, especially because many clam beds in the Bay are already believed to be overharvested (McHugh, 1977). In addition, there were reports that harvested clams had shorter shelf lives than usual, causing many to die before reaching market.

The objective of this study was to sample selected clamming grounds and to assess and document the effects of the winter of 1976-77 on hard clam populations in Great South Bay. The study was limited to those parts of the Bay controlled by the Townships of Islip and Brookhaven (Figure 6). The central part of the Bay is owned by a private shellfish company, Bluepoints Company, Inc., which made its own assessment of the winter's effects on its clam resource (Emil Usinger, personal communication). The extreme western part of the Bay is under jurisdiction of the Town of Babylon and was too far from the center of operations to be adequately sampled in this study.

METHODS

Sampling was done at 31 stations in Great South Bay (Figures 7 and 8). Stations were chosen so that important clamming grounds would be sampled and a variety of different bay environments would be represented. A minimum of 200 clams was taken at every location except 4, at which bad weather limited sample size. All samples were taken with standard clam tongs. Sampling was done by anchoring at the station site and letting out more anchor line as the area around the boat was depleted of clams. The actual area sampled ranged between 5 and 40 m^2 depending upon the abundance of clams. The use of tongs biased the sample by allowing most clams thinner than the spacing between the grates (about 1.5 cm) to pass through. Therefore, only a small percentage of clams under a year old were taken.

At each station, the following data were recorded: number of clams sampled, number of dead clams, water temperature, depth and clam abundance. In determining mortality, only those dead clams with tissue still attached to the shell or those with an unmistakably foul odor were considered winterkills. Presumably, meat would not remain in the shell of the dead clam unless the clam died over the winter when water temperatures were low enough to retard decomposition. Clam abundance was estimated from the average number of clams captured by each tonging.

In addition to the data recorded at each station, water and sediment samples were taken and later analyzed at the Marine Sciences Research Center. Salinity of each water sample was determined with a Autosal Model 8400 Salinometer. Particle size distribution of each sediment sample was determined by wet sieving and pipette analysis using techniques described by Folk (1954). Organic content of each sediment sample was estimated from weight loss on ignition at 550° C. The relation of these data to observed mortalities was then examined. Size distribution of live and dead clam populations at two stations of high mortality were calculated to see if mortality was related to clam size.

To determine if there were differences in dried meat weights (as an indicator of physiological condition)

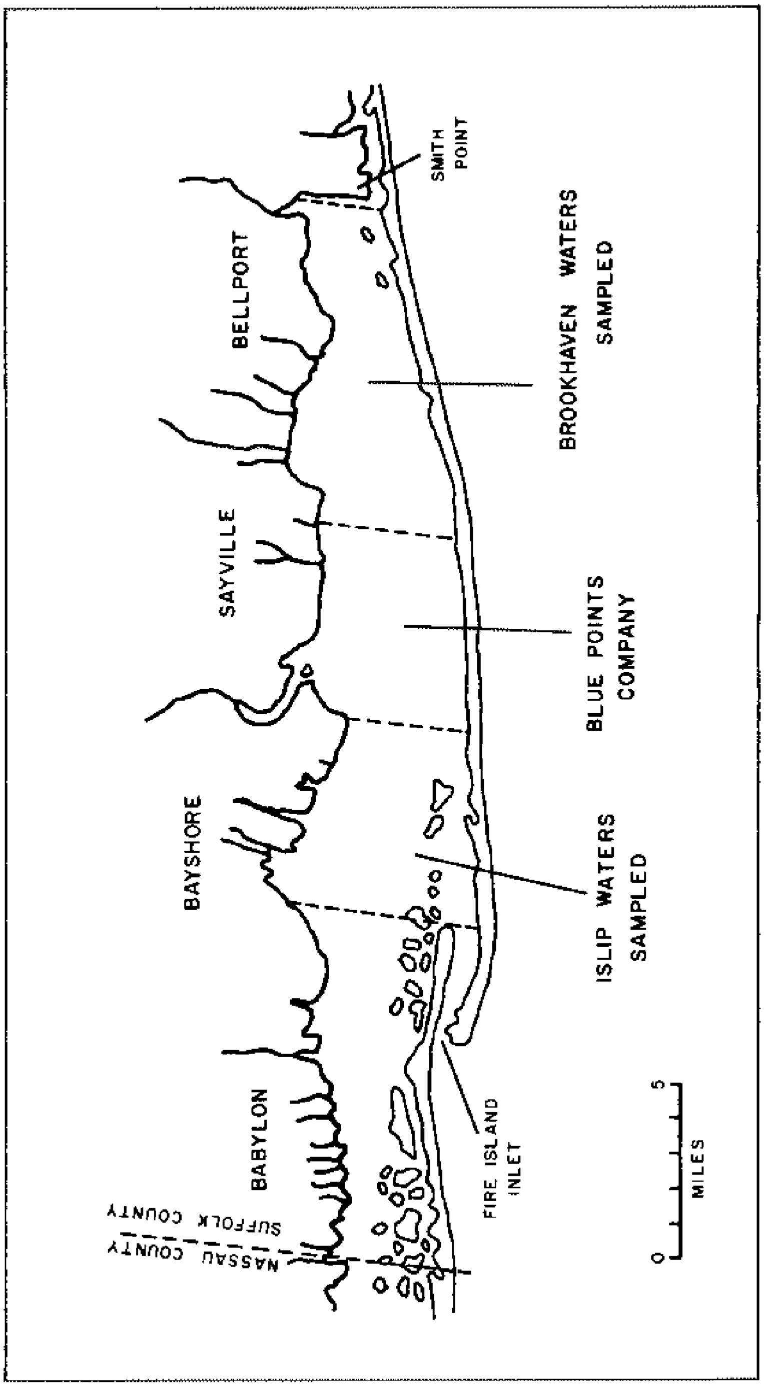

Figure 6. Areas Sampled in This Study.

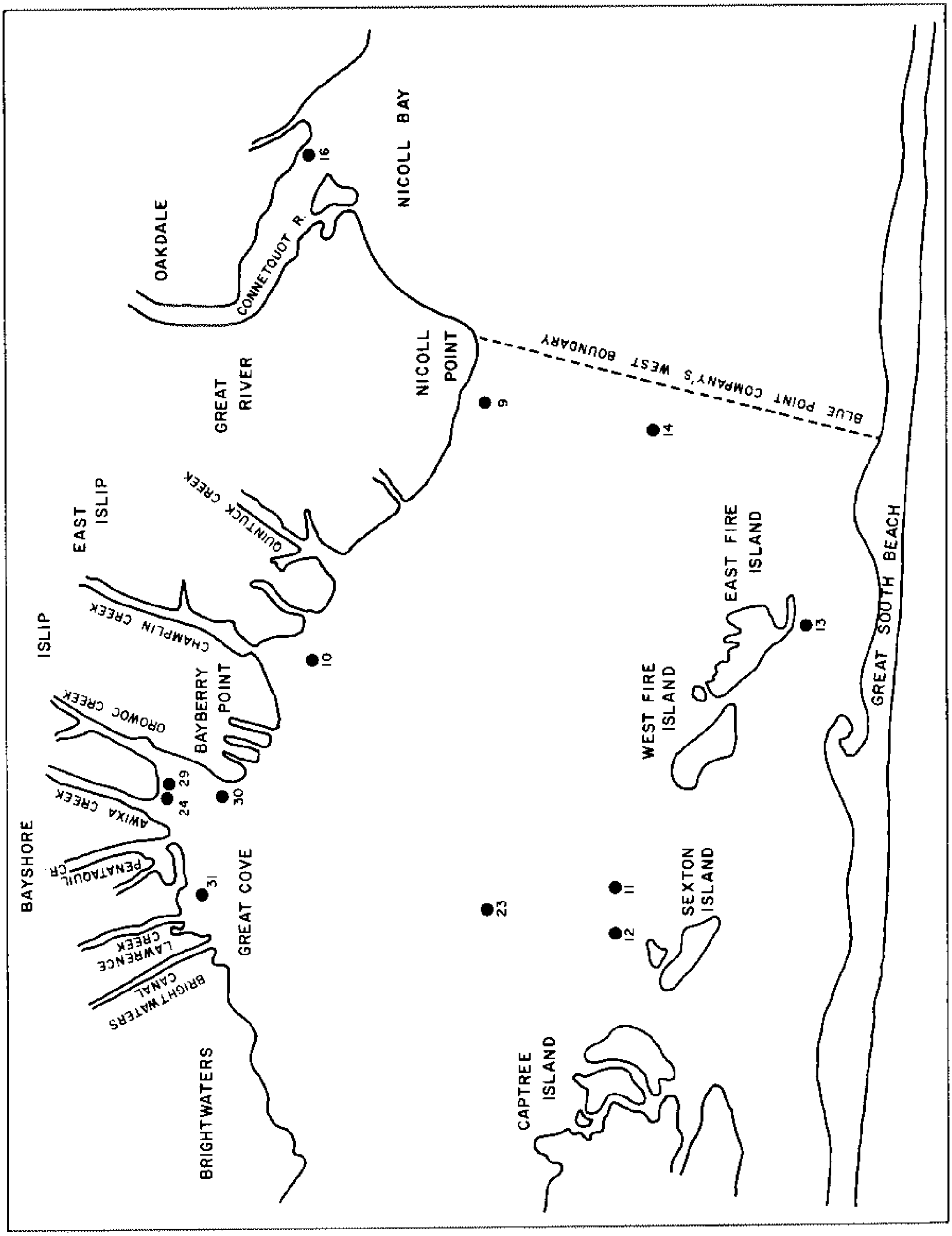

Figure 7. Locations of Stations in Islip Town Waters.
(Station 16 is in Brookhaven Waters.)

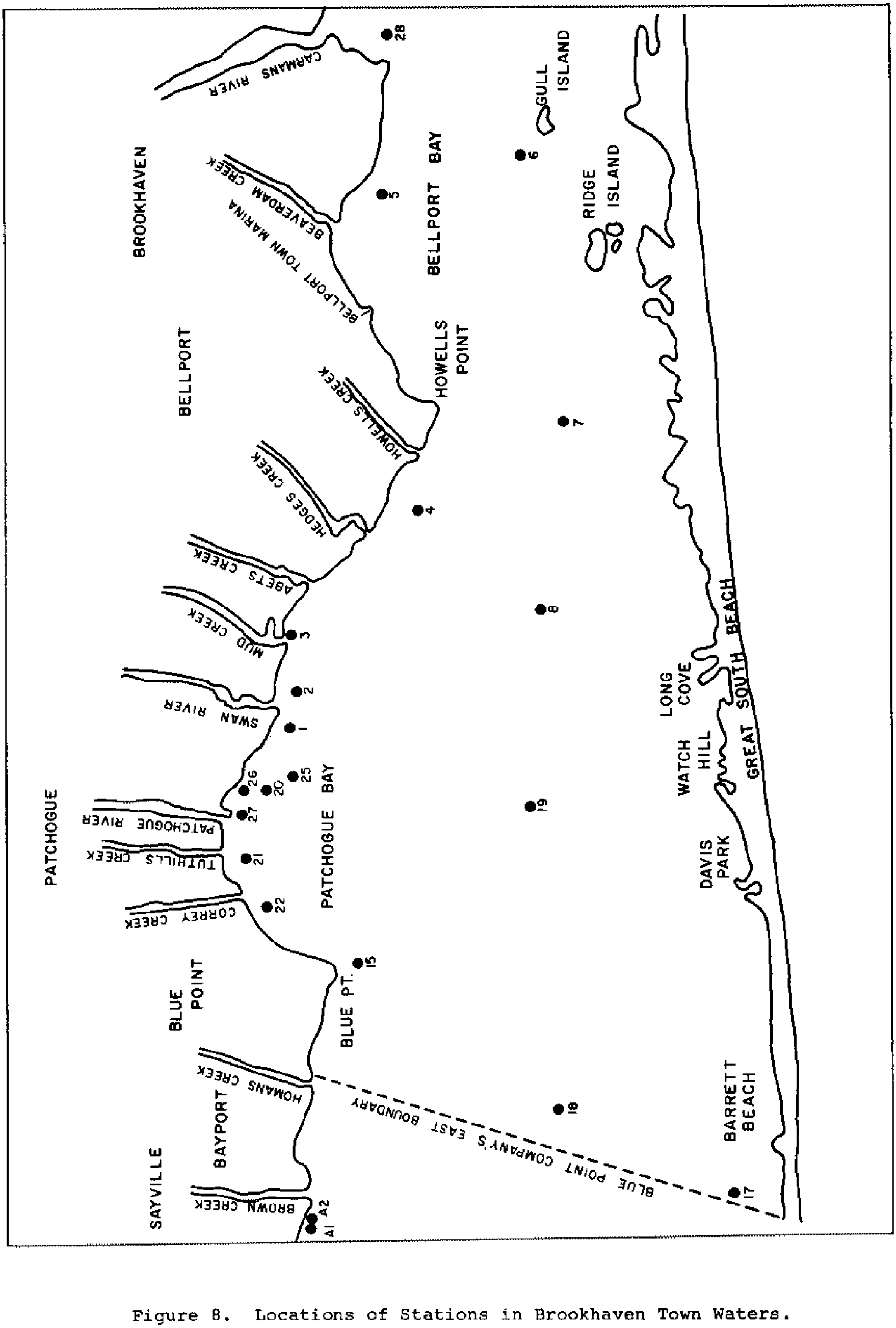

Figure 8. Locations of Stations in Brookhaven Town Waters.

between clams from high mortality areas and clams from low mortality areas, subsamples of 25 clams in the 48-64 mm shell length size range were taken from 6 stations with different mortalities. Meats were dried and weighed and shell dimensions (width, height and length) measured. Average meat weight to shell dimension ratios for the stations were then compared.

To investigate the shelf life of clams, a random subsample of 30 clams from the little neck size category (48-70 mm, shell length) were taken from each station sample and kept in an incubator at constant temperature (9° C ± 1° C or about 48° F) and constant humidity. A temperature of 48° F was chosen to simulate conditions under which clams are usually stored commercially. The Great South Bay Farmers Co-Op Association, Inc. for example, normally stores clams at temperatures between 45 and 50° F (Art Egidi, personal communication). Only little necks were used in this part of the study because they are commercially most valuable and because they took up less incubator space than larger clams. The time in days that it took for the first clam and the first 10 clams from each station to die was recorded. These data were then compared to determine if there was a relation between shelf life and mortality.

In addition to the actual experimental work, we attempted to get information on other research that may have been done on mortality of hard clams in the Great South Bay during the winter of 1976-77. Very little research of this type had been done, but a few other estimates of winter mortality for selected areas of Great South Bay were made and are included later in this report.

RESULTS - MORTALITY AND SHELF LIFE

Table 1 presents clam mortalities observed at each station and Table 2 presents the other station data measured in this study. Stations 23 and 24 are lacking much of this information because they were sampled in a preliminary study before the complete sampling scheme was organized.

Mortality was quite variable, ranging from 0 to 27.2 %. Because it became apparent after the initial sampling that Patchogue Bay had considerably higher mortalities than other areas of the Bay, samples were subsequently taken at 7 additional stations in the area to define more clearly the localized nature of the high mortality. High mortality was limited to the part of Patchogue Bay adjacent to the shoreline from Blue Point to Mud Creek. Highest mortality was 27.2 % at Station 20 and the average mortality at the 8 stations in Patchogue Bay was 12.4 %. The rest of Great South Bay had mortalities ranging from 0 to 5.7 % with an average of 1.6 %.

Results of the shelf life experiment are shown in Table 1. Time for the first clam to die for each station ranged from 3 to 22 days. Time for the first 10 clams to die for each station ranged from 15 to 38 days, with an average of 25 days. Regression analysis failed to show any significant relation between shelf life and mortality.

DISCUSSION

Winter Mortality of Mercenaria mercenaria

Winterkill of shellfishes can be caused by 5 basic processes:

1) Direct freezing of tissues, causing disruption of metabolic activities, cellular damage, and dehydration by ice crystal formations;
2) Suffocation or starvation from lack of oxygen or food in waters in which ice cover drastically reduces circulation;
3) Crushing of shells or transport of shellfish to uninhabitable

TABLE 1

Clam Mortality and Shelf Life Data

Station Number	Date Sampled	Sample Size	Percent Mortality	Shelf Life* t_1	Shelf Life* t_{10}
1	3/12	250	12.0	3	15
2	3/12	229	5.7	8	16
3	3/12	231	2.2	3	21
4	3/12	220	2.7	12	22
5	3/12	210	0.0	15	21
6	3/12	202	0.0	19	22
7	3/12	230	5.7	13	21
8	3/12	210	4.8	16	21
9	3/15	219	0.5	22	29
10	3/15	202	0.5	17	36
11	3/15	229	4.8	7	33
12	3/15	210	0.5	12	26
13	3/15	202	0.5	22	37
14	3/15	163	1.2	22	36
15	3/17	217	2.3	17	38
16	3/17	205	0.0	18	24
17	3/27	206	0.5	16	37
18	3/27	150	0.0	11	35
19	3/27	209	1.4	14	28
20	3/27	290	27.2	14	21
21	3/27	240	12.9	8	21
22	3/27	211	3.3	15	28
23	3/5	213	0.5		
24	3/5	118	1.7		
25	3/30	111	12.6	11	27
26	3/30	237	10.5	12	24
27	3/30	321	15.3	15	21
28	3/30	207	1.0	7	22
29	4/1	236	1.0	11	17
30	4/1	247	4.0	14	18
31	4/1	222	0.5	16	22

*Shelf life expressed as: t_1 = time taken for the first clam to die
t_{10} = time taken for the first 10 clams to die

TABLE 2

Station Characteristics

Station Number	Depth (m)	Percent Organic Matter	Percent Gravel	Percent Sand	Percent Silt	Percent Clay	Salinity (ppt)	Clams per m^2
1	1.2	0.44	10.0	88.6	0.1	1.3	24.5	38
2	0.8	0.50	0.1	97.7	0.7	1.4	23.4	32
3	0.6	0.71	1.5	96.3	0.7	1.9	23.8	32
4	1.1	0.47	1.7	96.2	0.7	1.4	23.3	22
5	1.2	1.27	0.4	89.6	4.6	5.1	22.6	16
6	1.2	1.36	0.0	87.1	9.0	3.9	24.9	16
7	1.4	0.48	0.0	96.3	1.5	2.2	25.3	16
8	1.4	0.96	0.0	94.4	3.0	2.6	26.1	16
9	1.8	0.47	1.0	97.3	0.1	1.6	27.4	11
10	1.8	0.58	3.3	93.9	0.3	1.5	26.7	11
11	2.3	0.99	2.3	90.9	3.3	3.5	28.7	22
12	0.6	0.51	0.2	97.1	0.3	2.4	29.9	5
13	1.2	0.97	0.0	93.3	3.6	3.1	30.8	16
14	1.5	0.67	0.0	96.1	1.2	2.7	29.2	11
15	1.5	0.33	2.9	93.9	0.7	2.5	25.8	22
16	0.8	0.82	0.3	96.0	1.5	2.2	25.4	5
17	1.2	0.40	0.0	97.4	0.9	1.7	28.5	16
18	2.4	0.74	0.1	95.6	1.3	3.0	28.4	11
19	1.5	0.47	0.0	98.1	0.0	1.9	28.0	22
20	1.8	0.79	2.5	86.8	5.1	5.6	27.3	50
21	1.8	0.55	0.3	94.4	1.9	3.4	27.5	38
22	1.5	0.42	1.7	95.3	0.8	2.1	27.5	22
23	1.5							16
24	0.9							43
25	2.4	4.27	5.1	9.4	78.4	7.1	25.3	5
26	1.2	0.48	1.8	95.5	0.7	2.0	26.5	65
27	1.5	1.41	50.0	43.1	4.0	2.9	26.5	81
28	1.2	3.98	0.2	33.6	55.6	10.3	4.4	27
29	0.9	0.92	12.4	84.4	0.9	2.4	26.5	43
30	1.5	18.89	11.7	78.0	5.4	11.6		32
31	1.2	0.62	1.6	95.0	1.0	2.3	27.2	38

environments from mechanical action of shifting ice;

4) Inhibition of other life sustaining activities, such as silt removal and burrowing from prolonged periods of low water temperature and consequential inactivity of poikilothermic animals;

5) Mortality resulting from stresses which inhibit recovery in late winter and early spring.

For several reasons hard clams, particularly those in Great South Bay, are not severely affected by these processes in most cases. There are no significant intertidal clam beds in Great South Bay. Tidal range in the Bay is small, less than 0.3 m in the main part of the Bay and there are no extensive intertidal sand bars or mud flats to contain commercially valuable clam beds. Intertidal clams can suffer high mortality in winter because they can be exposed directly to severe cold, wind, and ice. Intertidal species such as *Mytilus edulis*, *Modiolus modiolus* and *Littorina littorea* can survive partial freezing of their tissues, but *Mercenaria* and other predominantly subtidal shellfishes are extremely sensitive to tissue freezing (Kanwisher, 1955; Kanwisher, 1959). Even a thin layer of salt water provides protection from extreme cold. Ice cover can actually provide insulation and prevent additional cooling of water and of the shellfish below. In a study of winterkill of young hard clams in Maine, Dow and Wallace (1951) demonstrated the importance of a protective cover of water. They found high mortalities of intertidal clams when sediment cover over clams was scoured or eroded away and clams left fully exposed at low tide. On clam flats where waters drained off completely during low tide, winter mortalities averaged 53.5 % and were as high as 100 % for some clam beds. In contrast, the average winter mortality rate where depressions permitted clams to remain covered was only 14 %.

Mechanical action of ice usually has its greatest impact on marine organisms in intertidal areas over which tidally- or wind-induced ice flows scour the substrate. Intertidal shellfishes, particularly those, like oysters and mussels, not burrowed into the substrate, can be crushed by moving ice sheets or carried away from their habitat. *Mercenaria* in Great South Bay are not highly susceptible to such mechanical action because the beds are not intertidal and because the clam lives beneath the substrate surface. Insignificant amounts of clams are occasionally scoured out of the bottom and pushed up onto the beach by moving ice where they are then usually consumed by gulls.

Hard clams can easily survive low oxygen and low food conditions brought on by icing because their metabolism is extremely low at low temperatures. Below temperatures of approximately 3° C, clams remain closed and hibernate, and their food and oxygen requirements are near zero (Loosanoff, 1939; Kanwisher, 1955; Hamwi, 1967; Savage, 1976). Since oxygen and food requirements are minimal at low temperatures, clams are little affected by even severe icing of surface waters and consequent reductions in water circulation and food and oxygen renewal. Even at higher temperatures, Savage (1976) has shown that clams can survive long periods under impoverished oxygen conditions. Continuous exposure to low oxygen water (less than 1 mg/l) for three weeks did not severely or permanently affect clams even at 21° C, a temperature at which metabolism and oxygen requirements are relatively high. Under extremely harsh conditions clams can close their valves and live by anaerobiosis. Using the $CaCO_3$ on the inner shell surfaces to neutralize acidic metabolic wastes, clams can respire anaerobically and live many weeks with their valves closed (Dugal, 1939; Crenshaw and Neff, 1969).

For some species of shellfish, prolonged periods of cold and the resulting inhibition of metabolism and activity can interfere with particular life-sustaining activities. When oysters become dormant from low temperatures, for example, the mechanism by which they rid themselves of dirt and silt is inactive. Winter storms tend to cover inactive oysters with silt and, untimately, they are smothered. Such a process led to extensive mortality of oysters in Chesapeake Bay during the winter of 1976-77 (Anonymous, 1977). During the severe winter of 1962-63 in southern England, intense cold caused oysters to gape and fill with silt. As the temperature rose at winter's end, the oysters could not expel the mud, and although they survived the cold, mortalities of 70 to 90 % were incurred from the secondary effect of choking (Waugh, 1964; Newell, 1964). *Mercenaria* are not as susceptible to silting and burial, but it is not known whether or not cold paralysis leads to the disruption of other life-sustaining activities in the hard clam.

Winter mortality of many shellfishes often occurs during the late winter or very early spring when waters are actually warming. Apparently mortality results from stresses which inhibit life-sustaining activities, such as feeding and respiration, and prevent recovery of normal metabolic activity after the winter hibernation. Many clammers report that winter mortality of hard clams in Great South Bay often occurs at the end of the winter. The exact causes of such mortality, however, are not known.

Studies on winterkill of shellfish during the winter of 1962-63 in Southern England demonstrate very well the hard clam's ability to withstand environmental extremes, particularly in comparison to other shellfish. Mortality of hard clams, a species that was originally transplanted to Great Britain from the United States, was 4.6 %, while the native shellfish *Cardium edule* and *Venerupis decussata* in the same areas suffered mortalities of 62.5 % and 55.9 %, respectively. Other shellfish heavily impacted with mortalities ranging from 60 to 100 % by the severe winter and cold water temperature (as low as 1.8° C) were *Ostrea edulis*, *Crassostrea angulata*, *Anomia ephippium*, *Ensis ensis*, *Mya arenaria*, *Barnea candida* and *Crepidula fornicata*. *Mytilus edulis* and *Mercenaria mercenaria* were the only shellfish relatively unaffected (Newell, 1964; Waugh, 1964). The increase in abundance of the hard clam in certain British waters is thought to be at least partly caused by its high survival compared to native species during a series of exceptionally cold winters (Mitchell, 1974).

Our study showed that winter mortality of hard clams in Great South Bay was low, with the exception of clams in Patchogue Bay. Excluding Patchogue, mortality in the Bay ranged from 0 to 4.8 %, and averaged 1.6 %. The cause of local variations in mortality could not be related to environmental variables at each station; depth, salinity, sediment grain size, sediment organic content, and clam abundance. Because clams in shallow water are more subject to extremes in environment than deep water clams, we expected that mortality would be highest at shallow water stations (Stations 3, 12 and 29). Shallow stations receiving significant inputs of cold land runoff water, such as Station 16 in the Connetquot River, especially were expected to have high mortalities, but this was not so. Apparently even a thin layer of salt water is enough to shelter clams from freezing and ice, as discussed before.

High organic sediments exert a high oxygen demand (Bader, 1954; Hallam, 1965). If oxygen depletion under the ice could have been a problem, high mortality would be expected in areas with highly organic sediments, such as Station 28 in the Carmans River and Station 30 in Great Cove. These stations also showed low mortality, however. If clams in dense populations are subject to intra-specific competition or high rates of infection by parasites and disease, it would be reasonable to expect such clams to be more sensitive to environmental stress and suffer higher winter mortalities. Dense populations of clams in Patchogue Bay experienced high mortality but dense populations in Great Cove, Bayshore, (Stations 24, 30 and 31) did not. Correlations between mortality and depth, sediment organic content, sediment clay, silt and sand content, and clam abundance were all insignificant at the 5 % significance level.

During the coldest part of the winter many clammers reported occurrence of "anchor ice". Ice forms in the sediment, supposedly because freshwater seeping up from the ground freezes, while the overlying water remains unfrozen. Clammers also reported that most of the clams in such anchor ice areas were still alive when the ice thawed and clamming resumed there. Clamming grounds around Bayberry Point in the vicinity of Station 30 were reportedly areas of anchor ice formation. This might explain the slightly above average mortality (4 %) found at that station.

Mortality in Patchogue Bay

Clams in the area around the mouth of Patchogue River had a very high mortality during the winter of 1976-77 that could not have been caused by ice and cold alone. Average mortality in Patchogue Cove was 12.4 %, with a maximum at Station 20 of 27.2 %, compared to 1.6 % for the rest of the Bay. The entire cove had elevated mortality but it increased toward the mouth of Patchogue River and was highest approximately 200 m southeast of the river mouth. The area in which the high mortality occurred is considered polluted by the New York Department of Environmental Conservation and is uncertified for shellfishing. The major source of pollution in Patchogue Bay is Patchogue River. Developments adjacent to the river include a petroleum products depot, a sewage treatment plant, a dredging and dock building company, yacht clubs, marinas, ferry docks, various small industries and apartment buildings. Other creeks draining into the cove (Corey Creek, Tuthills Creek, Swan River, Mud Creek, Abets Creek, Hedges Creek and Howells Creek) are used primarily as mooring and servicing areas for small pleasure boats. Since parts of Patchogue Cove have been closed to shellfishing for 35 years, clams are very abundant there.

Winter cold and ice are unlikely to have been the sole causes of the high mortality. No such mortality was found at comparable areas of the Bay, such as the other areas sampled near the mouths of rivers and in other coves (Stations 1, 2, 5, 10, 16, 29, 30 and 31) and particularly other areas closed to shellfishing by pollution and containing high concentrations of clams (Stations 29, 30 and 31). In addition, the inner sides of the valves of gapers found in the cove contained blister-like markings and raised $CaCO_3$ deposits, apparently caused by some type of irritating, infecting agent which clams had tried to seal off with a layer of shell material. Diameters of the blisters ranged from 1 to 5 mm and numbered 1 to 5 per valve. Blisters were definitely associated with high mortality. At Station 20, 67.6 % of the clams found dead had blisters, while only 6.1 % of living clams were so affected. None of several hundred live clams sampled from stations outside of Patchogue Cove had similar infections.

The blisters were apparently caused by some type of parasite that does not bore through the shell but creeps into the valve opening and travels into the clam between the inner shell surface and the mantle. The parasite was nonboring because no holes were present in the shells. Although it has been difficult to identify the parasite from its trace on the shell alone, it seems likely that the blisters were caused by the metacercariae of some trematode (M. Logue, University of Maine, personal communication). The genus *Parvatrema* causes pits on the inner shell surface of various clams. *Parvatrema borealis* is especially common on the Atlantic coast in *Gemma gemma*.

Inner faces of the valves of many of the dead clams contained small $CaCO_3$ ridges parallel to and inside of the pallial lines, suggesting prolonged mantle retraction before death (Jeffries, 1972). The inner faces were also exceedingly chalky, indicating that the clams may have been closed tight and living anaerobically much of the time before death (Dugal, 1939).

Most clams in the Patchogue Cove were in the 25-75 mm shell length size range. Clams of all sizes within this range were found dead and mortality was apparently not related to clam size (Figures 9 and 10). Chi-square goodness of fit tests were performed to determine how well the size-frequency distribution of the dead clams matched the size-frequency distribution of the live clams for Stations 20 and 27. The chi-square tests were consistent with the hypothesis that the size-frequency distribution of dead clams was not statistically different from the size-frequency distribution of live clams. (For Station 20, $0.25 < P < 0.50$, and for Station 27, $0.50 < P < 0.75$.)

Using meat weights as an index of condition, the dried meat weights of clams from 2 high mortality stations (20 and 21) in Patchogue Bay and 4 low mortality stations (17, 18, 19 and 22) were compared to determine if the stress apparently affecting the Patchogue clams was reducing meat weight. Average meat weight to shell dimension ratios (meat weight/shell length, meat weight/shell height and meat weight/shell width) for each station, based on a sample size of 25 clams per

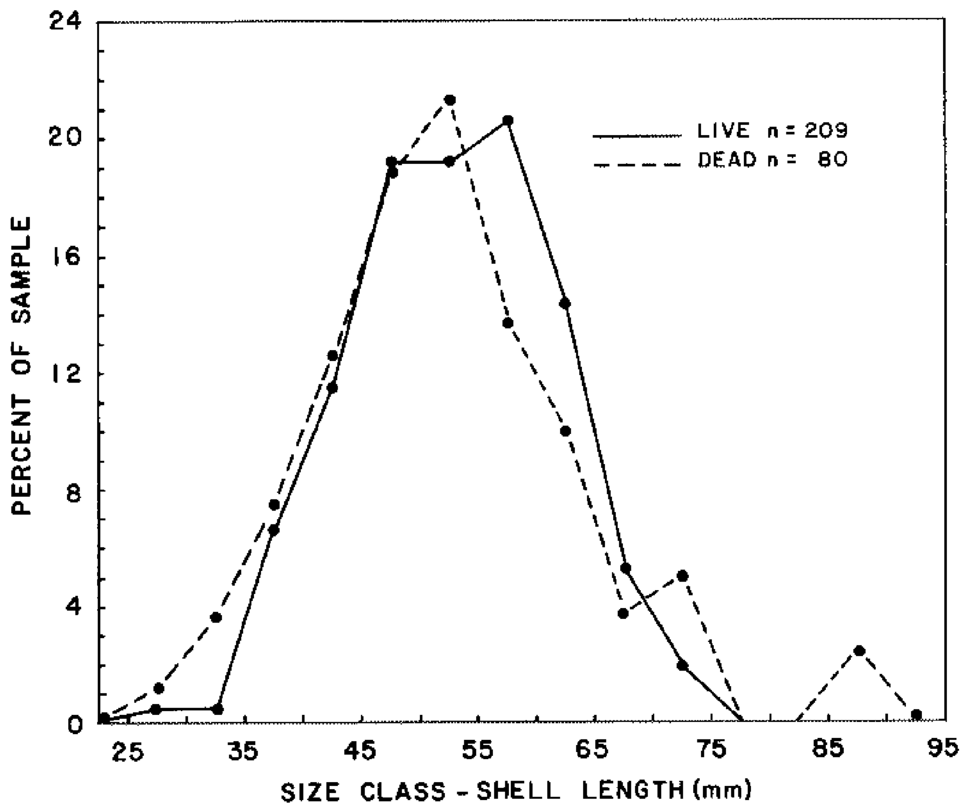

Figure 9. Size-Frequency Distribution of Live and Dead Clams at Station 20.

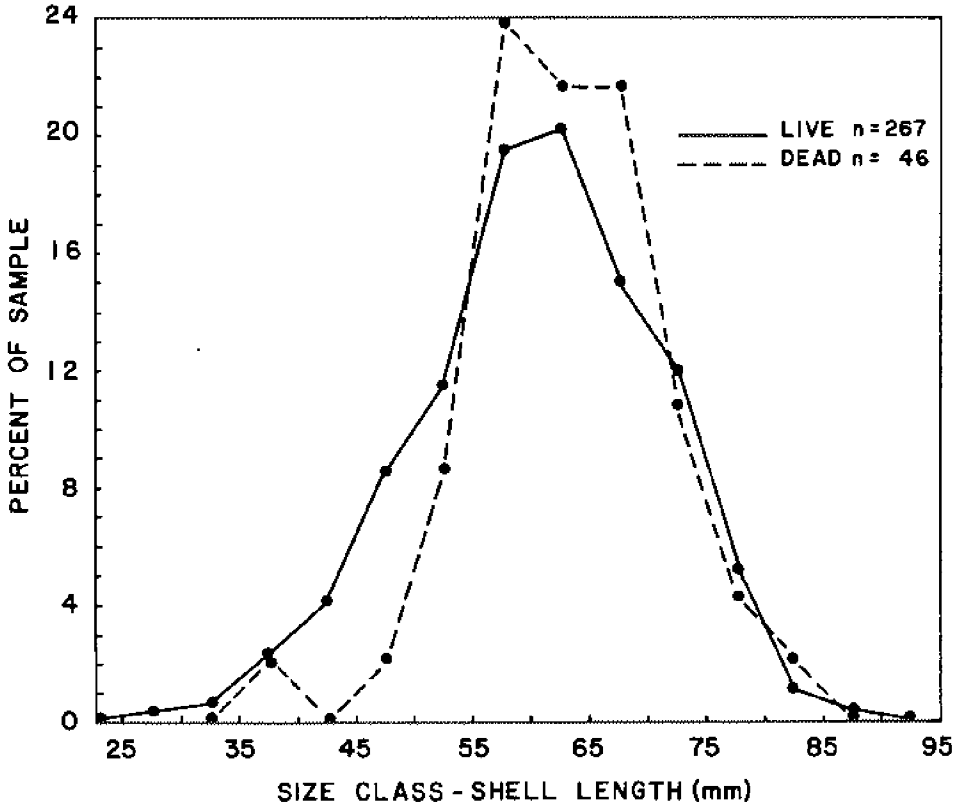

Figure 10. Size-Frequency Distribution of Live and Dead Clams at Station 27.

station, were determined (Table 3). Meat weights to shell dimension ratios were used to account for differences in individual clam shell sizes. Analysis of variance was done to determine if there were significant differences in the

TABLE 3

Average Dry Meat Weight to Shell Dimension Ratios

station	mortality	weight/length			weight/height			weight/width		
		mean	s.d.	c.l.	mean	s.d.	c.l.	mean	s.d.	c.l.
17	0.5	3.63	0.47	±0.18	3.98	0.53	±0.53	6.91	1.02	±0.40
18	0.0	3.52	0.60	±0.24	3.86	0.67	±0.26	6.79	1.26	±0.49
19	1.4	2.93	0.58	±0.23	3.22	0.63	±0.25	5.53	1.10	±0.43
20	27.2	3.06	0.42	±0.16	3.41	0.46	±0.18	5.96	0.79	±0.31
21	12.9	3.17	0.46	±0.19	3.52	0.50	±0.20	6.04	0.94	±0.37
22	3.3	3.47	0.45	±0.18	3.88	0.48	±0.19	6.56	0.81	±0.32

n = 25 clams for all stations

s.d. = standard deviation

c.l. = 95 % confidence limits on the mean means of the meat weight to shell dimension ratios between the two groups of clams. Meat weights per unit shell size of clams from the high mortality stations (20 and 21) were significantly less than meat weights of clams from low mortality stations (17, 18, 19 and 22). Results were significant at the 1 % level for meat weight/shell length and meat weight/shell height and at the 5 % level for meat weight/shell width. (F ratio values for length, height and width ratios were 9.573, 8.016 and 6.562, respectively. Values for significance are: $F_{0.05} = 3.907$ and $F_{0.01} = 6.813$.) This indicates that even clams that did not die at the high mortality stations were being adversely affected, as shown by lower meat weights per unit shell size compared to a control group.

To determine if high mortality in Patchogue Cove was a usual winter occurrence, a second sampling was done at Station 20 on May 24, 1977, and live clams as well as empty shells were collected. The accumulation of empty shells and the approximate time since their death can provide information on past yearly mortalities. Station 20 has a hard substrate, no rapid sedimentation rate, and no fast currents, so that shells of dead clams are not removed or buried deeply into the substrate after death. Shells were divided into 4 categories:

1) live clams;
2) fresh clappers, with valves still connected and no shell fouling. These clams presumably died after the fall of 1976, representing winterkill in the 1976-77 winter. Fouling and deterioration would have occurred if the clams had died while the water was still warm;
3) older clappers with valves loosely connected despite ligament deterioration. Shells were fouled with algae. These were presumably clams that died before the fall of 1976, underwent one summer's fouling only, and hence represent mortality of 2 years ago;
4) all other clam shells. Valves were totally separated, highly eroded and encrusted with worm tubes and boring sponge. These shells were in various degrees of deterioration and represented all years of mortality before the winter of 1976-77 and the preceding year. They had undergone more than a single summer of encrustation and erosion. Total sample size was 209.

Based on the results of the second sampling, mortality over the 1976-77 winter was 26.2 % at Station 20 (27.2 % was the initial estimate based on the first sampling.). Estimated mortality for the previous winter and summer was 16.6 %. Only 35.5 % of all dead shells recovered represented mortality for all of the past years represented in the shell record. This is a strong indication that mortality in the winter of 1976-77 was indeed extreme and that mortality during the previous year was lower, but still much higher than average. Most importantly, this shows that there was no great accumulation of empty shells that would have to exist at Station 20 if mortaltiy had been extremely high each year in the past.

The second sampling on May 24, 1977, at Station 20 also showed that the clams were recovering. No meat-containing gapers were found and almost all the clams were growing. Of the living clams sampled, 81.5 % had from 1 to 5 mm of new growth at their shell edges, 15.5 % had approximately 0.75 mm growth, and only 2.9 % showed no new spring growth. In March, none of the clams at Station 20 showed new growth, but most clams from outside of the high mortality area did.

In summary, mortality in Patchogue Cove had the following characteristics:

1) mortality was seasonal, occurring

over the winter but ceasing after March;

2) mortality increased toward the mouth of Patchogue River;
3) dead clams had been infected by some type of parasite;
4) survivors of the mortaltiy were affected enough to have delayed spring growth and reduced meat weights;
5) recovery was fairly complete, as indicated by resumption of growth;
6) heavy mortality is not a normal occurrence for Patchogue Cove.

Jeffries (1972) found an area of high clam mortality in Narragansett Bay at the mouth of the Providence River. He concluded that the clams there were irritated by hydrocarbon pollutants, specifically cyclic alkanes and aromatics derived from petroleum and sewage pollution and incorporated into the sediments. The hydrocarbons clogged the renal sacs of clams and plugged tubules, thus interfering with kidney function. These weakened clams had a high incidence of mud blisters (5 - 10 %) caused by *Polydora* infection, a condition usually uncommon in burrowing animals. The clams were apparently emerging from the sediments in response to the irritants. Clam shells also contained longitudinal ridges on their inner surfaces caused by prolonged mantle contraction, apparently in response to irritants. Similarities between these clams and the Patchogue clams are apparent. The infection in Patchogue clams, however, is not a typical *Polydora* infection since the clams contained no bore holes, no mud blisters and none of the usual tubular excavations, as described by Landers (1967), Davis (1967), and Davis (1969).

Extensive mortality in Patchogue Cove could have been caused by some type of toxic contaminant originating from the Patchogue River. The contaminant could have weakened the clams, allowing infestation by parasites and making them more susceptible to the stress of the severe winter. Parasite infection itself also could have been the cause. Although it is unusual for parasites to cause mass mortalities of their hosts, the severe winter could have imposed an atypical and unexpected stress on the already weakened host clams, causing them to die. Further studies, including a search for the infecting parasite in live clams and histological examination of meats from live and dead clams, are needed to determine what factor or combination of factors caused the mortality.

Shelf Life

The shelf life of clams is an important consideration to the hard clam industry since clams are shipped alive and are usually not killed until shortly before they are eaten or they are eaten alive. Shelf life can also be used as an index of condition because the length of time a clam can live out of water is dependent on its initial health. Contrary to what we expected, clams from high mortality areas did not have significantly shorter shelf lives. We expected that even the survivors from high mortality areas would be weak compared to clams from low mortality areas and thus would not be able to live as long out of water. The correlation between shelf life and mortality was negative, but not statistically significant at the 5 % level.

At only two stations did clams die within the first 5 days of the shelf life study. At Stations 1 and 3, each had a single clam die on the third day. Five days is a typical travel time for clams from digger to consumer. The average time for onset of mortality for all stations was 13 days. This was usually followed by the gradual mortality of the rest of the clams at the rate of usually 1 to 4 clams a day for several weeks. If a bushel containing 500 of these clams was being shipped commercially, approximately 17 clams would be expected to have died in transport. This number of dead clams would cause the entire bushel to smell and would be very noticeable. Such an early death of a small percentage of clams could account for complaints by clam shippers of shorter clam shelf lives during the 1976-77 winter. The few clams that died much sooner than the rest may have been those that were weak and particularly sensitive to winter stress.

Some clams stayed alive for the entire duration of the shelf life study. After 59 days, many of the remaining clams still shut their valves tightly when disturbed, showing that they were still alive after spending such a long time out of water. By the process of anaerobiosis, clams are able to anaerobically utilize energy stored in their tissues. Anaerobic respiration in the clam results in the formation of alanine and succinic acid. The succinic acid waste product is neutralized by dissolution of $CaCO_3$ from the inner shell surfaces (Crenshaw and Neff, 1969; Dugal, 1939). Clams from the shelf life experiment showed considerable amounts of $CaCO_3$ dissolution on the inner surfaces of their valves.

Other Estimates of Winter Mortality of the Hard Clam

As part of an earlier preliminary study of the effects of the severe winter on clams, a sample of clams was taken on February 2, 1977 from Station A2, an area which had been frozen over for more than a month. The station was approximately 20 m offshore at a depth of 0.4 m. At the time of sampling, ice cover was resting solidly on the bay bottom. Sand and shells were even incorporated into the underside of the ice. Three 0.2 m^2 holes were chopped into the ice and all clams in the substrate below were recovered. Twenty-eight large chowder clams (80 - 100 mm in shell length) and 40 seed clams (40 - 46 mm long) were taken. All appeared tightly closed and healthy. The clams had not burrowed to any unusually great depth; all were approximately 2 - 3 cm below the sediment surface and the ice. Because there was a minimum of water circulation beneath the ice, the clams apparently were not able to siphon water and feed and presumably were in hibernation. Microscopic e amination of several of the clam meats showed that their stomachs were completely empty, but otherwise the meats appeared to be in normal condition.

To see if the clams could revive, 38 of the seed clams were placed in an aquarium at 21° C. The clams may have undergone a small amount of conditioning to higher temperatures; they were at room temperature for approximately 1½ hrs while being examined in the laboratory. Acclimation during transport in the trunk of the car was not likely because outdoor temperatures were below freezing. After being in the aquarium for an hour, some clams started burrowing into the sediment, and within 8 hrs all had buried themselves. This is a striking demonstration of the hardiness of hard clams and of their ability to survive severe and prolonged ice conditions and sudden temperature change.

At Station A1, growth and mortality of a group of transplanted clams had been monitored since June 1976 (by G. T. Greene, as part of another study). The clams ranged in shell length from 41 to 47 mm, were individually labelled, and planted directly into the substrate marked off on each side by a line of bricks. The area was very shallow (0.3 m) and was entirely frozen over for approximately 1½ months with an ice cover that penetrated completely to the bottom (as shown by sampling on January 20 and February 2, 1977). Mortality from November to April on a total population of 295 clams was 4.7 %. During the preceding summer and fall, mortality had been 0 %. Shells of dead clams were recovered and death had apparently been caused by extensive shell breakage. Shell breakage was too extreme to have been caused by whelks, crabs or other predators, and may have been caused by the mechanical action of shifting ice blocks during the mid-February thaw.

Bluepoints Company estimated winter mortality on its own grounds, the central portion of Great South Bay not sampled in this study. The company for the most part harvests natural beds with hydraulic escalator dredges. The company's biologists found that winterkill tended to be localized and estimated an average winterkill of approximately 2 % on their beds in about 2 m of water and deeper, which they say is a normal winterkill on their grounds (Emil Usinger, personal communication). This is consistent with our estimate of 1.6 % mortality for the rest of the Bay. Bluepoints Company also reported that all blue crabs (*Callinectes sapidus*) incidentally caught by the clam dredges during the spring of 1977 were dead. Heavy mortalities of blue crabs, up to 75 % in some areas, were also reported to have occurred in Chesapeake Bay from severe winter conditions (Anonymous, 1977).

CONCLUSION
IMPACT OF THE WINTER OF 1976-77 ON THE CLAM INDUSTRY

Mortality of hard clams in Great South Bay during the winter of 1976-77 was not severe. Clams apparently survived extensive cold and icing very well. The exception was the clam population in Patchogue Cove, particularly near the mouth of Patchogue River, which suffered heavy winter mortalities. This was most likely caused by a combination of factors to which winter stress may have been only partly contributory. These clams are in an uncertified area and were not of direct commercial importance. Heavy mortalities in the area have had one positive effect. In many areas of Patchogue Cove, poaching of polluted clams has become less profitable and less tempting because approximately ¼ of the clams have been killed off.

Ironically, the effects of the severe winter may prove to be beneficial to the clam resources of Great South Bay. The 1½ months of ice cover on the Bay brought a halt to clamming on many heavily-exploited clam beds and, in effect, gave the resource the benefits of a closed season. There is also evidence that severe cold may have seriously hurt a major clam predator, the blue crab. The small percentage of clams that did die over the winter probably were the weakest of the population or perhaps carriers of diseases and parasites. Thinning out of such unhealthy individuals through the process of natural selection may tend to strengthen the general population.

One negative effect of the winter could be a slight reduction in the annual growth rates. Clams probably spent more time in hibernation during the winter and may have started spring growth later than usual. Because clam growth during winter is very small, and maximum growth occurs in late spring and early fall, this effect should not be serious.

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