Northeast Fisheries Science Center Reference Document 03-10

Comparison of Invertebrate Abundances in Four Bays of the Northeastern United States: Two Bays with Sparse Quahogs and Two Bays with Abundant Quahogs

by

Clyde L. MacKenzie, Jr.

August 2003

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Science Center
Woods Hole, Massachusetts

August 2003

Northeast Fisheries Science Center Reference Documents

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This document's publication history is as follows: manuscript submitted for review -- February 12, 2003; manuscript accepted through technical review -- August 6, 2003; manuscript accepted through policy review -- August 11, 2003; and camera-ready copy submitted for publication -- August 20, 2003. This document may be cited as:

MacKenzie, C.L., Jr. 2003. Comparison of invertebrate abundances in four bays of the northeastern United States: two bays with sparse quahogs and two bays with abundant quahogs. *Northeast Fish. Sci. Cent. Ref. Doc.* 03-10; 25 p. Available from: National Marine Fisheries Service, 166 Water St., Woods Hole, MA 02543-1026.

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INTRODUCTION

Northern quahogs, *Mercenaria mercenaria*, have been harvested in eastern North America for centuries (MacKenzie and Burrell, 1997). The bays from Rhode Island through New Jersey have been principal harvesting areas (Fig. 1). In the 1960s and 1970s, Great South Bay in Long Island, New York, accounted for around half the total U. S. production of quahogs, as many as 700,000 bushels a year (Anonymous, 1987). In 1879, Barnegat Bay, New Jersey, produced 150,000 bushels of quahogs (Ingersoll, 1887), and as late as the early 1970s it yielded as many as 100,000 bushels (Ford, 1997). Since then, quahog landings in Great South Bay and Barnegat Bay have fallen sharply, and in 2000 Great South Bay produced about 3% (20,000 bushels of quahogs) of peak harvests in the 1960s and 1970s (D. Barnes[1]), and Barnegat Bay produced 0.6% (600 bushels) of the harvest in the early 1970s (P. Lauer[2]). In contrast, quahog harvests/fisherman from Point Judith Pond, RI, have been large because the pond has large stocks of quahogs, and in the 1990s and through 2002, quahog landings from Raritan Bay, NY and NJ, actually rose to about 150,000 bushels/year (MacKenzie and Pikanowski, 1999; MacKenzie et al., In Press; and recent data). The quahogs in Point Judith Pond (12-15 fishermen year-round) and Raritan Bay (180 fishermen) have been heavily harvested.

People have been attempting to explain the causes of the declines in the quahog stocks in Great South Bay and Barnegat Bay. Fishermen and hatchery operators (C. Strong[3], J. Zatilla[4]) on Long Island and fishermen (J. Harry[5], W. Jenks[6]) in New Jersey believe a prime factor has been a decline in water quality, because brown tides in the two bays first appeared almost consistently at the time the quahog seed started to become scarce and their quahog harvests began to decline. In addition, the meats of market-sized quahogs have since been thin and gray.

The thin, gray meats of adult quahogs suggest they have difficulty feeding during the blooms and also that the picoplankton accumulates on the surfaces of their meats. Another cause of the quahog declines may be a steep rise in the abundance of blue crabs, *Callinectes sapidus,* in New York (Briggs, 1998) and New Jersey beginning in the 1970s (Stehlik et al., 1998). Yet another cause of the declines may be overharvesting of the quahogs.

Before implementing the current project, some information was collected concerning the possible importance of predation on quahog abundances. In June 2002, the manager of the Bluepoints quahog-oyster hatchery in West Sayville, New York, informed me that if he planted seed quahogs then in Great South Bay blue crabs or lady crabs, *Ovalipes ocellatus,* would destroy them within a few days. This hatchery had been planting hatchery quahog seed in the bay since the 1960s. Quahog farmers in Barnegat Bay were placing screens over the seed quahogs they had purchased from local hatcheries to prevent blue crabs from destroying them. In July 1986, we obtained 15,000 quahogs 4-5 mm in length from the Tuckerton quahog hatchery. They were divided into five groups of 3,000 quahogs each and then spread in five scattered sites around Barnegat Bay. When the planted sites were examined about 30 days after the planting, all but 4-5 quahogs had been crushed and eaten by crabs, presumably blue crabs, at every site.

In the current project, abundances of benthic invertebrates that inhabit the quahog beds were surveyed in the four bays above: Point Judith Pond, Great South Bay, Raritan Bay, and Barnegat Bay. If invertebrate abundances were much lower in Great South Bay and Barnegat Bay than in Raritan Bay and Point Judith Pond, the cause of the quahog scarcity was unlikely overharvesting of the quahogs, but was more likely related to poor water quality and predation.

HABITAT CHANGES IN GREAT SOUTH BAY AND BARNEGAT BAY SINCE THE 1970s

Great South Bay and Barnegat Bay have relatively narrow openings to the Atlantic Ocean, and thus water exchanges with ocean water is limited. The residence time of water in Great South Bay is 8-12 weeks (anon. 1978), and in Barnegat Bay, in the summer, it is about 10 weeks (Guo et al. 1997). In contrast, Raritan Bay has a wide opening, 9 km, and resident time of its water is 2 weeks (Jeffries, 1962). The residence time of water in Point Judith Pond is unknown.

Great South Bay and Barnegat Bay have had major environmental changes in the past 30-40 years, that coincided with the quahog declines. Their shorelines have experienced extensive residential development followed by excess nutrient loadings, which are diluted only slightly by ocean waters due to the narrow openings. Another change has been an extension of municipal sewerage lines that once emptied treated freshwater into the bays to the far side of their barrier beaches where they empty the freshwater into the ocean. This change resulted in raised salinities in the bays. Concurrently, dense blooms of *Aureococcus anophagefferens,* a coccoid picophytoplanktonic alga*,* and other algae, including the chlorophyte *Nannochloris atomus* and the dinoflagellate *Alexandrium fundyense,* have developed in the bays during summers. *A. anophagefferens* requires salinities above 22 ppt to grow (Olsen and Mahoney, 2001). They are the causative agents of “brown,” “green,” and “red” tides, respectively. Blooms of *A. anophagefferans* cause high mortalities to quahog larvae and prevent the growth of juvenile quahogs (Greenfield and Lonsdale, 2002), and laboratory studies demonstrated that monospecific cultures of *N. atomus* do not support growth of larval or juvenile quahogs (Tiu et al., 1989; Bass et al., 1990). *A. anophagefferens* has small cells (about 2*u*m in diameter)

(Grizzle et al, 2001), that the quahogs cannot filter (Tracy, 1988). In excised quahog gill tissues, these cells have been shown to inhibit their ciliary beats (Gainey and Shumway, 1991).

The increase in blue crab abundances occurred during and after the 1970s. New York landings of blue crabs increased from about 1,000 pounds/year during the 1960s and 1970s to 513,000-1,215,000 pounds/year during the early 1990s (Briggs, 1998). In New Jersey, blue crab landings increased from less than 1 million pounds/year during the 1960s to nearly 8 million pounds in 1993 (Stehlik et al., 1998). Substantial portions of the landings were from Great South Bay and Barnegat Bay, while most New Jersey landings were from Delaware Bay. Blue crabs are a devastating predator of juvenile quahogs when abundant (Kraeuter, 2001; MacKenzie et al., in press). They also feed on a wide array of invertebrates that are associated in the bottom with quahogs (Stehlik et al., 1998). Lady crabs and rock crabs are also present in Great South Bay and Barnegat Bay.

DESCRIPTIONS OF THE BAYS' HABITATS AND QUAHOG FISHERIES

Point Judith Pond (Fig. 2)

Point Judith Pond, 5 km long and about 1 km wide, has a relatively wide, deep inlet to the Atlantic Ocean, and there is little shoaling on its inside or outside. The rise and fall of tide inside the pond is the same as it is outside in Block Island Sound, which suggests a large exchange of pond and ocean waters. There has been little obvious pollution in the pond, and as it has few noticeable plankton blooms the water is relatively clear (MacKenzie et al., In Press).

Point Judith Pond is a productive quahog-producing area in Rhode Island. Year-round, the pond usually has 12-15 quahog diggers, each harvesting about 1400 quahogs/day, over 90%

of which have been littlenecks (1.75-2.25 in. in diameter), the size that brings the highest landed price (about 20 cents ea.). The diggers have seen large numbers of quahog seed in the beds and have not mentioned any scarcity of quahogs (MacKenzie et al., In Press).

Great South Bay (Fig. 3)

Great South Bay, along the south side of Long Island, N.Y., is about 50 km long, 10 km wide, and has an area of about 50,000 acres. The public bottoms of the bay extend for nearly 50,000 acres and comprise about 55% of the total extent of quahog harvesting area; the reminder has been privately owned or leased. The bay has one major inlet, Fire Island Inlet, an opening to the Atlantic Ocean, at its southwestern end. This opening is rather narrow and is shoaled on its inside, which limits the rise and fall of tide in the bay is about 60 cm. Two other inlets to the ocean, Jones Inlet located farther west, and Moriches Inlet in Moriches Bay at the east end of Great south Bay, are much smaller than Fire Island Inlet. The bay's bottom is mostly fine sand with oyster shells occurring in small zones. Its water depth throughout is 2-3 m.

The percentage of total U.S. landings of *M. mercenaria* coming from New York (mainly Great South Bay) reached about 50% in 1947, but it dropped afterward to just under 20% in 1954. In 2 years in the late 1950s and early 1960s, quahog juveniles set densely throughout most of Great South Bay. In 1958 Moriches Inlet was widened and deepened by dredging, and it led to an increase in water exchange with the ocean and an increase in salinity. This opening apparently set the environmental stage for the boom in quahog abundance in Great South Bay in the 1960s and 1970s. Because the bay's quahogs grow slowly, they remained as seed and littlenecks for several years (MacKenzie et al., 2001; MacKenzie et al., in press). By the mid-

1960s, a few thousand fishermen were harvesting the quahogs on the bay's public bottoms; most were landing 5-10 bushels/day. Quahog production from the bay rose steadily to slightly above 60% of the U.S. total in 1978 and remained slightly above 50% of the total until 1980 (McHugh 1991). Afterward, the bay's landings fell sharply. In 1999, only about 50 men raked quahogs on the public bottoms of the bay. Each usually harvested 1.5-2 bushels of quahogs/day. Since then, the quahogs have become even scarcer, and in 2002 each raker landed only about 500 quahogs (slightly less than a bushel per raker/day) (MacKenzie et al., In Press).

A Great South Bay survey of quahog abundance in 1975 showed there were relatively few seed under the length of 40 mm (Fig. 4). This shows that little setting had occurred for 4 to 5 years before that, i.e., 1971-1975. Normally there would be far more seed in each length grouping than in the groupings between 40 and 55 mm. A glance at Figure 4, upper panel, shows quahog landings in that period were between 570,000 and nearly 700,000 bushels/year, about the most ever produced from the bay. The bay obviously had a large quantity of mature quahogs, enough to produce huge quantities of quahog larvae.

Summer blooms of *N. atomus* and *A. anophagefferens* were documented in the 1950s and in 1985, respectively, in Great South Bay (Cosper et al., 1987). Both have reappeared in them nearly every summer since about 1985 (Bricelj and Lonsdale, 1997). In the continued presence of *A. anophagefferens* in Great South Bay, the meats of quahogs are thin and gray and the quahogs grow slowly (D. Relyea[7], C. Strong[3]).

Raritan Bay (Fig. 5)

Raritan Bay is triangular-shaped and about 19 km long. Its deeper areas in New Jersey consist of mud, the shallower areas of sand. Raritan Bay has an opening to the ocean that is 9 km wide, allowing a large exchange of its waters with ocean waters. The rise and fall of tide (2 m) are about the same inside the bay and in the nearby ocean. The bay is polluted with nutrients, but the large tidal exchange prevents nearly all deleterious blooms from developing in it. Newell (2003) stated Raritan Bay waters have four times the quantity of chlorophyll as Great South Bay, but does not have its picoplankton.

In recent years, Raritan Bay has been a large producer of quahogs. But in 1990, only about 15 men were digging clams in the southeastern part of the bay and the harvesting was limited to 3-4 small areas. The quahogs were relayed to Barnegat Bay for depuration. During the 1990s, quahog abundance increased sharply over about 6,000 acres. The quahog harvesting fleet swelled to about 100 bull rakers by 1999. Two quahog depuration plants began operations and they purchased most quahogs landed; the remainder were relayed to Barnegat Bay. Each fishermen harvested 4-8 bushels of quahogs/day (MacKenzie and Pikanowski, 1999). The New Jersey fishermen were not harvesting the quahogs fast enough to keep up with quahog growth. Consequently, the littlenecks and topnecks (about 2.3-2.8 cm long, a market size slightly larger than littlenecks), the two quahog sizes that bring the highest market prices, grew to the cherrystone and chowder sizes before the fishermen could harvest them, and now the bay has mostly the larger quahogs. The fishermen usually return the chowders to the bottom because they sell for low prices, \$3.00/bushel (J. Harry[5]).

Barnegat Bay (Fig. 6)

This paper will consider the sections of New Jersey's coastal bays known as Barnegat Bay and Little Egg Harbor. Collectively, they span a longitudinal distance of 62 km and they range from 1.5 to 6.5 km in width. As in Great South Bay, most of their bottoms consist of fine-grained sand, but some consist of mud. Barnegat Bay has one opening directly to the ocean, Barnegat Inlet, located in the southern part of the bay. The bay also has a narrow inlet, the Point Pleasant Canal that connects with the Manasquan River, at its north end, and it is connected with Little Egg Harbor though Manahawkin Bay, that is slightly less than 2 km wide at its southern extremity. Barnegat Inlet is relatively narrow (340 m wide) and extensive shoaling with a narrow winding channel (185 m wide) snaking through the shoal. The rise and fall of tide in the bay is about 20 cm (Chant, 2001) vs. 2 m on its outside beaches. Little Egg Harbor also has one opening, Beach Haven Inlet, at its south end. This inlet also has extensive shoals in its inside with a channel 8-9-km long running through it; in places it is 170 m wide.

During summers in the 1950s when quahogs were abundant, about 250 fishermen were harvesting quahogs in Barnegat Bay and Little Egg Harbor. Most used tongs and short rakes for harvesting, while some used bull rakes and some treaded (MacKenzie et al., In Press). A 1969-73 survey of the invertebrates in Barnegat Bay showed the abundance was about 2,775 invertebrates/m^2 (Loveland and Vouglitois, 1984)

After the late 1970s, the numbers of fishermen fell when the quahogs became scarcer, and from 1998 to 2002 only about 8 men were digging quahogs in the summer (P. Lauer[2]). They observed little seed in the beds (J. Chadwick[7]). As in Great South Bay during the late summer, the meats of most quahogs in Barnegat Bay have been gray: The mantles, gills, and soft parts of the clams' bodies were so colored, and they became darker when cooked. The meats have been much thinner than meats of normal quahogs. When quahogs have been transferred from Raritan Bay to Barnegat Bay for depuration, after 6 months their meats have become thinner (they usually are harvested in 1-2 months)(J. Harry[5]).

Dense picoplankton blooms in Barnegat Bay and Little Egg Harbor are fairly widespread and prolonged. The distance between Barnegat Inlet and Beach Haven Inlet is about 32 km. The blooms are concentrated over a distance of 20-22 km roughly mid-way between the two inlets. They are dominated by *N. atomus*, but *A. anophagefferens* has had a similar abundance at times. The first occurrences of dense picoplankton blooms causing brown water discoloration in the summer were observed in 1985, but they may have occurred and been unnoticed before that (Olsen and Mahoney, 2001).

METHODS

In 2001, densities of benthic invertebrates in Point Judith Pond, Great South Bay, Raritan Bay, and Barnegat Bay were sampled with a Petite Ponar grab with an opening of 15 X 15 cm; the mesh openings of the sieve used wwere 0.25 *u*m. The grab was operated by hand from small boats. The bottoms sampled all had sand sediments. Two or three grab samples were taken at each station. One station was sampled in Point Judith Pond at a distance of 3.75 km from its inlet; two stations in Great South Bay, both 25 km east of Fire Island Inlet; three stations in Raritan Bay, 5 km south, 5 km west, and 15 km west of its inlet; and three stations in Barnegat Bay, 3 km south, 7 km north of Barnegat Inlet, and another opposite the inlet. All invertebrates initially were preserved in formalin and within 4 days the formalin was replaced with 70% alcohol. The animals then were identified in broad groupings and counted.

Statistical Analysis

Estuary-specific differences in invertebrate community assemblages were identified by constructing station by species Bray-Curtis similarity matrices from the log transformed mean numbers of individuals at each of the stations. A 1-way analysis of similarity (ANOSIM) test, with estuary as a factor, was applied to the matrices to test for significant differences ($p<0.05$) in assemblage structure. The species responsible for differences in assemblage structure were determined by performing the SIMPER analysis. Non metric multidimentional scaling was also performed to visualize similarities in community structure at the stations in the estuaries. All analyses were performed with Primer Software (Clarke, 1993).

RESULTS OF INVERTEBRATE SURVEYS

Mean numbers of invertebrates found in the four bays are shown in Figure 7. The samples from all four bays contained a fairly broad array of invertebrate groups: mollusks, crustaceans, polychaetes, and nemerteans, and also a few anemones in Great South Bay and Barnegat Bay (Tables 1 and 2). Nearly all invertebrates were juveniles (young-of-the-year). Point Judith Pond and Raritan Bay grab samples had an average of about 1,200 invertebrates, whereas the grab samples from Great South Bay and Barnegat Bay had far fewer. The Great South Bay samples had an average of 186 invertebrates, or 15.5% as many, and the Barnegat Bay samples taken at a distance from the inlet had about 365 invertebrates, or 30% as many.

The densities of Barnegat Bay invertebrates apparently have fallen sharply since the Loveland and Vouglitios (1984) survey in 1969-73.

The 1-way ANOSIM test showed that community structures in the 4 estuaries were significantly different (R 0.621, P= 0.001). In addition, pairwise comparisons tests showed all the estuaries, except for Point Judith Pond and Raritan Bay (R=0.095, P=0.225)(Table 1), had significantly different community structures ($R>0.661$, $P<0.018$)(Fig. 8). Shallow coastal bay (Barnegat and Great South bays) stations had low scores on axis 1 of the non-metric multidimentional structure plot while those in Raritan Bay and Point Judith Pond had high scores. Point Judith Pond and Raritan Bay had far more polychaetes (779/grab, both bays together), clams (39 clams/grab, both bays together), and *Crepidula* (8.5/grab, both bays together) than were in Great South Bay and Barnegat Bay. The latter had a combined 194 polychaetes/grab, 1.5 clams/grab, but no *Crepidula*. The grab samples did not collect quahogs in Point Judith Pond, Great South Bay and Barnegat Bay, but they were present in Raritan Bay (3.7/grab).

Differences in community structures at stations in Great South Bay and Barnegat Bay were distinguishable on axis 2 of the ordination plot in Figure 8. The Barnegat Bay samples had more phylogenetic groups than Great South Bay (10 vs. 7), and it had over 40 times more amphipods (353.8 vs. 8.33/grab) and about 3 times as many polychaetes and nemerteans. There are two differences in the habitats where the stations were located in Great South Bay and Barnegat Bay. The stations in Great South Bay were 25 km from Fire Island Inlet, its nearest inlet, whereas the stations in Barnegat Bay were 1 to 7 km from Barnegat Inlet, its nearest inlet.

The other difference is in the orientation of the bays. Great South Bay is oriented in an almost east-west direction. During the summer, wind speeds usually are low in the morning, but they are brisk in a southerly direction most every afternoon. Because of the bay's orientation, the afternoon breezes blow across the bay and would likely have relatively little effect on the bay's water currents. On the other hand, Barnegat Bay is oriented in a north-south direction, and the afternoon breezes from the south blow up the bay and likely have a strong effect on the bay's water currents. The stronger water currents in Barnegat Bay might bring more food to its benthic invertebrates.

CONCLUSION

The survey reveals the benthic invertebrate densities in Great South Bay and Barnegat Bay, where quahogs have become scarce, were much lower than they were in Point Judith Pond and Raritan Bay, where quahogs are abundant. The declines in quahog abundances in Great South Bay and Barnegat Bay probably were related to poor water quality and crab predation. Their brown tides likely interfere with egg production, spawning, and larval development of their invertebrates. Little quahog harvesting has occurred in Great South Bay and Barnegat Bay in the past twenty years, yet abundances of quahogs and invertebrates have not rebounded. Thus, it is unlikely the declines were related to harvesting.

ACKNOWLEDGMENTS

I thank Charles Balsamo, D. G. McMillan and Karen A. Tammi for manning survey vessels. John Manderson provided advice on the statistical analyses and reviewed an earlier draft of the manuscript. Joseph Vitaliano ran the ANOSIM calculation, D. S. Haven and R. N. Reid critically reviewed an earlier draft of the manuscript, and T. Finneran produced the maps.

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Personal Communications

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Table 1. Average abundance (expressed as mean number per grab) and percent contribution of invertebrates to the average dissimilarity of Point Judith Pond and Raritan Bay sample groups as indicated by cluster analysis and ordination of grab collections in June, 2003.

Average Dissimilarity = 33.22

	Abundance (No./Grab)		
Species	Point Judith Pond	Raritan Bay	Percent Contribution
Nucula	67.67	23.00	14.72
Unidentified clams	152.67	47.43	11.81
Tellina	0.00	13.71	10.58
Nemerteans	107.00	124.71	10.20
Crepidula	1.33	15.71	7.72
Harpacticoids	81.00	37.43	7.62
Mites	0.00	13.43	6.94
Amphipods	12.67	84.71	6.11
Juvenile hard clams	0.00	3.71	5.30
Isopods	0.67	4.29	4.81
Polychaetes	785.00	772.14	3.55
Lunatia	0.00	1.71	3.19

Table 2. Average abundance (expressed as mean number per grab) and percent contribution of invertebrates to the average dissilimilarity of Great South Bay and Barnegat Bay sample groups indicated by cluster analysis and ordination of grab collections in June, 2003.

Average Dissilimilarity = 36.07

Species	Abundance (No./Grab) Great South Bay	Barnegat Bay	Percent Contribution
Amphipods	8.33	353.80	23.83
Nemerteans	52.00	156.20	11.38
Unidentified clams	5.50	0.60	9.37
Isopods	3.83	0.80	8.77
Polychaetes	95.50	291.60	8.33
Harpacticoids	21.50	29.00	8.29
Solemya	0.00	2.20	6.77
Anemones	0.50	2.20	6.30
Tellina	0.00	2.00	6.24
Nucula	0.00	2.00	6.24

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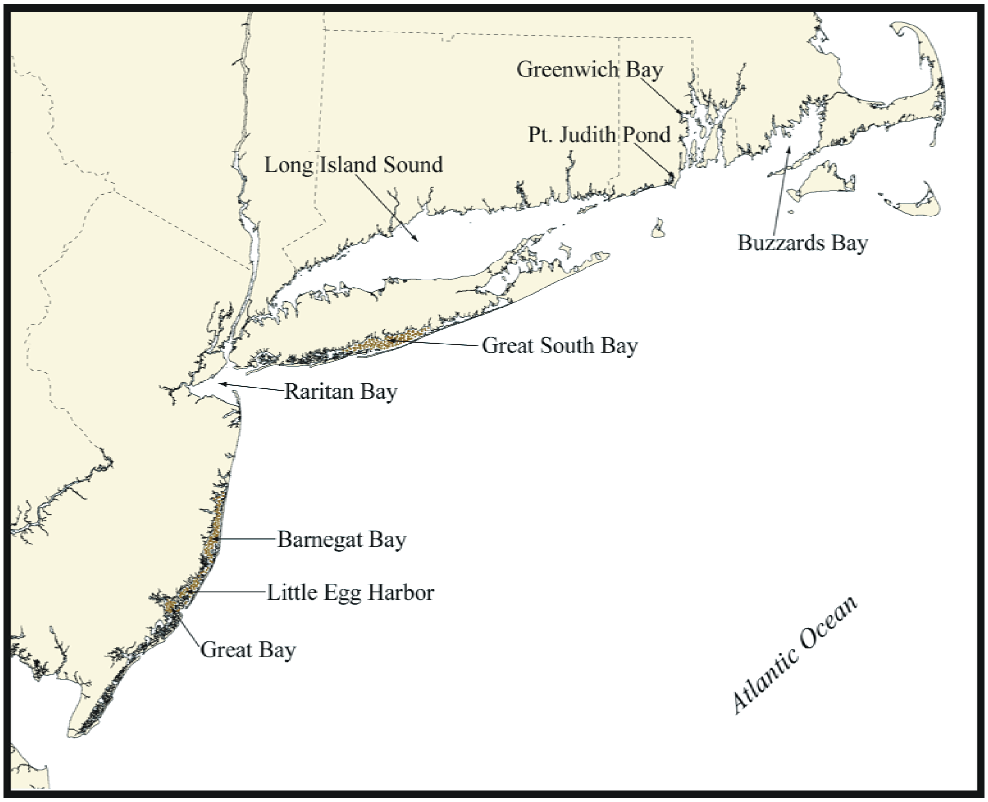

Figure 1. A portion of northeastern United States showing the locations of Pt. Judith Pond, Great South Bay, Raritan Bay, Barnegat Bay, and Little Egg Harbor.

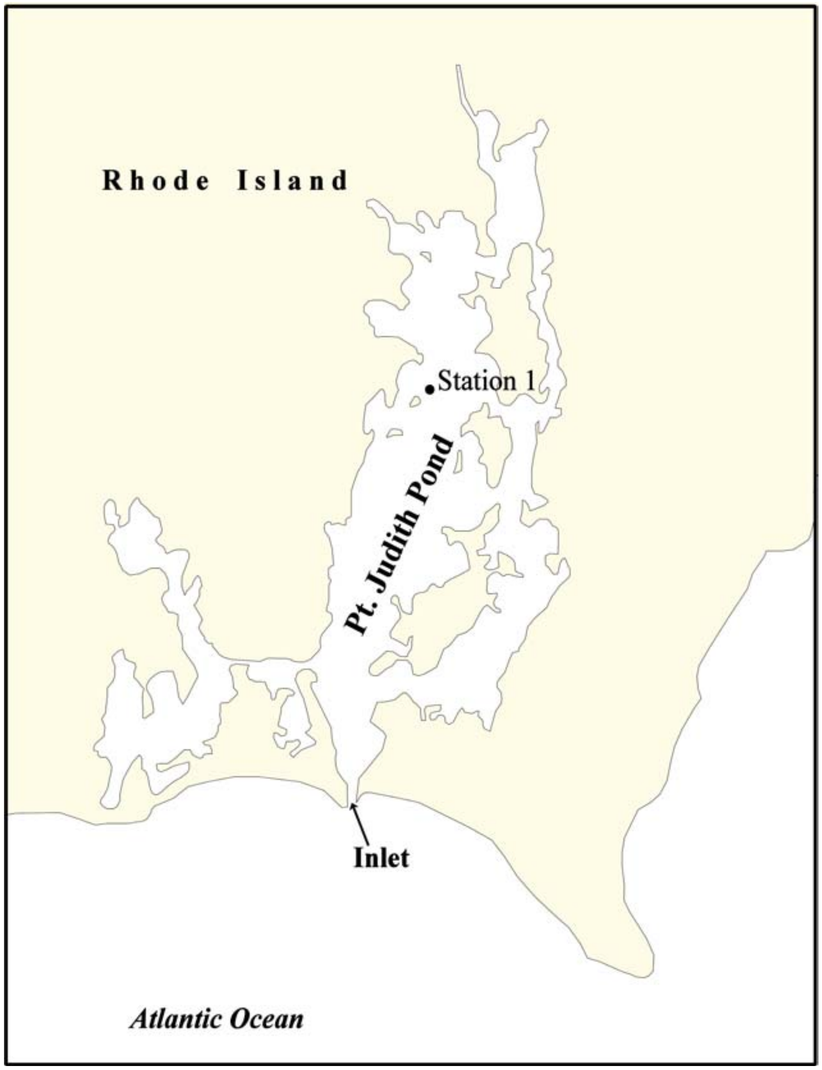

Figure 2. Pt. Judith Pond showing the locations of its inlet and Station 1.

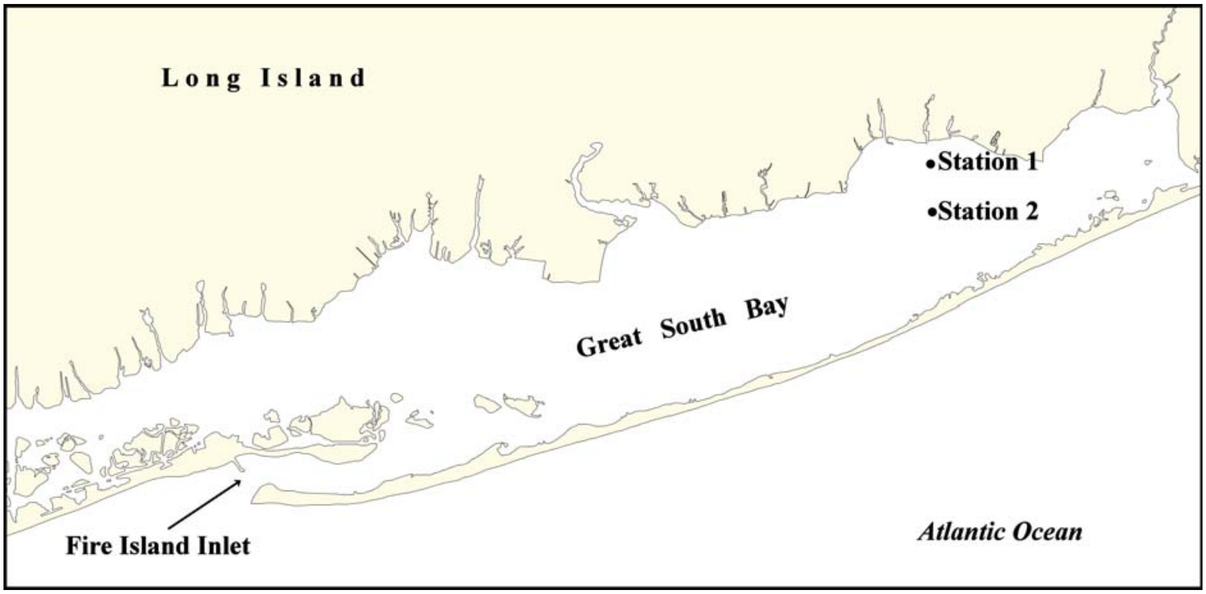

Figure 3. Great South Bay showing the locations of Fire Island Inlet and Stations 1 and 2.

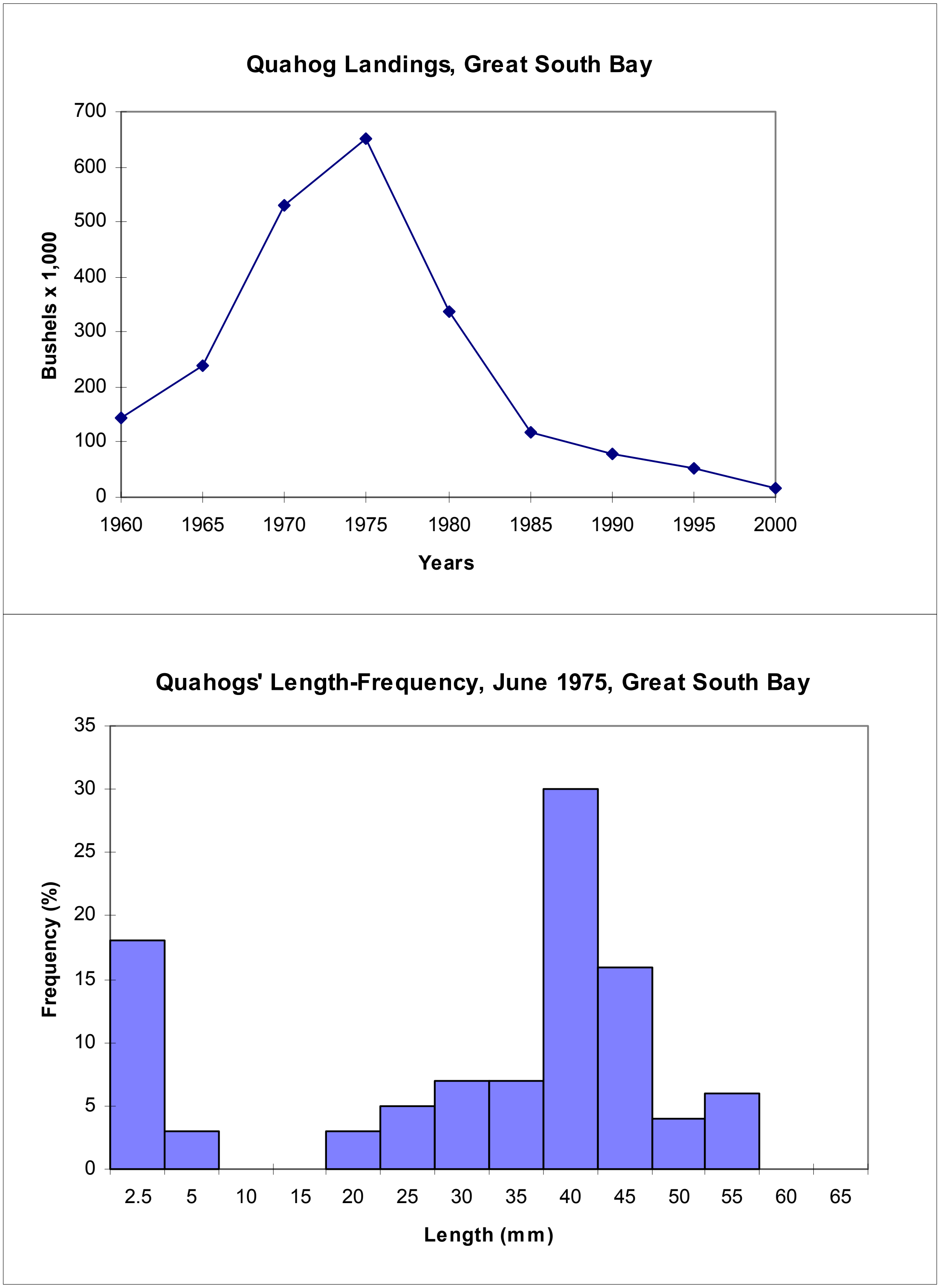

Figure 4. Great South Bay data on historical landings and lengths of quahogs, *Mercenaria mercenaria*. Upper panel shows commercial landings from 1960 to 2000 (data from New York State DEP). Lower panel shows length-frequency data from collections of quahogs on June 10, 1975 (data from MacKenzie, 1977).

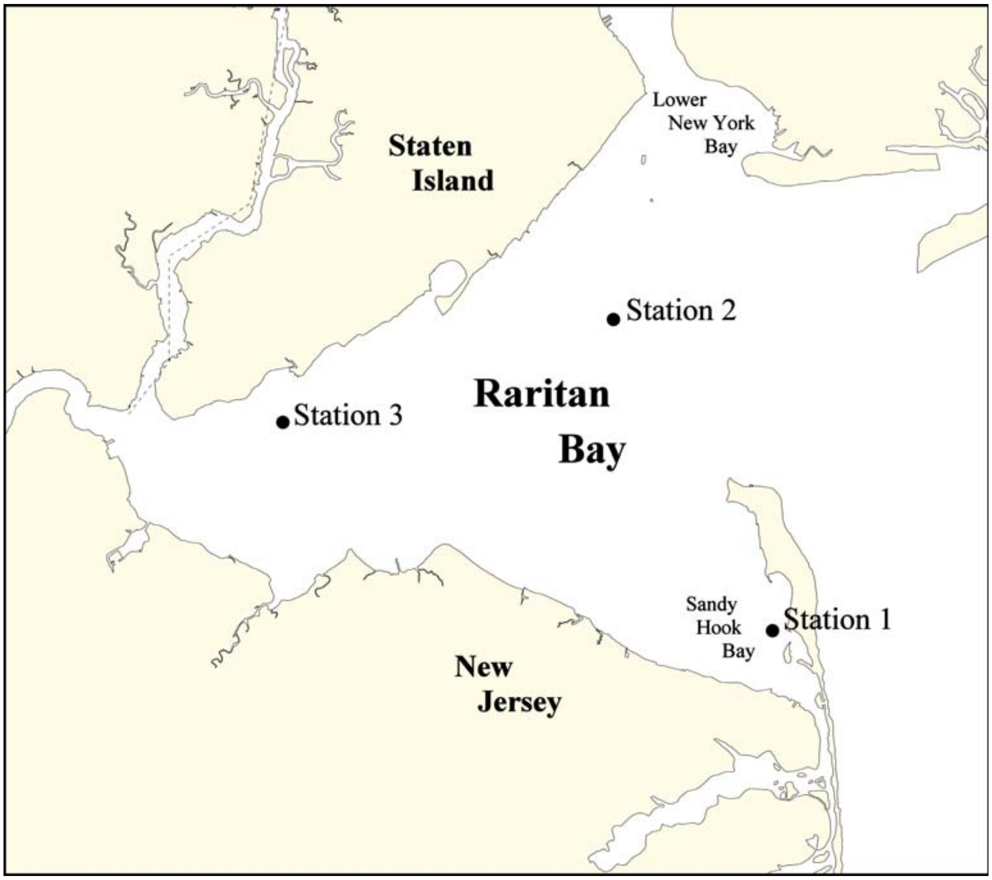

Figure 5. Raritan Bay showing its wide opening to the Atlantic Ocean and the locations of Stations 1, 2, and 3.

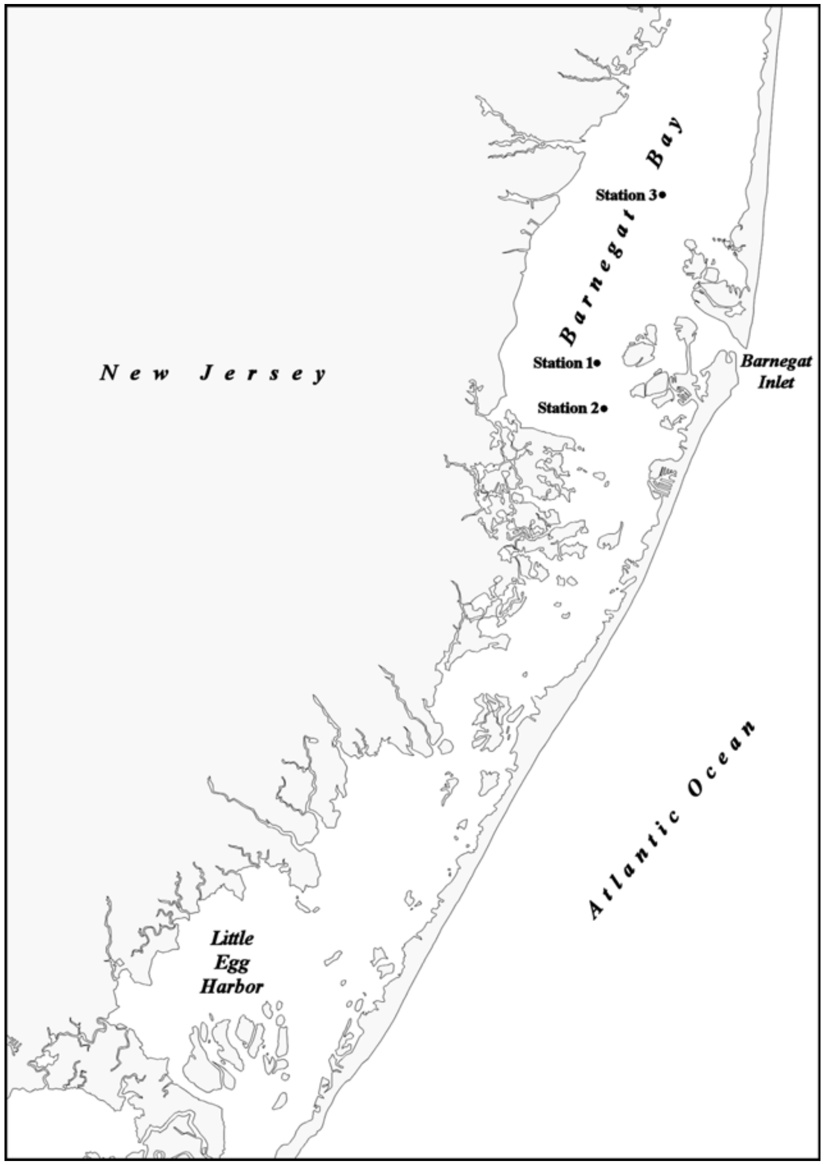

Figure 6. Barnegat Bay and Little Egg Harbor showing the locations of Barnegat Inlet and Stations 1, 2, and 3.

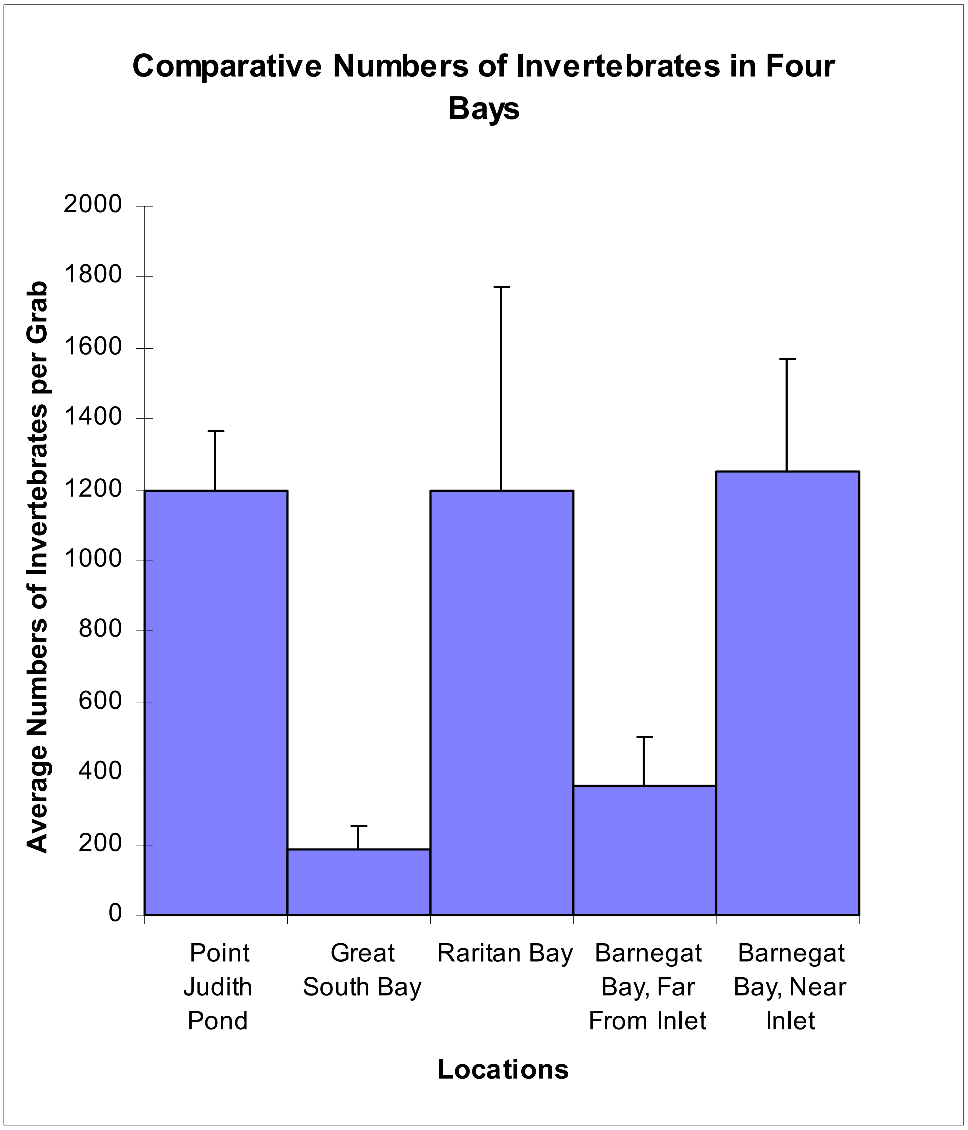

Figure 7. Histobars show the average numbers of invertebrates/grab in the four bays. In Barnegat Bay, the average number of invertebrates/grab at two stations farthest from the inlet and one station directly opposite the inlet are shown.

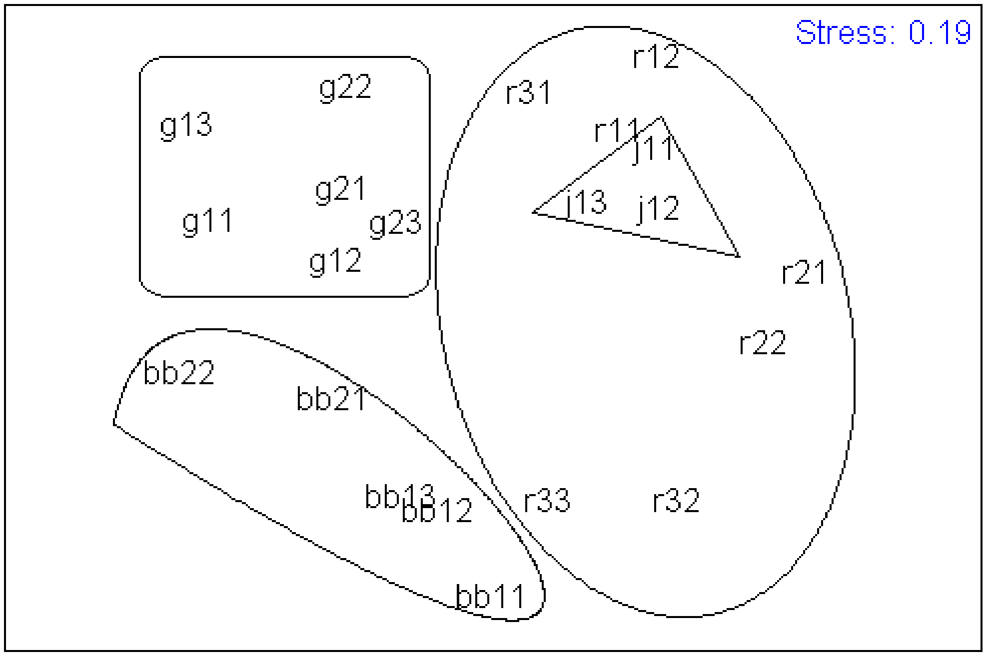

Figure 8. Estuarine station groups based on n-m ordination of Bray-Curtis similarities computed from 4th-root transformed abundances of invertebrates collected at 21 stations (j-Point Judith Pond; g-Great South Bay; r- Raritan Bay; and bb-Barnegat Bay).

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