Sea Grant
New York

Impacts of Barrier Island Breaches on Selected Biological Resources of Great South Bay, **New York**

New York Sea Grant

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Final Report

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INTRODUCTION

The formation of breaches and new inlets along Long Island's south shore barrier island system is a topic of intense interest among coastal planners, managers, decision-makers and the public. Due to the dynamic nature of the processes operating along the coast, new inlets can have a profound impact on the back bay ecosystems. Because these bays are important and productive habitats for a variety of environmentally and economically important species, there is considerable concern about how these physical changes may, in turn, affect living resources found there.

Numerical models are being used to make predictions of how new inlets and breaches may change the hydrodynamic regime of the bays. Computer models can provide insights and quantitative estimates of the effects these features may have on circulation patterns, currents, salinity, water levels and other important physical parameters. However, little is known about the ecological consequences of these potential physical changes and what they may mean for the biota in the bays. To develop effective, technically-sound management policies and plans, decision-makers need quantitative information on how new inlets might affect environmentally and economically important living resources

Towards this end, New York Sea Grant worked with the Marine Sciences Research Center of the State University of New York at Stony Brook with support from the National Park Service to identify and assess the types of information required to properly evaluate the potential impacts of breaches on selected estuarine resources in Great South Bay, the largest of the south shore bays. As part of this effort, a team of experts with extensive scientific research experience and knowledge in the areas of finfish, shellfish and benthic communities, submerged and intertidal vegetation, and water column productivity and plankton was assembled. The team used the results of a numerical computer model (Conley 2000), developed as part of a separate effort, that simulated physical changes associated with new inlets at two likely locations on the Fire Island barrier to begin assessing their potential effect on living resources. The experts identified the resources most likely to be impacted, and evaluated the nature of the impacts and their effects on abundance and distribution of important biota. Steps that could be taken to better define and quantify these impacts from a management perspective were also identified and discussed.

To ensure important management issues were addressed, the experts' findings were reviewed by federal, state and local agency representatives. The resulting information then served as the basis of a workshop which brought together coastal managers, planners, and scientists with local expertise to share information and provide comments.

The results of this effort are summarized in this report. It includes a discussion of selected resources likely to be affected by the presence of new inlets, the factors important in controlling the abundance and distribution of these resources, how they may be affected and what can be done to better understand and quantify the potential biological impacts of inlets. Although not the focus of this effort, a brief summary of the numerical modeling predictions used and the uncertainties associated with these predictions is also included.

This information should be of interest and use to resource managers, planners and decision-makers with responsibilities for developing management policies and strategies related to these features, as well as scientists and researchers.

Background

Historically, the barrier island system along Long Island's south shore has been subject to breaching and the formation of new inlets during storm events. Evidence of these features can be found on charts and maps dating back to the 1700's (Leatherman and Allen 1985). In some cases, storm induced breaches have been artificially stabilized with structures for navigation purposes (i.e., Shinnecock and Moriches Inlets).

More recently, a breach through the barrier during the 1962 "Ash Wednesday" northeast storm precipitated the construction of the Westhampton groin field. In 1980, scour on the bayside east of Moriches Inlet weakened the barrier causing a breach when elevated bay water levels during a storm broke through the island and flowed into the ocean. The inlet was closed artificially one year after it opened (Schmeltz et al. 1982). In December 1992, another northeast storm opened two inlets in the Westhampton barrier. One was closed immediately. The other, known as Little Pike's Inlet, grew rapidly before it was closed artificially some eight months after its creation.

Although the exact conditions that lead to breach formation are not well defined, studies done by the U.S. Army Corps of Engineers (1996) and others (Allen et al. 2000) indicate that portions of the barrier are vulnerable and there is a strong probability that breaches, and perhaps new inlets, may occur in the future.

Breaches can grow into sizable features very quickly. The breach at Moriches Inlet reached a width of 2,900 feet in less than a year, effectively doubling the cross-sectional area of the inlet (Schmeltz et al. 1982). Within 10 months, Little Pike's Inlet breach grew to 2,500 feet wide (U.S. Army Corps of Engineers 1996) and increased the tidal range in Moriches Bay by 30 percent (Conley 1999). The increased tidal range also resulted in a significant increase in salinity in parts of the Bay (Conley 1999). Clearly, new inlets can have a tremendous impact on the physical and environmental characteristics of the surrounding area, which in turn can affect the living resources. For instance, the creation of Moriches Inlet in 1931 increased flushing and raised salinity, allowing predators to invade the bay and destroy the oyster sets (Glancy 1956).

Impacts of new inlets can be beneficial or detrimental depending on the resources of interest and specific management objectives. However, because there is not enough information to accurately predict these impacts, the present state and federal policy governing the management of these features is to close breaches as they occur. This policy is embodied in the Breach Contingency Plan (U.S. Army Corps of Engineers 1996), a cooperative program between the state and the Corps of Engineers which provides a framework for actions to be taken to initiate the emergency closure of breaches.

Current policy can be traced to the Governor's Coastal Erosion Task Force, which was established in 1993 to respond to problems caused by a severe northeast storm that struck the New York marine coast in 1992. The Task Force recommended short and long-term approaches to storm-induced coastal flooding and erosion management. In their final report (Governor's Coastal Erosion Task Force 1994), this group found:

> The available scientific evidence indicates that new inlets would have significant impacts on the physical and environmental characteristics of the bay and barrier ecosystems and environmental conditions. While some impacts may be beneficial, others could adversely affect a number of traditional uses in these areas. As a result, prudent management measures suggest these new inlets be closed as a matter of policy until enough information is available to quantitatively assess the potential impacts of these features.

The Task Force also recommended:

> ...that further scientific studies be undertaken to address and weigh new inlet impacts (environmental and economic) at other locations, and that this policy be amended or confirmed in the near future to reflect the results of those studies.

In line with the recommendations made by the Task Force, the National Park Service, concerned about how new inlets may affect the resources within Fire Island National Seashore, implemented a research project to identify the probable locations of breaches in this area and to quantify the physical changes these features may cause in the back bays. The Park Service's research program included a geomorphological analysis (Allen et al. 2000) and a numerical hydrodynamic modeling component carried out by the Marine Sciences Research Center at the State University of New York at Stony Brook (Conley 2000).

Approach

While the National Park Service's geomorphic and hydrodynamic modeling studies provided quantitative data on the types of physical changes that could be expected from new inlets, they did not address how these changes might impact the biological resources and ecological characteristics of the back bay areas. At the request of the Park Service, New York Sea Grant and the Marine Sciences Research Center initiated a project to assess how the information supplied by the modeling could be used to evaluate potential changes to selected biological resources. The purpose of this effort was to identify the biological resources most likely to be affected by a breach and the types of research and monitoring efforts needed to quantitatively estimate the impacts based on the modeling results.

As the first step in this process, a physical oceanographer conducted an independent review of Conley's (2000) numerical modeling effort and results. Although the National Park Service had done a more rigorous technical analysis of the modeling project as part of their peer review process, a more limited review was done as part of this project to independently assess the soundness of the model and its application and the reasonableness of the predictions. This review also considered the uncertainty and limitations associated with the various predictions provided by the model.

The summary of the model review, including the predictions and limitations, was then provided to experts in each of the following resource areas:

- Water column productivity (plankton and nutrients) (Dr. Elizabeth Cosper)
- Shellfish and benthic invertebrates (Dr. Robert Cerrato)
- Intertidal and submerged aquatic vegetation (Dr. Stuart Findlay) and
- Finfish (Dr. David Conover).

Obviously, the above list does not include all the biological resources that could be impacted by new inlets. However, the limited scope of this project resulted in a decision to concentrate on these four areas. The selection of these categories was based on a number of factors. These resources are extremely important from an environmental and/or economic perspective. A large amount of information on these particular resources had already been compiled and synthesized as part of an earlier project identifying and examining the estuarine resources of Fire Island National Seashore (Bokuniewicz 1993). Finally, one would expect these resources to be relatively sensitive to the changes in environmental conditions associated with a new inlet.

In addition to the summary of modeling results and uncertainties, the experts were also provided with a list of questions they were asked to address regarding the specific resource of concern. The questions were designed to have the experts do the following:

- Identify environmentally/economically important species and critical habitats for the resource category,
- Describe and define environmental parameters controlling resource abundance and distribution by habitat,
- Assess the potential impact of modeled physical changes on critical environmental parameters and the resources and provide estimates of direction and magnitude of the change where possible and
- Identify information needed to better assess and quantify impacts on the resources.

The experts' written responses were compiled and distributed to each of the authors to ascertain whether there might be indirect or synergistic effects where potential changes in one resource might impact another.

The draft document was sent to federal, local and state managers and agency personnel for review. A revised draft report served as the basis for a workshop, held on January 23, 2001, that brought together a wide range of federal state and local agency and government representatives, as well as local scientists (see Appendix for the workshop agenda and list of attendees). The purpose of the workshop was to share the findings of the experts and solicit input from the managers and planners. Specifically, the audience was asked to identify and provide information on:

- Additional published studies, data, or reports that may have been overlooked,
- On-going or planned studies or monitoring projects relevant to these resources,
- Critical management issues and
- Management information needs

This final report was then revised based on discussions at the workshop and written comments provided after the meeting.

Although not the focus of this effort, the report begins with a summary and review of the numerical hydrodynamic modeling results which provided the necessary background for the discussions of the impacts on the individual biological resources in the sections following the model summary.

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SUMMARY AND REVIEW OF A NUMERICAL MODELING STUDY OF BREACH IMPACTS ON GREAT SOUTH BAY, NEW YORK

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Introduction

In an effort to begin quantifying the effects new inlets through the Fire Island barrier may have on living resources within the Fire Island National Seashore, the National Park Service funded a hydrodynamic modeling study to examine how these features may change the present physical characteristics of Great South Bay. This section provides a summary of the modeling results along with a discussion of some of the uncertainties associated with the various predictions. Observations made here are based on available data and past experience with the system. The purpose is not to criticize the modeling effort, but rather to frame the findings in a manner that will facilitate their use in evaluating the potential impacts new inlets may have on the ecosystem and the ecologically and economically important resources found there. Impacts on the biological resources are discussed in later sections of this report.

Model Description

The modeling study (Conley 2000) used a high-resolution, two-dimensional, depth-integrated, finite difference hydrodynamic model to evaluate possible changes in bay water levels, circulation patterns, and salinity distributions for new inlets at two separate locations on Fire Island. The model was adapted from the SWK3D model (Koutitonsky et al. 1987) which was designed for use in shallow, semi-enclosed bodies of water. This model as been applied to, and validated in, other coastal and shallow water environments (Valle-Levinson and Wilson 1994; Chant 1995; Ullman and Wilson 1998). For this application, the model was modified to include a wetting and drying scheme (to more accurately simulate the shallow conditions around bay margins) and a freshwater input.

Simulated inlets of interest in this study were located at Old Inlet and at Barrett Beach (**Figure 1.1**). (The modeling effort also included a simulated breach at the site of the former Little Pike's Inlet on the Westhampton barrier, but this simulation is not included in these discussions since the focus here is on Great South Bay.) These were judged as the most likely sites for inlet formation based on physical characteristics of the

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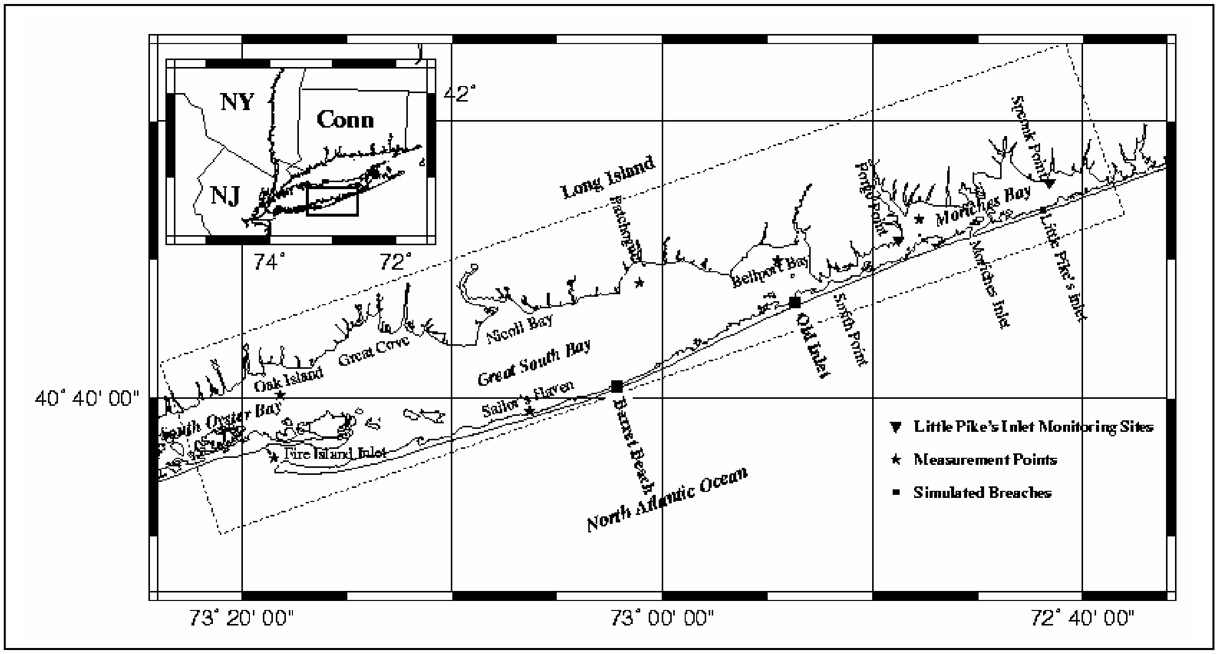

Figure 1.1. Location Map. Dashed line indicates model boundaries. This report focuses primarily on the effects associated with potential breaches at Old Inlet and Barrett Beach.

barrier island and on the location of historic inlets. The simulated breaches in the model were sized to replicate the hydraulic characteristics of the Little Pike's Inlet. Dimensions for the breach were determined by treating the breach as a gap in the barrier island at the location of Little Pike's Inlet and adjusting its size so the model tidal transmission prediction approximated that actually measured by tide gages deployed when this inlet was open.

The parameters actually modeled in this effort were tidal transmission, current speed and direction (circulation), salinity and bottom shear stresses. Although not actual model outputs, Conley used the results of the model to make observations regarding bay water residence times, storm surges and inlet stability. In general, it was felt the model is technically sound and appropriately applied in this situation. However, as with virtually all numerical model simulations of complex natural processes, there are inherent uncertainties that must be considered when evaluating the results. Specific model predictions and associated limitations are discussed below.

Model Results

Tidal Transmission

Under normal conditions, the model indicates a new inlet would only increase the present 35 centimeter tidal range of Great South Bay by approximately 4 percent (approximately 1 to 2 cm) (**Figure 1.2**). For a breach in the vicinity of Old Inlet, the model predicts the average range would increase by 4 percent for more than 60 percent of the Bay, while a small area immediately near the breach in the eastern portion of the bay would actually experience a 4 percent reduction in tidal range (**Figure 1.2b**). For a breach in the vicinity of Barrett Beach, the predicted tidal range will also increase for the bay as a whole, but the change will be variable with the higher increases (approximately 4 percent) occurring in the western portion of Great South Bay (**Figure 1.2c**).

Measurements taken during the period when Little Pike's Inlet was open in Moriches Bay showed the new inlet caused a 30 percent increase in the tidal range in Moriches (Conley 1999), which is considerably more than the changes predicted for new inlets in Great South Bay. This difference is due primarily to the fact that the total volume of Great South Bay is much larger. As a result, the potential impacts of new inlets are buffered here as compared to the smaller Moriches Bay.

Limitations/Uncertainties: The model predictions of changes in the tidal range for Great South Bay appear reasonable and of the proper magnitude. The precision of these estimates is comparable to the magnitude of the predictions. These predictions are based on normal tidal conditions and not extreme events such as storms.

Salinity Distribution

The model indicates new inlets could significantly increase the bay salinity. For existing conditions, mean average salinity for Great South Bay was on the order of 25.9 parts per thousand (ppt) with higher salinities near the inlets and lower values along the north shore of the Bay due to freshwater inputs (Figure 1.3a). An inlet in the vicinity of Old Inlet in the eastern Bay could cause increases on the order of 2 - 4 ppt (Figure 1.3b). Much of the southeast portion of the bay would have salinities approaching ocean values while fresh water pockets in the northern reaches would become more saline. Overall, the model predicts a mean Bay-wide increase of 3.6 ppt, from 25.9 ppt to 29.5 ppt. This increase is due not so much to the increased tidal range as it is to a change in the circulation pattern. Net transport in the Bay changes due to the development of a mean current, that begins to flow between the new inlet and Fire Island Inlet (see *Net Transport* section below).

A new inlet at the Barrett Beach location would also increase salinity by about 3 - 5 ppt with the greatest increases occurring in the western portion of Great South Bay (**Figure 1.3c**). Salinities in the northeast portion of the Bay may show a decrease, but overall the mean salinity of the Bay is predicted to increase by 2.8 ppt to 28.7 ppt.

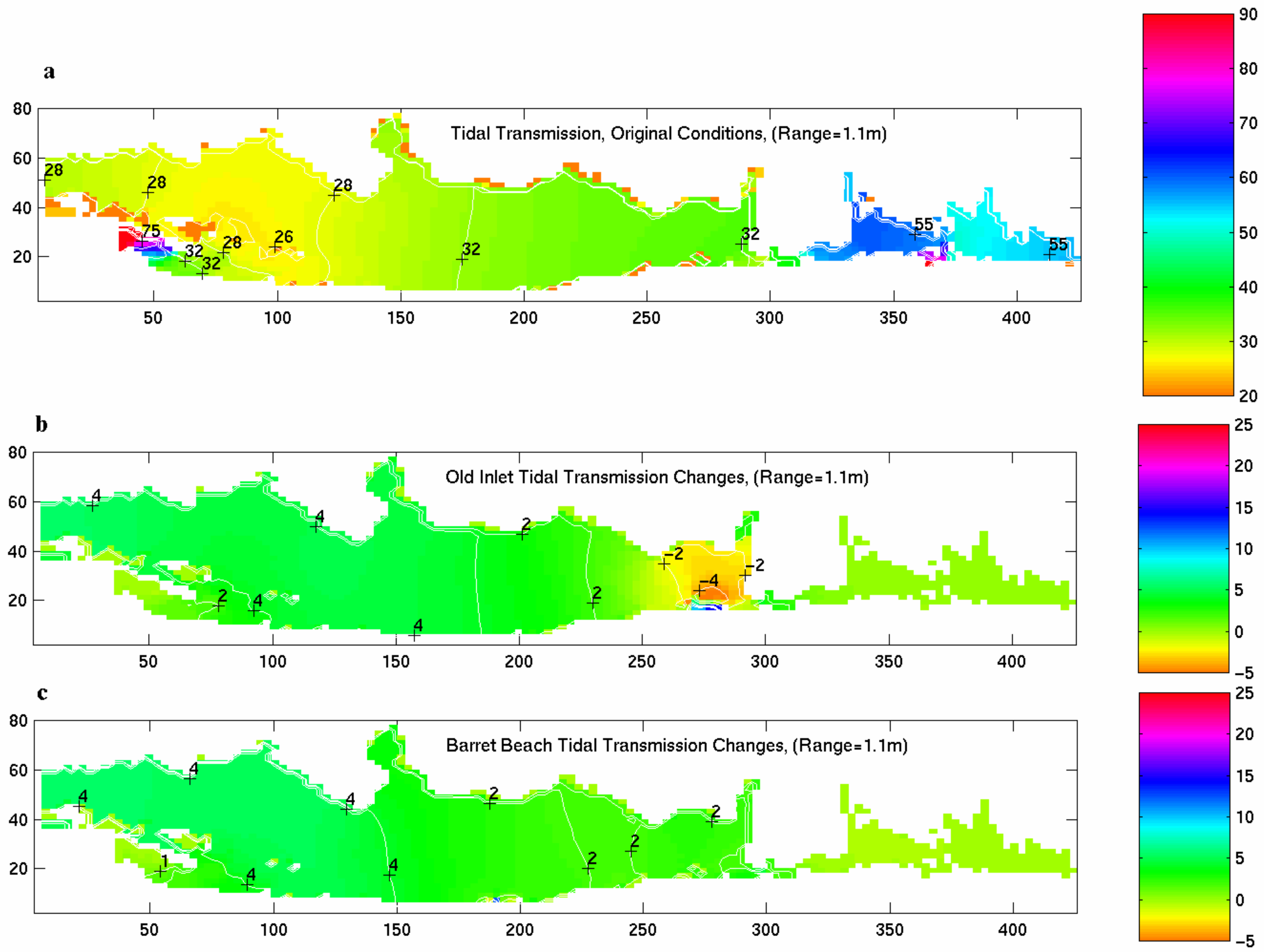

Figure 1.2. Tidal transmission. (a) Tidal transmission for existing conditions expressed as percentage of ocean tide at Fire Island Inlet. Predicted changes in tidal transmission (expressed as percent change from existing conditions) for a new inlet at Old Inlet **(b)** and Barrett Beach **(c).** Color indicates value with scale bars at right. Horizontal and vertical scales are in model grid units which have a 150 meter spacing.

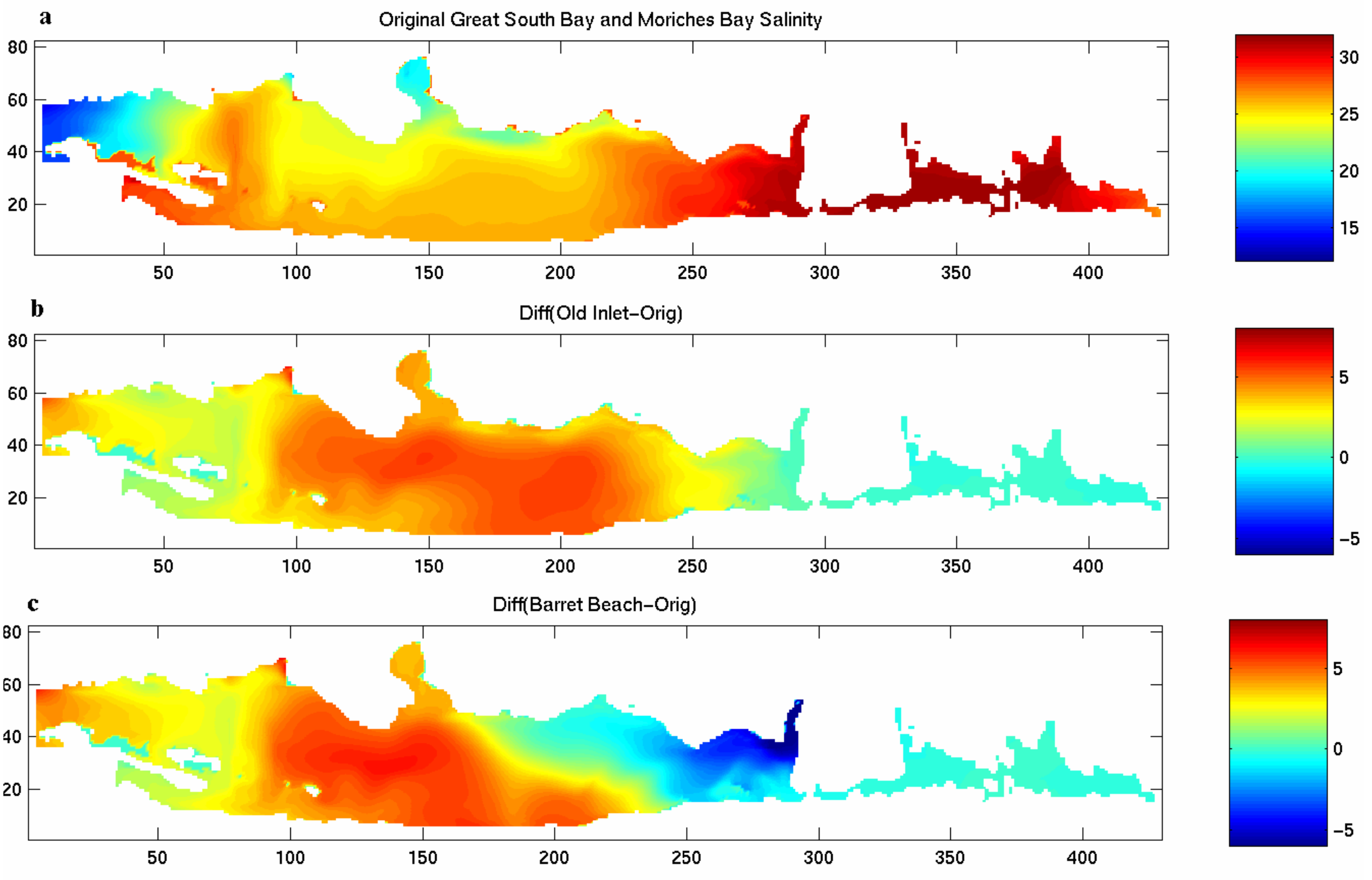

Figure 1.3. Salinity Distribution. (a) Modeled salinity distribution for existing conditions during slack after ebb at Fire Island Inlet. Color scale at right in ppt. Predicted change in salinity due to an inlet at Old Inlet **(b)** and at Barrett Beach **(c)**. Scale bars in parts per thousand (ppt).

Limitations/Uncertainties: Unfortunately, no current velocity or continuous salinity measurements were available to calibrate or validate the model results. Salinity distributions are dependent, in part, on circulation patterns and associated hydrodynamic transport processes. Although there are no available current data to check against the model, the predicted trends and patterns of current flow appear reasonable. However, the simulated current velocities should be considered less precise than the simulated tidal elevation changes. As a result, predictions of salinity changes are less precise than the predictions of changes in tidal elevation. In addition, the distribution of the freshwater influx to the Bay is not well defined, so it is not possible to accurately describe the spatial distribution of the salinity changes with the available information. The salinity predictions appear reasonable in terms of trends and relative changes. However, it is not possible to determine the uncertainty associated with the absolute values without additional data. While the absolute magnitude is uncertain, it does appear safe to say the changes in salinity distribution would be significant for both of the new inlet scenarios modeled.

Residence Time

Predictions regarding potential changes in the residence times (representative of the average time a parcel of water will remain in the estuary) were not calculated directly with the model (e.g., by a "slug" test or particle tracing). Rather, estimates were derived using the modeled salinity changes and employing the fraction of freshwater dilution method which estimates residence time based on how long it takes the freshwater input to replace the freshwater in the bay using differences between the salinity of bay and ocean water. For Great South Bay, this calculation indicated that the average residence time decreased from about 100 days to 40 days for a breach at Old Inlet and from 100 days to 53 days for an inlet at Barrett Beach. These estimates suggest that new inlets would enhance flushing characteristics in Great South Bay. However, flushing would not be uniform across the entire Bay. Reductions in residence times may be considerably less in the northern portions of the Bay near the mainland and greater in the southern reaches

Limitations/Uncertainties: As mentioned above, residence times calculated using this method would vary for different parts of Great South Bay. In areas with large freshwater inputs, such as the northern portions of the Bay, residence times may decrease by 10 percent or less while areas with high salinities under present conditions may see greatly reduced residence times. The spatial differences in residence times could be better defined by performing this calculation for discrete reaches of the Bay.

Another more simplistic way to calculate the residence time is to use the ratio of the tidal prism (intertidal volume) to the bay's volume. Assuming that about half of the water entering the Bay on flood is "new" ocean water due to mixing of the outgoing bay water, the residence time calculated from the tidal prism based on measurements at

Fire Island Inlet (Wong 1981**)** is about 6 days (R. Wilson, Marine Sciences Research Center, State University of New York, Stony Brook, personal communication 2000). This is a low estimate since the tidal prism method does not take into account transport within the estuary itself and assumes that the volume of new water introduced with each flood tide completely mixes with bay water, a rather optimistic assumption. It also assumes an arbitrary level of mixing between ocean and bay waters at the inlet. Because the predicted change in the tidal range due to a new inlet is about 5 percent, the change in residence time calculated by this method should be about the same. Thus, an increase of 5 percent would decrease the residence time calculated by this method to 5.7 days.

Under normal tidal conditions, the actual residence time of Great South Bay is probably somewhere between the two values calculated by the freshwater dilution and the tidal prism methods. While the true residence time is probably closer to the estimate provided by the freshwater dilution method, it is not possible to provide a more accurate estimate with the information presently available. In addition, neither method takes into account important parameters such as subtidal forcings associated with storms and local winds or the effects of longshore currents which could have a significant impact on flushing characteristics.

Bottom Shear Stresses

To help identify potential impacts to benthic communities, the model was used to examine potential changes in both the mean and peak bottom shear stress resulting from changes in current velocities and patterns due to new inlets. Changes in the mean shear stresses are shown in **Figure 1.4** for the two breach conditions. A breach at Old Inlet results in greatly increased shear stresses in eastern Great South Bay near the new inlet and extending northward (**Figure 1.4a).** There is a reduction of up to 60 percent in shear stress for the central and western portions of the Bay. The scour patterns associated with a breach at Barrett Beach are similar to those for the Old Inlet breach but smaller in terms of spatial extent (**Figure 1.4b).** The model was also used to calculate peak shear stresses (maximum shear stresses experienced during a tidal cycle). A shear stress value of 1 dyne/cm^2 was considered representative of the critical threshold necessary to mobilize fine grain sands. Contour plots of this value for different inlet scenarios are provided in **Figure 1.5.** The area encompassed by the **1** dyne/cm^2 contour presumably experiences currents that would remove fine grain sand. For the Old Inlet breach, these data suggest that fine-grained material may be scoured in the vicinity of the inlet and deposited in the central basin where shear stress is reduced (**Figure 1.5b).** For the case of an inlet at Barrett Beach, the patterns of bed stress change are similar, but the extent of increased scour is more limited due to the greater surrounding depths (**Figure 1.5c).**

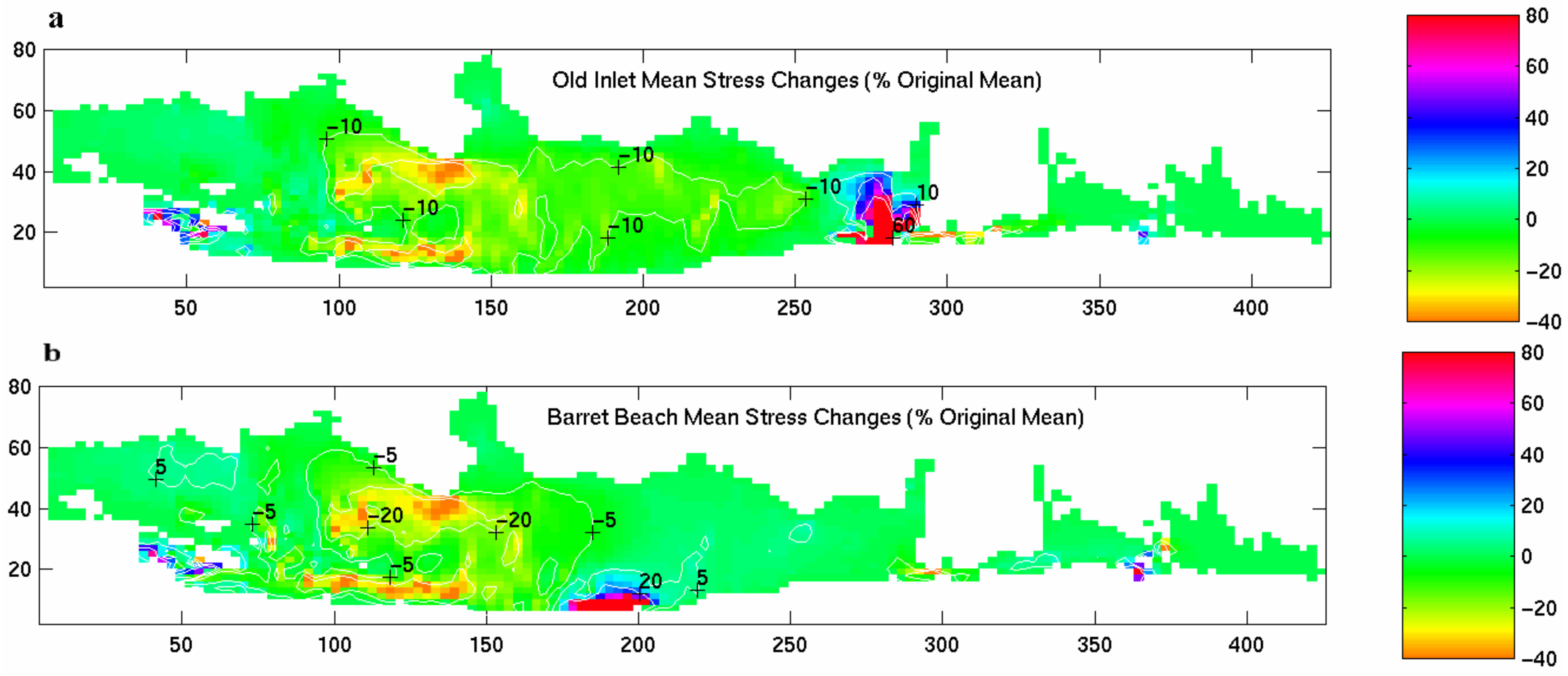

Figure 1.4. Mean bottom shear stress. Change in mean bottom shear stress expressed as percent change from original conditions for a new inlet at Old Inlet **(a)** and Barrett Beach **(b)**.

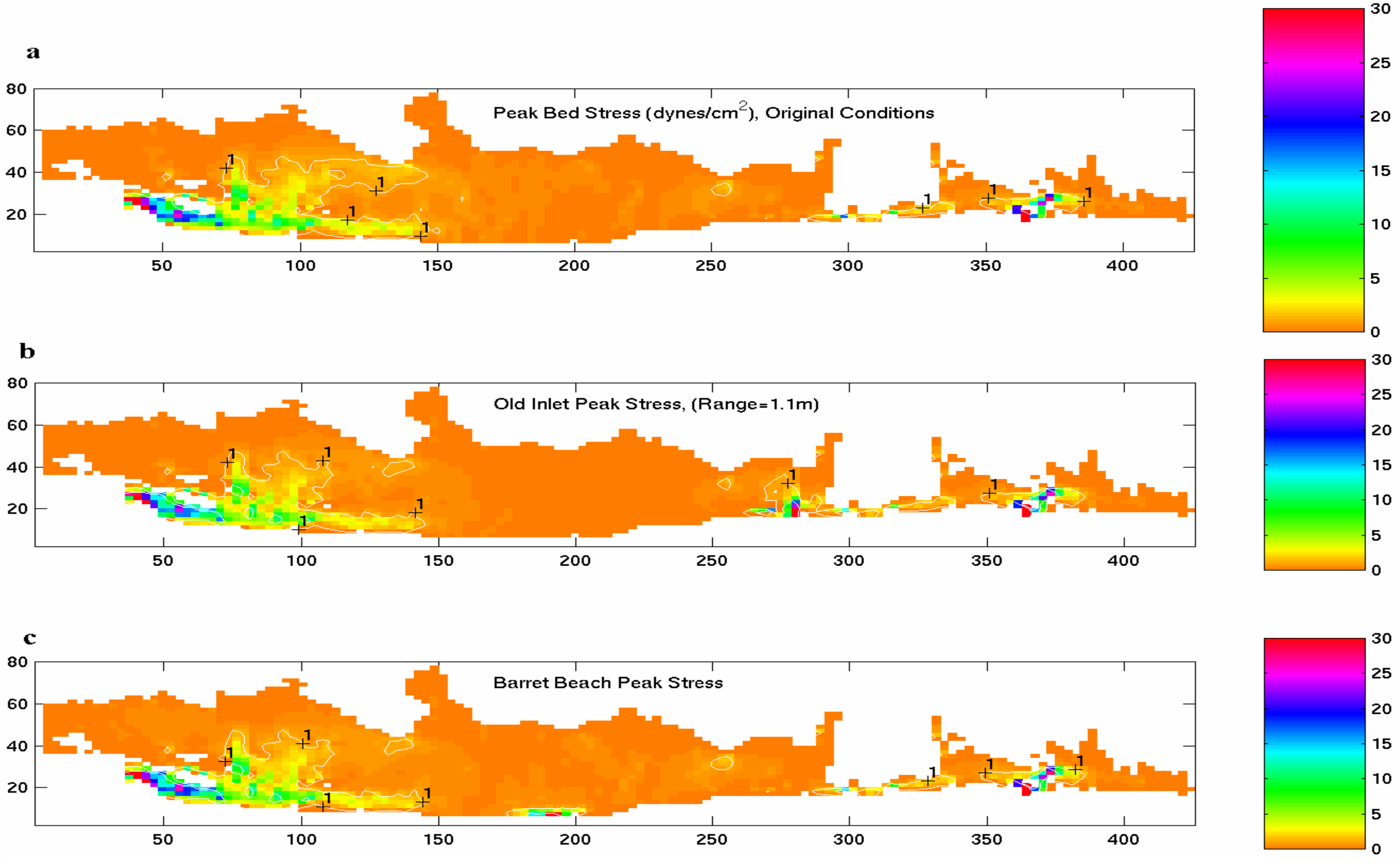

Figure 1.5. Peak Bottom Shear Stress. Peak bottom shear stress in dynes/centimeter^2 for existing conditions **(a)**, a new inlet at Old Inlet **(b)** and a new inlet at Barrett Beach **(c)**. The white lines labeled +1 indicate the 1 dyne/centimeter^2 contour which is the threshold for mobilization of fine sand. Scale bars are in dynes/centimeter^2.

Limitations/Uncertainties: The calculated changes in bottom shear stress are reasonable but uncertain because, as mentioned previously, the model could not be fully calibrated due to the lack of current velocity data. The actual effective bottom shear stress would include and, in places, be dominated by waves, which were not considered here. Whether these changes in the bottom shear stress will actually alter the substrate depends upon how long the effect persists and how much sediment is being supplied to the affected area. It is thought that Great South Bay's floor is largely relict sediment with little new sediment input so that changes in substrate due to changes in shear stress may require long time periods (many decades) except in the immediate vicinity of the new inlet. Near the new inlets, where the change in shear stress exceeds 50 percent (**Figure 1.4**), flood tidal shoals built of sand derived from the littoral drift and the erosion of the inlet channel itself may develop.

Net Transport

The fine resolution of the model grid allows a detailed view of circulation and current patterns in the Great South Bay. Of particular interest in terms of the model results are the changes in net transport in response to the presence of new inlets (**Figure 1.6).** Under existing conditions, residual circulation features permanent counter-clockwise flowing eddies in Bellport Bay, Patchogue Bay and north and south Nicholl Bay. Clockwise flowing eddies are found in Moriches Bay, the basin below Great Cove and mid-Nicholl Bay. There is a net transport from Moriches Bay to Great South Bay, and net transport occurs out of both Fire Island and Moriches Inlets. A new breach in the vicinity of Old Inlet changes the net transport considerably, wiping out the stationary eddies and creating a relatively large mean current flowing from Old Inlet along the north shore of the bay to Fire Island Inlet. (This current is what causes the salinity to change by 10 - 15 percent while the tidal range only exhibits a 4 percent change.) Mean flow from Moriches Bay is substantially reduced. A new inlet at Barrett Beach has a similar impact with a large net flow developing from Barrett Beach up through Nicholl Bay and out into Fire Island Inlet.

Limitations/Uncertainties: Since the net transport calculations are based on the predicted currents, they are subject to the same limitations and uncertainties associated with the shear stress due to the lack of measured current data for calibration. However, the magnitude and trends of circulation changes indicated by the model appear reasonable. Actual transport would also be affected by wind stress which was not modeled.

Storm Surges

Storm induced changes were not modeled as part of this effort. However, possible impacts of storms on tidal transmission and flooding were discussed in light of the model results. Conley (2000) made the following observations:

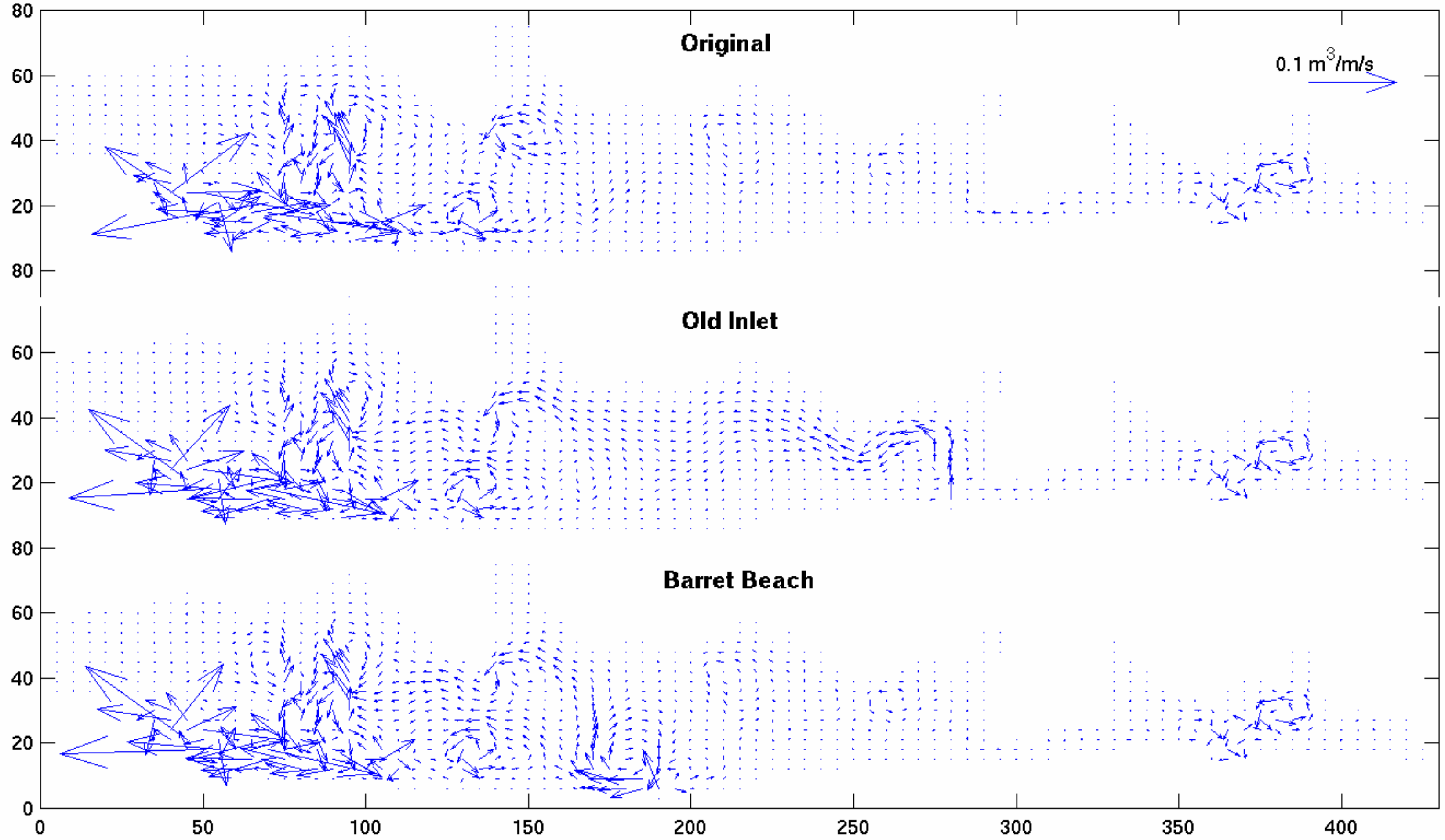

Figure 1.6. Net transport. Net transport vectors for existing conditions and new inlets at Old Inlet and Barrett Beach. Arrow indicate magnitude and direction of transport calculated over one tidal cycle and averaged over 3 grid points across the bay and 5 grid points along the bay. Large net transport gradients over relatively small spatial scales result in confused pattern in the vicinity of Fire Island Inlet.

A. For storms lasting 24 hours or longer (i.e., northeasters) with a surge on the order of 1 meter, the level of the storm tide would not be changed by a new inlet but high water would arrive sooner and recede faster, with a total duration about equal to what would be expected for existing conditions.

B. For faster moving storms, such as hurricanes, passing the area in 12 hours or so (approximately the tidal period), the transmission of the storm surge should approximate the tidal transmission and a new inlet would be expected to increase storm tides by about 5 percent in Great South Bay.

Limitations/Uncertainties: For storm surges lasting less than 12 hours, the model does not offer much guidance. Such occurrences would be rare and it is thought that surge transmission associated with these events would be dampened to an even greater extent than those associated with storms of 12 hours duration. As a result, increases in water elevation associated with faster moving storms would probably be less than 5 percent even with a new inlet. However, it is not known how a new inlet would affect Bay water levels for storms with a period between 12 hours and 24 hours. Storm surges associated with these "intermediate" storms may be more efficiently transmitted into the Bay with a new inlet, resulting in higher surges. More work is needed to adequately assess the potential impacts of these events. Calculation of the pumping mode frequency of the Bay was suggested as a first step towards this end.

Inlet Stability

Although an inlet stability analysis was not performed as part of this study, a considered argument is made that a new inlet at Barrett Beach would tend to remain open while one at Old Inlet would be less likely to maintain itself and would tend to close. This observation is based largely on the bed stress and current results, and knowledge of the existing Bay bathymetry. Bay water depths behind Barrett Beach are greater than they are behind the Old Inlet.

Limitations/Uncertainties: Observations regarding the likelihood of a breach remaining open were, admittedly, conjecture. Inlet stability was not modeled or quantified because it was beyond the scope of Conley's (2000) modeling effort. Even an inlet that "tends to close" may remain open for many years and one that "tends to remain open" may last only a few years. Historical evidence indicates that the previous inlet at the Old Inlet site existed for over 60 years and may have co-existed with two other inlets in the area for more than 50 years (Leatherman and Allen 1985; U.S. Army Corps of Engineers 1999). Unfortunately, it is not possible to predict the potential stability or life times of new breaches from the Park Service's model. A reliable analysis of inlet stability would require significantly more effort.

Suggestions for Model Improvements

While the model provides reasonable predictions and seems to be internally consistent in terms of the parameters examined, there are a number of steps that could be taken to help minimize the uncertainty associated with the results and provide more reliable predictions of those changes important to the biological resources. The information gained by implementing the actions discussed below could be used to improve the present model, as well as provide data required for other modeling efforts.

Salinity is an important environmental parameter and the model indicates new breaches could significantly alter the salinity distribution. The model assumed the freshwater input occurred as a constant line source along the north shore of Great South Bay. To improve salinity predictions both in terms of the absolute magnitude and spatial variability, the distribution of freshwater inputs, both surface water and groundwater, should be better defined and characterized. The model did not take into account subtidal effects (processes such as wind-induced changes in ocean and Bay water levels that occur over time periods greater than one tidal cycle) which may play an important role in controlling circulation and mixing in the bay. Measurements of water surface elevations, currents and salinity are needed to develop a better understanding of the role these extra-tidal effects have on circulation and water quality in the Bay. Better characterization of the western boundary with South Oyster Bay is also needed. The model assumes this boundary is closed. While this assumption does not appear to have a significant effect on tidal elevation predictions, exceedingly low estimates of the salinity in this area indicate this boundary is not really closed as assumed in the model. More detailed information on the exchange processes along this boundary are needed. Obviously, more accurate measurements of the forcing sea level elevations at the open ocean boundaries would be useful in improving model predictions.

In the event a breach occurs, a contingency plan should be in place to quickly take essential measurements while the inlet is open. The model predictions of net transport are important because they appear to reduce residence times significantly. Monitoring programs using current meters to measure net transport are not practical due to the high degree of spatial resolution required. Since net transport is difficult and costly to measure, it may be more practical to conduct tracer studies (e.g., a slug release test) first to measure residence times directly and to calibrate the transport component of the model. This type of study would be particularly useful if conducted both before and after the next breach occurrence (before filling), so as to quantify impacts of the breach. Dye tracer studies can be expensive ($100,000 would not be an unreasonable estimate for Great South Bay). Use of synthetic gas tracers, such as those recently used in the Hudson Estuary, may help reduce costs.

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WATER COLUMN PRODUCTIVITY

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Planktonic Species in Great South Bay

The relative importance of different plankton species in Great South Bay has varied over time. Within the phytoplankton community the importance of any single species, except during bloom periods, is not what is critical. The overall production levels of the plankton present are what is most important. Great South Bay is one of the most productive estuaries known (Mandelli et al. 1970, Hair and Buckner 1973, Weaver and Hirschfield 1976, Cassin 1978, Lively et al. 1983, Kaufman et al. 1984). It is generally understood that Great South Bay is more productive than Moriches or Shinnecock Bays, although information for the latter Bays is relatively sparse and fragmentary. Nutrients are abundant in Great South Bay and primary production is light and temperature limited. When the dominant small microalgae, <5um in diameter, are very diverse (Lively et al. 1983) then trophic coupling is well balanced between grazing and primary production. Caron et al. (1989) first described the diverse microzooplankton which graze on these small primary producers including many loricate and aloricate ciliates and heterotrophic dinoflagellates. The larger mesoplankton of Great South Bay are dominated by copepods, particularly *Acartia tonsa* and *Acartia hudsonica*, with large populations developing during the summer and spring months, respectively, typical of neritic coastal waters (Duguay et al. 1989). Among ichthyoplankton, bay anchovy eggs and larvae (*Anchoa mitchilli*) are dominant (Duguay et al. 1989, Monteleone 1988, 1992). The growth rates of the bay anchovy have been found to be high in Great South Bay compared to other bay systems (Shima and Cowen 1989, Castro and Cowen 1989), suggesting a high degree of trophic transfer of plankton productivity.

Great South Bay has been characterized as highly susceptible to eutrophication and chronic algal blooms due to the abundant nutrients (NOAA/EPA 1989). Dramatic algal blooms have occurred and been documented over the past fifty years, for example, green tides of the 1950's (Ryther et al. 1956,1957, 1958, Guillard et al. 1960) and brown tides (*Aureococcus anophagefferens*) of the 1980's and 1990's (Cosper et al. 1990, SCDHS 1999). However, the occurrence of these blooms on a Bay-wide basis is the exception rather than the rule. Apparently, powerful stabilizing trophodynamic processes act to prevent blooms most of the time. When there have been extensive algal blooms, however, the consequences have been severe, resulting in drastic disruption of trophic structure and shifts in all levels of plankton groups. Through impacts on shellfish feeding and shading effects, such blooms ultimately can lead to the demise of economically important resources such as clams, scallops and oysters as well as important habitats such as eelgrass beds (Cosper et al. 1987).

Environmental Parameters Important to Planktonic Species Abundance and Distribution

Pelagic production in Great South Bay is temperature driven, so the peak abundances and productivities generally occur during the warmer, summer months (Cosper et al. 1989a, Duguay et al. 1989, Lonsdale et al. 1996). Species succession is an ongoing process throughout the year with diversity being high throughout most of the year. Even when temperatures are extremely low, just above freezing, primary producers and grazers are found to be quite active with no indication of the typical coastal, winter-spring bloom phenomenon (Lonsdale et al. 1996). The trophic coupling and structure in this Bay develops complexity early during the year, and well-balanced trophic linkages are maintained generally over most of the year with large algal blooms being anomalies.

North to south distribution of planktonic species and biomass reflect the new inputs of nutrients from the north shore tributaries with higher levels being found in more northern waters (Hair and Buckner 1973, Lively et al. 1983, Cosper et al. 1989a, 1989b, Dennison et al. 1991). East to west gradients of plankton reflect the longer residence time of waters in the eastern portion of the Great South Bay, up to hundreds of days (Vieira 1989), so that potentially greater biomass can accumulate in the eastern portions. The inflowing coastal waters through Fire Island Inlet can affect the distribution of species in the southwestern portions of Great South Bay since larger, oceanic species are mixed into Bay areas (Weaver and Hirschfield 1976).

Numerous chemical, physical and biological factors contribute to the selection of plankton species. Many of these factors remain undefined, such as trace elements, organic nutrients, light regimes, turbulence, etc., although much research in recent years has begun to examine these issues in terms of the complexity and interaction of multiple factors in determining phytoplankton communities and their successions (Reynolds 1997). Some of these studies have focused specifically on Long Island bays (LaRoche et al. 1997, Gobler 1999). The high variability in factors affecting species composition in estuarine areas leads to the high diversity in the plankton communities by constantly changing the environment to select for different species *a la* the Paradox of the Plankton (Hutchinson 1961). That is, even though all species compete for the same nutrients, species differ in their abilities to acquire and use these resources. As a result, many species can co-exist without competitive exclusion.

The question is, particularly for Great South Bay, what developments allow for the occurrence of extensive (bay wide) and enduring (over several months and recurring over several years) phytoplankton blooms which can have such significant impacts on the ecological balance and natural resources of the Bay? This topic is being addressed by numerous research groups, nationally and internationally, who are looking at many types of algal blooms. The factors influencing any particular bloom are most likely specific for the species of concern, but several factors have been identified to be contributory to blooms, generically. For the consideration of a breach scenario in the Great South Bay system, hydrodynamic stability and salinity are the most relevant factors.

Hydrodynamic stability, created by increased residence time of waters and decreased turbulence, for example, can increase the competitive environment between species allowing for the emergence of a dominant species (Kierstad and Slobodkin 1953, Margalef et al. 1978, Reynolds 1997).

Large shifts in salinity due to excessive rainfall and/or changes in hydrography within the Bay can select for entirely different groups of phytoplankton such as during the green tides of the 1950's when salinities were much reduced. That condition selected for *Nannochloris* sp. and *Stichococcus* sp., species tolerant of salinities below 15 ppt (Ryther 1954). Part of the reason for the changes during the 1950's related to inlets closing up and ultimately reopening. This has important implications for the topic of breaches being considered, since the model predicts salinities above 25 ppt if a new inlet is formed.

The threshold values and ranges for factors of consequence to shift phytoplankton composition and initiate massive blooms are poorly understood, but research is ongoing to better define them, particularly as they relate to the brown tides of recent time (Brown Tide Research Initiative Reports).

Effects of Predicted Changes in the Physical Factors Caused by a Breach

Salinity

The model predicts that each of the two simulated new inlets would significantly elevate salinities in the bay to levels well above 25 ppt. This might select for plankton more tolerant of high salinities such as the brown tide species, Aureococcus anophagefferens, or other picoplankton (2-5 um in size) such as cyanobacteria and small diatoms. The picoplankton species generally present in the bay waters are quite euryhaline, that is, tolerant to a wide range of salinity (Ryther 1954). Significant shifts in species composition would most likely require exceptionally high salinities, over 30 ppt, for a relatively long period of time, on the order of several months (Cosper et al.

1987). Changes of this magnitude could result in a species previously unknown to Great South Bay becoming dominant. Information is not available to ascertain whether or not such shifts have occurred naturally in Shinnecock Bay where the existing salinity is higher. Another possibility is that, with the increased mixing caused by a new inlet, species typical of coastal oceanic waters, such as larger diatom species (Weaver and Hirschfield 1976), might develop greater populations. This would not necessarily be detrimental but could affect the trophic structure of the Bay waters, particularly the grazer populations. The shift to larger algae (20-200 um) might adversely affect the microzooplanktoncommunity (Caron et al. 1989) but benefit the benthic bivalve grazer populations (Mohlenberg and Riisgard 1978). The very small brown tide organism is tolerant of high salinities, but seems to thrive only if the residence time is high. In the breach model, salinity goes up but residence time goes down, making it difficult to predict the change in potential for brown tide blooms. The most likely scenario is that brown tide blooms will decrease as more oceanic conditions are approached, similar to thosefound in Moriches and Shinnecock Bays where the brown tide blooms seem to be less severe.* However, blooms could still be expected in areas where the residence times are not significantly reduced by the presence of the breach.

Nutrients

Other water chemistry factors such as nutrients (specifically the concentration of organic nutrients and other trace elements) will most likely also be affected by a new breach, being reduced due to the mixing of oceanic water into the Bay. This reduction might prevent some species from achieving full growth potential and lead to reduction in overall productivity (Cosper et al. 1989, Dzurica et al. 1989, Gobler 1999).

Water Level

The model predicts a new inlet would increase the tidal range by only 1-2 cm. The location of a breach would change this to a certain degree, but again only minimally. For plankton, this effect would not be significant.

Circulation

The model results suggest substantial reductions, 50 percent, in residence times due to breaches and potentially significant changes in net flow patterns. The reductions in residence times would be lessened in the northern areas of the Bay which might ameliorate any reduction in productivity due to lowered nutrient levels. Increased flushing of areas in Great South Bay could be beneficial to overall water quality (light,

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***Editors' Note:** As discussed earlier, model predictions indicate that a breach would cause salinity in Great South Bay to increase, becoming closer to the higher salinities found in Moriches and Shinnecock. Residence times would, for the most part, tend to decrease, again becoming closer to those found in Moriches and, probably, Shinnecock Bays (see **Table 6.1** and *Summary and Discussion* section).

nutrients, etc.) and could reduce the potential for the brown tide or any blooms to occur. However, these changes could also result in the selection of species different from the present composition (as discussed in the sections above). Changes in species composition could have unforeseen consequences and the high productivity and trophic transfer in Great South Bay might be reduced. For instance, the phytoplankton species shifts during the green tides of the 1950's led to the failure of oyster populations. On the other hand, the resilience of the plankton community to adapt to change could quickly be realized, resulting in a new equilibrium of species well adapted to the new regime with little consequences to the overall trophic structure.

The above predictions are based on fragmented data from a variety of sources which indicate there are gradients in plankton from east to west and north to south (Hair and Buckner 1973, Lively et al. 1983, Cosper et al. 1989a, 1989b, Dennison et al. 1991, Vieira 1989). Although not yet examined for this purpose, data do exist which could be used to further characterize plankton in different areas of the Great South Bay, such as areas of:

- low flushing and low salinity,
- high flushing and low salinity,
- high flushing and high salinity, and
- low flushing and high salinity.

These characterizations would make for more definitive predictions based on water quality plankton habitats extant in Great South Bay, which could easily be enhanced or ameliorated by the breaching effects. How this could be accomplished is suggested in the next section, *Research, Management and Monitoring Information Needs.*

A working hypothesis of the types of impacts that may be expected from a breach is depicted in **Figure 2.1.** If a breach occurs and oceanic water is mixed into Great South Bay areas to a greater extent, the salinity and light penetration with depth will increase in certain areas **(**see **Table 6.1** and *Summary and Discussion* section) and the relative concentrations of nutrients from runoff and groundwater inputs will be diminished **(Figure 2.1, A).** While increased light is generally favorable for bloom formation, the concurrent reduction in nutrients would be a more detrimental factor that would lead to fewer phytoplankton blooms. This could lead to dominance of benthic communities of eelgrass beds and benthic fauna such as clams or other bivalves. For a breach at Barrett Beach, however, the model indicates that the residence time in the eastern part of Great South Bay will not necessarily decrease. These areas would remain essentially pelagic-dominated communities due to poor light penetration and relatively large

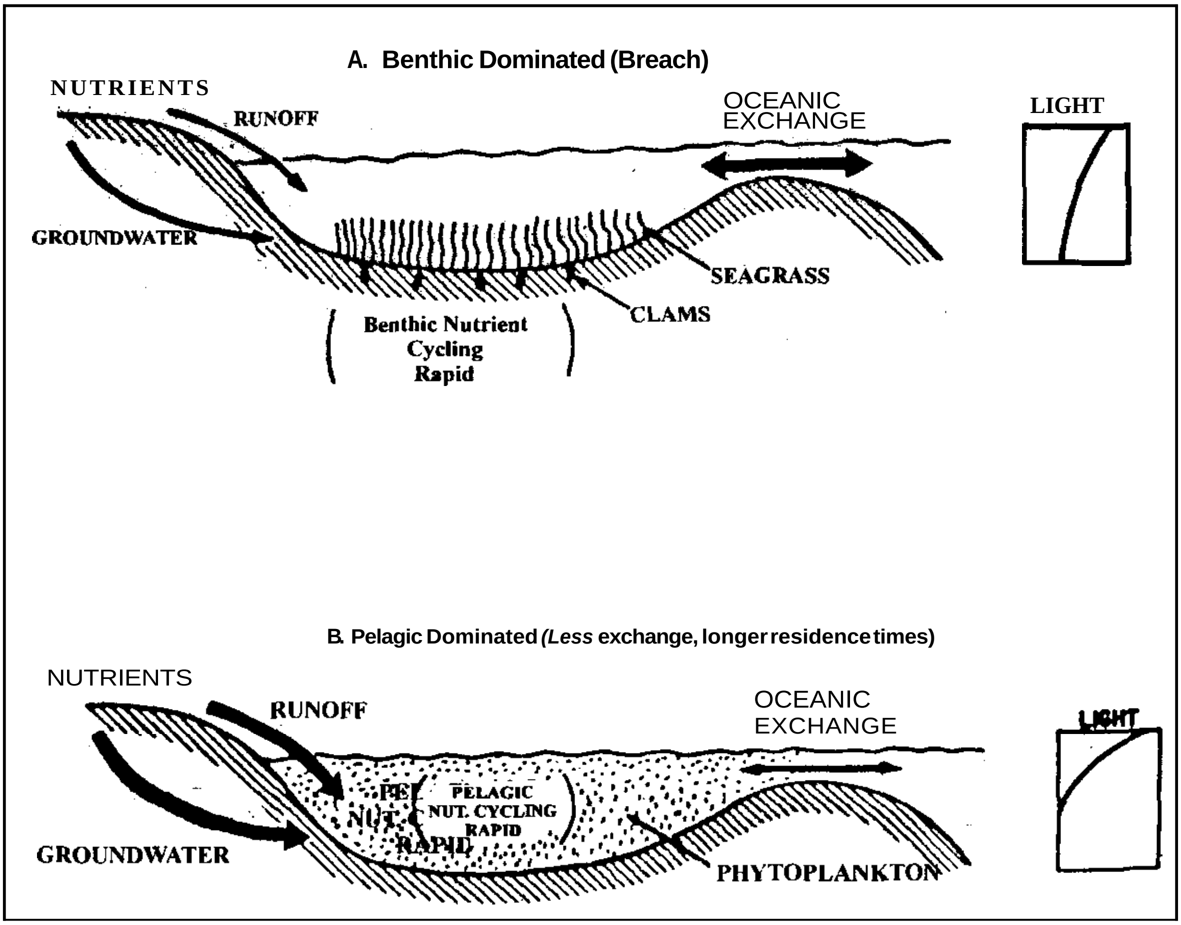

Figure 2.1 Pelagic and Benthic Dominated Systems. A. Benthic dominated system with oceanic mixing enhanced by breach. **B.** Pelagic dominated system with limited exchange and longer residence times.

nutrient inputs fueling phytoplankton growth and possibly bloom conditions (**Figure 2.1, B**). Great South Bay presently has areas which reflect both scenarios of **Figure 2.1,** but with a breach more areas would become similar to the benthic dominated scenario (**Figure 2.1, A**).

Since warmer temperatures are more conducive to bloom formation, the moderating effect of a breach could prolong the cooler, less favorable conditions for phytoplankton blooms in the spring and early summer, depending on its actual influence on Great South Bay's water temperatures.

Research, Management and Monitoring Information Needs

The nature and productivity of the plankton community are extremely important to a number of important Great South Bay resources. Plankton serve as the food source for clams but may become unpalatable under bloom conditions, such as has been seen with the brown tide blooms. Juvenile fish in the Bay rely on plankton as the basis of the food chain, supplying the zooplankton they feed on. Submerged aquatic vegetation, which provides important habitat to many species, depends to a large extent on light penetration which can be influenced by plankton abundance. Often, perceived water quality or clarity problems associated with plankton blooms can adversely affect submerged aquatic vegetation as well as recreational uses such as swimming or boating.

Barrier island bays such as Great South Bay have historically in geologic time frames experienced breaches and the concomitant changes in salinity, residence times, etc. Thus, breaches can be considered a natural process for these Bay waters and the species and communities have evolved over time to be resilient to changes and adaptive of variable conditions. However, if variations are drastic enough, the communities can be dramaticallv changed. For instance, while a breach could eliminate or greatly reduce the brown tide blooms, other species, as well as the brown tide organism, might develop blooms in any areas of the Bay that may remain poorly flushed.

The information needed in order to make very definitive statements or predictions regarding the potential impacts of breaches on the plankton community, and ultimately Great South Bay, requires a better understanding of the factors controlling the dynamics of plankton and its trophic fate. Unfortunately, many of the questions that must first be answered can only be addressed using experimental research. However, from a management perspective the following assessments would be helpful in evaluating the potential for changes, positive or negative, in the Great South Bay ecosystem.

Comparative studies should be conducted between Great South Bay and two neighboring bays, Moriches Bay and Shinnecock Bay, which are reflective of the higher salinities and greater oceanic mixing of waters that may be expected with a new inlet in Great South Bay. How these three Bays have changed through time relative to salinity regimes and changes in hydrology might be indicative of changes to expect in plankton and productivity given breaching in the future. Better delineation of freshwater inputs to these Bays would make the model more robust and is an important consideration to include in evaluations of salinity and nutrient shifts. It might be helpful to plan a contingency study to go into effect in the event a breach does occur.

Since the model indicates salinity and residence time of Great South Bay waters may be significantly affected by a breach, both in a north to south direction and an east to west direction, respectively, the following evaluations should be made of data existing from previous years and planned for the future by ongoing monitoring programs of the Suffolk County Department of Health Services and the National Park Service, as well as any other organizations:

A) Measure the spatial and temporal variability in the major inorganic nutrients from north to south and east to west along gradients of salinity and residence times. This will give an idea of the short term, as well as longer term (month to month and yearly), variation in these factors for areas of Great South Bay subject to radically different variations in freshwater inputs and water stability. If similar data can be collected or is available for organic nutrients and trace nutrients (such as iron), an identical assessment for them would be extremely useful, since recently the importance of such nutrients has been demonstrated, particularly for the brown tide.

B) Measure the spatial and temporal variability in the major plankton groups (phyto- as well as zooplankton) from north to south and east to west along gradients of salinity and residence times. This will give an idea of the short term, as well as longer term (month to month and yearly), variation in these factors for areas of Great South Bay subject to radically different variations in freshwater inputs and water stability. Fractionated chlorophyll levels could be used to assess biomass levels and species identification could be performed on selected samples from areas representative of the gradient extremes as well as from intermediate zones.

C) Evaluate the above assessments in terms of the degree of spatial and temporal variations already occurring in Great South Bay waters along the known gradients. This will allow for further prediction about the consequences of breaches. If the changes predicted by the model for breaches are within the variations already observed within Great South Bay areas, then there would probably only be a shift of the populations into areas not previously occupied and the extent could be mapped. If the changes predicted by the model are beyond the variations normally extant in Great South Bay, then predictions of changes in plankton, etc. would be more difficult but would indicate the possibility of major shifts in trophic structure. Also, the evaluation of bloom conditions (not just brown tides but others also) along the gradients would help to elucidate threshold conditions for bloom formation.

The consensus among the participants at the workshop was that the basic information which would be developed in the studies detailed above is necessary before an assessment of the overall impact of a breach can be made for Great South Bay. The evaluation of historical data in the context described above would most likely allow for a much more educated prediction regarding the effects a breach would have on plankton in the Bay.

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SHELLFISH AND BENTHIC INVERTEBRATES

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Benthic Habitats and Important Shellfish and Benthic Invertebrates

There are four major benthic habitats in Great South Bay: non-vegetated bottom, vegetated bottom, salt marshes, and intertidal beaches. A description of the invertebrate fauna in these habitats is contained in an earlier report entitled *Estuarine Resources of the Fire Island National Seashore and Vicinity* (FINS Report) (Bokuniewicz et al. 1993). This description will not be repeated here. The information reported in this section should be regarded as an update and supplement to the FINS Report.

The benthic fauna of subtidal non-vegetated areas in Great South Bay has been known mainly from three studies: Marine Sciences Research Center (1973), WAPORA (1982), and Wiggins (1986). As an update, Larson (2000) recently studied non-vegetated bay bottoms in eastern Great South Bay to determine how local sediment properties regulated community structure of this estuarine fauna. Roger Flood (Marine Sciences Research Center, State University of New York, Stony Brook, personal communication 2000) used side scan sonar to map a 4,000 hectare portion of eastern Great South Bay (approximately 17 percent of the Bay bottom). He identified four distinct sediment types: mud, muddy-sand, sand, and shell/gravel bottoms. Based on this map, Larson (2000) collected benthic samples on a seasonal basis using a 0.05 m^2 suction sampler within three of these sediment types (mud, sand, and shell bottoms). Samples in the different sediment types were taken in close proximity to one another (200-400 meters) at locations where the three sediments types intersected, to minimize differences in salinity and other water column parameters. In her study, Larson also obtained samples at transition areas between mud and sand sediments. These transition areas were muddy-sand bottoms, and the fauna was probably similar to the muddy-sand areas mapped by Flood. All samples were washed through a 500 micron sieve.

No new benthic macrofaunal studies have been carried out in vegetated Great South Bay bottom areas since the FINS Report (Bokuniewicz et al. 1993). Based on available data in O'Connor (1972), Marine Sciences Research Center (1973), WAPORA (1982), and Cerrato (1986), collected by grab in seagrass beds, the fauna is largely similar to that found in unvegetated subtidal sand flats. However, since grab samples do not efficiently collect epifauna, there is little information on the fauna living on or among seagrass blades. Recently, Raposa and Oviatt (1997) collected several larger decapod species in throw traps collected along the north shore of Fire Island. Four decapod species were commonly collected in both seagrass and sand flats within the study area: the sand shrimp *Crangon septemspinosa,* the shore shrimp *Paleomonete spugio,* the grass shrimp *Hippolyte pleurocanthus*, and the blue crab *Callinectes sapidus.* Abundances of *Crangon septemspinosa* were about 70 percent greater in *Ruppia maritima* compared to *Zostera marina* beds (**Table 3.1**). Abundances of *Paleomonetes pugio*, *Hippolyte pleurocanthus*, and *Callinectes sapidus* were several times greater in Zostera marina beds compared to adjacent unvegetated sand flats. The efficiency of a throw trap with 6 mm mesh in collecting these species is unknown.

Table 3.1. Abundance (per m^2) of several decapods collected by throw traps in various habitats along the north shore of Fire Island. Data from Raposa and Oviatt (1997), n=15 in each habitat listed in the upper table and n=27 in the lower table. Comparisons with significant differences are indicated by an asterisk.

Species	***Zostera marina* areas**	***Ruppia maritima areas***
Crangon septemspinosa *	**31.00**	**53.87**
Paleomonetes pugia	**8.93**	**21.60**
Hippolytepleurocanthus	**9.60**	**16.53**
Callinectes sapidus	**0.60**	**0.27**

Species	***Zostera marina* areas**	**Sand**
Crangon septemspinosa	**34.22**	**25.7**
Paleornonetes pugio *	**4.33**	**0.59**
Hippolyte pleurocanthus *	**1.93**	**0.00**
Callinectes sapidus *	**0.85**	**0.07**

There are no readily available studies of the salt marsh fauna of Great South Bay. It is expected that the faunal assemblage includes infaunal and epifaunal species common in subtidal sand and mud habitats, along with species endemic to marshes. The endemic species would include the mud snail *llyanassa obsoleta,* the ribbed mussel *Geukensia demissa*, and the fiddler crabs *Uca pugilator* and *Uca pugnax*.

No new intertidal beach studies have been carried out in Great South Bay since the FINS Report (Bokuniewicz et al. 1993). Only one earlier study, of very limited extent, is available (Crocker 1970). In general, the intertidal beach fauna in Great South Bay has not been adequately characterized.

Landings of commercial shellfish have changed substantially in Great South Bay. Landings of soft shell clams, oysters, mussels, and conchs have been modest over the last decade (Figures 3.1 to 3.4). Hard clam landings have declined steadily since the peak during the mid-1970's (Figure 3.5). Over the last 10 years, landings have been consistently lowest in Babylon and highest in Brookhaven. Blue crab landings have increased in Great South Bay in recent years (Figure 3.6) and in New York State as a whole (National Marine Fisheries Services annual commercial landings data). This trend probably reflects both increased harvesting effort and increased productivity for this species. There are also anecdotal reports of increased harvesting razor clams in Great South Bay, but no regional data were available. Razor clams are primarily found in eastern Great South Bay.

Environmental Variables Affecting Benthic Fauna Abundance and Distribution

Environmental factors important in regulating the distribution and abundance of benthic fauna in Great South Bay include: light, temperature, substrate type and grain-size, currents, waves, tidal range, residence time of water in the Bay, dissolved oxygen, nutrients, salinity, food availability (especially the quality and quantity of phytoplankton), predation, disease and parasitism, and competition. The distribution of a species is determined by the suite of these (and probably other) environmental parameters acting together. In general, the environmental requirements of only a few species have been studied in detail; however, some useful information can be inferred from species' distributions in the field, and from laboratory and field studies.

When interpreting any data on a species' environmental relationships, it should be kept in mind that a species can often tolerate a greater range for an individual environmental factor than the range it experiences where it is found. For example, mussels are often restricted to intertidal habitats not because subtidal physical conditions are limiting (subtidal conditions are actually more optimal), but because predators restrict their seaward range.

It should also be noted that it is difficult, both in the laboratory and in the field, to determine an ecologically meaningful range for an environmental factor because a species response will always be conditioned by the suite of other environmental parameters. That is, responses to an environmental parameter must be interpreted in a multifactorial context to be ecologically meaningful. Davis and Calabrese (1964), for example, examined the effect of temperature on the growth of hard clam larvae. Their results for a given temperature varied both with salinity and with the type of phytoplankton used for food.

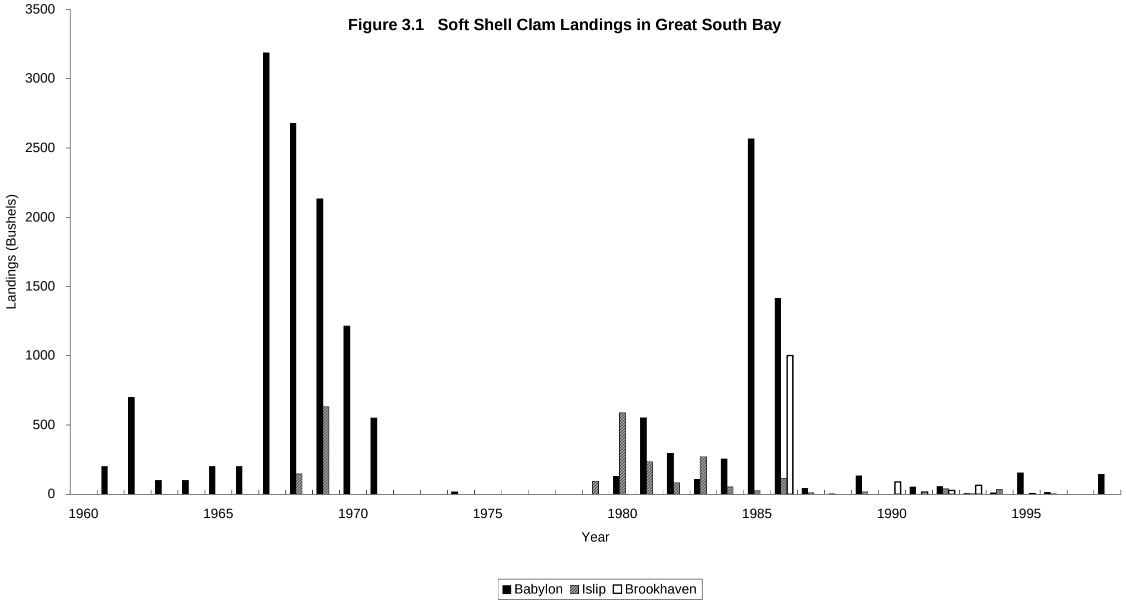


Figure 3.2 Oyster Landings in Great South Bay

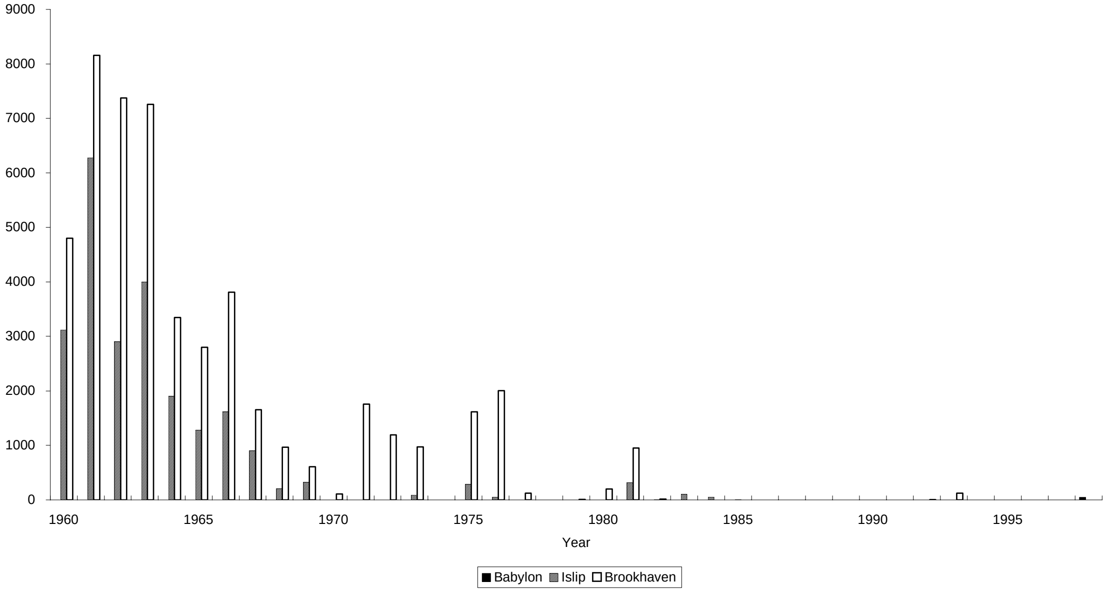


Figure 3.3 Mussel Landings in Great South Bay

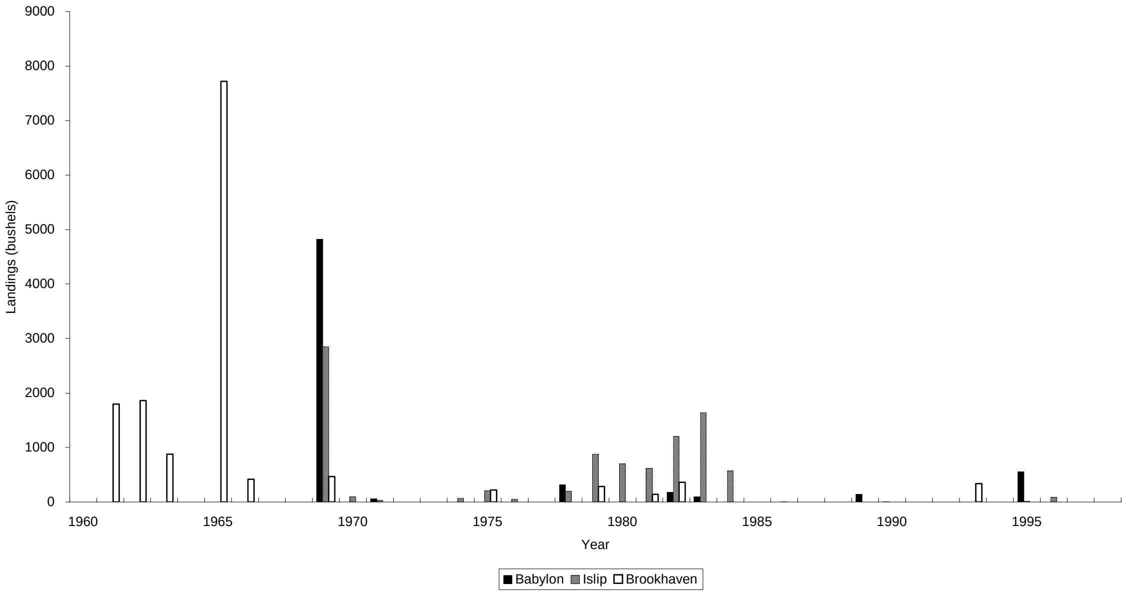


Figure 3.4 Conch Landings in Great South Bay

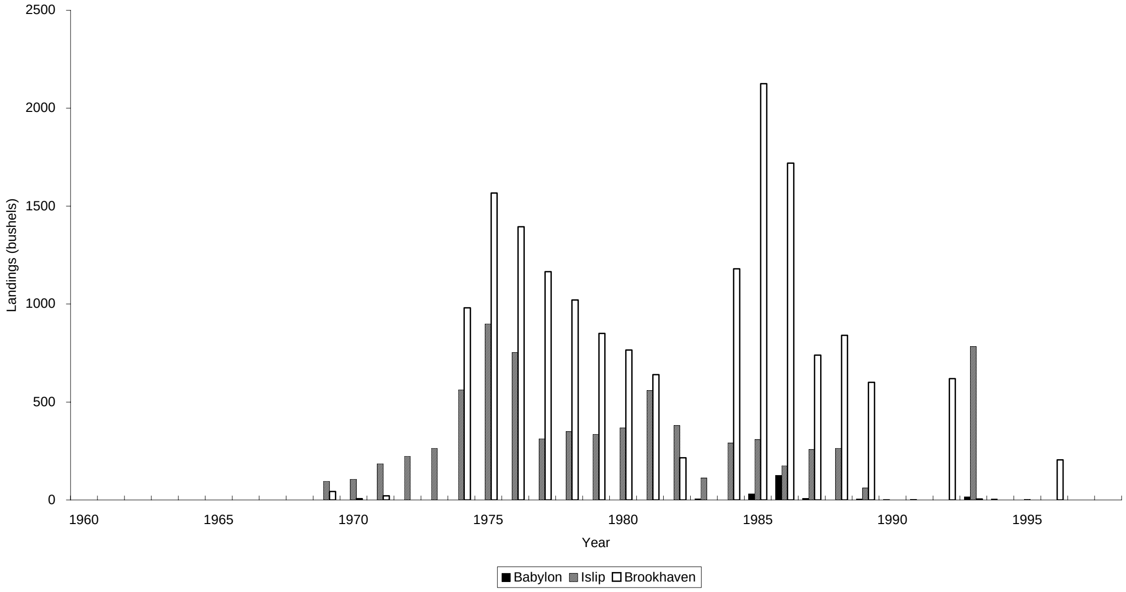


Figure 3.5 Hard Clam Landings in Great South Bay

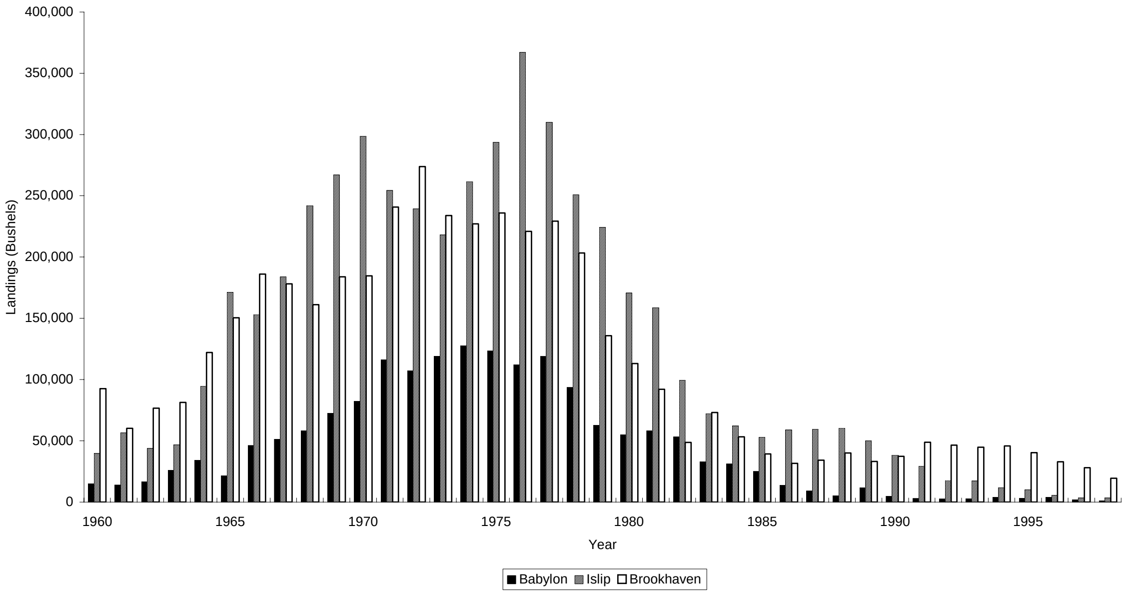
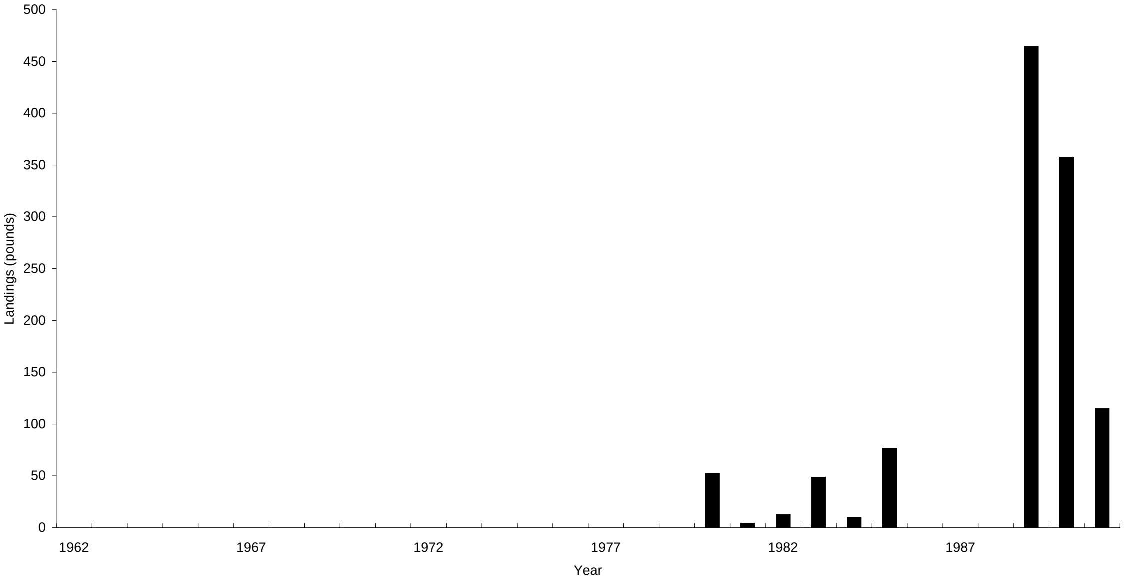


Figure 3.6 Blue Crab Landings in Great South Bay



The benthic fauna in unvegetated areas of Great South Bay is very diverse, and its distribution reflects flow conditions, water column gradients, and sediment. As reported in Bokuniewicz et al. (1993), existing data suggest the presence of a high salinity ≥ 30 ppt), high flow fauna associated with inlets (Fire Island Inlet and Moriches Inlet). Abundant species in inlet areas include the bivalves *Mytilus edulis* and *Tellina agilis*, the polychaetes *Nephtys picta* and *Nereis arenaceodonta*, the hermit crab *Pagurus longicarpus*, the lady crab *Ovalipes ocellatus*, and the sea star *Asterias forbesi*. Both high flow and high salinity contribute substantially to regulating the composition of this species assemblage. *Mytilus edulis*, for example, is found throughout the south shore bays but is especially abundant in the vicinity of inlets (WAPORA 1982, Cerrato 1986), probably because of high flow conditions. Asterias forbesi cannot tolerate low salinity, and its distribution, consequently, is restricted to inlet areas (WAPORA 1982). Additionally, the high flow conditions near inlets favor those invertebrates associated with coarse-grained sediments, especially suspension feeders.

Away from the immediate vicinity of an inlet, the fauna in unvegetated areas is more estuarine in character. Abundant species include the polychaetes *Sabellaria vulgaris* and *Trichobranchus glacilis*, the snails *Rictaxis punctostriatus* and *Acteocina canaliculata,* the bivalves *Mercenaria mercenaria, Mulinia lateralis* and *Gemma gemma,* the sand shrimp *Crangon septemspinosa,* and the blue crab *Callinectes sapidus* (WAPORA 1982, Wiggins 1986, Buckner 1984, Kassner et al. 1991, Larson 2000).

Although Bay-wide data are limited, a number of species show distinct west-east gradients, suggesting a relationship with changing water column properties that are coupled to Fire Island Inlet. For example, the bivalve *Tellina agilis* and the lady crab *Ovalipes ocellatus* were widely distributed in Islip waters but absent from Brookhaven waters in eastern Great South Bay (**Figure 3.7**) (WAPORA 1982). The razor clam *Ensis directus* was abundant in Brookhaven waters but totally absent from western Great South Bay (**Figure 3.8**) (WAPORA 1982). Bearing in mind the many limitations of interpreting landings data, hard clam harvests have been substantially greater in Brookhaven waters compared to western Great South Bay (i.e., Babylon and Islip waters) over the past decade, also suggesting a west-east gradient in the productivity of this species (**Figure 3.5).**

Larson's (2000) recent study indicates the presence during 1998-1999 of a very abundant and diverse benthic fauna with strong sediment associations (**Tables 3.2a** and **3.2b**). Macrofaunal abundances decreased with increased sediment grain-size, from 41,707 individuals per m^2 in mud to 19,418 per m^2 and 26,096 per m^2 in sand and shell, respectively. A total of 148 distinct taxa were present. The number of taxa present increased with sediment grain-size, from 91 in mud to 112 in shell. The opportunistic bivalve Mulinia lateralis was the most abundant species in the study. Its abundance decreased with sediment grain-size, from a high of 29,818 individuals per m^2 in mud

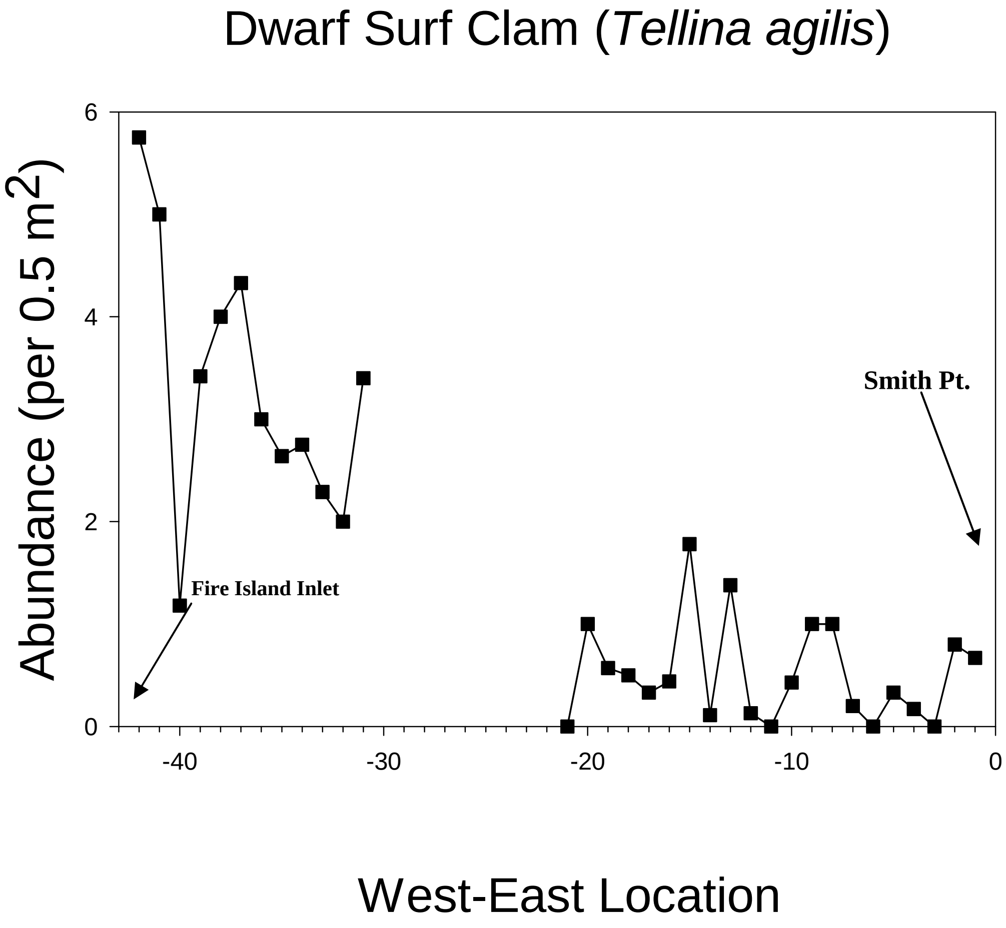


Figure 3.7 West to east gradient of dwarf surf clam abundance in Great South Bay from Fire Island Inlet (Station - 42) to Smith Point (Station 1). Data from WAPORA (1982).

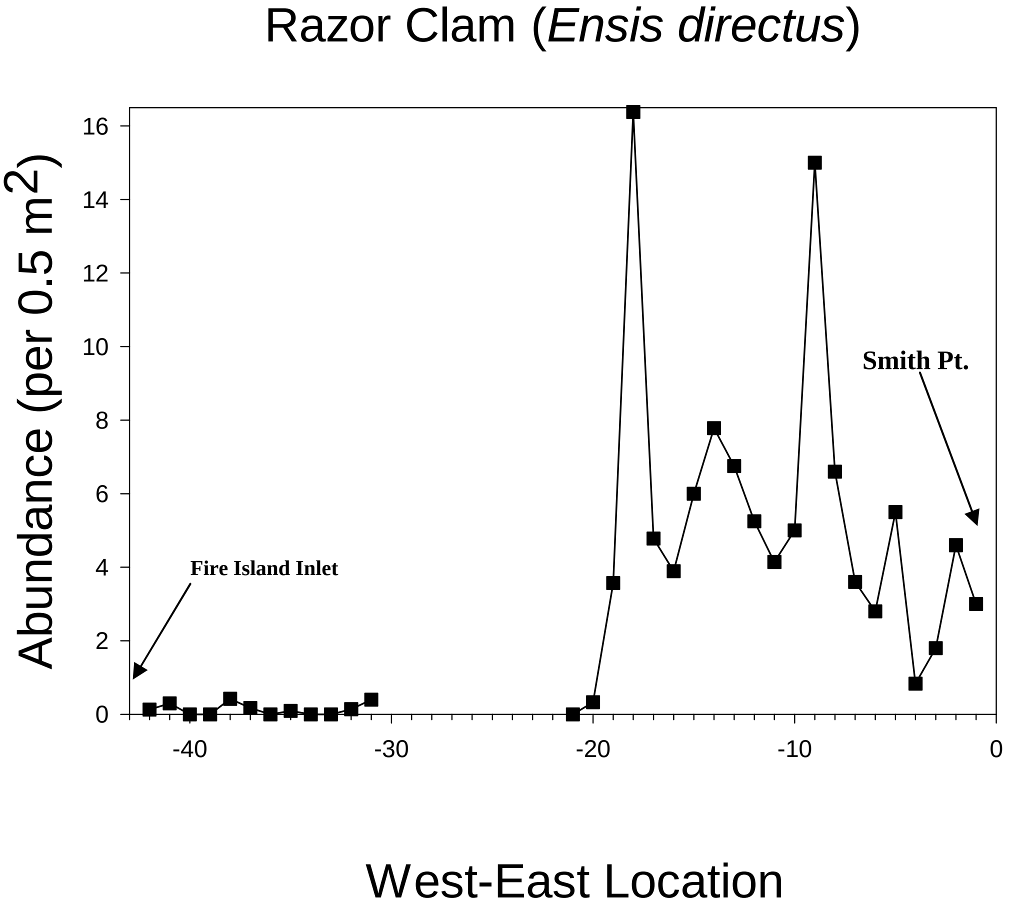


Figure 3.8 West to east gradient of razor clam abundance in Great South Bay from Fire Island Inlet (Station -42) to Smith Point (Station 1). Data from WAPORA (1982).

Table 3.2a Distribution and abundance (per square meter) of benthic macrofauna in eastern Great South Bay. From Larson (2000).

Phylum	Taxa	Fnc Grp	Mud	Mud/Sand	Sand	Shell
	Unk larvae A	PNM--			1	
Annelida	Arabella iricolor	INMC				10
Annelida	Asabellides oculata	ITSDs	1	2	8	13
Annelida	Autolytus cornutus	ENMC			2	
Annelida	Brania sp.	ENMC	1	8	3	13
Annelida	Capitella	ITMDi	1155	581	1029	2182
Annelida	Cirriforma grandis	INMDs	2	9	41	1015
Annelida	Clymenella torquata	ITSDi	19	22	48	481
Annelida	Enchytraeidae	INMDi	11	43	49	261
Annelida	Eteone	ENMC	33	28	15	68
Annelida	Eumidia sanguinea	ENMC	12	41	55	534
Annelida	Exogone dispar	INMC	349	620	613	590
Annelida	Exogone spp.	ENMC	3	3	18	95
Annelida	Fabrica sabella	ETSSf				1
Annelida	Glycera americana	INMC	38	13	32	27
Annelida	Glycera capitata	INMO			2	
Annelida	Glycera dibranchia	INMO	98	111	163	150
Annelida	Gonidella gracillis	INMC	17	22	38	140
Annelida	Harmothoe	ENMC	2	3		8
Annelida	Hesionidae	INMC	17	51	153	3253
Annelida	Hydroides dianthus	ETSSf	1	268	1349	3812
Annelida	Lepidametria commensalis	INMC	1			
Annelida	Lepidontus spp.	ENMC	6	2	5	31
Annelida	Lumbrineris spp.	INMO				2
Annelida	Melinna cristata	ITSDs	1	10		
Annelida	Naidid	INMDi	6	19	92	2287
Annelida	Nereis spp.	ITMC	3	8	83	513
Annelida	Nereis succina	ITMDs			3	8
Annelida	Ophelia	INMDi		1		
Annelida	Orbiniidae	INMDi	483	541	379	410
Annelida	Paranaitis speciosa	ENMC	8	5	2	67
Annelida	Paranoidae	INMDi	2			
Annelida	Paraprionospio pinnata	ITMDs	12	8	9	37
Annelida	Pectinaria gouldii	ITMDi	1098	1511	880	908
Annelida	Pholoe minuta	INMC		1		
Annelida	Phyllodoce	ENMC	4	3	8	8
Annelida	Polycirrus eximius	ITSDs		2	5	23
Annelida	Polydora aggregata	ETMSf	13		489	111
Annelida	Polydora quadrilobata	ITMDs				140
Annelida	Polydora websterii	ITMDs	727	843	612	832
Annelida	Potamilla reniformis	ITSSf			3	8
Annelida	Sabella crassicornis	ETSSf			1	63
Annelida	Sabella micropthalma	ITSSf			3	51
Annelida	Sabellaria vulgaris	ETSSf	2	108	351	864
Annelida	Schistomeringos rudolphi	INMC	5	1	2	189
Annelida	Sphaerosyllis erinaceus	INMO	3	3	8	24

Annelida	Spio filicornis	ITMSf			3	3
Annelida	Spio setosa	ITMDs				3
Annelida	Spiochaetopterus oculatus	ITSSf	3	8	14	8
Annelida	Spionid juv.	ITMDs			3	32
Annelida	Spiophanes bombyx	ITMDs	3	2	77	12
Annelida	Spirorbis spirillum	ETSSf	3		3	1
Annelida	Streblospio benedicti	ITMDs	1	4		
Annelida	Syllis gracilis	ENMC	2			29
Annelida	Tharyx spp.	INMDs				32
Annelida	Tubificoides	INMDi	196	248	384	925
annelida	Unk Syllidae A	INMO	1	11	2	4
Arthropoda	Ampelisca abdita	ITSDs	874	931	199	285
Arthropoda	Ampelisca sp.	ITSDs			1	
Arthropoda	Ampelisca vadorum	ITSDs	77	63	57	23
Arthropoda	Ampelisca verrilli	ITMDs	318	191	146	50
Arthropoda	Anoplodactylus lentus	ENMC	3	6	8	4
Arthropoda	Balanus spp.	ENSSf	1			35
Arthropoda	Batea catharinenis	ENMDs	8	57	63	82
Arthropoda	Callinectes sapidus	ENMO	2	1		1
Arthropoda	Calliopius laeviusculus	ENMDs		26	5	
Arthropoda	Callipallene brevirostris.	ENMC			1	
Arthropoda	Caprella penatis	ENMO	23	43	106	321
Arthropoda	Carcinus maenus	ENMO			1	
Arthropoda	Cerapus tubularis	ETMDs	13	41	66	47
Arthropoda	Chiriodotea sp.	ENMO		3	6	3
Arthropoda	Chirodotea cacea	ENMO	11	5	3	2
Arthropoda	Corophium	ITMSf	7	7	27	13
Arthropoda	Corophium bonneli	ITMSf	1			
Arthropoda	Crab megalope	PNMSf			1	2
Arthropoda	Crangon septemspinosa	ENMO	29	86	22	41
Arthropoda	Cumacean	ENMDs	337	463	282	384
Arthropoda	Cymadusa compta	ITMDs	2		1	
Arthropoda	Decapod (shrimp) Larvae	ENMO	18	5	60	43
Arthropoda	Dyspanopeus sayi	ENMO				6
Arthropoda	Edotea spp.	ENMO	45	22	46	21
Arthropoda	Elasmopus levis	ENMDs	2	1	104	4
Arthropoda	Erichsonella sp.	ITMO	2		1	
Arthropoda	Gammarus annulatus	ENMO		3		1
Arthropoda	Gammarus fasciatus	ENMO	4	26	36	44
Arthropoda	Harpactacoid A	ENMDs	22	5	18	
Arthropoda	Harpactacoid copepoda	INMDi		7	15	66
Arthropoda	Heteromysis formosa	ENMO	1		5	
Arthropoda	Idotea sp.	ENMO		1		
Arthropoda	Isopoda	ENMO			1	
Arthropoda	Lembos smithi	ITMSf	3		13	51
Arthropoda	Lembos websteri	ITMSf	1			
Arthropoda	Leptocheirus plumulosus	ITMSf	96	113	207	250
Arthropoda	Listriella clymenellae	INSSf				2

Arthropoda	Melita nitida	ENMDs		7		2
Arthropoda	Microdeutopus gryllotalpa	ETMSf	11	3	19	1
Arthropoda	Microprotopus raneyi	ITSSf		2		11
Arthropoda	Monoculodes edwardsi	INMO	50	226	124	33
Arthropoda	Neomysis Americana	ENMO	23	277	128	123
Arthropoda	Nymphion stromi	ENMC		1	3	
Arthropoda	Ostracoda A	ENMO	752	1159	780	1112
Arthropoda	Ostracoda B	ENMO	3	2	2	1
Arthropoda	Pagrus longicarpus	ENMO				2
Arthropoda	Palemonetes pugio	ENMO			1	
Arthropoda	Panopeus herbstii	ENMO	28	50	63	105
Arthropoda	Parametopella cypris	ENMDs	1	3	3	5
Arthropoda	Pontogeneia intermis	PNMG		1		7
Arthropoda	Praunus flervosua	ENMO	4			
Arthropoda	Pseudunicola obliquua	ITMSf		1		
Arthropoda	Semibalanus balanoides	ENSSf				1
arthropoda	Siphonostomidia	ENMC			1	
Arthropoda	Synchelidium americanum	INMDs	1			
Arthropoda	Unicola irrorata	ETMDs		8	25	88
Chordata	Botryllus sp.	ENSSf			3	4
Cnidaria	Diadumene lineata	ENSC			2	31
Cnidaria	Edwardsia elegans	INMC	1			
Cnidaria	Haloclava producta	INMC	21	30	8	6
Cnidaria	Urticina felina	ENSC				1
Echinodermata	Cucumaria frondosa	ENMSf				4
Echinodermata	Sclerodactyla briareus	ENMDs				7
Ectoprocta	Bryzoa	ENSSf	3	8	8	17
Ectoprocta	Bryzoa branching	ENSSf	2	2	2	3
Mollusca	Acteocina canaliculata	ENMC	1465	1626	998	307
Mollusca	Bittium alternatum	ENMG	1			
Mollusca	Crepidula convexa	ENMSf		1	2	54
Mollusca	Crepidula fornicata	ENMSf				3
Mollusca	Ensis directus	INMSf	3	47	85	95
Mollusca	Hydrobia totteni	ENMDs	3	2		27
Mollusca	Ilyanassa obselata	ENMO			1	
Mollusca	Juv. Bivalve	INMSf	8			
Mollusca	Mercenaria mercenaria	INSSf		5	7	14
Mollusca	Mitrella lunata	ENMC			3	2
Mollusca	Mulinia lateralis	INSSf	29818	16818	6648	618
Mollusca	Mytilus edulis	ENSSf	3	1	4	3
Mollusca	Nucula proxima	INMDi	4	7	18	19
Mollusca	Pyramidellidae	ENMC	36	43	60	88
Mollusca	Rictaxis punctostriatus	ENMC	3006	1032	1606	918
Mollusca	Tellina agilis	INSDs	22	65	104	104
Mollusca	Tenellia fuscata	ENMC			1	
Mollusca	Turbonilla spp.	ENMC		3		
Mollusca	Urosalpinx cinerea	ENMC			2	
Nemertinea	Nemertinea	INMC	23	52	58	153

Platyhelminthes	Platyhelminthes A	ENMO	72	24	48	18
Platyhelminthes	Platyhelminthes B	ENMO	118	229	67	46
Porifera	Cliona celata	ENSSf		2	2	11
Porifera	Halicliona canaliculata	ENSSf				1
Urochordata	Bostrichobranchus pilularis	INSSf			1	
Urochordata	Colonial tunicate	ENSSf				1
	Total Abundance		41707	28993	19418	26096
	Total Number of Species		91	92	108	112

Table 3.2b. Functional group assignment chart from Larson (2000):

	Infaunal (I)				Epifaunal (E)			
	Tubiculous (T)		Non-Tubiculous (N)		Tubiculous (T)		Non-Tubiculous (N)	
	Motile (M)	Sessile (S)	Motile (M)	Sessile (S)	Motile (M)	Sessile (S)	Motile (M)	Sessile (S)
Suspension feeder (Sf)	ITMSf			INSSf	ETMSf	ETSSf		ENSSf
Surface Deposit feeder (Ds)	ITMDs	ITSDs	INMDs	INSDs	ETMDs		ENMDs	
Infaunal Deposit feeder (Di)	ITMDi	ITSDi	INMDi					
Carnivore (C)	ITMC		INMC				ENMC	ENSC
Omnivore (O)			INMO				ENMO	

to a low of 618 individuals per m^2 in shell. Similar trends were found for other numerically abundant species such as the amphipods *Ampelisca spp*., the carnivorous gastropods *Rictaxis punctostriatus* and *Acteocina canaliculata.* In contrast, some common species tended to increase in abundance with grain-size. These include, for example, the tubiculous polychaetes *Hydroides dianthus* and *Sabellaria vulgaris* that construct calcareous tubes on hard surfaces, the surface deposit feeding polychaete

Cirriformia grandis, the mud crab *Panopeus herbstii*, and the hard clam *Mercenaria mercenaria*. Larson (2000) used multivariate statistical techniques to confirm significant community structure associations relating to grain-size. In addition, Cerrato et al. (1998), using Town of Brookhaven survey data, have determined that the distribution of hard clams closely follows bottom type throughout the whole 4,000 hectare area in eastern Great South Bay that was mapped by side scan sonar.

At the single species level, a variety of studies have related the distribution and abundance of hard clams (*Mercenaria mercenaria*) to environmental parameters. The optimal temperature and salinity for adult hard clam growth has been estimated to be 20^{o}-23^{o}C (Ansell 1968, Pratt and Campbell 1956) and 26-27 ppt (Rice and Pechenik 1992). Hard clams can tolerate temperatures from <0°C to > 30^{o}C (Pratt et al. 1992); however, growth does not occur over this entire range. There is evidence that high summer temperatures represent a period of stress and interrupt clam growth. Both Greene (1978) and Wallace (1991) reported the common occurrence of multiple growth breaks of the same morphology as heat shock breaks (Kennish 1980) in the shells of clams collected in Great South Bay. Shell growth in hard clams significantly declines when temperatures fall below 9^{o}C (Ansell 1968). The salinity tolerance of adult hard clams has been estimated to be 12.5-35 ppt by Castagna and Chanley (1973). Small salinity changes are generally not thought to have a major influence on growth rate (Rice and Pechenik 1992).

Hard clam embyros and larvae are more sensitive to temperature and salinity conditions than adults. Davis and Calabrese (1964) and Lough (1975) examined the combined effects of temperature and salinity on the development of eggs and growth of hard clam larvae. Broadest tolerances for one environmental factor occurred near the optimum for the other, and the tolerance range narrowed away from the optimum. The optimum temperature for embryos and larvae appears to be about 23^{o}C, and the broadest temperature range is from 17.5^{o}-30^{o} C at a salinity of 27.5 ppt (Davis 1969). Within that range, >50 percent of embryos developed normally and >50 percent of larvae survived and grew at a reasonable rate. There was no distinguishable difference in temperature tolerance between embryos and larvae. Davis (1958) reported that the optimum salinity for development of fertilized eggs into normal straight-hinge larvae was 26.5-27.5 ppt at 23^{o} C. A high percentage of eggs developed normally within the range of 22.5 ppt to 30 ppt; however, the percentage of eggs reaching the straight-hinge stage quickly fell below 50 percent at salinities above and below this range. For example, at 22.5 ppt only 16-22 percent developed normally and at 32.5 ppt only 34-52 percent had normal development. Unlike temperature, tolerances changed during development, and larvae had much broader tolerances than embryos. For example, Calabrese and Davis (1970) reported greater than 50 percent survival and reasonable growth for larvae at a salinity of 15 ppt. In addition, Davis and Calabrese (1964) found that the effects of temperature and salinity on larval growth and survival were influenced by both the quality and quantity of food present, indicating that temperature and salinity tolerances cannot be examined independently of other environmental factors.

Food quality and quantity are critical determinants in the growth of bivalves (Rice and Pechenik 1992). At first sight, the very high chlorophyll a levels (10 to >25 micrograms per liter) in Great South Bay reported in Lively et al. (1983) would suggest correspondingly high growth rates in hard clams. However, two noteworthy features place doubt on the ability of this high phytoplankton standing stock to support high hard clam growth. Lively et al. (1983) found that small forms (2-4 micron chlorophytes) were chronically dominant and represented about half of the total phytoplankton biomass in Great South Bay. Small forms pass through the gut of hard clams almost completely undigested and cannot support clam growth (Bass et al. 1990). Additionally, during many years since 1985, south shore bays on Long Island have been plagued by blooms of the brown tide organism *Aureococcus anophagefferens*. This organism has been shown to interfere with suspension feeding in hard clams (Draper et al. 1990, Bricelj and Lonsdale 1997).

Hard clam growth rate is also sensitive to suspended sediment loads (Pratt and Campbell 1956, Bricelj et al. 1984) and seston fluxes (Hadley and Manzi 1984, Manzi et al. 1986, Grizzle and Morin 1989, Grizzle and Lutz 1989); Grizzle and Lutz (1989) found a relationship between hard clam growth and seston fluxes, with maximum growth occurring at moderate seston flux rates (90-130 mg particulate organic carbon cm^{-2}s^{-1}). Seston fluxes outside this range resulted in reduced growth. Bricelj et al. (1984) found significant reductions in growth (-16 percent) of juvenile hard clams at extended (21 day) exposures to high silt concentrations (44 mg l^{-1}). While such high silt concentrations occur in Great South Bay, they are characteristic of storm events (Bricelj et al. 1984) and are maintained for only short periods of time (hours to days). Finally, Judge et al. (1992) found that under adequate food concentrations, doubling current speeds had no effect on hard clam growth.

Hard clam distribution and abundance is also regulated by bottom type. Cerrato et al. (1998) examined the relationship between hard clam abundance and sediment type in a 4,000 hectare area in eastern Great South Bay. Using a combination of side-scan sonar, sediment grain-size, and sediment-profile data, they found discrete, well defined habitats that corresponded closely with hard clam abundance. Based on hard clam abundance data from the 1991 Town of Brookhaven shellfish census, lowest abundance occurred in mud (1.5 clams m^{-2}) and muddy-sand (2.9 clams m^{-2}) habitats. Sandy bottom represented about 49 percent of the study area and had average abundances of 8.2 clams m^{-2}) Greatest abundance (19.6 clams m^{-2}) occurred in a number of small, often elongated patches 100-200 meters wide and 100-600 meters long, representing the remains of relict oyster reefs. This bottom type was found at about 16 percent of the study area.

Predators also regulate distribution and abundance of hard clams. WAPORA (1982) identified a significant number of hard clam predators in Great South Bay, mud crabs *Dyspanopeus sayi* and *Panopeus herbstii*, blue crabs *Callinectes sapidus*, rock crabs *Cancer irroratus*, horseshoe crabs *Limulus polyphemus*, sea stars *Asterias forbesi* and *Asterias vulgaris*, hermit crabs *Pagurus longicarpus* and *Pagurus pollicaris*, channeled whelks *Busycon canaliculatum*, moon snails *Neveritas duplicata* and *Euspira heros*, calico crabs *Ovalipes ocellatus*, and oyster drills *Eupleura caudata* and *Urosalpinx cinerea*. Many of these hard clam predators (e.g., calico crabs) showed distinct west-east spatial gradients in the Bay, while others were widely distributed but had distinct sediment preferences (e.g., mud crabs) (WAPORA 1982, Larson 2000).

Another shellfish species of commercial and recreational importance, the blue crab *Collinectes sapidus*, occurs near the northern end of its range in Great South Bay, as a result of the crab's susceptibility to low winter temperatures (Epifanio 1995). Blue crabs are also especially vulnerable to predation when the water temperature declines below 5^{o}C (Auster and DeGoursey 1994). They are euryhaline animals, although zoea larvae require salinities above 25 ppt (Costlow 1967). Crabs are found in a variety of habitats, including hard bottoms, sand and mud bottoms, seagrass and macroalgae beds, and marsh creeks (WAPORA 1982, Ryer et al. 1990, Fitz and Wiegert 1991). They show seasonal movement patterns, tending to be in deeper, warmer waters in winter (Epifanio 1995).

Effects of Predicted Changes in the Physical Factors Caused by a Breach

The Conley (2000) study predicts that a breach in eastern Great South Bay in the vicinity of Old Inlet or Barrett Beach would substantially increase salinity, enhance flushing and reduce residence times, increase bottom shear stress in the vicinity of the breach, and alter circulation patterns. The model results appear reasonable, although the model appears to overestimate existing salinity conditions in Bellport Bay, and especially in the Carmens River. Although it was not modeled, a breach would also be expected to moderate extreme winter and summer water temperatures. With a breach, Great South Bay would probably be cooler on average.

Breach impacts on the benthos will depend in part on the duration of the breach. In shallow nearshore areas, benthic communities are adapted to frequent physical disturbances, and recovery after a physical disturbance tends to be rapid, taking place in a year or two, even after a severe physical disturbance (Rhoads et al. 1978). Thus, rapid recovery would be expected in the case of a short duration breach (e.g., open < 1 year) that causes no permanent habitat alteration. Cerrato (1986), for example, found evidence for substantial change in the benthic fauna of Moriches Bay during 1981-1982 that was consistent with succession and rapid recovery after the 1980 breach. Such short term phenomena are not of major concern. It is only breaches of long duration, especially those that create a permanent inlet, that need to be addressed in detail. The remainder of this section assumes that the breach results in the creation of a permanent inlet.

Benthic community structure in eastern Great South Bay would probably change in response to a permanent breach at Old Inlet or Barrett Beach. The limited existing data suggest that a high salinity–high flow assemblage, such as that found associated with Fire Island Inlet and Moriches Inlet, would develop in the immediate vicinity of the breach. Since the breach would also tend to eliminate existing west-east water column gradients in the Bay, it would be likely that the community structure in eastern Great South Bay would more closely resemble that of the western part of the Bay and Moriches Bay. Thus, for example, species with documented west-east distribution patterns (WAPORA 1982), such as the bivalve *Tellina agilis*, the lady crab *Ovalipes ocellatus* and the razor clam, *Ensis directus*, would be affected. Additionally, any local habitat (e.g., changes from vegetated to unvegetated bottom) or sediment alterations (e.g., sediment coarsening due to increased scour) that occurred would also be expected to change the community structure.

Changes associated with a permanent breach would probably have both negative and positive impacts on the hard clam, with the net effect impossible to predict based on existing data. On the negative side, greater salinity and cooler spring and summer water temperatures would increase mortality and slow the development of fertilized eggs and larvae. Coupled with reduced residence times, fewer larvae would reach the pediveliger stage within the Bay. Altered conditions would also be expected to change the assemblage of predators in eastern Great South Bay, probably increasing the abundance of channeled whelks *Busycon canaliculatum*, moon snails *Neveritas duplicata* and *Euspira heros*, calico crabs *Ovalipes ocellatus*, and oyster drills *Eupleura caudata* and *Urosalpinx cinerea* based on results in WAPORA (1982). Cooler overall water temperatures could decrease clam shell growth in eastern Great South Bay, as suggested by the results in Turner's (1983) field study of the impact on Moriches Bay clams caused by the 1980 breach at Moriches Inlet.

The most important positive impact of a breach on hard clams would probably involve changes in the quality and flux of its food (i.e., phytoplankton). Increased flushing would shift the plankton community in eastern Great South Bay to a more oceanic assemblage, both through exchange at the new inlet and through the occurrence of more oceanic environmental conditions. Increased flushing would locally increase the flux of phytoplankton through the inlet, the phytoplankton-assemblage would tend to shift away from small forms, and it is conceivable that the new conditions would also reduce brown tide. All of these possible changes would increase hard clam growth. Additionally, milder winter temperature conditions would reduce over-winter mortality, and more moderate temperatures during both winter and summer might reduce the number of growth interruptions that occur during seasonal extremes. Some localized sediment coarsening would be favorable to clams, since existing data indicate a positive relationship between abundance and sediment grain size (Cerrato et al. 1998). The change in circulation along the north shore of the Bay predicted by Conley's model (2000) could locally benefit the clam population in these areas by increasing the flux of larvae and phytoplankton. This is, however, a very tenuous conclusion since wind driven currents probably drive circulation in the Bay, easily overwhelming tidal flow patterns.

The overall impact on hard clams of the multiple environmental changes associated with a permanent breach is impossible to predict based on available data. As mentioned previously, landings data over the past 10 years indicates that clam productivity may be lower in western Great South Bay and Moriches Bay compared to eastern Great South Bay. This geographic trend, if truly inlet related, would suggest that a breach would have an overall negative impact on the hard clam population in eastern Great South Bay. However, an improvement in food quality and flux is also suggested, and this change could easily produce a large positive effect on hard clam growth. In particular, a substantial positive impact on growth would occur if a breach were to eliminate or at least reduce the duration of brown tide events in Great South Bay.

A permanent breach would probably positively affect the blue crab population in Great South Bay. WAPORA (1982) found only three blue crabs during extensive 1978 sampling in Great South Bay. The moderate winters experienced over the last 10 years are probably responsible for the increased abundance of this species. Since a breach would moderate extreme winter conditions even further, over-winter survival might be enhanced. Higher salinity associated with a breach might also increase blue crab zoea survival within the Bay.

Research, Management and Monitoring Information Needs

Studies are needed to identify, map, and describe the current state of benthic habitats in Great South Bay. Great South Bay comprises a diverse assemblage of benthic habitats. Of the few existing studies of its benthic fauna in these habitats, most were carried out over 15 years ago; consequently, an accurate, reliable characterization of the benthos cannot be made. Recently, ecologists have recognized that processes structuring benthic populations and communities operate at a variety of spatial scales (Thrush 1991, Hewitt et al. 1998, Legendre et al. 1997). The complete range of scales present can only be recognized by identifying and mapping habitats in a quantitative way. An integrated approach to habitat characterization is needed for Great South Bay that would couple water quality data, acoustic data, such as that obtained by side-scan sonar, measures of sediment characteristics produced by sediment-profile images and grain-size analysis, along with faunal data. Larson (2000) used such an integrated approach successfully in her spatially-limited study in Patchogue Bay. Habitat identification studies would be of fundamental importance for monitoring, since an accurate and reliable characterization of the benthos would be an important first step in designing a monitoring program to assess change.

The diversity of benthic habitats also make Great South Bay a natural laboratory for detailed investigations of animal-substrate relationships. Research should be directed toward understanding benthic processes within the various habitats, identifying functions key or unique to each habitat, and determining how various substrates and changes in substrate type affect the benthic resources. Such studies would have both basic and applied value. As an example of a practical application of this research, at the breach impacts workshop, participants felt that information on how hard clam abundance, distribution, and productivity would change after a breach would be needed on a habitat-specific basis in order to be useful.

Our current knowledge of hard clam (or of any other species in Great South Bay) biology does not allow us to reliably predict how populations would change in response to a breach at Old Inlet or Barrett Beach. To alleviate this problem, research is needed on population responses to multiple environmental changes associated with a breach. For hard clams, this would involve research to investigate on a seasonal basis the separate and combined effects of breach-associated changes in food quality, food quantity, temperature, and salinity on survival, growth, and fecundity. It would require an assessment of predator populations and predation rates for a varietv of habitat types in the Bay. It would also require a comprehensive study of larval transport and larval ecology. Participants at the breach impacts workshop indicated that it would be useful to conduct hard-clam studies comparing different geographic regions within Great South Bay, Great South Bay versus other south shore bays, and the bays over time. Such studies could provide information on how, for example, different suites of predators affect hard clam survival. A comparative hard clam study attempting to assess potential breach impacts on growth in the field is already underway in Moriches Bay, funded by the U.S. Army Corps of Engineers. However, all such studies should involve both a laboratory and field component. The laboratory component is absolutely essential if mechanisms are to be identified, since multiple environmental factors tend to covary in the field and cannot be separately resolved.

Uncertainty about the extent of environmental change and the threat of flood damage has led managers in the past to close breaches. While workshop participants could not arrive at overall consensus regarding breach impacts on benthic and shellfish resources, it was felt that benthic organisms in shallow water systems like Great South Bay have a major impact on both bottom and water column processes. Consequently, decision-makers need to continue considering impacts on benthic community structure and their subsequent ecological effects when assessing breach scenarios and responses.

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SUBMERGED AQUATIC AND INTERTIDAL VEGETATION

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Important Submerged Aquatic Vegetation Species

The submerged plant communities of Great South Bay are comprised of mixtures of seaweeds (non-vascular plants) and at least two species of rooted vascular plants. The seaweeds include *Cladophora gracilis, Ulva lactuca, Enteromorpha* and the exotic Codium fragile. Macroalgal biomass can reach 350 g dry mass/m^2 (Bokuniewicz et al. 1993). These plants are a natural component of most estuaries and do provide some habitat and food for invertebrates. In many cases however, (particularly with "bloom" species or non-native plants such as *Codium*) high abundance of macroalgae are presumed to have negative consequences for rooted plants and have been proposed as indicators of poor water quality (Valiela et al. 1992).

Eelgrass (*Zostera marina*) is the predominant submerged vascular plant in Great South Bay with scattered small patches of *Ruppia maritima* (Bokuniewicz et al. 1993). *Zostera marina* is one of the best-studied marine plants and there is extensive evidence for its habitat value (Heck et al. 1995, Short and Wyllie-Echeverria 1996). Some species of fishes in Great South Bay are strongly influenced by biomass of both eelgrass (e.g., northern pipefish, winter flounder and American eel) and macroalgae (e.g., fourspine stickleback and seaboard goby) (Raposa and Oviatt 2000). Eelgrass has occupied as much as 38 percent (about 91 km^2) of the area of Great South Bay (Dennison et al. 1989) although its areal extent has fluctuated wildly in response to wasting disease, the occurrence of brown tides and probably other factors as well.

Environmental Variables Affecting Eelgrass Abundance and Distribution

Eelgrass abundance and long-term stability in a region appear to be related to three main factors: light availability, nutrient enrichment and presence of a fungal pathogen. The first two factors are occasionally inter-related in that nutrient enrichment encourages water column phytoplankton growth that diminishes light penetration and excess nutrients may stimulate epiphytic growth on the eelgrass itself (Short et al. 1995, Short and Burdick 1996).

There is a suggestion that *Zostera* was absent from Great South Bay from 1835 to 1931 due to much lower salinity, presumably related to poor exchange with ocean waters (Bokuniewicz et al. 1993). Under present conditions, the salinity is high enough to support *Zostera.*

The response of *Zostera* photosynthetic rate to light is very steep below about 200 µE/m^2/s and values above this are saturating at least in the short term (**Figure 4.1**). In a tributary of the Chesapeake Bay, Stevenson et al. (1993) found that light extinction coefficients less than 2 m^{-1},combined with low nutrient conditions (dissolved inorganic nitrogen < 10 µM, phosphate < 0.35 µM) allowed growth of submersed plants. Well-developed models of light requirements exist for common species such as *Zostera*. Minimum light requirements are typically 15-25 percent of incident light, which translates to maximal depths of 2-10 m under typical nearshore conditions of turbidity (Dennison et al. 1993). Maximal depths for *Zostera* in Great South Bay are reported to be 3-4 m under average conditions of turbidity (Dennison et al. 1989). It is important to recognize that although Great South Bay is relatively shallow and roughly 70 percent (170 km^2) of the Bay is shallower than the depth of minimum light requirement, the plants (except in the shallowest locations) are still existing under less than saturating light conditions. Previous surveys showed the densest patches of Zostera (250-375 g dry mass/m^2) generally occurred near the southern shore of Great South Bay, with less dense patches trending towards the center of the Bay (Greene et al. 1977). Therefore, even small changes in light penetration should affect individual plant photosynthetic capacity.

Many areas of Zostera in deeper waters may be particularly susceptible to competition from other plants, disturbance or other stresses. Therefore, plants in the deeper regions will be the best indicators (most sensitive) to even relatively small changes in light.

Effects of Predicted Changes in the Physical Factors Caused by a Breach

The breach model predicts several changes with obvious consequences for light-limited submersed plants. The residence time of water in Great South Bay is predicted to decline by roughly 50 percent under the breach scenarios. At a minimum, such an increased flushing would tend to deplete phytoplankton standing stocks due to faster "wash-out" of existing populations. The magnitude of the resulting change in water clarity cannot be predicted with the information at hand, but it seems reasonable to predict clarity will increase under these new conditions.

If we assume that water clarity after a new breach would approximate that in Moriches Bay (i.e., the Secchi disc depth would increase to 1.4 m from 1.16 m under current conditions, see **Table 6.1** and *Summary and Discussion* section), such a change can lead to as much as a two-fold difference in oxygen evolution (a short-term measure of productivity) for plants growing at certain depths (**Figure 4.2**). The consequence would

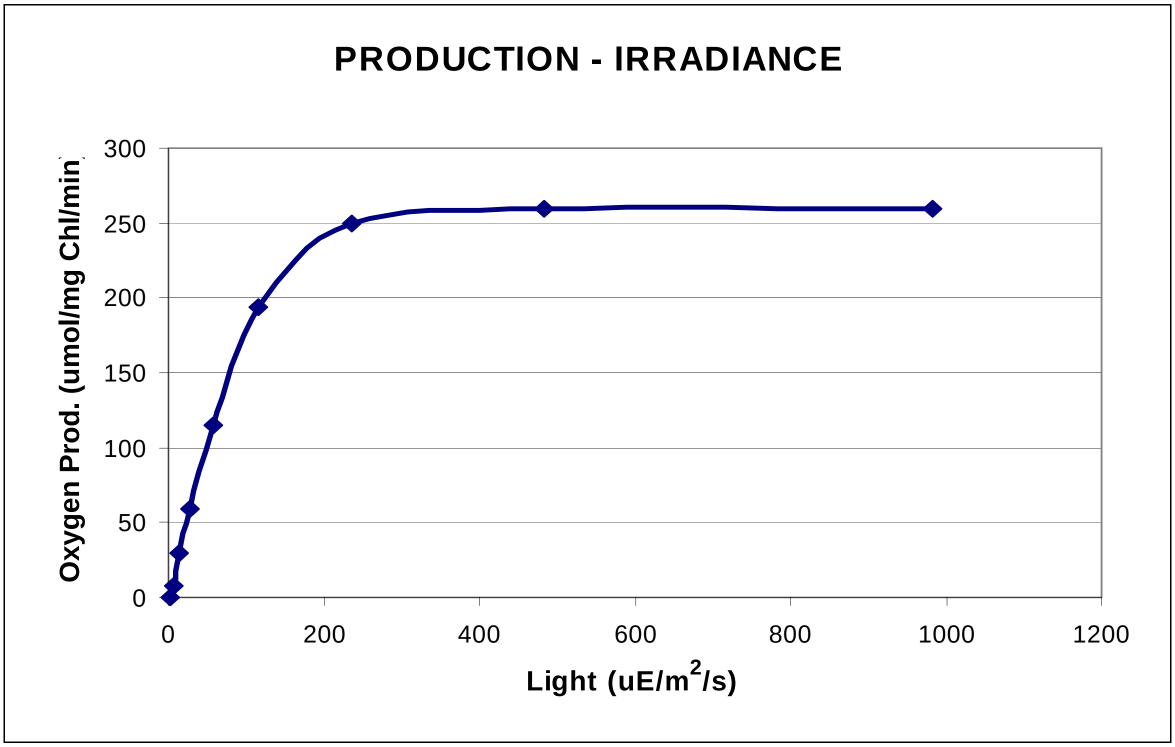

Figure 4.1 Production Irradiance Curve for Eelgrass. Relationship between photosynthesis as measured by oxygen production and irradiance for eelgrass (*Zostera marina*). Curve calculated from data presented in Dennison and Alberte (1985).

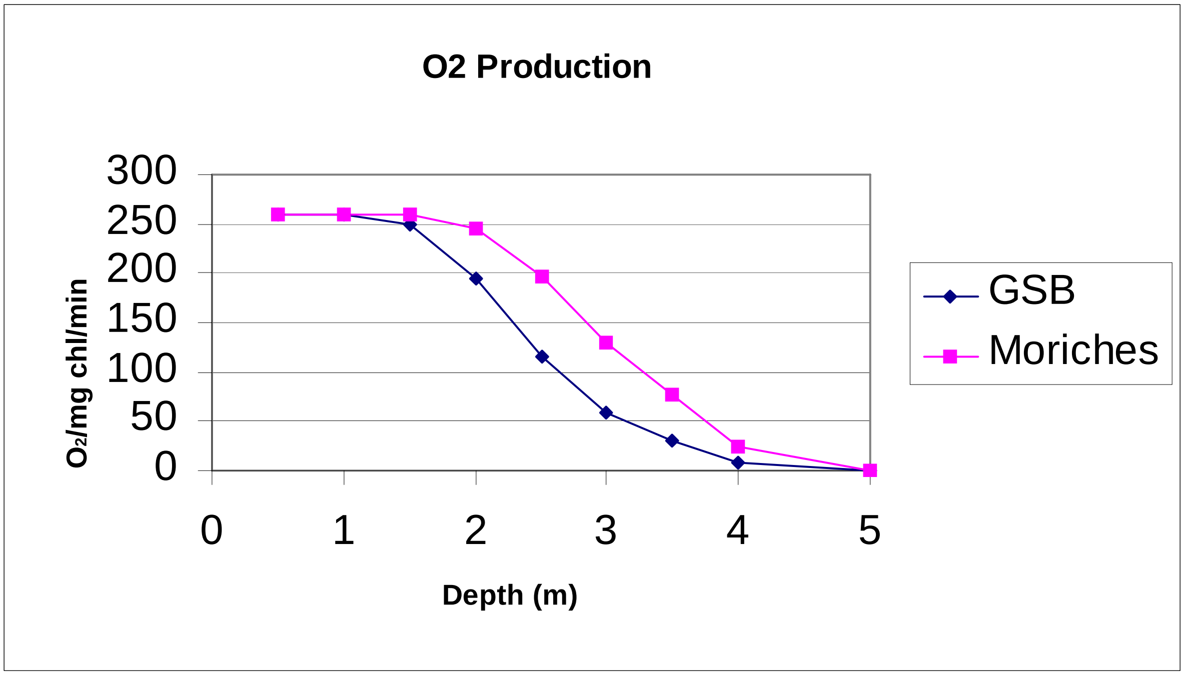

Figure 4.2 Eelgrass Oxygen Production With Depth. Difference in oxygen production by *Zostera marina* under two scenarios of water clarity. The GSB curve assumes a secchi disc depth of 1.16 m and the "Moriches Bay" example assumes a secchi depth of 1.4 m. Incident PAR is 2000 uE/m2/s in both cases. O2 production calculated using the P-I curve shown in Figure 4.1.

be an increase in the maximum depth of *Zostera* and, depending upon bathymetry, potentially a significant increase in coverage by plants. Overlaying the predicted difference in oxygen evolution with Great South Bay hypsometry shows that the depth range of maximum difference in photosynthesis (~2.5-4 m) corresponds to 10-15 percent of bottom area (24 to 36 km^2) (**Figure 4.3**). At depths less than roughly 2.5 m, plants under either scenario are growing under conditions of sufficient light while plants (if any) occurring deeper than 4 m would not experience a significant increase in light availability. Plants between 2.5 m and 4 m would experience the greatest change in light availability and thus have the greatest likelihood of increasing their coverage. Moreover, plants at intermediate depths would probably increase their biomass and various leaf characteristics.

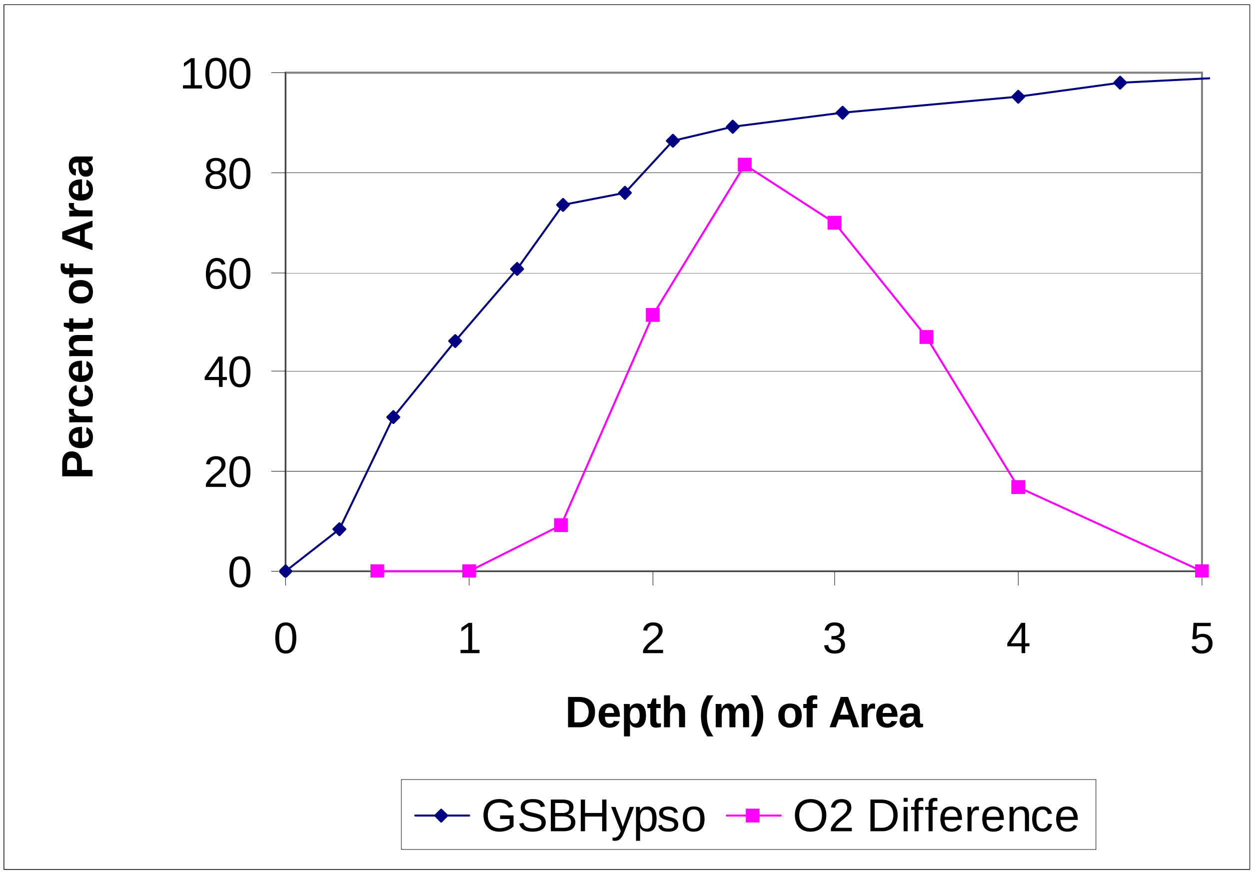

Figure 4.3 Oxygen Production Differential and Bay Hypsometry. Overlay of estimated difference in oxygen production (umole/mg Chl/min) with GSB hypsometry showing the proportional area of the Bay anticipated to have the greatest shift in *Zostera* performance. Depths between 2.5 – 4 m are expected to experience the greatest increase in plant photosynthesis. And this critical depth range is represented by about 15% of the bottom area of GSB.

In Woods Hole, Massachusetts, Dennison and Alberte (1985) found significant changes in plant performance within a few weeks of a light manipulation (shading and augmentation) suggesting that at least the physiological response can be quite rapid. In their study, increases in plant biomass per m^2 at deep sites were observed after 30 days of greater light availability although expansion into new areas would presumably require 1-3 years.

Increased flushing will also tend to remove nutrients delivered from uplands, tributaries or groundwaters, again likely causing a decline in phytoplankton and perhaps in epiphytic fouling of eelgrass leaves themselves. These declines would be most apparent in shallow water where light availability is high and nutrients may be limiting. Both of these changes would translate to increased light availability for *Zostera*. The direction of the predicted change in coverage is also positive.

Based on changes in salinity distribution shown in **Figure 1.3,** the change in flushing is not evenly spread across Great South Bay and there may be significant interactions between where the bathymetry permits plant growth or expansion and where the change in flushing is expected. For instance, if regions with the greatest increases in flushing are inherently too deep for *Zostera* (roughly 3 m or deeper), then obviously flushing will have minimal effects on plant coverage.

Acting counter to the predicted effects of increased flushing are the accompanying changes in bottom shear stress and local sediment deposition. Greater shear stress may alter sediment resuspension and redistribute sediments throughout the Bay. If resuspension were to increase, there would be obvious negative effects on water clarity and submerged plant performance. Overwash deposits can bury *Zostera* beds (EEA Inc. 1999), but these are probably relatively small-scale changes restricted to the immediate area of the overwash. If sediment redistribution is sufficient to alter the hypsometry of Great South Bay, then the potential habitat for *Zostera* will be changed in a predictable fashion. Given the uncertainty in the model about the change in shear stress and consequences for sediment dynamics, it seems prudent to keep these potential mechanisms in mind although there must be low confidence in any of the predicted consequences.

Research, Management and Monitoring Information Needs

There is an obvious need for studies of the extent of *Zostera* and seaweeds (*Codium* and *Ulva*) in Great South Bay together with documentation of habitat (depth distribution, bottom type) and water column attributes such as clarity, chlorophyll and inorganic nutrients. Good information on the light environment of existing eelgrass beds would enable application of existing models of plant performance as a function of light in predicting potential change under novel light regimes. The relative abundance and depth distribution of macroalgae versus eelgrass should be documented together with consideration of factors potentially causing changes in these plants. Absolute depth, salinity, proximity to nutrient sources and other factors may cause the submerged plant community to change in the future.

Important Intertidal Vegetation Species

There are reasonably large areas of salt marshes in Great South Bay with a total area of roughly 250 ha (2.5 km^2) found within the borders of the Fire Island National Seashore alone (Bokuniewicz et al. 1993). Based on existing reports it is clear that much of the vegetated intertidal shoreline of Great South Bay is occupied by typical salt marsh vegetation, including *Spartina alterniflora* and *Spartina patens*. There is a large literature dealing with the habitat values, ecological constraints on distribution and potential management issues for these types of systems. These are very productive ecosystems that serve both a nursery function for a host of fishes and provide a subsidy of detrital organic carbon to nearby foodwebs (Mitsch and Gosselink 1986).

Environmental Parameters Controlling Abundance and Distribution of Intertidal Vegetation

Intertidal salt marsh vegetation is controlled (directly or indirectly) by hydroperiod and salinity. Hydroperiod simply refers to the duration of flooding at a given elevation and it controls plant distributions by altering oxygen availability within the sediments and/or exposure to water of different salinity. Oxygen is required to support root respiration but also has several indirect effects on sediment chemistry. For instance, if oxygen is present, sulfides (toxic to many plants) do not accumulate so oxygenated sediments represent a less stressful habitat for most rooted plants. Surface water salinity affects the species capable of inhabiting certain locations due to differences in susceptibility to osmotic stress (Odum 1988) and alters many important characteristics of the sediment porewaters. Aside from strictly osmotic effects, seawater provides a source of sulfate which is reduced to sulfide in the absence of oxygen. The dramatic zonation usually observed in these intertidal marsh communities is clear evidence that these plants are sensitive to differences in degree of flooding, although there is some debate about whether these patterns are due to direct, indirect or subtle biotic effects (Bertness 1991, Hackney et al. 1996).

Effects of Predicted Changes in the Physical Factors Caused by a Breach

The physical alterations predicted by the breach model appear to be small relative to spring/neap differences in tidal range or storm surges. Nonetheless, the apparently strong control exerted by hydrology (elevation) and water chemistry suggests that even small changes, if persistent, can have significant effects. For instance, Warren and Niering (1993) found that a difference in relative elevation of 10 cm was sufficient to cause significant changes in vegetation and inundation frequency. In their study, areas that could not accumulate peat at a rate close to relative sea level rise (~2.5 mm/year) underwent shifts in vegetation from *Juncus gerardii-Spartina patens* to a mixture of forbs, *Distichlis spicata* and *Spartina alterniflora*. The stable community was 14 cm above mean tide level while the changed community was on average 4.6 cm above mean tide.

In many cases, intertidal marshes migrate landward in response to rising sea level, and the extent to which this enables marsh area to be maintained depends on local slopes and possible human alteration of the landward margin of marshes. If the upland border is not constrained by steep slopes or hardened boundaries, it is possible that plant communities will simply move rather than suffer any net change in coverage. If the upland border does not allow for marsh migration, the high marsh communities will suffer the greatest loss in areal contribution while low or mid-marsh communities may actually increase in relative coverage. Furthermore, if marshes can migrate, they will replace existing upper fringe habitats which may be significant areas for bird breeding. Information on the upland marsh border could probably be derived from the existing photographs (FPM 2000) and these photographs also serve as a useful baseline for detection of future change.

The time scale of marsh response is likely to be slow and unresponsive to transient breach openings. Plant expansion in response to the small changes in water level or salinity expected in Great South Bay would take months to several years. A new breach that did not persist for more than 1-2 years would probably have no effect on intertidal vegetation outside of the immediate area of the breach or away from any local sediment deposition/erosion. At longer time scales, intertidal marshes seem able to colonize overwash sediments (EEA, Inc. 1999).

Differences in ability of sediment porewaters to drain at low tide have large effects on porewater sulfide accumulation, which indirectly affect nitrogen acquisition by *Spartina alterniflora* (Howes et al. 1986, Portnoy and Valiela 1997). *S. alterniflora* growing on creek banks with drainage of porewaters at low tide yield higher standing crop than *S. alterniflora* growing in the marsh interior. Specifically, a 5 cm drop in water table depth was associated with a doubling of plant biomass (Howes et al. 1986). An increase in tidal range, as predicted by the model, should allow more porewater drainage and therefore greater *S. alterniflora* growth although it is impossible to make a quantitative prediction of the magnitude of the change.

Moreover, recent research has shown that shallow groundwater movement from uplands to fringing saltmarshes can dramatically alter the nutrient supply and porewater salinity (Valiela et al. 1990, Portnoy et al. 1998, Nowicki et al. 1999). It is feasible that even small differences in mean water elevation or tidal range will affect these flowpaths. In Nauset Marsh on Cape Cod, porewater salinity varied from 25 ppt to 0 ppt over a vertical distance of about 10 cm (Nowicki et al. 1999) indicating that groundwater discharge occurs via fairly well-defined layers. If mean water elevation drops, it could increase the groundwater discharge thus increasing the delivery of nutrients to the Bay. Whether the change in Bay water level is sufficient to affect groundwater input is speculative and depends on the hydrostatic head of the groundwater and local soil/sediment characteristics that define the flowpath.

Aside from contributing nutrients, groundwater also affects porewater salinity which is particularly relevant to the issue of *Phragmites australis* expansion. Invasion of the higher elevations of salt marshes by *Phragmites australis* is a serious and widespread management issue. The salinity intolerance of this plant (Hellings and Gallagher 1992) suggests that even relatively small changes in sediment salinity may influence Phragmites colonization or spread. As described above for *Spartina alterniflora*, porewater sulfide also inhibits nitrogen acquisition by *Phragmites australis*. For example, Chambers et al. (1998) show that a reduction of porewater salinity from 20 ppt to 10 ppt leads to a doubling in nitrogen uptake by *Phragmites*. Thus, a breach may have a positive impact on wetlands by increasing porewater salinity, which in turn could inhibit growth of Phragmites and its expansion into wetland areas. As with the other indirect effects, it is impossible to say with any certainty these consequences will come about, but the linkage among processes has been documented and so these potential changes must be at least kept in mind.

Research, Management and Monitoring Information Needs

The most obvious information need relative to the effects of a breach on intertidal vegetation is ascertaining the confidence in predicted changes in Bay tide range, mean water elevation and salinity. The currently predicted elevation and tidal changes are relatively small but if many intertidal areas have gradual slopes, even small changes can ultimately affect a large area. A slope of 0.1 percent implies a 1 cm increase in mean tidal elevation would inundate an additional 10 m of shoreline.

If an active research/monitoring program becomes a reality, a priority task will be to document (using existing variability among locations) the strength of the control of hydrology and salinity on marsh vegetation structure. In simplest form, a survey of a variety of marsh "types" together with site-specific information on hydroperiod and salinity could demonstrate what range in controlling factors is necessary to cause a biologically relevant change in plant species composition or performance. A regression approach could document the relationship (if any) between inundation (or surface, porewater salinity) and plant species composition. If expected changes in the independent variables were within the range of observations used to construct the relationship, these models would be powerful tools in generating quantitative predictions of future biotic responses. The aerial photointerpretation and digitization (FPM 2000) would be very helpful in site selection by allowing random selection of sites containing given communities. For instance, *Spartina alterniflora* apparently can be differentiated from *Spartina patens* so random locations of each species could be selected and relevant hydrological variables (inundation, etc.) measured. These species presumably differ in elevation (hydroperiod) so this exercise would establish how large a variation in hydroperiod is necessary to drive a change in species. Similarly, sites of *Phragmites* can be identified in the digital database again providing an opportunity to test whether *Phragmites* is associated with particular elevations, porewater salinities, etc. The influence of these physical factors on the likelihood of *Phragmites* invasion, or persistence, should be a topic of particular interest.

Lastly, as recognized by Bokuniewicz et al. (1993) there have been several mapping efforts for both submerged aquatic vegetation and wetlands that apparently have not been carried through to their logical conclusion. Digital data on habitat occurrence and surrounding land cover seem a prerequisite for efficient detection of change in the future.

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FINFISH

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Ecologically and Economically Important Finfish Species in Great South Bay

The finfish of Great South Bay are represented largely by a transient assemblage of warm-water species that migrate into the Bay in spring and summer and back out onto the shelf with the onset of winter. Such migratory species include silversides, bay anchovies, sticklebacks, bluefish, summer flounder, tautog and black sea bass. These species either spawn in the Bay or use it as a summer nursery ground for young-of-the-year life stages. Other species, such as the winter flounder and sand lance, prefer colder waters and tend to be more abundant and spawn in the Bay in winter. A number of diadromous species, including American eels, lampreys, river herrings and three salmonid species, utilize the freshwater tributaries to Great South Bay as habitat during a portion of their life cycles. Finally, a few species, such as the killifishes, are entirely Bay residents throughout the year. Hence, for most species, the inlets to the south shore bays function as the corridors through which migratory fishes must pass at critical points in their life cycles.

The following species accounts were taken from a more extensive review of the fishes of Great South Bay reported by D.O. Conover in Bokuniewicz et al. (1993), and supplemented with more recent data provided in Raposa and Oviatt (1997).

Ecologically Important Finfish Species and Their Habitats

Atlantic silverside (*Menidia menidia*)

The dominant member of the ichthyofauna of Great South Bay throughout much of the year is *Menidia menidia*. Hanlon (1983) found that 79 percent of the fish captured by all methods (trawls, beach seines, gill nets) in his survey were *M. menidia*. Raposa and Oviatt's (1997) study of Fire Island National Seashore also showed that *Menidia* numerically dominates among fishes captured close to shore.

Habitats utilized by silversides vary with life stage. In the spring, spawning occurs en masse amongst schools of fish that deposit eggs at specific locations where large mats of intertidal algae are found. Intertidal spawning protects the embryos from aquatic predators. In the summer and fall, larvae and young juveniles are found in the neuston close to shore over both vegetated and unvegetated intertidal and subtidal bottoms. They are extremely abundant in the shore zone virtually everywhere in the Bay. Shallow inshore waters such as those of the Great South Bay are the prime habitat of silversides. They are found in offshore waters of the continental shelf only in mid-winter when low temperatures close to shore reach levels that are lethal (Conover and Murawski 1982).

Silversides are primarily zooplanktivores. Grover (1982) reported that Atlantic silversides in Great South Bay fed primarily on copepods during all seasons of the year. In the spring and early summer, however, up to 40 percent of the diet consisted of fish eggs and larvae. The silverside is an important forage species for piscivorous fishes. Juanes (1992) reported that *M. menidia* is a major portion of the diet of young-of-the-year (YOY) bluefish in Great South Bay. In addition, the Atlantic silverside is consumed by several other piscivores in the Bay including striped bass (Schaefer 1970, Briggs and O'Connor 1971), weakfish and summer flounder (Poole 1964).

M. menidia is one of the main species used as bait in the recreational fishery. Commercial landings of silversides of about 50,000 lbs/yr have been harvested from Great South Bay to supply bait shops.

Bay *anchovy (Anchoa mitchilli)*

The bay anchovy is also one of the major forage species found in Great South Bay. Although its numerical abundance in beach seine samples is moderate (Hanlon 1983, Raposa and Oviatt 1997), its dominance in the summer ichthyoplankton suggests it to be the dominant component of the water column fauna in the middle bay (Monteleone 1992). Castro and Cowen (1991) found that the peak in spawning of bay anchovy in Great South Bay was in late June and July, and coincided with the summer peak in microzooplankton abundance. They found no difference between eelgrass and unvegetated areas of Great South Bay in egg or larval densities (but see Shima and Cowen 1989), larval growth rates, or egg and yolk-sac larvae mortality rates of bay anchovy. Mortality of older bay anchovy larvae was higher over eelgrass beds than over unvegetated bottom, perhaps because of greater exposure to predators inhabiting the eelgrass beds. Bay anchovies are not, however, an estuarine dependent species. They are also abundant in the open water column of continental shelf waters throughout most seasons of the year.

The bay anchovy is a major food source for piscivorous fishes in Great South Bay. They constitute a large fraction of the diet of young bluefish in the Bay during late summer and fall (Juanes 1992) and are also consumed by virtually every piscivore in the Bay including striped bass (Schaefer 1970), summer flounder (Poole 1964) and weakfish (Merriner 1975).

Killifishes: mummichog *(Fundulus heteroclitus)*, striped killifish *(Fundulus majalis)*, sheepshead minnow *(Cyprinodon variegatus)*

Members of the family Cyprinodontidae are generally very abundant in the shore zone of Great South Bay. The mummichog predominates in high and low salt marsh habitats, especially salt marsh creeks, ditches, rivulets, or beaches where the sediment is soft, and/or where vegetation is present. The striped killifish prefers sandy bottom habitats. These differences in habitat preference are evident in Briggs and O'Connor's (1971) study in Great South Bay. Hanlon (1983) generally collected about twice as many striped killifish as mummichog. The habitat types where he found mummichogs to outnumber striped killifish were over subtidal mud and gravel. *Cyprinodon variegatus* may be found in either habitat, but both Briggs and O'Connor (1971) and Hanlon (1983) collected more over sand-filled bottoms than over naturally vegetated or mud habitats.

Killifishes feed on a variety of invertebrate marsh organisms including insect larvae (Kneib 1986). Because they rarely stray further than a few meters from the shoreline, they are not usually a large component of the diet of piscivorous fishes. On the other hand, they represent a major food source for crabs and wading birds (Kneib 1986). *Fundulus heteroclitus* is used extensively as bait in the summer flounder fishery (Briggs and O'Connor 1971).

Fourspine stickleback (*Apeltes quadracus*)

The fourspine stickleback was the second most abundant fish overall in Briggs and O'Connor's (1971) study of shore zone fishes, and it ranked first in abundance in naturally vegetated habitats. In Hanlon's (1983) study, however, the relative abundance of four-spine stickleback was less (overall rank = 6) than found by Briggs and O'Connor (1971). Raposa and Oviatt (1997) also found *Apeltes* to be an abundant species in vegetated and marsh habitat along the Fire Island National Seashore/Great South Bay shoreline. Abundance of *Apeltes* was positively correlated with macroalgal but not eelgrass biomass. Sticklebacks spawn in the spring and summer and are nest-building species that use vegetation for nest concealment and protection from predators. *Apeltes* appears to remain in Great South Bay throughout much of the year.

Due probably to their close association with cover and their armor of lateral plates and spines, sticklebacks do not represent a major fraction of the diet of most piscivores, but they have been found occasionally in the stomachs of striped bass (Schaefer 1970) and summer flounder (Briggs and O'Connor 1971).

Northern pipefish (*Syngnathus fuscus*)

Pipefish are abundant both as larvae in the summer plankton (Miller 1977) and as juveniles and adults in vegetated areas (Briggs and O'Connor 1971, Hanlon 1983). Raposa and Oviatt (1997) reported that the abundance of pipefish was positively correlated with eelgrass biomass in the Fire Island National Seashore, and their adult morphology mimics that of eelgrass. They feed on zooplankton in the water column and are themselves consumed by summer flounder and striped bass. Pipefish represent a substantial fraction (~10 percent) of the diet of summer flounder in Great South Bay (Poole 1964).

American sand lance (*Ammodytes americanus*) - A major component of the winter fish assemblage in Great South Bay is probably the sand lance. Although this species does not appear to be abundant in the Bay based on catches reported by Hanlon (1983), Briggs and O'Connor (1971) or other studies of Great South Bay, this may be largely because of lack of sampling with appropriate gear in winter. Miller (1977) found that the sand lance was overall the most numerous larval fish collected in the Bay. Larvae were collected from January to May with a peak production in late January through the end of February.

American sand lance are found almost exclusively over sandy bottoms and are one of the most abundant fishes over the inner half of the continental shelf (Grosslein and Azarovitz 1982). They have the unique habit of burrowing in the sand in dense aggregations. They feed at all levels in the water column, primarily on copepods, crustacean larvae, chaetognaths, and various invertebrate and fish eggs (Grover 1982, Grosslein and Azarovitz 1982). The sand lance is itself preyed upon by numerous piscivores. In Great South Bay, the main predators on sand lance are likely to be adult bluefish, striped bass, weakfish, summer flounder and birds.

Primary Harvested Finfishes

Great South Bay supports a modest commercial fishery with annual landings of 100,000-300,000 pounds. Chief species in the commercial fishery are bluefish, eels, winter flounder, weakfish and menhaden (Bokuniewicz et al. 1993). The primary gears used are gill nets, pound nets and pots. State regulations prohibit trawling in Great South Bay.

The recreational fisheries of Great South Bay include charter boats, most of which sail from Captree State Park, bank and pier fishermen, surf fishermen and private boaters. Although the overall sport fisheries of the Bay have not been described in detail since Briggs (1962), total recreational landings for New York as a whole suggest that fluke, winter flounder, bluefish, weakfish, striped bass, tautog and black sea bass are the main species landed in Great South Bay (Bokuniewicz et al. 1993). Ecological importance and habitat requirements of those species that utilize Great South Bay as both a juvenile nursery and adult feeding area are described below.

Bluefish (*Pomatomus saltatrix*)
Both young-of-the-year and adult bluefsh are of great ecological importance in Great South Bay during the late spring, summer and fall because they represent the most abundant piscivores in the system. Bluefish spawn over the continental shelf in spring

and summer. The recruitment of young-of-the-year bluefish migrating into Great South Bay has been studied in great detail (see citations in Bokuniewicz et al. 1993). The arrival in Great South Bay of young-of-the-year bluefish from continental shelf waters occurs in two waves: a May and June recruitment consisting of spring-spawned fish, and an August recruitment consisting of summer-spawned fish. Young bluefish in Great South Bay are found in the shore zone where they feed largely on young silversides in June and July and then shift their diet over to young bay anchovy in August and September (Juanes 1992). Adult bluefish congregate near the inlets where they feed on a variety of species including sand lance, menhaden, bay anchovy, butterfish and squid.

Winter flounder (*Pseudopleuronectes americanus*)

Winter flounder are probably resident in Great South Bay most of the year, and may represent a subpopulation unique to the area. Spawning occurs in the Bay from about March to May and, together with sand lance, winter flounder are a major portion of the winter ichthyoplankton (Bokuniewicz et al. 1993). Juveniles and adults are generally found on muddy bottoms of bays, coves and tidal creeks. Although winter flounder are generally believed to migrate offshore as temperatures increase in summer, Olla et al. (1969) showed that some winter flounder remain in Great South Bay throughout the summer, burying themselves in the sediment when temperatures exceed 23^{o}C. Winter flounder feed primarily on a variety of benthic invertebrates including amphipods, polychaetes, sand shrimp (*Crangon septemspinosa*), soft-shelled clam (*Mya arenaria*), and blue mussel (Mytilus edulis). Larvae feed mainly on copepods. Winter flounder in Great South Bay are themselves preyed upon by a variety of species, including summer flounder and bluefish.

Summer flounder or fluke (*Paralichthys dentatus*)

Summer flounder spawn over the continental shelf in the fall. Young fish enter estuaries along the mid-Atlantic coast in the winter and spring (Able et al. 1989). Poole (1961) found that young summer flounder in Great South Bay grow rapidly during their first summer, reaching a size of about 23 cm by autumn. Adult summer flounder migrate into Great South Bay in May. Summer flounder feed mainly on crustaceans and fish. Poole (1964) found that sand shrimp (*Crangon*), winter flounder and blue crabs constituted 28.5 percent, 27.8 percent and 12.1 percent, respectively, of the total weight of food contents of summer flounder in the Bay.

Reef species: tautog (*Tautoga onitis*), black sea bass (*Centropristis striata*)

The biology of tautog has been studied extensively in Fire Island Inlet (see citations in Bokuniewicz et al. 1993). Spawning occurs in the summer and newly-settled juveniles occupy shallow eelgrass (*Zostera marina*) or sea lettuce (*Ulva lactuca*) vegetated habitats beginning in late summer, and continuing until reaching a size where they can take up residence on reef structures. Shallow water vegetated habitat coupled with deep water reefs are critical habitat requirements for these species. Fish tend to be active by day and inactive by night. Older fish move offshore in winter, but younger fish remain on inshore reefs, enduring the winter in a state of torpor. Young tautog in eelgrass beds feed primarily on copepods and amphipods in Great South Bay. Larger tautog in the Bay feed primarily on the blue mussel (*Mytilus edulis*) in May and June (Olla et al. 1975).

Diadromous fishes

The south shore of Long Island contains numerous small creeks and rivers that drain into Great South Bay. Historically, these have supported sea-run populations of various salmonids (brook, rainbow and brown trout). American smelt (*Osmerus mordax*) and river herrings (*Alosa* spp.). The current status of the sea-run component of these populations, and their migration patterns at sea, are poorly understood. It has been speculated that a decline in the sea-run trout fishery in the Carman's River was associated with the closing of Old Inlet (South Shore Estuary Reserve 1998).

Habitat Utilization

The major sources of information on the distribution and abundance of fishes by habitat are Briggs and O'Connor (1971) on shore zone fishes from naturally vegetated vs. sand-filled areas and Hanlon (1983) who provides extensive tables on the combined catches from otter trawls and beach seines in Great South Bay, Moriches Bay and Shinnecock Bay for nine different types of habitats. Raposa and Oviatt (1997) provide data for nekton collected with a small beach seine and throw traps from the north shore of Fire Island during May to October 1995. The summary provided below is based on a more detailed synthesis of available literature in Bokuniewicz et al. (1993).

Intertidal beach

Intertidal beaches are used by several species as a spawning site. The Atlantic silverside deposits its eggs in filamentous algae (*Enteromorpha sp.*) or other vegetative material in the upper intertidal zone of salt marshes and open beaches where they are protected from predation by aquatic predators. The mummichog also deposits eggs in the upper intertidal zone either on stems of marsh cordgrass (*Spartina*), within empty mussel shells or amongst filamentous algae. Both of these species spawn on a semilunar schedule that corresponds with the occurrence of new and full moons.

Salt marsh

The primary inhabitants of polyhaline mid-Atlantic salt marshes are Menidia menidia and *Fundulus* spp. *Cyprinodon variegatus* and *Anchoa mitchilli* are also abundant but less so than the above. Hanlon (1983) collected primarily striped killifish, Atlantic silversides, mummichogs and bluefish (in descending order of abundance) from the salt marsh habitats of the south shore bays he sampled.

Eelgrass beds

Based on the work of Briggs and O'Connor (1971) in Great South Bay, Hanlon (1983) in Great South Bay, Moriches and Shinnecock Bays and Raposa and Oviatt (1997), those species in Great South Bay that are probably most dependent on eelgrass or other vegetated habitats include Apeltes *quadracus, Gasterosteus aculeatus, Syngnathus fuscus*, and juvenile *Tautoga onitis* and *Tautogolabrus adspersus*. Other major species frequently captured over eelgrass beds but also caught frequently elsewhere include *Menidia menidia*, *Fundulus heteroclitus, Pseudopleuronectes americanus* and *Cyprinodon variegatus*.

Non-vegetated shoals

Unvegetated bay bottom is preferred habitat of several benthic fishes. Briggs and O'Connor (1971) found six species in Great South Bay that were more abundant over sand-filled than vegetated habitats, the main ones being *Menidia menidia, Fundulus majalis* and *Cyprinodon variegatus*. Hanlon (1983) caught relatively more *Pseudopleuronectes americanus* and *Paralichthys dentatus* in unvegetated than vegetated bottom habitats.

Water column

The main species dependent on the water column are silversides, herrings and anchovies, and their predators, but this habitat is the least well-studied portion of Great South Bay. Bay anchovy is probably the dominant planktivore in the middle of the Bay during much of the year, but the existence of a modest commercial fishery for menhaden suggests that they, too, may be an important component of the pelagic fauna. Atlantic silversides, which dominate virtually all habitats in Great South Bay, are probably also very important in the water column, especially close to shore. Both juvenile and adult bluefish are probably highly dependent on the abundance of silversides and anchovies in the pelagic zone, based on the dominance of these species in their diets.

Environmental Parameters Affecting Finfish Abundance and Distribution

The primary environmental factor affecting fishes in Great South Bay is temperature. The fish community of the Bay, for example, is controlled largely by the annual temperature cycle. In winter, the primary active species in the Bay are probably sand lance and winter flounder. With the return of warmer temperatures in April and May, the summer suite of species including Atlantic silversides, summer flounder, bay anchovy and bluefish return to the Bay from offshore, and species which have overwintered in a torpid state (killifishes, tautog, cunner) become active again. Within the summer season when temperatures and fish abundances in Great South Bay are maximal, temperature is not a likely limiting factor for the main species described above as most are common in even warmer environments at more southern latitudes. The one possible exception is winter flounder, which is a cold water species near the southern end of its distribution in Great South Bay.

With the exception of anadromous fishes (white perch, alewife, brook and brown trout) found in the numerous small freshwater creeks and rivers that enter from Long Island, variations in salinity probably have little influence on the fishes of Great South Bay. Most of the marine and estuarine fishes of the Bay are polyhaline (those fishes commonly found at 15-28 ppt; see Bulger et al. 1990) and can easily acclimate to the relatively minor fluctuations in salinity that typically occur there. Salinity is not therefore a likely environmental factor affecting the abundance of fishes presently found in Great South Bay.

Dissolved oxygen can, in some systems, represent a limiting factor to estuarine fish populations. However, because Great South Bay is very shallow, dissolved oxygen levels are unlikely to drop so low as to negatively affect fishes to a measurable degree.

Effects of Predicted Changes in the Physical Factors Caused by a Breach

Salinity

The predicted increase in overall salinity of Great South Bay, from 26 ppt to 29.5 ppt, is not likely to have a major influence on the overall species composition of finfishes. The Bay is inhabited largely by polyhaline and euhaline (true marine) fishes. Except in the freshwater tributaries themselves, existing salinities in Great South Bay are already well above the 15-19 ppt threshold that separates mesohaline fishes from those found at higher salinities. Moreover, according to Bulger et al. 1990) existing salinities are also well above the 23 ppt threshold that marks the lower boundary for penetration of euhaline fishes into mid-Atlantic Bight estuaries. At most we might expect a slight increase in the abundance of primarily marine species that are more commonly found more abundantly on the continental shelf. Such species might include dogfish and skates, northern kingfish, black sea bass, tautog and Atlantic herring (in winter).

Water level

There is not likely to be any direct effect of water level on fishes. However, increases in tidal range may affect the access of transient fishes to high marsh areas for purposes of foraging, refuge or breeding. The small increase in tidal range predicted for Great South Bay as a whole may be magnified as tidal waves move up tidal creeks and these differences in water may have effects on opportunities for fish movements.

Circulation

Circulation patterns will likely affect only those species with planktonic egg and larval stages that spawn in Great South Bay, most notably winter flounder and American sand lance in winter and bay anchovy in summer. For these species it is not clear what effects a change in circulation would have. All three of these species spawn both inside and outside Great South Bay. Hence, even if a new inlet were to cause increased exchange of larvae from the Bay to shelf waters, the overall impact would probably be small. The other species that spawn primarily within the Bay either have adhesive eggs or are deposited in nests and the early life stages are not typically found in the plankton (except perhaps pipefishes). For the nektonic juvenile and adult stages, effects of circulation changes are probably minimal.

Temperature

Although the model does not make specific predictions about the change in temperature due to a breach, it is likely that changes in thermal regime will occur. The annual cycle of temperature change for shelf waters is less variable than shallow inland waters that more closely track air temperatures. This means that during respective mid-winter and mid-summer periods, minimum and maximum temperatures are more extreme and the change in temperature during autumn and spring is more rapid in Great South Bay than on the shelf. The diurnal change in temperature is likely also more variable in Great South Bay than offshore. A new inlet will increase the flushing rate of the Bay and therefore make its thermal regime somewhat more like that of offshore waters. For example, the summer maximum temperature may be somewhat less than before, and the tendency for Great South Bay to freeze over in winter may be reduced. The Bay may warm more slowly in spring and cool more slowly in autumn. Such changes in thermal regime may have a moderate influence on growth rates of fishes, but the effect will depend on each species' temperature-growth rate response curve.

Indirect Effects of Physical Changes

The most important indirect effects of a breach on fishes will probably be due to changes in ratio of unvegetated to vegetated benthic habitat. A new inlet will likely cause the loss of eelgrass beds in the immediate vicinity, but increases in water clarity due to increased flushing of Great South Bay may lead to an increase in vegetated bottoms elsewhere in the Bay. Because the fish community changes somewhat in vegetated versus non-vegetated habitat, a shift in the fraction of vegetated bottom will likely have a commensurate effect on fish community structure.

Another impact of a new inlet may be increased access of piscivorous fishes to the extensive biomass of forage fishes in the Bay. Great South Bay appears to have very high abundances of silversides and bay anchovies, which are among the main species in the diets of bluefish, striped bass, summer flounder and weakfish. With the exception of weakfish, most of these predators tend to congregate near the inlets, as evidenced by the concentration of recreational fishing activity found in these areas. It is possible that inlets actually attract piscivorous predators, perhaps functioning for pelagic species in an analogous fashion to the attraction that artificial reefs have for certain benthic fishes. If so, an additional inlet would increase the ratio of piscivore to forage biomass in Great South Bay.

Effects on Habits of Fishery Participants

An almost certain effect of a new inlet will be changes in the distribution of fishing effort in Great South Bay. Recreational fishing tends to be concentrated in inlet areas, especially Fire Island Inlet. A new inlet may help to redistribute that effort more equitably throughout the Bay, perhaps drawing anglers away from Fire Island and Moriches Inlets.

Research, Management and Monitoring Information Needs

The relative importance of Great South Bay needs to be placed into the broader context of Long Island's south shore bays as a whole. Great South Bay is the largest of the south shore bays, and has a relatively lower salinity and flushing rate. The addition of an inlet to Great South Bay will essentially make it more like the other south shore bays in terms of those physical characteristics, i.e., with higher salinity and higher tidal exchange with shelf waters. Basically, Great South Bay will become more like Moriches and Shinnecock Bays.

Do the existing unique physical characteristics of Great South Bay translate into unique ecosvstem characteristics that would change with the addition of an inlet? This question can be answered best by analogy with the physical conditions and species found in the other south shore bays, especially Moriches and Shinnecock Bays. Research is needed to compare the physical parameters and species assemblages across the south shore bays of Long Island so that we have a better understanding of the unique ecological function of Great South Bay (if any) compared with other bays. One then needs to assess whether the unique properties of Great South Bay are due to its inlet size and structure. For the finfish community, this research could take the form of:

1) ichthyoplankton surveys to contrast the timing and extent of spawning by various species,
2) net-based (beach seine, gill net, trawl) capture surveys to compare juvenile and adult species composition and biomass,
3) hydroacoustic surveys to compare the ratio of piscivore to forage biomass and production across systems and particularly in and around the existing inlets,
4) ecological studies to compare growth and trophic interactions of species across systems and
5) comparisons of fishery landings and the distribution of fishing effort among the three Bays.

The workshop identified three management issues that should be considered with respect to impact of a breach. These were:

1) changes in the biomass of harvestable species,
2) changes in the availability of essential fish habitat and
3) changes in the overall biodiversity of the bay, including non-harvested species.

To address these issues, workshop participants determined that we need better information on the landings of species currently harvested from Great South Bay, habitat utilization by various species in the Bay, and more extensive sampling of the fishes occurring in all habitats of the Bay. This information would be provided by the five categories of research listed above.

Workshop participants were not able to reach agreement on whether a breach would provide an overall benefit to the finfishes of Great South Bay. Some species would likely benefit from a breach, while others would not. For example, piscivorous species that aggregate around inlets, such as bluefish or summer flounder, would likely benefit from the greater access to forage species. If submerged aquatic vegetation increases as a result of a breach, so too would those species that depend on submerged aquatic vegetation, such as pipefishes and sticklebacks. But others such as the silversides or winter flounder may not. Thus, the effect of a breach would likely vary among species. It was further pointed out that the effects of brown tide on fishes is not well known. Therefore, the effect of potential reduction in the frequency and severity of brown tide on fishes was uncertain.

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SUMMARY AND DISCUSSION

Management of breaches and new inlets along Long Island's south shore barrier island system is a topic of increasing interest among coastal planners, decision-makers, resource users and the public. Of particular concern are the potential impacts these features may have on the environmentally and economically important biological resources found in back bay areas, such as Great South Bay.

Computer modeling is being used as a tool to provide insights and quantitative estimates of the changes new inlets may have on the physical characteristics of these areas, but very little is known about what these changes may mean for the living resources in these bays. To help address this information need, New York Sea Grant worked with the Marine Sciences Research Center of the State University of New York to examine how breaches may affect selected biological resources in the Great South Bay and to identify the information needed to evaluate these impacts quantitatively. Funding for this effort was provided by the National Park Service.

A team of scientific experts in the areas of water column productivity, shellfish and benthic communities, submerged aquatic and intertidal vegetation, and finfish used the results of a hydrodynamic model that simulated the physical impacts of a new inlet at two different sites (Conley 2000) to identify the biological resources most likely to be impacted. They also identified the nature of the impacts and the measures that could be taken to better define, understand and quantify these impacts. The experts' initial findings were presented and reviewed at a workshop for other local scientists and federal, state, and local managers and agency representatives and were then revised in response to the workshop discussions.

Hydrodynamic Modeling

Results

The hydrodynamic model simulated the potential impacts that a new inlet would have if it occurred either at Barrett Beach or at Old Inlet on Fire Island. The modeled breaches had flow characteristics comparable to the Little Pikes Inlet breach that formed in 1992 at Westhampton. In terms of the biological resources considered here, the two most important model results regarding the impact of new inlets in Great South Bay were the significant increase in average salinity of 2 - 4 ppt over much of the Bay and a reduction in the average residence time of water in the Bay on the order of 50 percent. The model also predicted breaches will cause average tidal range to increase by 4 percent (1 - 2 cm) for most of the Bay under normal (non-storm) conditions.

Model results indicated that a new inlet through Fire Island could increase oceanic exchange in Great South Bay by changing circulation and the net tidal transport, causing conditions in this bay to become more like those found in Moriches and Shinnecock Bays. This change in the net transport was responsible for the relatively high predictions of changes in average salinity. The highest value of salinity predicted by the model (29.5 ppt) for Great South Bay is similar to both modeled and measured values in Moriches Bay and measured values in Shinnecock Bay (**Table 6.1**). When evaluating potential impacts on biological resources, the model predictions of higher salinity seemed to be more useful as an indicator of a shift to more oceanic conditions in the Bay and increased flushing rather than as a controlling factor in itself.

The model results showed that residence times in Great South Bay with the new inlets (40.3 days and 53.3 days) approach those for Moriches Bay (23.9 days, **Table 6.1**). Residence time for Shinnecock Bay has not been calculated but can be estimated to be about 38 days*.

Information Needs

The model provided reasonable predictions and was internally consistent in terms of the parameters examined. However, some suggestions were made for further improving the model. Better characterization of the volume and distribution of freshwater input to the Bay is needed to improve salinity and residence time predictions. Better measurements of water surface elevations, currents, and salinities are needed to improve our understanding of the role subtidal effects have on circulation and mixing in the Bay and to define boundary conditions.

In the event a breach occurs, a contingency plan should be in place to quickly take essential measurements while the inlet is open. Salinity measurements should be able to detect changes of the magnitude predicted by the model should they occur. The model predictions of net transport are important because they appear to reduce residence times significantly. Monitoring programs using current meters to measure net transport are not practical due to the high degree of spatial resolution required. It may be more practical to conduct tracer studies (e.g., a slug release test), first to measure residence times directly and then to calibrate the transport component of the

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***Editors' Note:** The formulation of the residence time using the model results can be rewritten as a linear expression in terms of the average salinity. At zero salinity, the residence time is the ratio of the volume of the Bay divided by the freshwater in flow rate. The residence time thereafter decreases with increasing salinity at a rate proportional to this same ratio divided by the oceanic salinity. Such a residence time curve is shown in **Figure 6.1.** The line is drawn between the y-intercept (bay volume/freshwater inflow rate) and the value of ocean salinity on the x-axis. The residence time calculated from the model for Moriches Bay is close to this line as is the predicted residence time for Great South Bay with a breach at Old Inlet. The residence time for Shinnecock Bay was not modeled, but if it follows a similar trend it would be 38 days based on a salinity of 29.9 ppt.

Table 6.1 Modeled, measured, and estimated physical parameters for south shore bays.

	SALINITY (ppt)	**RESIDENCE TIME** (days)	**SECCHI DEPTH** (feet)
Great South Bay	25.9* 26.7**	100.2*	3.8**
Great South Bay (w/ inlet at Old Inlet)	29.5*	40.3*	5.3***
Great South Bay (w/ inlet at Barrett Beach)	28.7*	53.3*	4.8***
Moriches Bay	31.5* 29.0**	23.9*	4.6**
Shinnecock Bay	29.9**	38***	5.8**

* From Conley (2000) model
** From field measurements (SCDHS 1999)
*** Estimated values extrapolated from model results and observed trends (see text and Figures 6.1 and 6.3).

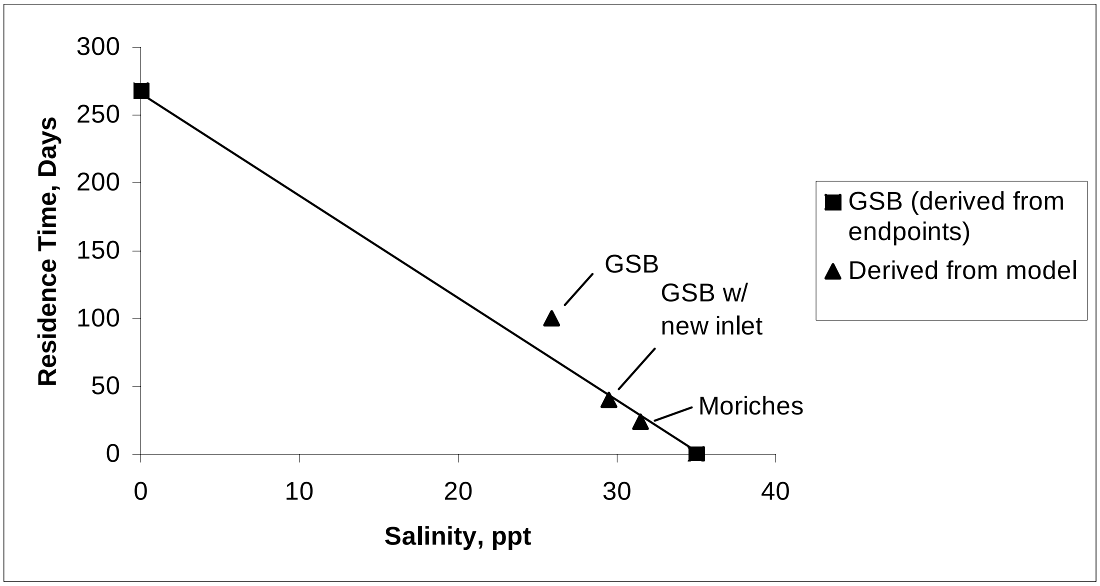

Figure 6.1 Residence time as a function of salinity (GSB = Great South Bay).

model. These studies would be particularly useful if conducted both before and after the next breach occurrence (before filling), so as to quantify impacts of the breach.

Water Column Productivity

Impacts

The model predicts salinity would increase and indicates residence time would decrease for much of the Bay in the event of a new inlet. While increasing salinity might favor smaller phytoplankton species, such as brown tide, the lower residence times and increased flushing would cause a concomittant decrease in nutrients. If, as expected, a new inlet makes Great South Bay more similar in environment to Moriches Bay and Shinnecock Bay, Great South Bay should become a less favorable environment for nuisance algal blooms like brown tide or green tide. Species typical of coastal oceanic waters, such as larger diatoms, might develop greater populations changing the trophic structure of the Bay. The shift to larger algae might decrease overall phytoplankton productivity in the Bay and adversely affect the microzooplankton and other pelagic trophic levels but benefit the benthic bivalve grazer populations by improving food quality. However, breaches would not necessarily increase flushing and decrease residence times uniformly across the Bay. Model predictions indicate that residence times in certain areas, such as the northeast portion of Great South Bay, in the case of an inlet at Barrett Beach, may not be reduced and, in fact, may even be increased. In these areas, brown tides would tend to keep occurring and may even be aggravated.

Information Needs

From a management perspective, the following assessments would be helpful in evaluating the potential for changes, positive or negative, to the plankton community in the Great South Bay ecosystem due to a new inlet. Comparative studies of productivity should be conducted between Great South Bay and the two neighboring bays, Moriches Bay and Shinnecock Bay, which are reflective of the higher salinities and greater oceanic mixing of waters that may be expected with a new inlet in Great South Bay. While the productivity of Great South Bay has been measured (450 gmC/m^2/yr) (Lively et al. 1983), values for Moriches and Shinnecock Bays need to be determined.

Characteristic plankton populations of Great South Bay, Moriches Bay and Shinnecock Bay need to be determined to serve as empirical predictors of the effects of more oceanic conditions as might be realized with a new inlet. Gradients in the plankton population from east to west and north to south within Great South Bay would also be a useful, empirical predictor of the changes to be expected with a shift from less oceanic conditions (as exist in the eastern portion of the Bay) to more oceanic conditions currently found near Fire Island Inlet.

Brown tides have a large impact on the biological resources in the Bay. For this reason, research is needed to better understand the factors that contribute to the occurrence of brown tide and how these factors will be changed by a new inlet. This information is needed to better predict the effect of a new inlet on the other resources.

Shellfish and Benthic Communities

Impacts

Breaches remaining open a year or less would probably have minimal long-term impacts on the benthos in Great South Bay. However, longer lasting inlets could cause substantial changes. Benthic community structure in eastern Great South Bay would probably change in response to a permanent breach at Old Inlet or Barrett Beach. The limited existing data suggest that a high salinity - high flow assemblage, such as that found associated with Fire Island Inlet and Moriches Inlet, would develop in the immediate vicinity of the breach. Since the breach would also tend to eliminate existing west-east water column gradients in the Bay, it would be likely that the community structure in eastern Great South Bay would more closely resemble that of the western part of the Bay and Moriches Bay. Thus, for example, populations of species with documented west-east distribution patterns, such as the bivalve Tellina agilis, the lady crab and the razor clam, would be altered in response to the changing conditions associated with a new inlet.

Changes brought about by a breach would have both negative and positive impacts on the hard clam. Although temperature was not modeled, a breach would be expected to moderate Bay water temperatures by introducing more ocean water into the Bay, resulting in cooler spring and summer temperatures and warmer winter temperatures (**Figure 6.2**). The expected salinity and temperature changes would slow the development of fertilized eggs and larvae as well as increase their mortality. The abundance of predators, such as channeled whelks and moon snails in eastern Great South Bay would also probably increase. On the other hand, larger oceanic plankton species may improve food quality and more moderate winter water temperatures may decrease over-winter mortality.

The net impact on hard clams of the multiple environmental changes associated with a permanent breach is impossible to predict based on available data. Landings data over the past 10 years indicate that clam productivity may be lower in western Great South Bay and Moriches Bay compared to eastern Great South Bay. This geographic trend, if truly inlet related, would suggest that a breach would have an overall negative impact on the hard clam population in eastern Great South Bay. However, an

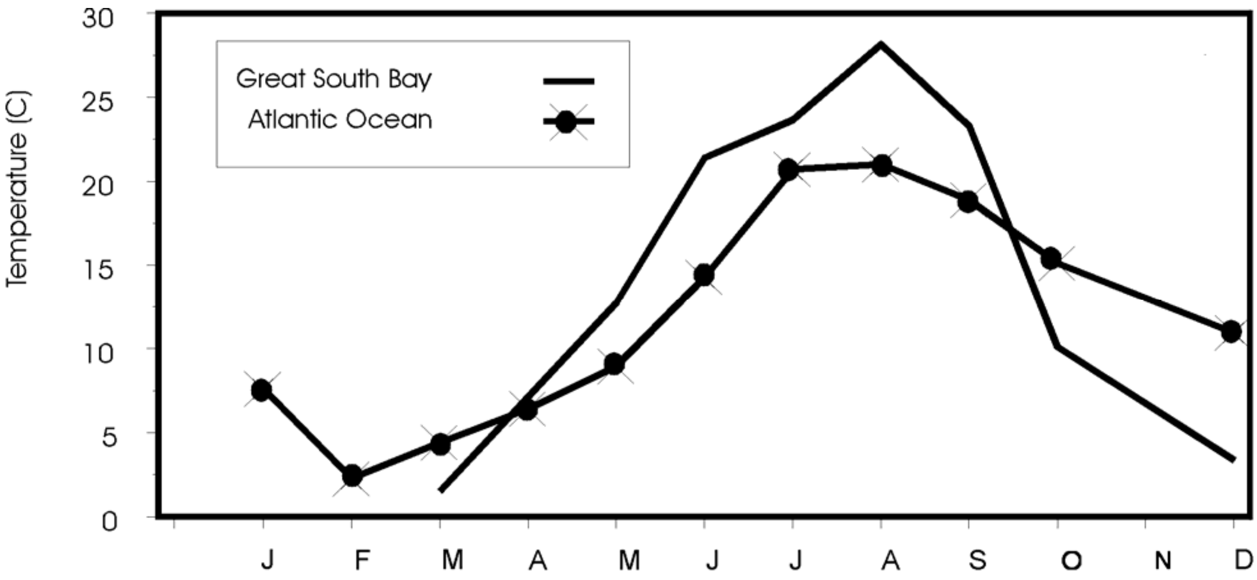

Figure 6.2 Seasonal water temperature variations in Great South Bay and Atlantic Ocean. (Sources: Walford and Wicklund 1968, Grumman Ecosystems Corp. 1975, Niedrauer 1981 and Lively et al. 1983.)

improvement in food quality and flux is also suggested, and this change could easily produce a large positive effect on hard clam growth. In particular, a substantial positive impact on growth would occur if a breach were to eliminate or at least reduce the duration of brown tide events in Great South Bay.

Information Needs

Our current knowledge of hard clam biology does not allow us to reliably predict how populations would change in response to a breach at Old Inlet or Barrett Beach. To address this problem, research is needed on population responses to multiple environmental changes associated with a breach. For hard clams, this would involve studies to investigate, on a seasonal basis, the separate and combined effects of breach-associated changes in food quality, food quantity, temperature and salinity on survival, growth and fecundity. It would require an assessment of predator populations and predation rates for a variety of habitat types in the Bay, as well as a study of larval transport and larval ecology. Comparative hard clam studies looking at different geographic regions within Great South Bay, Great South Bay versus other south shore bays, and the bays over time could provide information on how, for example, different suites of predators affect hard clam survival. However, all of such comparative studies must include both a laboratory and field component. The laboratory component is absolutely essential for identifying controlling mechanisms, since multiple environmental factors tend to covary in the field and cannot be separately resolved.

Submerged Aquatic and Intertidal Vegetation

Impacts

Eelgrass: Light availability is a major factor controlling eelgrass abundance and distribution in Great South Bay. Measured secchi disc depths (an indicator of light penetration and availability) are 177 cm (5.8 feet) in Shinnecock Bay, 140 cm (4.6 feet) in Moriches Bay and 116 cm (3.8 feet) in Great South Bay (**Table 6.1**). Presumably increased flushing in Shinnecock and Moriches Bays contributes to this difference. If a new breach caused the water clarity in Great South Bay to approach that of Moriches Bay*, there would be an increase in the maximum depth of eelgrass beds. Maximum increases in productivity would occur between 2.5 m (6.6 feet) and 4 m (13.1 feet). Plants in this depth range would have the highest likelihood of expanding their coverage. Based on the hypsometry of Great South Bay (**Figure 6.4**), this depth range corresponds to 10 - 15 percent of the bay bottom (24-36 km^2 or 5,930 - 8,895 acres).

Intertidal Vegetation: The model predicted relatively small changes in the average tidal range (4 percent increase). However, even small changes in water level elevations may affect intertidal vegetation if the new inlet persists for more than one or two years.

Marshes can migrate in response to water level changes as long as they are not constrained. If the total change in the tidal range is 2 cm (0.8 inch) we may expect an increase in the high tide of 1 cm (0.4 inch) and a decrease in the low tide of 1 cm. A hypsometric curve of the Bay floor (**Figure 6.4**) shows the slope of the submerged surface histogram at the shoreline is 3.4 cm per 1 percent change in area. A one centimeter depression in the elevation of low tide will expose an additional 0.3 percent of the Bay bottom or 0.7 km^2 (173 acres) of intertidal area below mean sea level. Selected cross-sections of topography at Heckscher Park indicate land slopes at the shoreline range between 0.0041 and 0.00078. A one centimeter rise in the height of high water could move the shoreline landward between 2.4 m (7.9 feet) and 13 m (43 feet) assuming the slope is constant over this distance. If the length of the entire Bay shoreline is taken as 40 kilometers, this change results in an additional area below high tide of between 0.1 km^2 and 0.5 km^2 (24 acres and 124 acres). For growth of marshland to be realized in this area there must be space to accommodate this landward expansion. However, if there are upland barriers to marsh migration such as steep slopes or hardened boundaries, high marsh communities would decrease in areal extent with an increase in tidal range.

***Editors' Note:** Based on available information, this appears to be a reasonable assumption. Observations indicate a direct relation between secchi depth and salinity (**Figure 6.3**) presumably because salinity is an indication of lower residence times, more oceanic conditions, and reduced phytoplankton productivity that would be expected to occur with a breach in Great South Bay. From the relationship between salinity and secchi disc readings existing in these three bays and the salinity predicted by the model, the secchi depth might increase from 116 cm (3.8 feet) to about 136 cm (4.8 feet) to 152 cm (5.3 feet), if a new inlet forms.

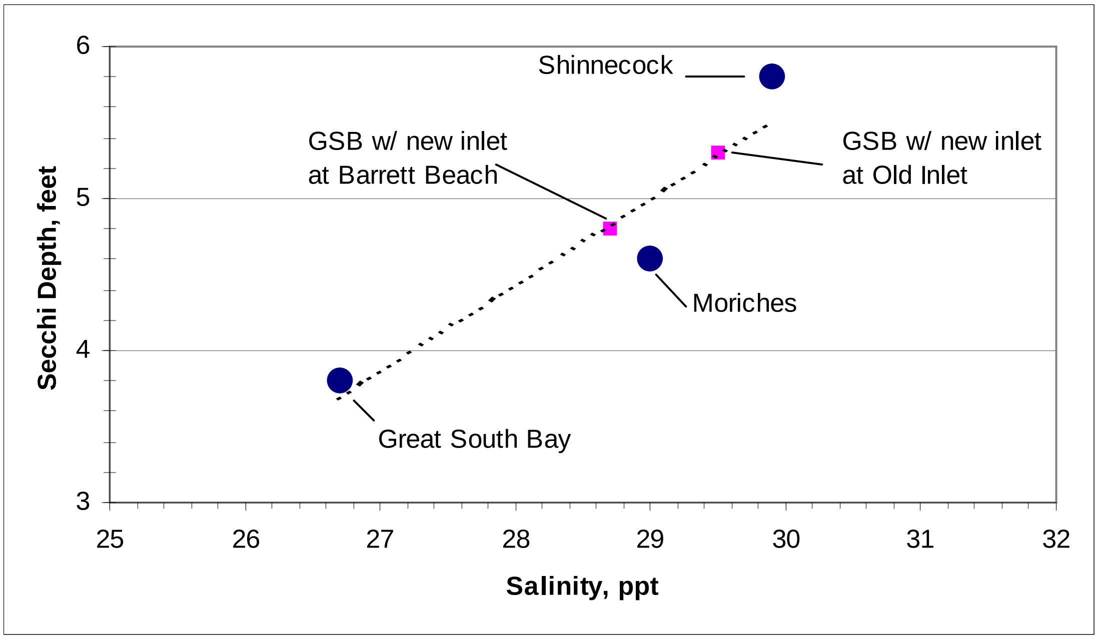

Figure 6.3. Secchi depth as a function of salinity in south shore bays. GSB = Great South Bay.

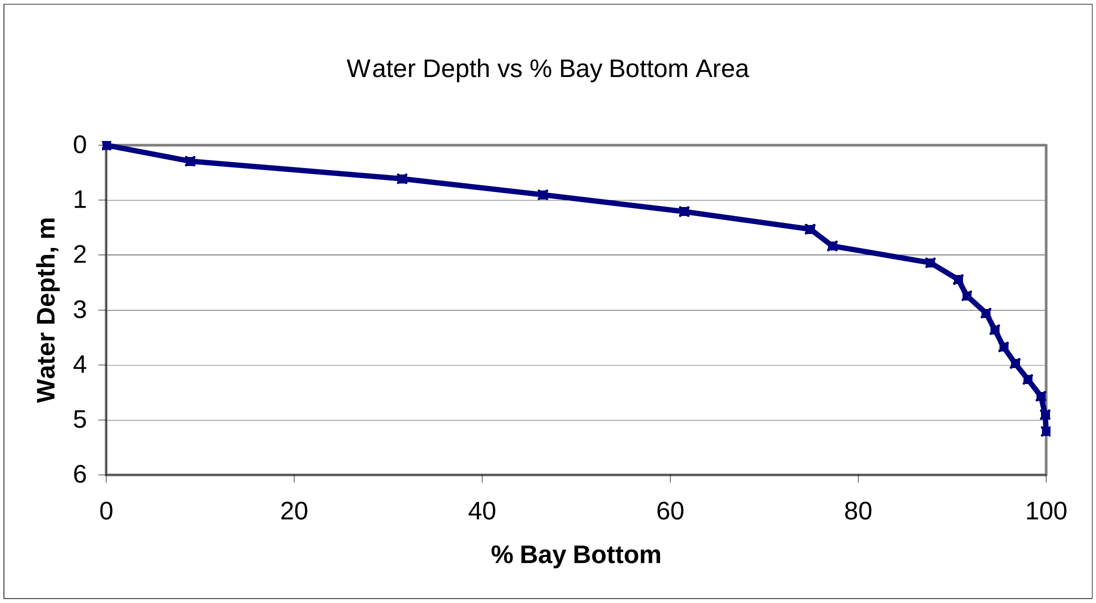

Figure 6.4. Hypsometric curve for Great South Bay.

Marsh growth, however, also depends on other factors. For example, groundwater flow affects salinity and nutrients in the root zone and can be altered by changes in the tidal range. Increases in tidal range can improve pore water chemistry for marsh plants and inhibit expansion of Phragmites into marsh areas. Although the trends of the anticipated effects of changes in tidal range on groundwater conditions are, in general, positive for marsh growth, the actual impacts can not be assessed without site specific studies.

Information Needs

Eelgrass: Surveys of the extent of eelgrass beds together with documentation of habitat (depth distribution and bottom type), water column attributes (clarity, cholorophyll and inorganic nutrients), and light environment would enable application of existing models to examine submerged aquatic plant response under different conditons.

Intertidal Vegetation: An updated inventory of wetlands and survey of adjacent upland areas is needed to identify those areas where barriers to landward expansion of marsh vegetation exist. Priority should also be given to documenting the strength of the control of hydrology and salinity on marsh vegetation structure using existing variability. A survey of a variety of marsh "types" together with site-specific information on hydroperiod and salinity could demonstrate what range in controlling factors is necessary to cause a biologically relevant change in plant species composition or performance.

Finfish

Impacts

The changes associated with a new inlet indicated bv the model would probably not have major significant impacts on the finfish in Great South Bay. Since, except for in the freshwater tributaries, salinities in the Bav are alreadv above threshold values and the existing fish populations are adapted to higher salinities, the predicted increase in salinity is not likely to have a major influence on the overall species composition. At most, we might expect a slight increase in the abundance of primarily marine species that are more commonly found on the continental shelf. Such species might include dogfish and skates, northern kingfish, black sea bass, tautog and Atlantic herring (in winter). Changes in circulation would only affect only those species with planktonic egg and larval stages that spawn in Great South Bay, most notably winter flounder and American sand lance in winter and bay anchovy in summer. However, since all three of these species spawn both inside and outside Great South Bay, the overall impact of a new inlet would probably be small.

Although not modeled, water temperatures in the Bay would probably change, becoming more like ocean temperatures, which are more moderate (**Figure 6.2**). Such changes in thermal regime may have a moderate influence on growth rates of fishes, but the effect will depend on each species' specific temperature-growth rate response curve.

The most important indirect effects of a breach on fishes will probably be due to changes in ratio of unvegetated to vegetated benthic habitat. Because the fish community changes somewhat in vegetated versus non-vegetated habitat, a shift in the fraction of vegetated bottom will likely have a commensurate effect on fish community structure. However, it is not possible to quantify this effect with the information available. It is also possible that inlets actually attract piscivorous predators, perhaps functioning for pelagic species in an analogous fashion to the attraction that artificial reefs have for certain benthic fishes. If so, a new inlet would increase the ratio of piscivore to forage biomass in Great South Bay. Since recreational fishing tends to be concentrated in inlet areas, an almost certain effect of a new inlet will be to redistribute fishing effort in the Bay, perhaps drawing anglers away from Fire Island and Moriches Inlets.

Information Needs

Important management issues that should be considered with respect to the impact of a breach include potential changes in the biomass of harvestable species, changes in the availability of essential fish habitat and changes in the overall biodiversity in the Bay. Since a new inlet would tend to make Great South Bay become more like Moriches and Shinnecock Bays, comparative studies of the physical parameters and species assemblages across the south shore bays of Long Island are needed to develop a better understanding of the ecological function of Great South Bay compared with the other bays. Specific studies needed to determine the impact of a new inlet on the finfish community should take the form of:

1) ichthyoplankton surveys to contrast the timing and extent of spawning by various species,

2) net-based (beach seine, gill net, trawl) capture surveys to compare juvenile and adult species composition and biomass,

3) hydroacoustic surveys to compare the ratio of piscivore to forage biomass and production across systems and particularly in and around the existing inlets,

4) ecological studies to compare growth and trophic interactions of species across systems and

5) comparisons of fishery landings and the distribution of fishing effort among the three Bays.

Conclusion

In some cases, the existing data and information allow a reasonable assessment of how certain biological resources may be affected by the formation of a new inlet. From this review of the available information and data and discussions at the workshop, however, it is clear that the impacts a new breach may have on the biological resources of Great South Bay are complex and not well understood. For certain resources, research is needed to develop a better understanding of basic biological processes and interactions before reliable predictions can be made. The impacts of a breach can be positive, negative, neutral or unknown depending on the particular resource being considered or the management objective that one is trying to achieve. Different, and sometimes conflicting, management mandates can result in the same impact being perceived as negative by one party or agency and positive by another, making it difficult to reach a consensus on whether a new inlet would be beneficial or detrimental. For other resources, surveys and monitoring programs, as opposed to research, can provide the information necessary to evaluate the potential impacts of new inlets.

The information provided here should help in identifying the biota most likely to be affected by new inlets and the general nature of the impacts. Just as importantly, it provides guidance on the types of information and data needed to fill in our knowledge gaps and on measures that can be taken to obtain this information. In addition to providing managers with information they can use immediately, it is hoped that suggestions and recommendations presented in this report will be of use in the development and design of research, monitoring and other data gathering programs.

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APPENDIX

Impacts of Barrier Island Breaches on Biological Estuarine Resources of Great South Bay

Workshop Agenda

Tuesday, January 23, 2001
Danford's Inn
Port Jefferson, New York

8:00AM Coffee (Continental Breakfast) and Registration

8:30 **Introduction and Background**
Jay Tanski, New York Sea Grant Program
Dr. Mary Foley, National Park Service
Dr. Jim Allen, United States Geological Survey

9:00 **Hydrodynamic Modeling Results**
Dr. Joseph DiLorenzo
Najarian and Associates, Inc.

9:30 – 12:15 **Potential Impacts to Selected Biological Resources**

9:30 ***Water Column Productivity (Plankton and Nutrients)***
Dr. Elizabeth Cosper
Cosper Environmental Services

10:00 ***Shellfish and Benthic Invertebrates***
Dr. Robert Cerrato
MSRC, SUNY at Stony Brook

10:30 **Break**

10:45 ***Finfish***
Dr. David Conover
MSRC, SUNY at Stony Brook

11:15 ***Intertidal and Submerged Aquatic Vegetation***
Dr. Stuart Findlay
Institute of Ecosystem Studies

11:45 **Additional Discussion**

12:15 PM **Lunch** (Provided)

1:15 **Summary of Impacts and Identification of Additional Management Issues and Information Needs**
Dr. Henry Bokuniewicz
MSRC, SUNY at Stony Brook

1:30 **Individual Group Discussion of Management Issues and Identification of Critical Data Gaps**

Break out sessions

Water Column Productivity (Plankton and Nutrients)
Dr. Elizabeth Cosper

Shellfish and Benthic Invertebrates
Dr. Robert Cerrato

Finfish
Dr. David Conover

Intertidal and Aquatic Vegetation
Dr. Stuart Findlay

2:45 **Break**

3:00 **Group Reports and Discussion of Management Information Needs**
Panel Discussion
Cornelia Schlenk, Moderator,
New York Sea Grant Institute

4:15 **Wrap Up/Adjourn**

Impacts of Barrier Island Breaches on Biological Estuarine Resources of Great South Bay

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Tuesday, January 23, 2001
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