Comparison of the Effects of Nutrient and Sediment Loadings on Seagrass Health at La Parguera, Puerto Rico, and Barnegat Bay,New Jersey

Heidi Hertler

Academy of Natural Sciences
Patrick Center for Environmental Research

Project: MPRD 19-RILA-101
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Research Report

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Sea Grant College Program
UNIVERSITY OF PUERTO RICO
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MAYAGUEZ, PUERTO RICO 00709-6000

SEA GRANT PROJECT SUMMARY

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Dr. Manuel Valdés Pizzini
Director
University of Puerto Rico
Sea Grant College Program
UPR-RUM, P.O. Box 5000
Mayagüez, Puerto Rico 00681-5000

Dr Michael P. Weinstein
President
New Jersey Marine Sciences Consortium
Building 22
Fort Hancock, NJ 07732

April 29, 2002

Dear Drs. Valdés Pizzini and Weinstein,

Please find enclosed the final report for the multi-program development grant supported by the Sea Grant College Programs of Puerto Rico and New Jersey. Funds supported my thesis research and built on this by comparing results from my work in southwest Puerto Rico with that available for Barnegat Bay, New Jersey. I am grateful for your support. Please contact me if you have any questions about this report, 215.299.3789.

Best regards,

Ms. Heidi Hertler
Staff Scientist III - Wetland Ecology

Enclosures: three copies of report

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Expiration Date 9/30/2004

SEA GRANT PROJECT SUMMARY FORM

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(22) OBJECTIVE:

The subject of this research was to evaluate whether the relationships seen for a tropical, *Thalassia*-dominated seagrass community are applicable in a broader context by comparison of findings to those reported in the literature for a temperate, *Zostera*-dominated seagrass community. Further, I sought to determine whether similar water quality parameters associated with land use impacts are affecting the seagrass community at La Parguera Puerto Rico, and Barnegat Bay, New Jersey.

(23) METHODOLOGY:

Historically, lumber, charcoal manufacturing, cranberry and blueberry cultivation, salt hay harvesting, and eelgrass (*Zostera marina*) harvesting supported the Barnegat Bay economy. Between 1960 and 1990 the population of the Barnegat Bay area quadrupled to nearly 435,000 people, with tourism leading the population boom. In summer, the population typically increases from two to ten fold, depending on the area. This large seasonal increase in human population has made the area susceptible to environmental degradation. Even small changes in land use have been associated with sizeable impacts on the ecosystem, resulting in part, because of the shallowness of the bay. Since the surface area to volume ratio of the bay is high, and because wetland acreage has decreased, increased stormwater and nutrient runoff directly contribute to degraded water quality of Barnegat Bay. Algal blooms resulting from high nutrient concentrations block sunlight from reaching benthic primary producers and can lead to hypoxic conditions even though the system is shallow. As a result, much of the fish and shellfish industries have been lost or diminished in this system.

Similar to Barnegat Bay, the economy of La Parguera was historically based on fishing and small-scale, local tourism. In 1990, approximately 1,200 people lived in La Parguera (US Census Bureau, 1990) with an economy supported by fishing and moderate recreational use. However, tourists have increasingly been attracted to this area for fishing, aesthetics, and Bahia Fosforescente. In 1994, the Puerto Rico Planning Board created a Tourist Zone in and around La Parguera, which lifted restrictions on development. Rapid development has ensued, which extends from the mangrove fringe and salt flats through the dry forest habitat of upland slopes. As a result, traditional users have been displaced and the pre-existing infrastructure (e.g. waste treatment plant, stormwater management system) has become obsolete. Like Barnegat Bay, the marine system at La Parguera is shallow, and increased sediment and nutrient runoff can lead to enormous increases in turbidity in the receiving waters.

Unlike La Parguera, however, the ecosystem in Barnegat Bay has been well documented and a Comprehensive Conservation and Management Plan exists for this watershed. Kennish and Lutz (1984) summarized the available data for this area. Historical changes in the vigor and distribution of Barnegat seagrasses have been monitored and reported (Moeller 1964; Taylor 1970; Loveland et al. 1974; Ohori 1982). A limited but useful source of water quality data also exists for this system. Using key water quality-seagrass relationships from our La Parguera findings to guide us, I reexamined the Barnegat Bay database to determine if similar significant relationships may be important in both systems.

(24) RATIONALE:

This research topic has widespread relevancy since seagrasses appear to be in a state of worldwide decline. Although previous research has demonstrated cause-effect relationships between specific aspects of water quality and seagrass health, there has been little comprehensive evaluation of the relative impacts of various water quality factors *in situ*. The rapid development occurring at one discrete location at La Parguera represents a rare opportunity for studying the disturbance response of the seagrass community as a natural experiment. Since Barnegat Bay is a temperate system dominated by a different seagrass species (*Zostera marina*) from La Parguera (*Thalassia testudinum*), any common relationships between specific aspects of degraded water quality and seagrass health are certain to have broad relevancy for other shallow marine and estuarine systems worldwide.

(25) PROGRESS TO DATE:

See attached report.

(26) ACCOMPLISHMENTS:

See attached report.

(27) BENEFITS:

See attached report.

Comparison of the Effects of Nutrient and Sediment Loadings on Seagrass Health At La Parguera, Puerto Rico, and Barnegat Bay, New Jersey

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Abstract

Seagrass beds are among the most productive of aquatic habitats and represent crucial ecotones at the land-water interface. But increasingly, the vigor and distribution of seagrasses are declining particularly in areas where changing land use and coastal development has led to increases in sediment and nutrient runoff. This is the case in La Parguera, Puerto Rico, and Barnegat Bay, New Jersey. In La Parguera, southwest Puerto Rico, hillside development has escalated significantly during the past five years. A quantitative relationship between the quality of receiving waters adjacent to this development and the health and biomass of seagrasses has been established. In areas near recent development, seagrass beds have been severely impacted or disappeared altogether. Turbidity and total suspended solids in the water column are significantly greater in areas adjacent to new development (34.79 mg/l) as compared to nearby undisturbed areas (31.78 mg/l). Elevated seston chlorophyll a concentrations were also measured in developed areas (1.60 µg/l), indicating that nutrient inputs may be fueling greater primary production within the water column, and thus altering the ecological balance. Similar to La Parguera, Barnegat Bay in Ocean County New Jersey is a shallow estuarine type system protected by barrier islands. Nutrient concentrations are usually low; however, chlorophyll a concentrations (2 – 10 µg/l) and light attenuation tend to be higher than in other east coast estuaries. *Zostera marina* contributes significantly to the biomass of submerged aquatic vegetation however its distribution is severely limited by the availability of light. Relationships between seagrass loss and water quality degradation associated with changing land use have been previously identified for Barnegat Bay. The same relationships were found to exist in La Parguera where rapid land development is leading to increased nutrient and sediment inputs. This study attempts to compare the effects of nutrient and sediment inputs on seagrasses to deduce whether common problems exist between a well-documented temperate marine ecosystem and a sub-tropical ecosystem.

Introduction

<u>La Parguera, Puerto Rico</u>

There are seven hundred miles of coast in Puerto Rico supporting special features and species such as bioluminescent bays, tropical rain forests, coral reefs, turtle nesting sites, mangrove lagoons, and caves. Living among these natural resources are nearly three million people.

Southwest Puerto Rico is unique in that thirty percent of the National Wildlife Refuges in the Caribbean and nearly all of the remaining subtropical dry forests, Guanica Biosphere Reserve, are located in this area. Puerto Rico is challenged as part of the Coastal Zone Management Program, established in 1978, with managing sedimentation, erosion, coastal hazards and illegal use of the island's maritime zones. The Department of Natural and Environmental Resources (DNER) and the Planning Board, in the office of the Governor, balance the preservation of natural resources with an increasing demand for development in coastal areas.

Unique limestone outcrops covered with swamp deposits of silt and clay dominate the geology of southwest Puerto Rico from Cabo Rojo on the west side of the island to Guanica on the south side of the island. La Parguera, including its bioluminescent bays, is located in this area. No rivers are present in this area; therefore, sheet runoff is the only local source of terregenous sediment to the marine system. Evaporation (1,900 – 2,200 mm per year) out competes precipitation (500 – 1200 mm per year) in this area contributing to the dry condition and pristine marine environment. May through November are considered rainier than other months. September and October have the greatest precipitation per rain event. Associated with these conditions is an extremely productive marine system. In the past, southwest Puerto Rico was known for its high productivity and most of the commercial fishing took place in this area.

The unique aestheticism and natural resources of La Parguera have historically attracted both tourist and fisherman. Until recently, development was limited, mangrove stands extensive, and salt flats buffered the mangroves from human developments. In 1945 the area experienced its first invasion of new residents when a Social Program Administration formed a rural community is the area. Project "Parceles" gave the working class land, materials and utilities; and the people built their own homes (Krausse 1994). The pristine setting and abundant natural resources made it a premiere location for tourists.

In 1960, the Planning Board proposed a comprehensive land use plan for La Parguera. It emphasized the expansion of tourism by forming new public beaches, boating facilities and access to bioluminescent bays, while acquiring land near the bays to preserve this natural resource. It also included a plan for the takeover and eventual elimination of the stilt houses built in the mangroves as summer homes (Planning Board 1960). This plan was never implemented. After an article published in National Geographic Magazine in 1960 on the phosphorescent bays, the US National Park Service conducted a feasibility study on establishing a national park in this area (National Parks Service 1968). Again, the Planning Board prepared a plan for La Parguera (Planning Board 1968). The objectives emphasized conservation of natural resources and control of development. Again, this plan was not implemented.

During the 1970s, a number of federal environmental laws were passed to regulate water quality and pollution. In 1972, the congress passed the Coastal Zone Management Act (CZM) to preserve, protect, develop, and where possible to restore and enhance, the resources of the Nations' coastal zone which it recognized as significance ecosystems (16 US §§ 1451-1464). Administered by the National Oceanic and Atmospheric Administration (NOAA), the Act established a program for states to voluntarily develop comprehensive programs. The Puerto Rico CZM Program was approved in September 1978 with the Department of Natural and

Environmental Resources designated as the administrating agency. The intention was to mange coastal development, improve, safeguard and restore the quality of coastal waters and habitats, and to protect natural resources and existing uses of those waters and habitats.

The Marine Protection, Research and Sanctuaries act, passed in 1972, was designed to ensure unique marine environments for recreation, science, education, aesthetic and historic purposes. Areas designated as US Marine Sanctuaries fall between reserves and multiuse forests. Sites are selected under the auspices of NOAA must prepare Environmental Impact Statements and a management plan. By this time much of the government authority for implementing these measures had shifted from federal to state governments; however, local agencies often lacked the technical expertise available to national governments (Valdes-Pizzini 1990).

As a part of this shift in authority the Environmental Quality Board was established (1970). By 1972 the Board had classified the coastal waters surrounding La Parguera based on established EPA guidelines. Areas around bioluminescent bays and several keys on the outer shelf were established as Class-SA, intended for conservation and research purposes where recreational use would be discouraged. Near shore areas including the mangrove channels were classified as Class-SB, used for boating, fishing and contact recreation (Environmental Quality Board 1972). In 1974, a primary treatment facility (100,000 gallon per day capacity) was build to help meet these water quality criteria (Aqueduct and Sewer Authority 1973).

The unique resources of southwest Puerto Rico attracted NOAA to include a 66.16 square nautical mile parcel of marine waters off of southwest Puerto Rico, including La Parguera, as part of the National Marine Sanctuary Program. An environmental impact statement and management plan were completed for this area in 1983 (OCRM 1983). In addition to the Commonwealth and Federal laws and regulation, this designation extended protection to important marine communities such as mangroves and seagrasses, required a comprehensive management plan be developed, instituted a program of surveillance and enforcement, and provided for resource studies and interpretive programs. Restrictions would be placed on taking of coral, wastewater discharge, cutting of mangroves, and prohibit gear used for the illegal taking of turtles. Although one of the main goals of this designation was the improvement of fisheries, the attempt to make La Parguera part of the National Marine sanctuary program was met with resistance by the local community who feared greater control over local natural resources by the federal as opposed to the local government.

In 1987 the Department of Natural Resource (DNER) and the US Army Cops of Engineers, still recognizing the importance of the natural resources in this area, signed an agreement providing for strict pollution control and declared La Parguera a Natural Wildlife Reserve, with the intention of creating a natural area. The goal of establishing a reserve is to maintain the ecological integrity of the resources; therefore, management decisions must be based on science. Decisions must account for the inevitable conflict between land use and conservation, since people, no matter how careful, make an impact on an ecosystem.

In direction contradiction to this designation in 1994, the Puerto Rico Planning Board rezoned the town to encourage development and tourism. The primary motivation for this rezoning appeared to be stimulation of tourism. This action was not supported by any scientific assessment of the resulting ecosystem impacts, nor did it consider impacts to prior land and resources user groups (e.g. fisheries). In addition, no environmental evaluation of these actions (i.e. Environmental Impact Statement required under both federal and commonwealth law) was ever conducted. The consequences of the resulting development on the reserve have gone unchecked. La Parguera has seen the construction of 148 new dwellings with an additional 368 under construction (Survey conducted in December 20, 1997). This represents a population increase of over 200% between 1994 and 1997. This estimate does not include the transient population associated with hotel rentals or tourist facilities. Associated with the increase in tourism to this area comes an increase in the demand for access to the marine system for recreation, thus more boat ramps and boat traffic. All of these changes were implemented without any analysis of the impacts on the environmental, cultural, social, or economic fabric of the area.

Near shore ecological effects include the destruction of seagrass beds and the loss of the function they serve as nurseries for reef fishes, thus diminishing the health of the reserve. Declining water quality in this area is of increasing concern to the community that depends on this resource for their livelihood. This and related studies indicate that the rezoning of the dry forest to increase tourism, and the associated land-use changes in this area, appear to be the primary cause of reduced ecological integrity, as indicated by lower water quality, increased turbidity and sedimentation rates, and decreased productivity of the seagrass ecosystem essential for a healthy fisheries industry.

Barnegat Bay, New Jersey

Early records indicate that transient Indians moved through the Jersey shore to gather shells and fish. Settlers recognized the importance and instability of barrier islands; temporary summer villages were restricted to the main land. The economy near Barnegat Bay was supported by lumber, charcoal manufacturing, cranberry and blueberry cultivation, salt hay harvesting, and eelgrass (*Zostera marina*) harvesting.

The value of the shoreline as a resort attraction was soon discovered. Tucker's Beach on Tucker's Island was the fist to be developed as a resort. Tucker's Island gradually subsided and disappeared completely under the ocean in 1938 (Allaback and Milliken 1995). As railroad transportation became more accessible, more resorts began to develop in this area. Recreational fishing was responsible for the growth of Beach Haven. The northern portion of the bay received visitors by train from New York and northern New Jersey while the southern portion of the bay received travelers from south Philadelphia (Sheppard 1997).

Barnegat Bay is situated almost entirely in Ocean County, one of the fastest growing counties in New Jersey (Barnegat Bay Estuary Program Scientific and Technical Advisory Committee. 2001). Between 1960 and 1990 the population of the Barnegat Bay area has quadrupled to nearly 435,000 people, with tourism being the main contributor to the population boom. In summer the population increases from two to ten fold, depending on the area. This large increase in human population has made the area susceptible to diminished natural resources and increased the susceptibility to storm damage (Nordstrom et al. 1986). Little planning had gone into the development of the Barnegat Bay shoreline and as a result the effects of this development on the bay and its effects of this development on the many ecosystems are poorly understood (Wilson and Able 1996).

Barnegat Bay and its sensitive habitats and endangered species are imperiled by a suite of emerging land use impacts including development pressure, non-point pollution, brown tides, boating conflicts, and personal water craft conflicts. Since the surface area to volume ratio of the bay is high, and because wetland acreage has decreased, increased stormwater and nutrient runoff directly leads to degraded bay water quality (Kennish et al. 1984). The average annual precipitation totals 117 cm (~46 in). Nutrients and contaminants are transported during rain events through the numerous rivers and stream that feed into Barnegat Bay.

Even small changes in land use have been associated with sizeable impacts on the ecosystem. Algal blooms resulting from high nutrient concentrations block sunlight from reaching benthic primary producers and can lead to hypoxic conditions even though the system is shallow (Mountford 1984). As a result, much of the fish and shellfish industries have been lost or diminished in this system.

Barnegat Bay is protected under a number of state and federal acts. The following legislation regulates land use within the watershed of the bay (Barnegat Bay Estuary Program 2001):

- ***Coastal Area Development Review Act*** (NJSE 13:19-1 et seq) and ***New Jersey Wetlands Act*** (NJSE 13:9A-1 et seq) regulates development near tidal waters and coastal wetlands.
- ***Waterfront Development Law*** (NJSE 12:5-1 et seq), along with the Wetlands Act, attempts to minimize the impact of development near tidal waterways
- ***Tidelands Management Act and Riparian Land Statues*** (NJSE 12:3-1 et seq) declare tidal land area owned and managed by the State of New Jersey acting as trustee for the people.
- ***Shore Protection Act*** (NJSE 12:6A-1 et seq) is the state version of the Coastal Zone Management Act and addresses man-made improvements to the shore line
- ***Pinelands Protection Act*** (NJSE 13:18A-1) established the Pinelands National Reserve, a 1.1 million acre area or 23% of the state's lands.
- ***Federal Clean Water Act*** (33 USCA 1251-1387, including Section 404) established NJ Pollution Discharge Elimination System and allowed NJ Department of Environmental Protection (DEP) to regulate all point source discharges through a permit process.
- ***Freshwater Wetlands Protection Act*** (NJSE 13:9A-1) requires permits for dredging, excavation or removal of soil
- ***NJ State Planning Act*** (NJSE 52:18A-196) manages physical growth and infrastructure decisions.
- ***Barnegat Bay Study Act*** of 1987 (PL 1987, Ch. 397) mandated DEP's five-year study of the BB and watershed, including the development of a Management Plan for improving the Bay's environmental and commercial values.

- ***NJ Coastal Management Program*** was designed to protect coastal ecosystems, preserve open space, and incorporate data in decision-making processes while encouraging residential, commercial and recreational development.

As part of the Federal Clean Water Act the National Estuary Program (NEP) was established. On July 10, 1995, Barnegat Bay-Little Egg Harbor Estuary and its watersheds, approximately 1,730 km^2, were named to the NEP and provided funds for non-point pollution research and the development and implementation of a comprehensive management plan. Attention focused on the negative impacts that increased development and recreational use of Barnegat Bay were having on the environmentally sensitive natural habitats. The health and biodiversity of the marine system were considered dependent on high-quality habitat.

Unlike La Parguera, however, the ecosystem in Barnegat Bay has been well documented and a Comprehensive Conservation and Management Plan exists for this watershed. Much of the historical data has been summarized by Kennish and Lutz (1984). Historical changes in the vigor and distribution of Barnegat seagrasses have been monitored and reported (Moeller 1964; Taylor 1970; Loveland et al. 1974; Ohori 1982). A limited but useful source of water quality data also exists for this system. Some relationships between seagrass loss and water quality degradation have already been identified for Barnegat Bay. Using key water quality-seagrass relationships from our La Parguera findings to guide us, I re-examined the Barnegat Bay database to determine if similar significant relationships may be important in both systems.

Objective and Rationale

This research evaluated whether the relationships seen for a tropical, *Thalassia*-dominated seagrass community are applicable in a broader context by comparison of findings to those reported in the literature for a temperate, *Zostera*-dominated seagrass community. Further, I sought to determine whether similar water quality parameters associated with land use impacts affect the seagrass community at La Parguera Puerto Rico, and Barnegat Bay, New Jersey.

Approach. I adopted the following two-step approach:

1. Identify which water quality parameters associated with changing land use are having the greatest impacts on the seagrass community at La Parguera Puerto Rico; and

2. Contrast seagrass/water quality relationships between La Parguera, Puerto Rico, and Barnegat Bay, New Jersey.

Methodology

An extensive review of the existing literature using a number of engines was done. In addition to Biological Abstract, Applied Science and Technology Abstracts (ASTA), BioAgIndex, ContentsFirst, Dissertations, GenSciAbs, GeoBase, GeoRefS, GPO, Library Lit, PapersFirst, Proceedingss, UnionLists, WorldCat were all searched for information on La Parguera and Barnegat Bay. Funding allowed for one visit to La Parguera for a review of dissertations and other resources not accessible from Philadelphia. Barnegat Bay was visited on several occasions to become familiar with the watershed and bay area.

Results and Discussion

La Parguera is located in a unique subtropical dry forest, very little of which still exists in the Caribbean. The high productivity of the near and off shore reefs has attracted both commercial and sport fisherman to this area for years. Unique resources such as the phosphorescent bays also attract tourists. A recent rezoning of this area led to increased development and tourism. This development, concentrated in the western portion of the town, is deteriorating the resources that attract tourists to the area. Associated with this development are a number of declining water quality parameters, including increased suspended material, decreased available light to the benthic community, and increased metal concentrations in benthic sediments. Differences in water quality parameters were seen among sites near new development as compare to controls and even sites near old development. Concentrations of both nitrogen and phosphorous have been positively related to development.

Terrestrial systems within the Barnegat Bay watershed area include coastal dune communities and pine/oak forests. Both part of a critical Pineland habitat protected by federal and local laws. The pineland habitat supports unique fish, amphibian, reptilian, mammalian and avian populations (Barnegat Bay Estuary Program Scientific and Technical Advisory Committee 2001). Development has resulted in habitat fragmentation and destruction. There are a wide variety of land use practices in the Barnegat Bay watershed including residential, commercial, industrial and institutional development, agriculture and forestry as well as parks and refuges. In contrast, land use at La Parguera is primarily limited to residential and light commercial uses. Development is more extensive on the northern portion of Barnegat Bay as compared to the southern region. Portions of the northern bay are anoxic in August and devoid of macrofauna (Loveland et al. 1984). Development increased from 18% in 1972 to 28% in 1995, resulting in more than 70% of the bay's shoreline being developed (Barnegat Bay Estuary Program 2001)

Nutrients

Concentrations of nitrate (NO_3), nitrite (NO_2), ammonia (NH_4) and phosphate (PO_4) were measured near land at La Parguera having variable stages of development. There are no rivers or streams that drain into the maritime system in this area; therefore, surface water samples are useful in nutrient concentration comparisons. All nutrient concentrations were low. This is not surprising for this sub-tropical marine system. Nutrients did not vary significantly among sites or with respect to rain or tide. Overall nitrate (1.36 mg-N/l), nitrite (0.004 mg-N/l), and ammonia (0.06 mg-N/l), concentrations were low. Overall phosphate concentrations (0.04 mg-P/l) were also low.

The Barnegat Bay area is considered moderately eutrophic. Most nutrient studies have focused on concentrations in rivers and streams to determine loading rates. Total nitrogen ranged from 1.43 to 5.71 mg-N/l, similar to La Parguera, and ammonia usually ranged between 0.18 and 0.29 mg/l, higher than La Parguera. Ammonia concentrations were highest during summer months, reaching a maximum in September (Durand 1984). Stream draining less developed areas were lower in nitrogen as compared to those draining more developed areas and concentrations usually increased downstream, closer to the Bay.

Nitrogen loads remained relatively constant between 1972 (441 mt/yr) and through the 1980s (454 mt/yr); however, the percent of this load attributed to residential/commercial land use increased from 29% to 79% over the same time period (Carter 1989). Surface water contributes approximately 3.9 x 105kg/yr, atmospheric deposit account for 3.9 x 105 kg/yr (deposited both on land and water), and ground water delivers approximately 9.1 x 104 kg/yr (Barnegat Bay Estuary Program Scientific and Technical Advisory Committee 2001).

The majority of the phosphorus loadings to Barnegat Bay, 80 to 90%, have been attributed to sewage treatment plants (Cahill Associates 1992). Phosphate in streams feeding into Barnegat Bay usually occurs at concentrations of approximately 0.03 mg/l (Barnegat Bay Estuary Program Scientific and Technical Advisory Committee. 2001). Phosphorus averaged ranged from 0.002 – 0.02 mg-P/l over vegetated areas and 0.01 to 0.03 mg-P/l over unvegetated areas (Seitziner and Pillings 1990; 1992; 1993). Phosphate concentrations in Barnegat Bay were much lower than La Parguera.

There are few industrial point sources in Barnegat Bay and none in La Parguera. It seems probable that present day pollution at both sites is mainly from non-point sources or localized sources such as development, roads or marinas and boat ramps. Comparison of nutrient data was difficult because studies from Barnegat Bay focus on streams and loadings. Both Barnegat Bay and La Parguera would benefit from continued monitoring, research and analysis of watersheds. Little is known about nutrient transport mechanisms.

Chlorophyll a

At La Parguera, seston chlorophyll a concentrations may be a better indicator of terrestrial nutrient inputs because planktonic producers are efficient at taking up dissolved nutrients from the water column. The overall mean chlorophyll a concentration near La Parguera was 1.26 µg/l. Chlorophyll a concentrations increased significantly with increasing development. Lowest concentrations were found near undeveloped areas (0.74 ± 0.11 µg/l) and established development (0.84 ± 0.11 µg/l). Chlorophyll a was nearly double near the waste treatment facility, 1.60 µg/l.

Similar to La Parguera, Barnegat Bay is a nitrogen-limited system (Durand 1984). Nitrogen concentrations were highest near development and addition of nitrogen was associated with algal blooms. Phytoplankton biomass is typically higher in the northern portions of Barnegat Bay, which is where the greatest amount of development is located. Chlorophyll a values in the southern end of the bay ranged from 0.0 to 16.9 ug/l (Schooley 1995).

Algal biomass was also greatest during summer months. Chlorophyll a can reach values of 10 mg /m3 decreasing the available light to benthic communities tremendously. Blooms of phytoplankton composed primarily of picoplanktonic green algae (*Nannochloris atomus*) and brown algae (*Aureococcus anophagefferens*) (Barnegat Bay Estuary Program Scientific and Technical Advisory Committee 2001).

Fecal Contaminants

There have been numerous complaints that the infrastructure cannot support the expansion of La Parguera. Stilt houses built along the immediate shoreline often disconnect themselves from the treatment plant to prevent back ups into their homes, particularly on weekends when use is highest. Fecal coliform has also been found in water samples downstream of La Parguera. High fecal coliform bacteria counts are also been responsible for the closure of bathing beaches and shellfish harvesting areas in and around Barnegat Bay (Barnegat Bay Estuary Program Scientific and Technical Advisory Committee 2001). It is clear that both locations have common contaminant issues that must be addressed.

Total Suspended Solids

In general, total suspended solids (TSS) in the water column near La Parguera were significantly different among sites with varying degrees of development. The overall average TSS was 32.93 mg/l. Sites in the vicinity of new development were significantly greater, 34.79 mg/l, than all other areas, mean 31.80 mg/l. Turbidity followed a similar trend to TSS. The overall mean turbidity was 2.35 NTU, ranging from 0.12 NTU to 10.5 NTU. Although the tidal fluctuation in La Parguera was less than 0.25 m, there was a significant difference in total suspended solids with respect to tidal cycle. The overall mean TSS during flood tides was less than ebb, 31.99 mg/l and 34.64 mg/l respectively. TSS was not significantly different among sites during flood tides; however, during ebb tides, sites in the vicinity of new development had significantly greater TSS concentrations than old development sites and undeveloped sites. Suspended organic material averaged 9.71 mg/l, ranging from 1.39 mg/l to 36.81 mg/l. There was no significant difference in suspended organic material with respect to site. Suspended inorganic material averaged 23.10 mg/l and ranged from 1.42 mg/l to 36.79 mg/l. The inorganic material was significantly greater during ebb tide, averaging 25.73 mg/l near developed sites as compared to all other sites.

Data on suspended sediment (quantity and quality) in streams of the bay watershed are limited. Concentrations of suspended sediment measured in streams of the Barnegat Bay watershed were low. Median values were less than 20 mg/l at all sampled streams (where data were available). Total suspended solids in the southern end of the bay were highly variable, which is characteristic of such shallow temperate waters (Berg and Newell 1986) ranging from 1 to 104 mg/l, with the higher values being found in mid bay areas (Schooley 1995).

Metal Contamination

Suspended sediment can be a transport mechanism for nutrients, organic chemicals, and metals to the estuary. Metal concentrations in sediments of the hills behind the development in La Parguera were found to be lower than in the adjacent marine sediments. Nickel was the exception. High nickel concentrations were attributed to the naturally occurring high concentrations of this metal in the area. Metal concentrations in the sediments of La Parguera Bay are affected by run-off from urbanization within the town of La Parguera. Concentrations increased adjacent to new development where the population has been increasing steadily over the last 10 years. Comparing data from La Parguera Bay to other data in the Caribbean and using sediment quality guidelines from Long and Morgan (1990), it is apparent that Cu, Ni, and possible Zn are at high enough levels in some locations to be a potential concern.

Copper seems to be the only metal within the La Parguera sediments that showed a significant anthropogenic influence. An enrichment factor for the each metal was determined by normalizing the data for an inert metal, aluminum (Ryan and Windom 1988). By comparing metal:aluminum ratios in sediments of La Parguera, it was possible to assess the overall enrichment of a particular metal at a sampling site. When enrichment factor values were assessed, Cu was the only metal within the bay sediments that showed a significant anthropogenic link. This enrichment could be attributed to the heavy boat traffic in La Parguera bay and leaching from the associated bottom paints that are know to contain Cu. Further studies are necessary in order to properly identify site-specific background values, and to better understand the geochemistry of La Parguera and La Parguera Bay sediments.

Increases in Cu concentration in sediments in the vicinity of bulkheads in Barnegat Bay have also been previously reported (Weis et al .1993). It is possible that the source of Cu here too comes from the use of copper as an anti-foulant in boat bottom paints and as a component in wood preservatives. Areas of concentrated human activities typically have increased concentrations of trace metals. Copper and lead are often seen to be of higher concentration at marina sites, somewhat lower at transitional sites and are usually lowest in open bay sites (Moser and Bopp 1996). The Cu/Pb ratios for bay sites are fairly constant from the core bottom (early 60s) to the late 70s, and then decrease to the present (Moser and Bopp 1996). Both marinas and transitional sites often show an increase in Cu/Pb ratios in the mid to late 1980s (Moser and Bopp 1996).

Seagrasses

Seagrasses serve as substrate for epiphytes and epifauna in areas that would otherwise not be able to support such communities. These communities provide shelter and habitat for fish, shrimp and other invertebrates. Both *Thalassia* and *Zostera* are among the most effective seagrasses in trapping fine suspended particles, both directly and indirectly, because of their broad leaves (Burrell and Schubel 1977). In undisturbed areas, communities of these plants are very efficient at cycling nutrients and binding sediments, resulting in high water clarity and quality.

Previous research has shown that seagrasses are negatively impacted by high turbidity and nutrient concentrations in a myriad of way. Reduced light availability to the seagrasses results from higher water column phytoplankton, higher total suspended solids in the water column, or shading by epiphytic accumulating on the leaves. Increased sedimentation rates can also lead to direct burial. Altered and elevated nutrient concentrations can have a suboptimal ratio for normal plant functioning or result in increased epiphyte loading.

Limited data exists on the historical extent of seagrass beds in La Parguera. Gonzalez-Liboy (1979) conducted a limited survey of the grass beds. Over the past three years, in conjunction with other research in the vicinity of La Parguera, the seagrass beds of La Parguera have been revisited. Areas previously described as having dense seagrass beds, are now unvegetated. Unvegetated areas area associated with new development. Further investigations are necessary to determine if areas will revegetate, similar to areas with established development.

New land development at La Parguera, Puerto Rico, has impacted the shallow benthic community by increasing sediment runoff and decreasing light available to the seagrass community. In areas near new development, seagrass shoot density and percent cover were reduced or absent compared with reference locations upstream in the long-shore current. Reduced seagrass health was associated with decreased light, increased sedimentation and increased epiphyte load. Elevated epiphyte loads near new development were correlated with high seston chlorophyll-a concentrations, suggesting the presence of a local point source of nutrients. Despite the terrestrial source, the overall sediment composition was not significantly different in areas devoid of seagrass compared with sites with abundant seagrass. Seagrasses might therefore be able to re-colonize disturbed areas near new development if nutrient and sediment inputs can be reduced, thereby reducing epiphyte fouling and increasing water clarity, respectively.

Loveland et al. (1984) recorded 116 species of benthic algae in Barnegat Bay, with the dominant forms being *Ulva lactuca*, *Gracilaria tikvahiae*, *Codium fragile*, *Zostera marina*, *Ceramium fastigiatum*, and *Agardhiella subulata*. There is a significant spatial and temporal variation in macroflora biomass (Loveland et al. 1974). However, the top five species, based on percent dry weight, remains *Ulva lactuca*, *Codium fragile*, *Zostera marina*, and *Gracilaria tikvahiae* and contribute 90% of the total dry weight (Loveland and Vouglitois 1984). *Ruppia maritime* also occurs in the bay particularly on the easterly sand flats (Loveland et al. 1974). Eelgrass (*Zostera marina*) is the dominant seagrass species in Barnegat Bay, forming dense beds particularly on sand flats along the backside of the barrier island system. Widgeon grass (*Ruppia maritima*) is of secondary importance, also attaining highest concentrations on the eastern sand flats. Locally dense beds of sago pondweed (*Potamogeton pectinatus*) appear north of Toms River, with lesser quantities of horned pondweed (*Zannichellia palustris*), widgeon grass, and eelgrass.

The SAV's of Barnegat Bay were first mapped by the US Army Corps of Engineers (1976) in 1968. In 1979, the second attempt at mapping the SAVs was undertaken using aerial photographs and ground truthing that produced a 1:24,000 scale map series for the entire bay (Macomber and Allen 1979). The U.S. Fish and Wildlife Service, as part of the National Wetland Inventory for, incorporated this data. SAV distribution was recorded between 1985 and 1987 by the Bureau of Shellfisheries of the NJ Department of Environmental Protection and Energy (Joseph et al. 1992). Field surveys were also conducted in 1996 and 1997 (McLain and McHale 1997). From this data the spatial and temporal distribution of the SAV has been determined. Productivity of *Zostera* has been measured between 23 and 43 g dry wt per m^{-2} during summer months (Ohori 1982). *Zostera* plays a significant role as habitat for aquatic organisms (Kikuchi and Peres 1977; Levinton 1977; Orth 1977).

Unlike La Parguera, disease is responsible for significant declines of seagrasses in Barnegat Bay during certain years. For example, McClain and McHale (1997) showed that wasting disease, presumably caused by the protist *Labyrinthula zosterae*, destroyed about 400 ha of eelgrass beds in Barnegat Bay in 1995. Less disease and SAV destruction occurred in 1996, although as much as 50% of eelgrass leaves exhibited wasting disease at this time.

Submerged aquatic vegetation habitat is being lost. There has been some difficulty comparing historic data because sampling methods have not been consistent. However, it is generally thought that habitat losses have occurred, particularly in the northern portions of the bay, where visibility has been most affected by increased land development.

<u>Fisheries</u>

There are no species of shellfish commercially harvested in La Parguera. The eastern oyster, *Crassostrea virginica*, and northern quahog or hard clam, *Mercenaria mercenaria*, are commercially harvested along the Atlantic coast and southern New Jersey (Ford 1997). The bay scallop, *Argopecten irradians,* inhabits eelgrass beds of the coastal bay and has been harvested sporadically (Ford 1997).

Conclusions

In many ways La Parguera and Barnegat Bay are similar. Both have continued concentrated development and changing land use in one area as opposed to throughout all watersheds. Tourism has been attracted to both areas for a number of recreational activities, notably boating, fishing, swimming, and aesthetic value. In both areas, development threatens the very resources that attract people to the areas in the first place. Nutrients and chemical contaminants continue to enter the both system and impact the health of submerged aquatic vegetation, what act as nursery and protect local fisheries. Further sampling and monitoring are necessary in both systems to relate land use changes and this impact they have on seagrass beds.

Nutrients primarily enter both Barnegat Bay and La Parguera from non-point sources. In Barnegat Bay nutrients are transported by stream into the bay, whereas at La Parguera nutrients primarily flow to the open water as sheet flow through the mangroves. Both systems are nitrogen-limited and hence increased nitrogen runoff results in algal blooms. This in turn decreases the available light to benthic flora and can cause anoxic conditions as the algae die and decay.

Changes in coastal environments often happen gradually, and these cumulative changes should be incorporated into regulatory and management procedures (Daily and Ehrlich 1992, Spaling and Smit 1993). Maintaining healthy ecosystems that function within the greater land-margin interface requires a landscape approach to assessing ecosystem diversity and integrity (Lapin and Barnes 1995). Managing ecosystems is clearly a social process (Norgaard 1992, Meffe and Viederman 1995). Solving many of our coastal problems may be linked to understanding how people use coastal resources, how they think the resources should be used in the future, and how they view the severity of environmental problems there (Burger 1998).

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