Development of the Benthic Index for San Juan Bay Estuary System

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1.0 Background

The San Juan Bay estuarine complex (SJBE) includes San Juan Bay, Condado Lagoon, San José Lagoon, Los Corozos Lagoon, La Torrecilla Lagoon, and Piñones Lagoon. Also included are the Martin Peña Canal, which connects San Juan Bay and San José Lagoon, the San Antonio Canal, which connects San Juan Bay and Condado Lagoon, and the Suárez Canal, which connects San José Lagoon and Torrecilla Lagoon (see figure 1).

Figure 1
Location of Major Features in the San Juan Bay Estuary Program Study Area (from SJBEP 2000)

Impacts to water and sediment quality include not only the high population density in some portions of the watershed, but also the very high density of automobiles used by the population. The density (vehicles per mile of paved road) in the San Juan Bay Estuary watershed is nearly three times the US mainland average (SJBEP 2000). Population densities were lowest in the region surrounding Piñones Lagoon, and highest in the regions surrounding Condado Lagoon (SJBEP 2000).The high level of automobile use in the watershed suggests that contaminants associated with such use (i.e., greases, PAHs, etc.) would also be elevated in the bay's sediments.

Water quality, and the quality of bottom sediments in the San Juan Bay system are impacted by point and non-point pollution, impacts to circulation from channel dredging and filling (especially adjacent to the Martín Peña Canal), erosion from upland areas of the watershed, and resuspension of bottom sediments (SJBEP 2000).

In recognition of these and other threats to the health of the SJBE, the Governor of Puerto Rico nominated the SJBE system for the U.S. Environmental Protection Agency's National Estuary Program in 1992. The goals of the SJBEP are the following:

- Establish a comprehensive water quality policy.
- Develop an administrative and regulatory framework for the SJBEP.
- Optimize the social, economic and recreational benefits of the estuary.
- Prevent further degradation, and improve water quality to ensure healthy terrestrial and aquatic systems and social well-being.
- Minimize health risks associated with bodily contact and the consumption of fish and shellfish.

These goals are to be accomplished via undertaking a series of actions meant to allow the SJBEP to meet specific measurable objectives:

- Identification of the major stressors to the system, and their relative importance.
- Develop action plans to remediate these stressors.
- Conserve and enhance the natural resources of the SJBEP system.
- Promote public awareness and address major concerns of various stakeholders.
- Develop a hydrologic model sufficient to determine appropriate mechanisms to improve circulation and guide future development.

In its early stages, the SJBEP completed a series of studies designed to collect baseline information, establish appropriate indicators of ecosystem health, and enable the analysis of such information to be used to assess progress toward achievement of program goals (Otero 2002).

This project was designed to provide the SJBEP with a regionally-appropriate benthic index for the SJBE. This index can then be used as an indicator of the environmental condition of the estuary. This indicator can be used to compare and contrast segments of the San Juan Bay Estuary system against each other, and also to track the health of the benthic communities over time both on a localized level (e.g., Torrecilla Lagoon) or a regional level (e.g., San Juan Bay Estuary as a whole).

A benthic index can be useful for summarizing complex information in a way that allows for review and assessment by technical staff without specific technical expertise in benthic ecology, and can also be a valuable tool for public education. According to EPA (2008) "Indicators can be a cost-effective, accurate alternative to monitoring the individual components of a system."

The EPA (2008) suggests that a suite of different indicators, such as the following, can be useful: 1) a water quality index, 2) a sediment quality index, 3) a benthic index, 4) a coastal habitat index, and 5) a fish tissue contaminants index. For a benthic index, the topic of this effort, EPA (2008) recommends it contain information on benthic community diversity, the presence or absence of pollution-tolerant taxa, and the presence or absence of pollution-sensitive taxa.

Benthic communities, and benthic indexes, can be a useful tool to track degradation and/or improvements in watershed-level pollutant loading, as they "integrate" water and sediment quality conditions on a longer timescale than a single point in time sample in a collection bottle.

With this information as background, we have developed a benthic index for the San Juan Bay Estuary, using the below-described approach.

2.0 Methods

2.1. Data Management

Benthic sampling data were provided by SJBEP in the form of Appendices C-E from Rivera (2005). These data were arranged into a single data table and data describing the family classification for each taxon were added based on a review of data via the Integrated Taxonomic Information System (ITIS, www.itis.gov). Location data for GIS maps were provided in Appendix J from Rivera (2005). These data were reviewed, and when the stated location (i.e. San Juan Bay, Condado Lagoon, etc.) did not agree with the provided coordinates these samples were removed from the maps. However some samples were still used in calculating descriptive statistics. The described location of a sample rather than provided coordinates was used to assign the station location for those stations where such a discrepancy occurred (Table 1).

Table 1
Benthic Stations at Which There Were Location Issues

STATION	COMMENT
BA-401	Is identified as being in a channel, however it's GIS position puts it squarely in San Juan Bay, index score of 1.78 seems to be more representative of the channels than San Juan Bay, use data for analysis of channels
JM-M001	Station is identified as being in a channel, it is located near the mouth of a drainage channel to SJL , this sample is within SJL proper and will be used in the SJL analyses
S1	Station is identified as being in SJB, however the GPS coordinates place it on land, the data from this station will be used for SJB analyses
S19	Station is identified as being in San José Lagoon (SJL), however the GPS coordinates place it in SJB, the Index Score would be the highest score in SJL, and would fit in very well in SJB, because of the uncertainty associated with the sample location it will not be included in the analyses
S29C	Station is identified as being in SJL, however the GPS coordinates place it on the Atlantic shoreline near CL, data from this sample will be included in the analyses for SJL
S4	Station is identified as "Atlantic", GPS coordinates place the sample in Torrecilla Lagoon (TL), there were no other TL samples from the Coastal 2000 study, so it is very likely that this sample actually occurred in TL, data from this sample will be included in the analyses
S43	Station is identified as being in Condado Lagoon (CL), however the GPS coordinates place it in SJB proper the Index Score of 2.85 appears to fit with either CL or SJB, because of the uncertainty associated with the sample location it will not be included in the analyses
S5	Station is identified as being in SJB, however the GPS coordinates place it in SJL, the index score of 3.33 does not fit in with the SJL samples surrounding it, because of the uncertainty associated with the location of this sample it will not be used in the analyses
SF-M001	Station is identified as being in a channel, it is located at the mouth of a small bay within SJB (see sample SJB_B004), this sample is within SJB proper and will be used in the SJB analyses
SJB_B004	Sample is in a small bay within SJB that is not representative of the general condition of SJB, Index score of 0.0 will be used in SJB calculations, but the site difference needed to be described

2.2. Calculating the Index

All calculations were performed using Statistical Analysis Software (SAS). For all analyses the family taxonomic level was utilized. The total abundance of each family of organisms was calculated for each sample. The initial component of the index is Shannon Diversity scores. These scores integrate taxonomic richness, abundance, and evenness of distribution into a single calculated number. The equation for Shannon Diversity is:

$$\underset{i=1}{\overset{S}{H}} = -\sum (Pi * LnP_i)$$

Where:

H= Shannon Diversity Index Score

P_i= Proportion of sample comprised of family i

S = Number of families in the sample

Based on recommendations found in the literature additional components were added to create the benthic index score. Adjustments were made so that the score would increase due to the presence of members of the families Aoridae and Ampeliscidae, which are generally pollution-sensitive organisms (Lee et al 2005, Weston 1996, Traunspurger and Drews 1996). The score also decreases due to the presence of members of the families Capitellidae and Tubificidae, which are regarded as pollution-tolerant, or indicative of disturbed benthic habitat (Paul et al 2001, Pinto et al. 2009). These components were added to the index equation in an iterative manner until the results matched a scale deemed appropriate. The resultant San Juan Bay benthic index equation is as follows:

$$B = H - P_{Cap}{}^{2} - P_{Tub}{}^{2} + P_{Aor}{}^{0.5} + P_{Amp}{}^{0.5} + 1$$

Where:

B = Benthic Index Score

H = Shannon Diversity Score

P_{cap} = Proportion of the sample in the family Capitellidae

P_{Tub} = Proportion of the sample in the family Tubificidae

P_{Aor} = Proportion of the sample in the family Aoridae

P_{Amp} = Proportion of the sample in the family Ampeliscidae

This equation was then applied to the provided benthic data and scores were generated based on those data. The results were reviewed with the ArcGIS software utilizing data for substrate type and depth to further explain the benthic index scores.

2.3. GIS Data

The SAV and bathymetry data were geo-referenced from the San Juan Bay Estuary Program Management Plan. The SAV data were then converted from raster data to vector features. All features corresponding to Non-Dredge SAV were selected and quantified. Bathymetry data was digitized and quantified.

In addition the shortest feasible non-landward route from each sample point to the Atlantic Ocean was measured in ArcGIS. An identity function was performed on the benthic stations, bathymetry, and habitat data for each station used in the Benthic Index.

3.0 Results

3.1. Benthic Index Scores

Mean benthic index scores ranged from 0 in the Suarez Canal to 2.74 in Torrecilla Lagoon. Torrecilla Lagoon, Condado Lagoon, and San Juan Bay were found to have higher mean benthic habitat scores than San José Lagoon and Piñones Lagoon (Table 2). Individual sample scores ranged from a minimum of 0.00 (in all waterbodies except Condado Lagoon and Torrecilla Lagoon) to a maximum of 4.13 in San Juan Bay.

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Table 2
Benthic Index Scores for Individual Waterbodies

Waterbody	Mean	Standard Deviation	Maximum	Median	Minimum	Number of Observations
San Juan Bay	2.74	0.80	4.13	2.86	1.45	15
Condado Lagoon	2.62	1.09	4.01	3.04	1.00	7
San José Lagoon	1.14	1.03	2.24	1.63	0.00	12
Torrecilla Lagoon	3.07	0.42	3.41	3.21	2.35	5
Piñones Lagoon	1.01	0.88	2.14	0.95	0.00	4
San Antonio Canal	3.09		3.09	3.09	3.09	1
Martín Peña Canal	1.00		1.00	1.00	1.00	1
Suárez Canal	0.00	0.00	0.00	0.00	0.00	2
Other Channel Sites	1.48	0.20	1.63	1.56	1.26	3

These data were tested for differences, if any, between waterbodies for those systems with at least four samples. Benthic Index Scores were found to be normally distributed and homoscedastic for each waterbody, therefore ANOVA and Fischer's Least Significant Difference (LSD) multiple comparison test were used to compare scores for waterbodies with at least four samples. ANOVA indicated that significant ($p < 0.01$) differences existed for scores. Fischer's LSD test indicated that two groups existed, concerning Benthic Index scores; Piñones Lagoon and San José Lagoon were not different from each other, but they were different from San Juan Bay, Condado Lagoon, and Torrecilla Lagoon (which were also not different from each other).

Figures 2 to 9 illustrate the spatial distribution of benthic index scores for San Juan Bay, Condado Lagoon, San José Lagoon, Torrecilla Lagoon, Piñones Lagoon, San Antonio Canal, Martín Peña Canal, and Suárez Canal, respectively.

Figure 2
Locations and Benthic Index Scores for Stations Located in San Juan Bay
Values are Color-Coded as to their Benthic Index Scores

Figure 3
Locations and Benthic Index Scores for Stations Located in Condado Lagoon Values are Color-coded as to their Benthic Index Scores

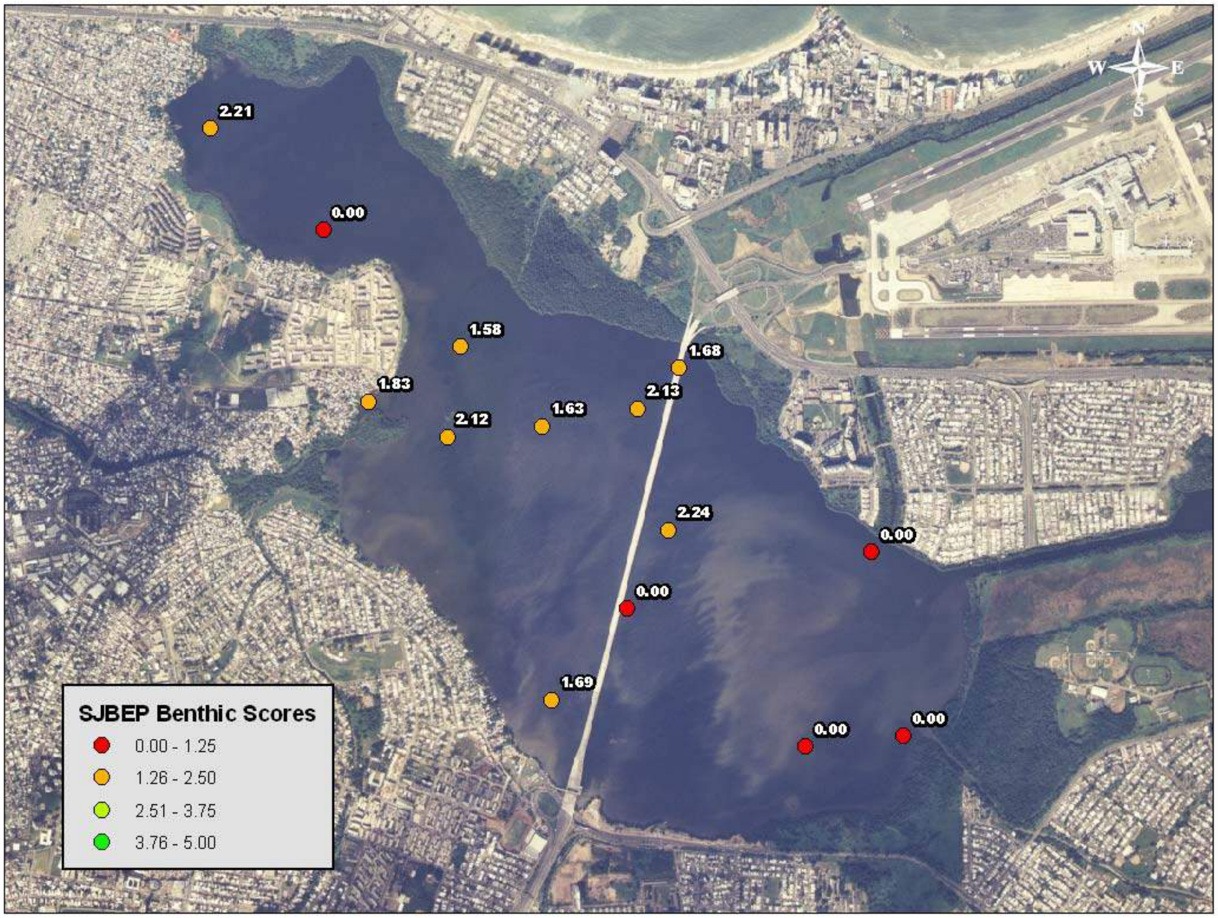

Figure 4
Locations and Benthic Index Scores for Stations located in San José Lagoon
Values are Color-coded as to their Benthic Index Scores

Figure 5
Locations and Benthic Index Scores for Stations located in Torrecilla Lagoon Values are Color-coded as to their Benthic Index Scores

Figure 6
Locations and Benthic Index Scores for Stations located in Piñones Lagoon Values are Color-coded as to their Benthic Index Scores

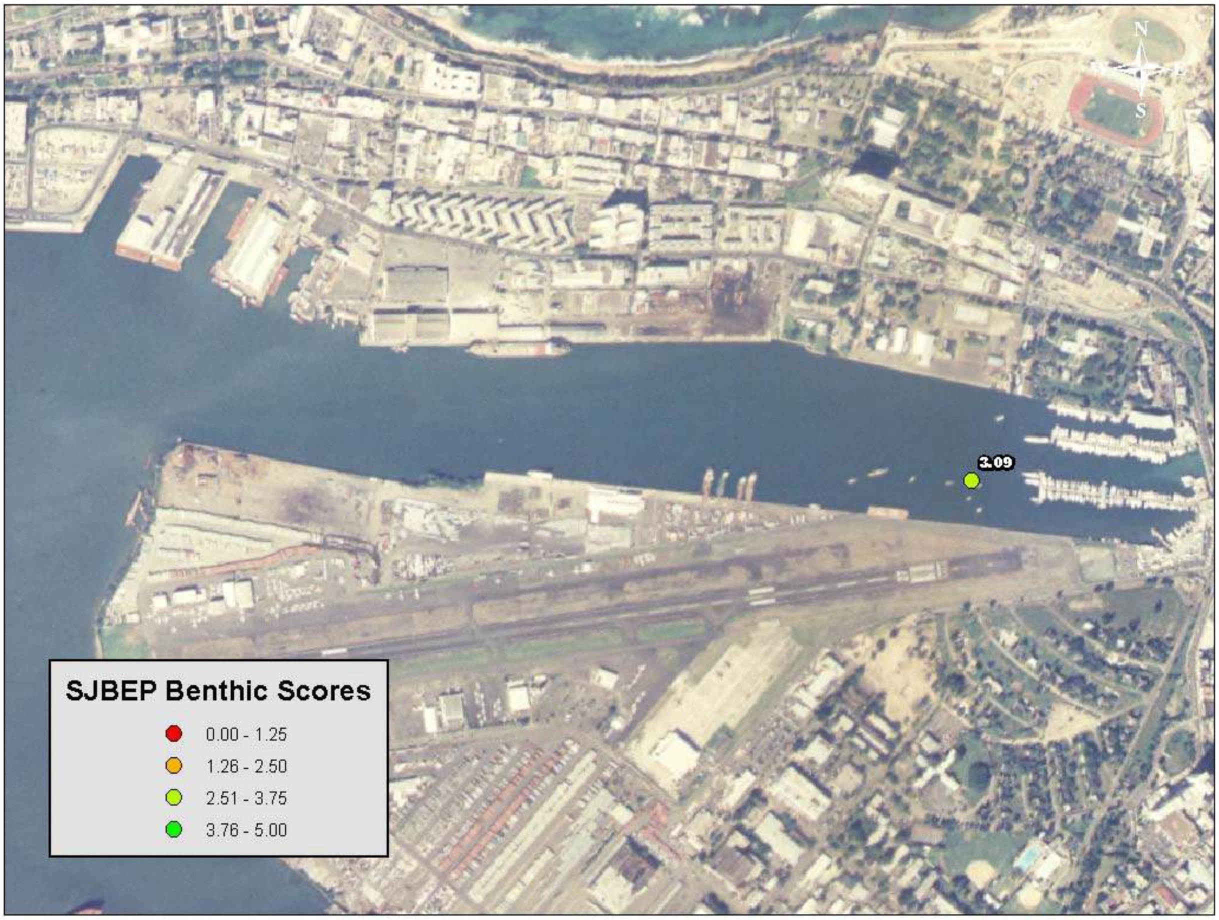

Figure 7
Locations and Benthic Index Scores for stations located in San Antonio Canal. Values are color-coded as to their benthic Index Scores.

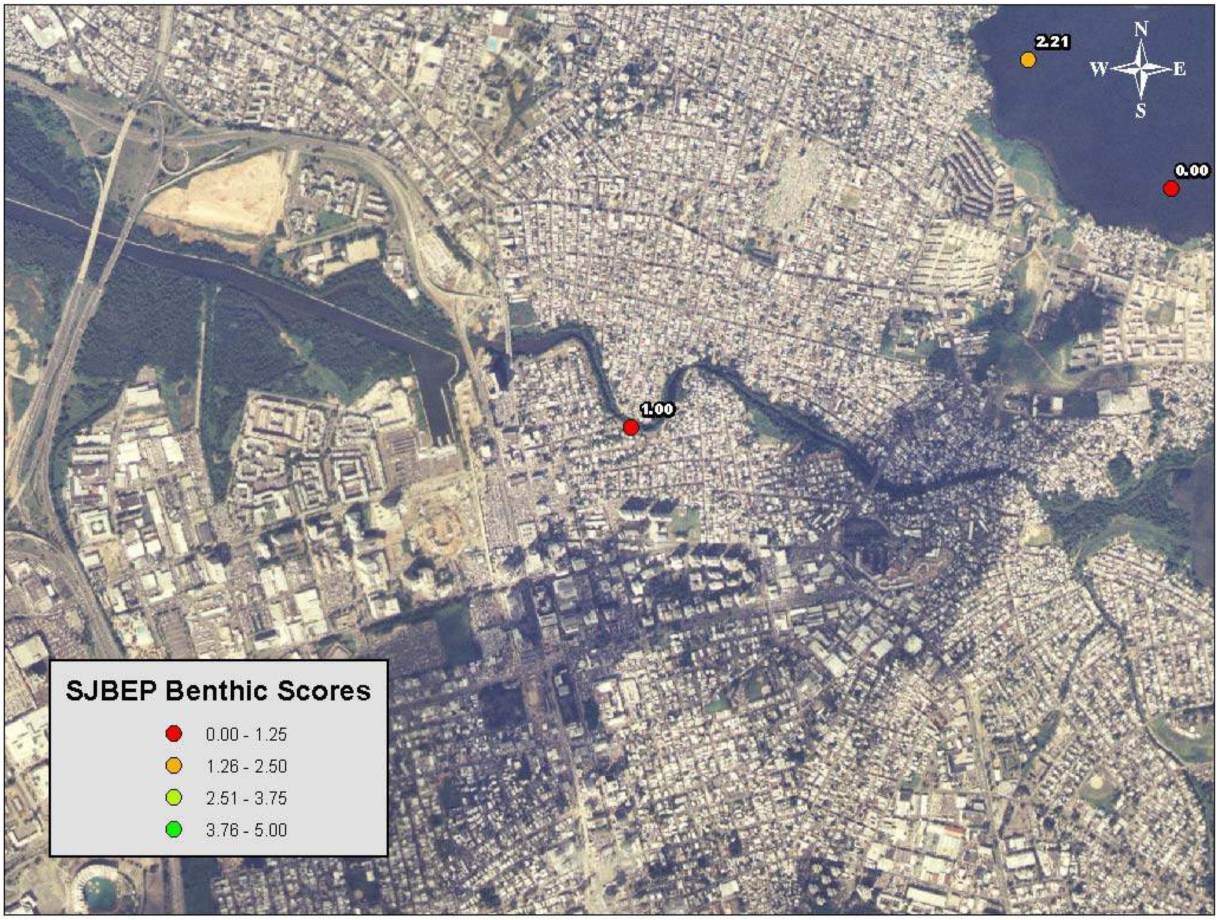

Figure 8
Locations and Benthic Index Scores for stations located in Martín Peña Canal. Values are color-coded as to their benthic Index Scores.

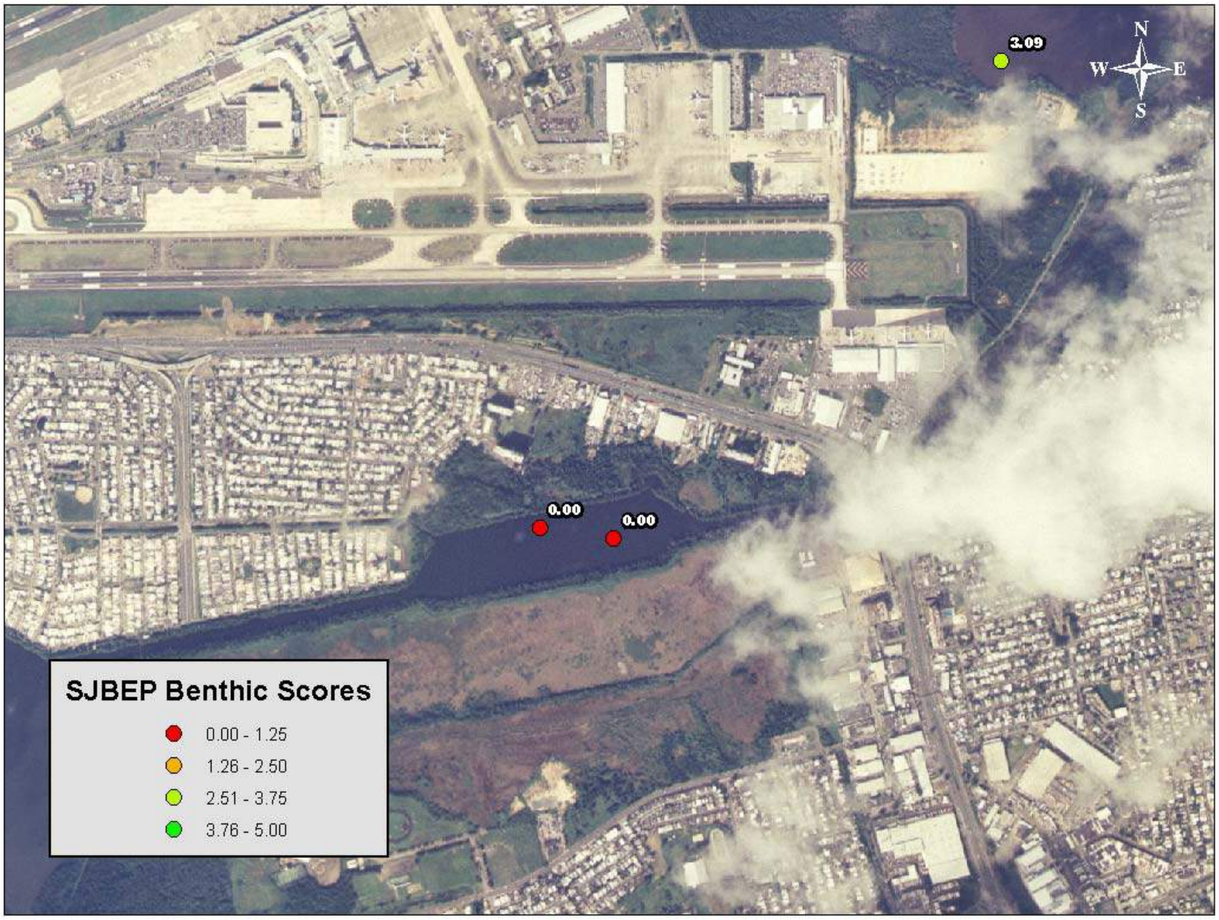

Figure 9
Locations and Benthic Index Scores for stations located in Suárez Canal. Values are color-coded as to their benthic Index Scores.

Additional data sets were analyzed to aid in the interpretation of the Benthic Index Scores. Using a bathymetry layer derived from the bathymetry map shown in SJBEP (2000), station locations were displayed on top the bathymetric contours derived from the map (Figure 10).

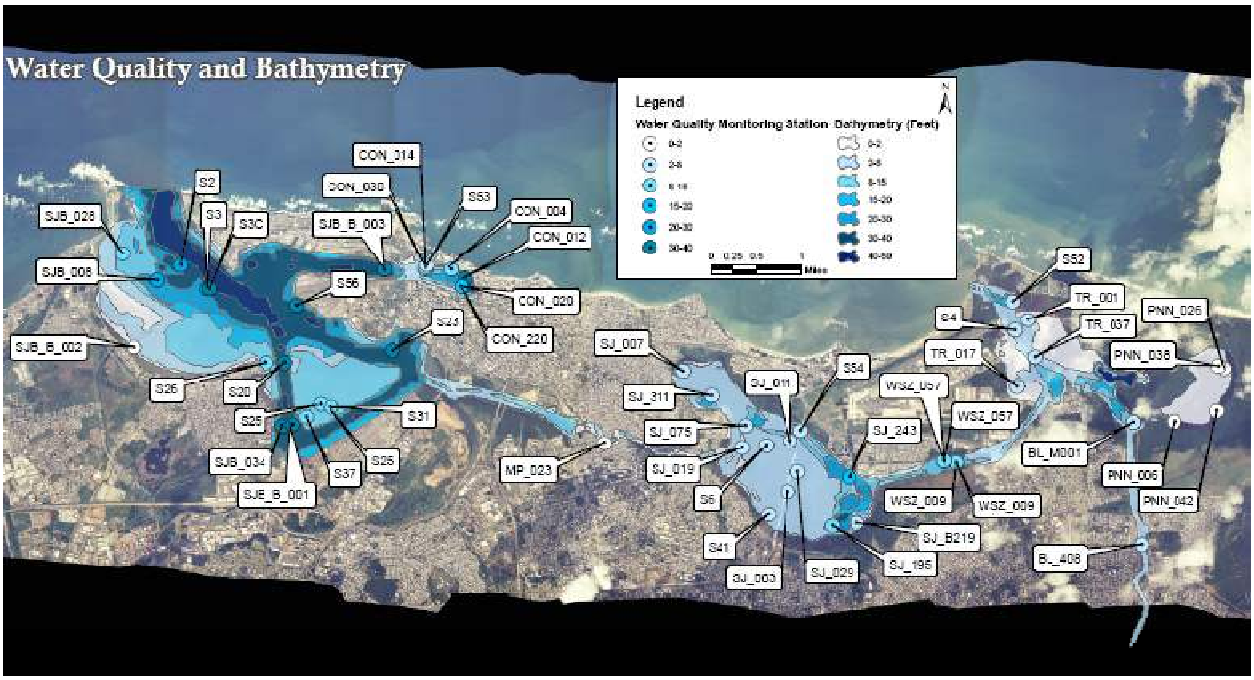

Figure 10
Locations of Benthic sampling Stations and Bathymetry
Bathymetry Data from SJBEP [2000)

Bathymetry within San Juan Bay itself is deeper along the northern boundary of the bay, especially near the opening to the Atlantic Ocean. There is a well-defined shipping channel in the southeastern portion of the bay, forming a triangle with a shallow shelf interior to the dredged channels. Within San Juan Bay, benthic sampling stations were located in both shallow water (0 to 2 feet), deep water (30 to 40 feet) and in all depth categories between these two extremes.

In Condado Lagoon, some of the sampling sites in the eastern part of the lagoon are located in dredged areas more than 20 feet in depth. Benthic sampling sites in the western part of Condado Lagoon are in shallower, non-dredged areas.

The bathymetry in San José Lagoon shows deeper dredged areas in the far eastern portions, with a mostly natural and shallow (2 to 8 feet) bottom. Two of the three benthic sampling sites in the easternmost part of San José Lagoon appear to be located in areas that have been dredged in the past.

In Torrecilla Lagoon, the irregular and angular boundaries of some of the bathymetry layer boundaries suggest significant dredging activities. Most of the benthic sampling sites in Torrecilla Lagoon appear to be located in areas that might be influenced by prior dredging.

The bathymetry data for Piñones Lagoon indicates no significant dredging activity, as the entirety of the lagoon appears to be uniformly shallow, with depths no deeper than 8 feet. Based on bathymetry data, Piñones Lagoon appears to have the least impact from dredging of any portion of the San Juan Bay system.

In addition to the existing bathymetry data, GIS was used to calculate the distance between benthic sampling sites and the nearest connection to the Atlantic Ocean. For each location, GIS was used to estimate the shortest practical distance between that location and the Atlantic; all routes were restricted to open water only, without crossing any land features. Flushing of San José Lagoon occurs almost entirely via the Suárez Canal, rather than the Martín Peña Canal. Therefore locations in San José Lagoon were measured based on an eastward connection to the Atlantic Ocean via Suárez canal.

Table 3 summarizes data for each station for Benthic Index Scores, water depth, and distance from that station to the Atlantic Ocean. These data were used for further analyses, described below.

Table 3
Summary of Benthic Index Scores, Water Depth (feet) and Distance to the Atlantic Ocean (m) for each Benthic Sampling Station

STATION	CODE	LONGITUDE	LATITUDE	BENTHIC INDEX SCORE	BATHYMETRY (ft)	Distance to Atlantic Ocean (m)
BL_M001	Channel	-65.96714	18.43283	1.26	8-Feb	4,097
BL_408	Channel	-65.96613	18.41338	1.56	8-Feb	6,248
S6	Channel	-66.02825	18.43009	1.63	8-Feb	8,097
S53	Condado Lagoon	-66.08413	18.45953	4.01	8-Feb	414
CON_030	Condado Lagoon	-66.08436	18.45916	3.04	15-Aug	452
CON_014	Condado Lagoon	-66.08436	18.45887	2.95	15-Aug	489
CON_004	Condado Lagoon	-66.08021	18.45889	1	15-Aug	690
CON_220	Condado Lagoon	-66.07837	18.4561	3.05	15-20	1,000
CON_012	Condado Lagoon	-66.07771	18.45734	1.24	30-40	1,014
CON_020	Condado Lagoon	-66.07814	18.45602	3.05	15-20	1,015
MP_023	Martin Pena Canal	-66.05505	18.43089	1	0-2	9,260
PNN_006	Pinones Lagoon	-65.96048	18.43277	2.14	0-2	4,906
PNN_042	Pinones Lagoon	-65.95335	18.43439	0.9	0-2	5,553
PNN_038	Pinones Lagoon	-65.95292	18.44151	0	0-2	5,948
PNN_026	Pinones Lagoon	-65.95203	18.44107	1	0-2	5,982
SJB_B_003	San Antonio Canal	-66.09133	18.45902	3.09	30-40	1,070
SJ_243	San Jose Lagoon	-66.0146	18.42487	0	15-20	6,364
SJ_B219	San Jose Lagoon	-66.01338	18.41753	0	8-Feb	7,064
SJ_195	San Jose Lagoon	-66.01749	18.41716	0	15-Aug	7,223
SJ_029	San Jose Lagoon	-66.02305	18.42589	2.24	8-Feb	7,522
SJ_003	San Jose Lagoon	-66.02484	18.42278	0	8-Feb	7,652
S54	San Jose Lagoon	-66.02249	18.43233	1.68	8-Feb	7,760
SJ_011	San Jose Lagoon	-66.02423	18.43075	2.13	8-Feb	7,780
S41	San Jose Lagoon	-66.02804	18.41918	1.69	8-Feb	8,026
SJ_019	San Jose Lagoon	-66.03222	18.42975	2.12	8-Feb	8,561
SJ_075	San Jose Lagoon	-66.03161	18.43332	1.58	8-Feb	8,679
SJ_311	San Jose Lagoon	-66.03724	18.43807	0	8-Feb	9,359
SJ_007	San Jose Lagoon	-66.04186	18.44217	2.21	8-Feb	10,127
SJB_028	San Juan Bay	-66.13472	18.46227	2.93	15-Aug	1,112
S2	San Juan Bay	-66.12514	18.46016	3	20-30	1,230
SJB_008	San Juan Bay	-66.12894	18.45788	2.27	20-30	1,420
S3	San Juan Bay	-66.12065	18.45645	2.86	20-30	1,802

S3C	San Juan Bay	-66.12025	18.45645	4.13	30-40	1,808
SJB_B_002	San Juan Bay	-66.13293	18.44726	3.04	0-2	2,922
S56	San Juan Bay	-66.10585	18.45357	2.25	30-40	3,115
S26	San Juan Bay	-66.11105	18.44456	4.1	15-Aug	3,445
S20	San Juan Bay	-66.10799	18.44453	2.68	30-40	3,631
S25	San Juan Bay	-66.10218	18.4378	2.5	15-Aug	4,584
SJB_034	San Juan Bay	-66.1086	18.43446	1.69	30-40	4,644
S37	San Juan Bay	-66.10463	18.4358	3.43	15-Aug	4,647
SJB_B_001	San Juan Bay	-66.10691	18.4346	3.03	30-40	4,664
S31	San Juan Bay	-66.10042	18.43726	1.45	15-Aug	4,743
S23	San Juan Bay	-66.09015	18.4461	1.69	30-40	5,102
WSZ_009	Suarez Canal	-65.9968	18.42689	0	20-30	4,642
WSZ_057	Suarez Canal	-65.99873	18.42719	0	20-30	4,936
S52	Torrecilla Bay	-65.98691	18.45223	3.21	8-Feb	887
TR_001	Torrecilla Bay	-65.98446	18.44926	3.29	8-Feb	1,323
S4	Torrecilla Bay	-65.98658	18.4477	3.41	8-Feb	1,475
TR_037	Torrecilla Bay	-65.98341	18.44341	2.35	8-Feb	2,004
TR_017	Torrecilla Bay	-65.9864	18.43869	3.09	8-Feb	2,587

These data were then used to test for the effects, if any, of water depth and distance from the Atlantic Ocean as potential influences on Benthic Index scores for the entire SJBE system combined (Figures 11 and 12, respectively).

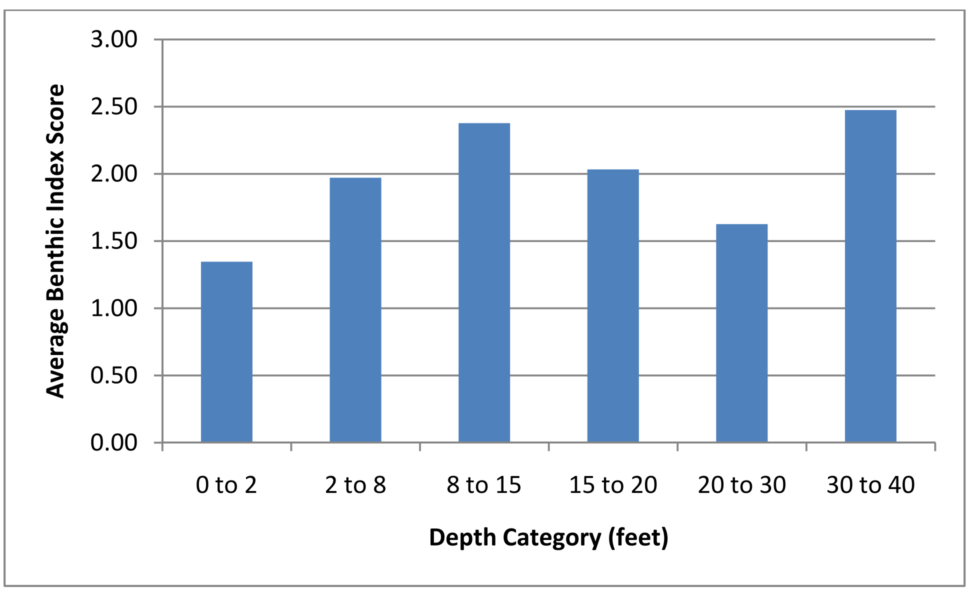

Figure 11
Benthic Index Scores across Different Depth Categories

When categorized for depth, Benthic Index scores were normally distributed and homoscedastic. ANOVA found no significant difference in Benthic Index scores between different depth categories ($p = 0.514$). As an additional assessment, the non-parametric Kruskal-Wallis test was employed, and it also found no affect of depth on Benthic Index scores ($p = 0.482$).

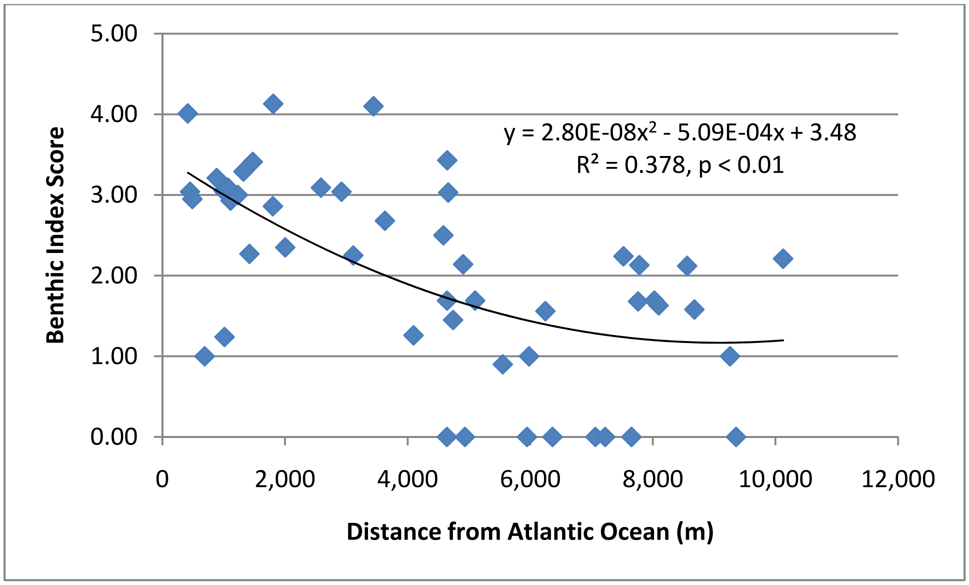

Figure 12
Benthic Index Scores vs. Distance from the Atlantic Ocean

Results shown in Figure 12 show a relationship wherein increasing distance from the Atlantic Ocean, an inverse proxy for the rate of flushing, is associated with a general pattern of decreasing Benthic Index scores. These data were found to be normally distributed and homoscedastic, and the polynomial equation relating Benthic Index scores to distance from the Atlantic was significant at $p < 0.01$. As an additional assessment, the non-parametric Spearman's Rho test was employed, which also found a statistically significant relationship between the ranked values of these two factors ($p < 0.01$).

When examining the distance vs. Benthic Index scores plot, it appeared as if the data more or less represented two groups of data, scores for stations less than 5,000 meters from the Atlantic Ocean, and scores for stations at greater distances. Figure 13 shows the results when data are segregated into these two groups.

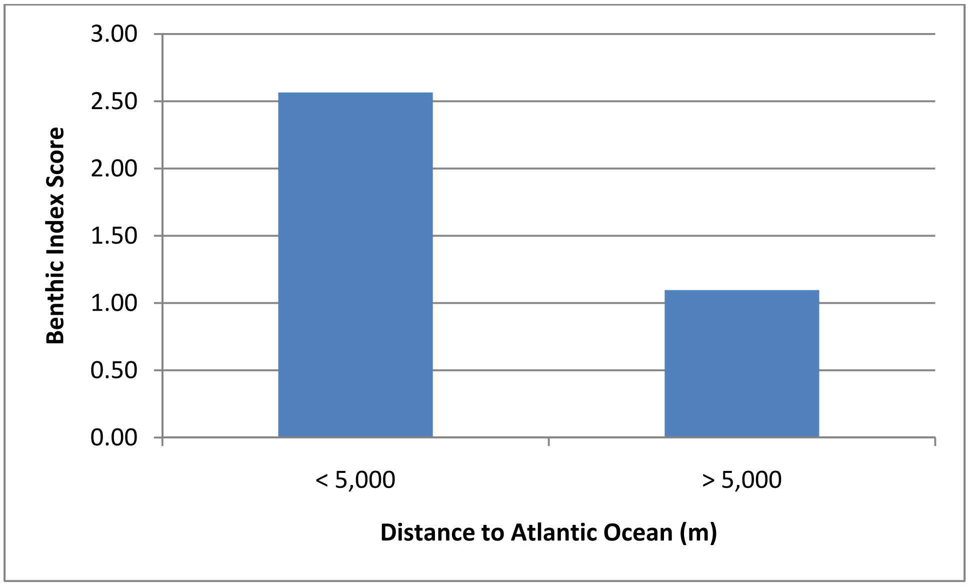

Figure 13
Benthic Index Scores for Stations Less Than and Greater Than 5,000 meters from the Atlantic Ocean

When grouped in this manner, the data are not normally distributed. The non-parametric Mann-Whitney U-test indicated that Benthic Index scores for stations less than 5,000 meters from the Atlantic Ocean were significantly higher ($p<0.05$) than for stations greater than 5,000 meters from the Atlantic. However, waterbodies such as San José Lagoon and Piñones Lagoon may have underlying features such as toxicity of sediments, frequency of disturbance, etc., that could be equally if not more important influences on Benthic Index scores than flushing rates. Caution is required when interpreting these results as suggesting distance from the Atlantic Ocean (with distance acting as an inverse surrogate for flushing) is the dominant influence on the health of benthic communities.

4.0 Discussion

4.1. Prior Characterization Efforts

The sediments within the San Juan Bay Estuary System have been previously characterized by Webb and Gomez-Gomez (1998) and Webb et al. (1998). These reports summarized results of sediment contamination levels and sedimentation rates from six sites throughout the SJBEP study area. Sediment dating techniques were used to compare contamination levels between the time periods of 1925 to 1949, 1950 to 1974, and 1975 to 1995.

For the earliest (deepest) sediments analyzed, levels of lead, mercury, and arsenic in sediment were similar to values from streams in undisturbed portions of the watershed. These results indicate contamination was minimal in the time period prior to 1950 (Webb and Gomez-Gomez, 1998; Webb et al., 1998).

After 1950, levels of PCBs (used in electrical transformers, etc.), lead (from leaded gasoline and paints) and mercury increased in the sediments. Agricultural chemicals such as dieldrin and DDT also increased post-1950. Results also indicate recent declines in levels of dieldrin and DDT, as well as a decline in levels of arsenic throughout the San Juan Bay Estuary (Webb and Gomez-Gomez, 1998; Webb et al., 1998). Declines in lead and DDT are expected to occur as a result of relatively recent (mid-1980s) phase-out of leaded gasoline and bans on DDT, but sediments do not yet show such a pattern.

Sedimentation rates appear to be nearly two orders of magnitude higher in the Martín Peña Canal than in other locations, suggesting that location is a probable “hot spot” for the accumulation of toxins in bottom sediments, a finding not at all in conflict with expectations (SJBEP 2000).

In addition to the potential impacts to benthic communities from toxins in sediments, benthic communities can also be stressed via fluctuations in salinity regimes (Montague and Ley, 1993, Fleischer and Zettler, 2008) and depressed levels of dissolved oxygen and other stressors (Dauer et al. 2000, Llanso et al. 2002).

In the San Juan Bay Estuary, Webb and Gomez-Gomez (1998) and Webb et al. (1998) showed evidence of declining levels of phosphorus within the waters of the bay itself, possibly related to upgrades in levels of wastewater treatment. As a whole, trends in sediment contaminant levels and water quality are suggestive of a situation where the San Juan Bay system may be degraded, but it also may be improving over time – albeit perhaps not at an equal rate in all locations.

4.2. Benthic Index Scores

The Benthic Index created for San Juan Bay can be used to compare the waterbodies of the SJBE against each other, as well as tracking waterbodies over time. Comparing waterbodies against each other, San Juan Bay, Condado Lagoon and the Torrecilla Lagoon all had median Benthic Index scores close to (San Juan Bay) or higher than (Condado Lagoon and Torrecilla Lagoon) a value of three. As a whole, these three systems appear to have the healthiest benthic communities, with greater species diversity, a lower percentage of pollution tolerant species, and a higher percentage of pollution intolerant species than other locations.

San José Lagoon and the various Channel locations (including the Martín Peña Canal) had median Benthic Index scores of 1.69 and 1.35, respectively. These data show that overall species diversity and the percentages of pollution intolerant organisms are lower in San José Lagoon and the various Channel locations than in San Juan Bay, and much lower than Condado Lagoon and Torrecilla Lagoon.

Based on median values, the lowest Benthic Index score of any waterbody was found in Piñones Lagoon (1.00). However, when comparing mean values, the Channel locations had slightly worse Benthic Index scores than Piñones Lagoon (1.18 and 1.21, respectively). The difference in order found when using mean vs. median values suggests that an appropriate classification scheme might be constructed as follows:

- Healthiest benthic communities: Torrecilla Lagoon and Condado Lagoon
- Healthy benthic communities: San Juan Bay
- Moderately healthy to stressed benthic communities: San José Lagoon
- Stressed benthic communities: Canal locations and Piñones Lagoon

The low scores in Piñones Lagoon should be interpreted considering the possibility that such a condition might be somewhat or entirely appropriate for that particular location. While Benthic Index scores were much higher in Condado Lagoon than in Piñones Lagoon, population density within the watershed of Condado Lagoon is much higher than in the region surrounding Piñones Lagoon (SJBEP 2000).

When comparing these Benthic Index scores to a previously constructed Water Quality Index (as summarized in the "Tarjeta de Calificaciónes" produced by the SJBEP) both similarities and differences in the "health" of various components of the San Juan Bay Estuary were found. The Water Quality Index was based on the parameters of dissolved oxygen, turbidity, fecal coliform bacteria, and pH, and was developed in consideration of the number of contaminants that exceeded appropriate water quality standards, the frequency at which contaminants exceeded those standards, and the amount by which exceedances were above relevant standards. The index was developed using data from fourteen water quality stations in total. In San Juan Bay proper, there were three open water stations. San José Lagoon had two stations, Torrecilla Lagoon had two stations, Piñones Lagoon had one station, and no stations were located within Condado Lagoon. In comparison, there is a larger number and wider geographical spread of sampling locations for the Benthic Index scores.

The Water Quality Index ranked San Juan Bay and Piñones Lagoon as having a score of "B", with San José Lagoon and Torrecilla Lagoon with ranks of "C". The Suárez Canal was given a grade of "D" and the Martin Peña Canal was ranked as an "F". To allow a comparison of findings between these two indices, median Benthic Index scores between 3.76 and 5 were given a rank of "A", values between 2.51 and 3.75 were given a rank of "B", 1.26 to 2.50 was given a "C", and scores below 1.26 were given a score of "D/F". Table 4 compares the relative scores for each main waterbody using the Water Quality Index and the Benthic Index.

Table 4
Comparison of Scores Produced using Water Quality Index and Benthic Index Techniques

Waterbody	Water Quality Index Classification	Benthic Index Classification
San Juan Bay	B	B
Condado Lagoon	N/A	B
San José Lagoon	C	C
Torrecilla Lagoon	C	B
Piñones Lagoon	B	D/F
Suárez Canal	D	D/F
Martín Peña Canal	F	D/F

Both the Water Quality Index and the Benthic Index characterized San Juan Bay as a "B". While individual sample locations had higher or lower scores, typical conditions indicate this waterbody has better than average water quality and benthic health, compared to the San Juan Bay Estuary system as a whole. While Condado Lagoon was not graded by the Water Quality Index, its Benthic Index score of a "B" was the same as in San Juan Bay. San José Lagoon was ranked as a "C" for both indices, indicating concurrence on this system's reduced ecological health. For Torrecilla Lagoon, the Benthic Index score of "B" was higher than its Water Quality Index score of "C".

The Suárez Canal was graded as a "D" for water quality, which matches its grade of "D/F" on the Benthic Index score. And the Martín Peña Canal's Water Quality Index score of "F" was matched with a Benthic Index score of "D/F".

The greatest discrepancy between Water Quality Index scores and Benthic Index scores was found in Piñones Lagoon; the Water Quality Index score of "B" is matched with a Benthic Index score of "D/F".

The Water Quality and Benthic Index scores both indicate that the least healthy waterbodies in the San Juan Bay Estuary are the Martín Peña and Suárez Canals. Both systems had the lowest possible scores for both indicators of ecosystem health.

In contrast, Piñones Lagoon had a relatively good Water Quality Index score, but a much lower Benthic Index score. Rather than suggesting Piñones Lagoon is "polluted", the benthic community in this system might be that of a natural condition that makes it inappropriate to compare it to other portions of the San Juan Bay Estuary. If water quality in Piñones Lagoon does in fact represent a healthy ecosystem (as would be expected based on its low population density) then a depauperate benthic community might be representative of a natural condition. Conversely, it could be that factors other than population density alone could be stressing the benthic communities in Piñones Lagoon without being manifested in those parameters used to construct the Water Quality Index.

5.0 Value and Use of the Benthic Index and Other Findings

The Benthic Index developed here is a tool that can be used to report on the status and trends (if any) of the health of the San Juan Bay Estuary and its individual component waterbodies. The technique is consistent with the wider body of literature on how such indices should be constructed, and it is consistent with guidance provided by EPA (2008) on the requirements of a benthic index.

This index can be used to grade portions of the San Juan Bay Estuary in a way that is technically sound, yet also able to be interpreted by non-technical stakeholders and the public and policy makers as well.

While researching topics related to water and sediment quality in San Juan Bay, we discovered a discrepancy in seagrass acreage estimates that may be of interest to the San Juan Bay Estuary Program. If the San Juan Bay Estuary system is improving over the past few years, as is indicated by results from Webb and Gomez-Gomez (1998) and Webb et al. (1998), then one of the bio-indicators that might be useful to track is the acreage of seagrass meadows throughout the system. Seagrass coverage has been previously found to correlate with spatial and temporal trends in water quality in Sarasota Bay, Florida (Tomasko et al. 1996), Lemon Bay, Florida (Tomasko et al. 2001), and Tampa Bay, Florida (Johansson 1995). Due to their proven relationships with water quality, seagrass coverage has been monitored as an indicator of ecosystem health in various locations in Southwest Florida for many years (Tomasko et al. 2005).

In the San Juan Bay Estuary, there does not appear to be a consistent approach to seagrass mapping and/or monitoring, even though one of the earliest papers relating seagrass distribution to water quality was conducted in Puerto Rico (Vicente and Riviera 1982). Also, some of the highest Benthic Index scores found in the San Juan Bay Estuary system were found in areas that appear to be associated with seagrass meadows.

Perhaps due to the differing techniques used, seagrass acreage estimates for the entirety of the San Juan Bay estuary range from 65 acres (listed as 26.5 hectares in SJBEP 2000) to 92 acres (derived from GIS data created by NOAA's Biogeography Program) to 375 acres (Rivera 2005). As seagrass coverage was previously shown to be sensitive to water quality in Puerto Rico (Vicente and Rivera 1982), and as seagrass coverage has been used a bio-indicator of system health in many locations, the finding that the San Juan Bay Estuary system may be recovering due to actions taken to reduce past pollutant impacts (Webb and Gomez-Gomez 1998, and Webb et al. 1998) highlights the need to have a consistent and repeatable program in place to track seagrass acreage over time. These results, in combination with the Water Quality Index and this Benthic Index, could be useful tools for determining the status and trends of overall ecological health throughout the San Juan Bay Estuary.

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