Tampa Bay Benthic Monitoring Program

Interpretive Report: 1993-2004

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Executive Summary

The Tampa Bay Benthic Monitoring Program was initiated in 1993 by the Tampa Bay National Estuary Program as part of a basin-wide monitoring effort to provide data to area managers and to track long term trends in the Tampa Bay ecosystem. The monitoring program is a cooperative effort between Hillsborough, Manatee and Pinellas Counties, with the Environmental Protection Commission of Hillsborough County handling the biological and sediment contaminant sample processing and data analysis. This report covers the first twelve years of monitoring data (1993-2004). A total of 1,217 sites were sampled and analyzed for environmental characteristics, sediment chemistry, and benthic community composition.

The median sample depth bay-wide was 2.8 meters (range 0 – 13.2 meters) with bottom salinities ranging from 0 to 35.9 psu. The bay-wide median salinity was 26 psu and nearly 80% of the sampling sites were within the polyhaline salinity range (18-30 psu). Salinities were variable between years with the lowest salinities occurring in 1995 and 2003 and highest in 2000. Salinities were significantly different between bay segments with the highest salinities being recorded in Boca Ciega Bay and Lower Tampa Bay and lowest salinities in the Manatee River. Bottom dissolved oxygen was relatively high bay-wide with a median value of 5.36 mg/L and 80% of the sampled locations had values ≥ 4.0 mg/L. Several areas of hypoxia were found, typically in Hillsborough Bay and portions of Old Tampa Bay. There was also an observed trend of increasing area of hypoxia in Hillsborough Bay over time. Medium grained sandy sediments predominated in all bay segments, but Hillsborough Bay had the highest percentage of muddy and very fine grain sediments with high percent silt+clay measurements also occurring in Boca Ciega Bay and the Manatee River. There was an observed trend of increasing fine grained sediments in the western and northern portions of Old Tampa Bay over time.

Results from the sediment contaminant analysis found that cadmium (Cd) levels tended to be high throughout Tampa Bay, with 36% of the samples exceeding the Threshold Effects Level (TEL) and 2.5% of the samples were above the Potential Effects Level (PEL) for toxicity. The cadmium:aluminum ratio however indicated that the observed Cd concentrations were not elevated above background levels. Chromium, copper, nickel, lead and zinc also were high at a small percentage of sites with elevated levels primarily found in Hillsborough Bay and the Manatee River.

Polycyclic Aromatic Hydrocarbons (PAHs) levels were generally low with no observed PEL exceedences and only 1.71% or the samples exceeding the TEL for total PAHs. Individual PAH compounds however did show some higher readings with the Low Molecular Weight PAHs Acenaphthene and Acenaphthylene exceeding their TELs at 15% and 14% of the samples respectively. Total High Molecular Weight PAHs were above the TEL at 3% of the sites and elevated levels of Dibenzo (a,h) anthracene were found at over 15% of the sites. Overall, the highest levels of PAHs were observed in Hillsborough Bay followed by the Manatee River and Boca Ciega Bay.

Total Polychlorinated Biphenyls (PCBs) exceeded TELs in 2.28% of the samples with highest values in Hillsborough Bay. Most of the measured pesticides were low with the exception of

Total DDT and the DDT derivative DDE, both of which exceeded their respective TELs in around 2% of the samples and were highest in Hillsborough Bay and the Manatee River.

Analysis of the benthic community identified around 1,500 taxa during the first twelve years of monitoring. The overall median number of taxa per sample was 35 and ranged from 0 to 125 taxa per sample. There was a general trend of increasing species richness towards the mouth of the bay, with the highest number of taxa being recorded in Lower Tampa Bay and Boca Ciega Bay. The abundance of benthic organisms ranged from 0 to 183,400 organisms/m^2 with a median of 5,150 organisms/m^2. Middle Tampa Bay and Old Tampa Bay had the highest median abundances while the lowest median abundance was in Terra Ceia Bay. Seven of the approximately 1,500 taxa identified accounted for 25% or the overall benthic abundance. The cephalochordate *Branchiostoma floridae* was the most abundant species and accounted for 5% of the total benthic abundance. The other top seven taxa included the polychaete *Monticellina cf. dorsobranchialis* (4.48%), the brachiopod *Glottidia pyramidata* (4.18%), unidentified tubificid oligochaetes (3.30%), the gastropod *Caecum strigosum* (2.99%), the amphipod *Ampelisca holmesi* (2.95%) and the bivalve *Mysella planulata* (2.81%). The Shannon Diversity Index increased towards the lower bay and was highest in Boca Ciega Bay, Terra Ceia Bay and Lower Tampa Bay, with no statistical differences between these segments. The lowest median diversity values were in Hillsborough Bay and the Manatee River.

Analysis of benthic community similarity between sampling years indicated that the Tampa Bay benthic community fell into two main temporal groupings, 1993 - 1997 and 1998 - 2004, due in part to higher abundances of *Glottidia pyramidata* during the latter period. Analysis done on the species similarity averaged by bay segment indicated that the Tampa Bay benthic community fell into two main spatial assemblages, with the lower segments of the bay (Middle and Lower Tampa Bay and Boca Ciega Bay) forming one group and Hillsborough Bay, Old Tampa Bay, Terra Ceia Bay, and the Manatee River forming the second group. The lower bay segments were characterized by higher abundances of *Branchiostoma floridae*, unidentified tubificid oligochaetes, the spirorbid polychaete *Janua (Dexiospira) steueri* and the maldanid polychaete ("bamboo worm") *Axiothella mucosa*. The other bay segments were characterized by higher abundances of *Ampelisca holmesi, Monticellina cf. dorsobranchialis*, the bivalve *Mulinia lateralis*, *Mysella planulata* and the spionid polychaete *Paraprionospio pinnata.*

The BIO-ENV analysis between the environmental factors and the benthic species composition indicated that the sediment composition was the strongest factor structuring the benthic community, followed by dissolved oxygen. Chromium and copper had the strongest correlation with the benthic assemblage of the metal sediment contaminants measured, while total DDT had the highest correlation among the measured pesticides. Analysis on the PAHs found the hydrocarbon pyrene had the strongest correlation with the benthic community structure.

The Tampa Bay Benthic Index (TBBI) was developed using the monitoring data from this program as a measure of the health of benthic habitats in Tampa Bay. The TBBI is scaled from 0-100 with values < 73 classified as "Degraded", from 73-87 as "Intermediate" and >87 as "Healthy". Depauperate samples were assigned a TBBI score of 0 and classified as "Empty". The overall TBBI for the 1993-2004 sampling period had a median value of 81.41 which falls within the "Intermediate" category for benthic habitat health. The highest TBBI values were in the main portion of Tampa Bay (Old Tampa Bay, Middle Tampa Bay, and Lower Tampa Bay) and lower values were found in Hillsborough Bay, the Manatee River, Terra Ceia Bay and Boca Ciega Bay. Hillsborough Bay had the highest number of empty samples (4.83%) and one-third of the sites were classified as "Degraded". The Manatee River, Terra Ceia Bay and Boca Ciega Bay also had a large percentage of "Degraded" sites (38-40%). Old Tampa Bay, Middle Tampa Bay and Lower Tampa Bay had few empty sites (0-0.6%) and <20% of the sites in each segment was classified as "Degraded" while approximately 35% of the sites in each of these segments were classified as "Healthy". Bay-wide 1.48% of the samples were empty, 26.8% were classified as "Degraded," 45.6% as "Intermediate," and 26% as "Healthy". There was a notable increase in the spatial extent of "Degraded" benthic habitat in western Old Tampa Bay.

The National Estuary Program Coastal Condition Report published in 2007 included an evaluation of the estuarine condition in Tampa Bay based on samples collected by the National Coastal Assessment (NCA) monitoring program (USEPA 2007). The NCA collected sediment samples from 25 sites throughout Tampa Bay in July 2000. These samples were analyzed for benthic invertebrate community structure and the condition of the benthic community was evaluated at each site using the Gulf Coast Benthic Index (GCBI) developed for the Louisianan Provence EMAP program (Engle et al., 1994; Engle and Summers 1999). The condition of the benthic community at each station was rated as "Good" if the GCBI score was ≥ 5.0, "Fair" if the GCBI score was between 3.0 and 5.0, and "Poor" if the GCBI score was < 3.0 (USEPA 2007). The overall benthic community condition for the estuary was rated based on the following criteria: "Good" if < 10% of the sites had a poor benthic index score and >50% had a good benthic index score; "Fair" if 10% to 20% of the sites had a poor benthic index score or >50% of the sites had a combined poor and fair benthic index score; and "Poor" if >20% of the sites had a poor benthic index score. The overall benthic community condition for Tampa Bay based on these criteria was rated as "Poor" with 36% of the NCA sites having poor benthic index scores, 20% rated as "Fair", and 44% as "Good" (USEPA 2007).

The benthic community condition of the bay-wide monitoring samples was evaluated applying the same criteria for "Good", "Fair", and "Poor" as outlined in the Coastal Condition Report (USEPA 2007) but we utilized the Tampa Bay Benthic Index and its scoring criteria for the individual samples rather than the GCBI used by the EPA. Results from this analysis are presented in the table below by year and bay segment, as well as the overall bay-wide condition. The bay-wide benthic condition was calculated two ways: 1) by simply evaluating all of the samples equally and 2) by proportionally weighing the samples based on their bay segment area in order to compensate for differing sampling densities in the different bay segments. Overall bay-wide results were consistent with the NCA rating of "Poor" for all years with only one individual year (1999) having a rating of "Fair". For all years 28.3% of the samples rated as "Poor", 45.6% as "Fair" and 26.1% as "Good". Weighing the samples proportionally by their segment area did increase the bay-wide rating from "Poor" to "Fair" in just over half of the individual years (7 of 12). Using the weighted method the overall bay-wide results had 22.3% of the sites rated as "Poor", 46.8% rated as "Fair", and 30.9% rated as "Good". Hillsborough Bay, Terra Ceia Bay, the Manatee River, and Boca Ciega Bay all had "Poor" benthic community conditions overall. Terra Ceia Bay rated as "Good" in 2004; however this was based on a single sample that was collected that year. Old Tampa Bay, Middle Tampa Bay, and Lower Tampa Bay had overall "Fair" benthic community conditions. Both Middle and Lower Tampa Bay rated as

"Good" in 2004, while Old Tampa Bay had "Poor" benthic community conditions from 2001 – 2004. These trends, however, correlate with a decrease in sampling effort and may be influenced by the smaller sample size per year.

Condition of Tampa Bay benthic communities based on the TBBI using the EPA's National Coastal Assessment program criteria.

Year	Status								
	HB (n)	OTB (n)	MTB (n)	LTB (n)	MR (n)	TCB (n)	BCB (n)	Bay-wide (n)	Weighted Bay-wide*
1993	Poor (19)	Fair (16)	Fair (20)	Poor (17)	Fair (11)	Poor (7)	N/A	Poor (90)	Poor (90)
1994	Poor (19)	Poor (17)	Poor (20)	Poor (16)	Poor (10)	Poor (7)	N/A	Poor (89)	Poor (89)
1995	Poor (29)	Fair (23)	Fair (21)	Fair (22)	Poor (11)	Poor (7)	Fair (21)	Poor (134)	Fair (134)
1996	Poor (27)	Fair (15)	Poor (24)	Poor (24)	Fair (13)	Fair (8)	Poor (21)	Poor (132)	Poor (132)
1997	Poor (22)	Fair (16)	Fair (22)	Fair (21)	Poor (13)	Fair (8)	Poor (21)	Poor (123)	Fair (123)
1998	Poor (26)	Fair (16)	Fair (20)	Fair (17)	Poor (13)	Fair (7)	Poor (21)	Poor (120)	Fair (120)
1999	Fair (23)	Fair (19)	Fair (21)	Good (18)	Fair (13)	Poor (8)	Poor (21)	Fair (123)	Fair (123)
2000	Poor (22)	Fair (11)	Fair (23)	Fair (8)	Poor (9)	Poor (7)	Poor (6)	Poor (86)	Fair (86)
2001	Poor (25)	Poor (7)	Fair (26)	Fair (5)	Fair (2)	Poor (1)	Poor (14)	Poor (80)	Poor (80)
2002	Poor (25)	Poor (8)	Good (21)	Fair (9)	Poor (7)	Poor (4)	Poor (9)	Poor (83)	Fair (83)
2003	Poor (28)	Poor (9)	Fair (9)	Fair (12)	Poor (7)	Poor (3)	Poor (10)	Poor (78)	Poor (78)
2004	Fair (25)	Poor (9)	Good (11)	Good (11)	Poor (10)	Good (1)	Poor (10)	Poor (77)	Fair (77)

*Weighted by Bay Segment Area

The overall "Poor" rating of benthic condition in Tampa Bay, the observed trends towards increased areas of hypoxia in Hillsborough Bay, the increased area of finer grained sediments, and corresponding degraded benthic habitat in parts of Old Tampa Bay emphasize the continued need for benthic monitoring in Tampa Bay. In order to maintain sufficient monitoring efforts to detect changes in the benthic conditions over time while meeting current budgetary constraints the following recommendations were implemented retroactive to the 2005 sampling year:

- Reduce sampling effort to control increasing monitoring costs.
  - Increase reporting period to five years from current four year reporting period reducing the number of samples collected per year but maintaining long term statistical power.
  - Combine MTB and LTB into a single reporting unit since these two bay segments are the least impacted by sediment contaminants and low dissolved oxygen, have similar benthic species assemblages and are also the most costly samples to process due to the high species diversity in these two segments.

These additional recommendations are proposed for future monitoring of sediments and benthic communities in Tampa Bay:

- Redirect sampling effort to address gaps in the current data and focus on areas of special interest.
  - Continue focus on special study sites – areas of known or suspected environmental degradation or sites with known upcoming impacts such as dredging or proposed mitigation sites.
  - Revisit past special study sites.
  - Increase monitoring efforts in the major river systems (Hillsborough, Palm, Alafia and Little Manatee) and tidal stream areas since few low salinity areas are included in the current data base and these systems serve as nursery areas for commercial and recreationally important species. There are also known problems with high sediment contaminants in several rivers, potential impacts due to continued development, and surface water withdrawals for drinking water.

The implementation of these recommendations will allow for the continued monitoring of Tampa Bay's sediment quality and benthic habitats while focusing the sampling effort on areas of special concern and maintaining the cost effectiveness of the program.

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Introduction

Tampa Bay is the largest open water estuarine system in the state of Florida covering a surface area of over 1,030 km^2 with a surrounding watershed of 5,700 km^2 (Lewis and Estevez 1988). The bay is surrounded by three counties (Hillsborough, Pinellas, and Manatee) which have a combined population of 2,395,449 people (U.S. Census Bureau 2007; estimated population for 2006) and include the cities of Tampa, St. Petersburg, Clearwater, and Bradenton.

Program Background

The Tampa Bay National Estuary Program (TBNEP) [now known as the Tampa Bay Estuary Program (TBEP)] was started in 1991 with the objective of developing a Comprehensive Conservation and Management Plan (CCMP) for Tampa Bay (TBNEP, 1996). As part of the CCMP, the TBNEP developed a basin wide monitoring program in order to measure the effectiveness of management decisions implemented under the CCMP and to gather further information to reevaluate and revise the CCMP in the future (Hochberg et al. 1992). During the design phase of the monitoring program it was recommended that the benthic community should be included in the monitoring effort and that the EPA’s Environmental Monitoring and Assessment Program (EMAP) sampling design be adopted (Hochberg et al. 1992).

The bay-wide Tampa Bay Benthic Monitoring Program was initiated in 1993. During the first two years of the program field sampling was conducted by the Environmental Protection Commission of Hillsborough County (EPCHC) and the Manatee County Department of Environmental Management (MCDEM) and included the following bay segments: Hillsborough Bay, Old Tampa Bay, Middle Tampa Bay, Lower Tampa Bay, Manatee River, and Terra Ceia Bay. Starting in 1995, Pinellas County Environmental Management joined the monitoring efforts, initiating annual sampling in Boca Ciega Bay.

The TBNEP finalized the Comprehensive Conservation and Management Plan “Charting the Course” for Tampa Bay in December 1996 (TBNEP, 1996). The CCMP outlined the goals for restoring and protecting Tampa Bay, set restoration targets, and put forth a list of specific action plans for achieving these goals. The benthic monitoring program plays an important role in tracking the progress of these actions and providing important data for management decisions.

The benthic monitoring program’s objectives and sampling design were reevaluated in 2003 (Janicki Environmental, 2003). As a result of this assessment, the reporting period was increased from one year to four years and the number of samples collected annually was cut in half (from 124 to 64 samples per year). These changes were made retroactive to the year 2000 in order to alleviate a backlog in sample processing at that time (Janicki Environmental, 2003). The resulting savings in sampling effort were further redirected towards collecting samples from several areas of concern (“Special Studies”) during the 2002-2004 sampling seasons.

Methods

Sampling Design

The Tampa Bay Benthic Monitoring Program employs a stratified-random sampling strategy adopted from the EPA's Environmental Monitoring and Assessment Program – Estuaries (EMAP-E) design (Coastal Environmental, 1994). Tampa Bay is divided into seven segments (after Lewis and Whitman, 1985): Hillsborough Bay, Old Tampa Bay, Middle Tampa Bay, Lower Tampa Bay, Boca Ciega Bay, the Manatee River, and Terra Ceia Bay. Each designated segment is treated as a sampling stratum with the Manatee River and Terra Ceia Bay being combined into a single stratum (Coastal Environmental, 1994). Each stratum is overlaid by a hexagonal grid system and a random sampling point is generated within each grid cell. The size of the sampling grid used is variable. A grid size of 13 km^2 is used for Old Tampa Bay, Middle Tampa Bay, and Lower Tampa Bay (Grabe et al. 1996) or a "7x7" grid density meaning a grid density twice enhanced by a factor of 7 from the base EMAP hexagon (= 40 km^2) (Coastal Environmental, 1994; Grabe et al. 1996). A "7x7x3" grid (4.4 km^2) is used for Hillsborough Bay and Boca Ciega Bay and a "7x7x7" (1.9 km^2) is used for the Manatee River/Terra Ceia Bay stratum (Coastal Environmental, 1994; Grabe et al. 1996). Sampling points within each grid cell are re-randomized each year, with the exception of the first two years of the program. The sampling for the Manatee River/Terra Ceia Bay stratum used the initial random points generated in 1993 which were resampled in subsequent years until the program redesign in 2003. The Manatee River/Terra Ceia Bay sampling sites have been randomized annually after 2003.

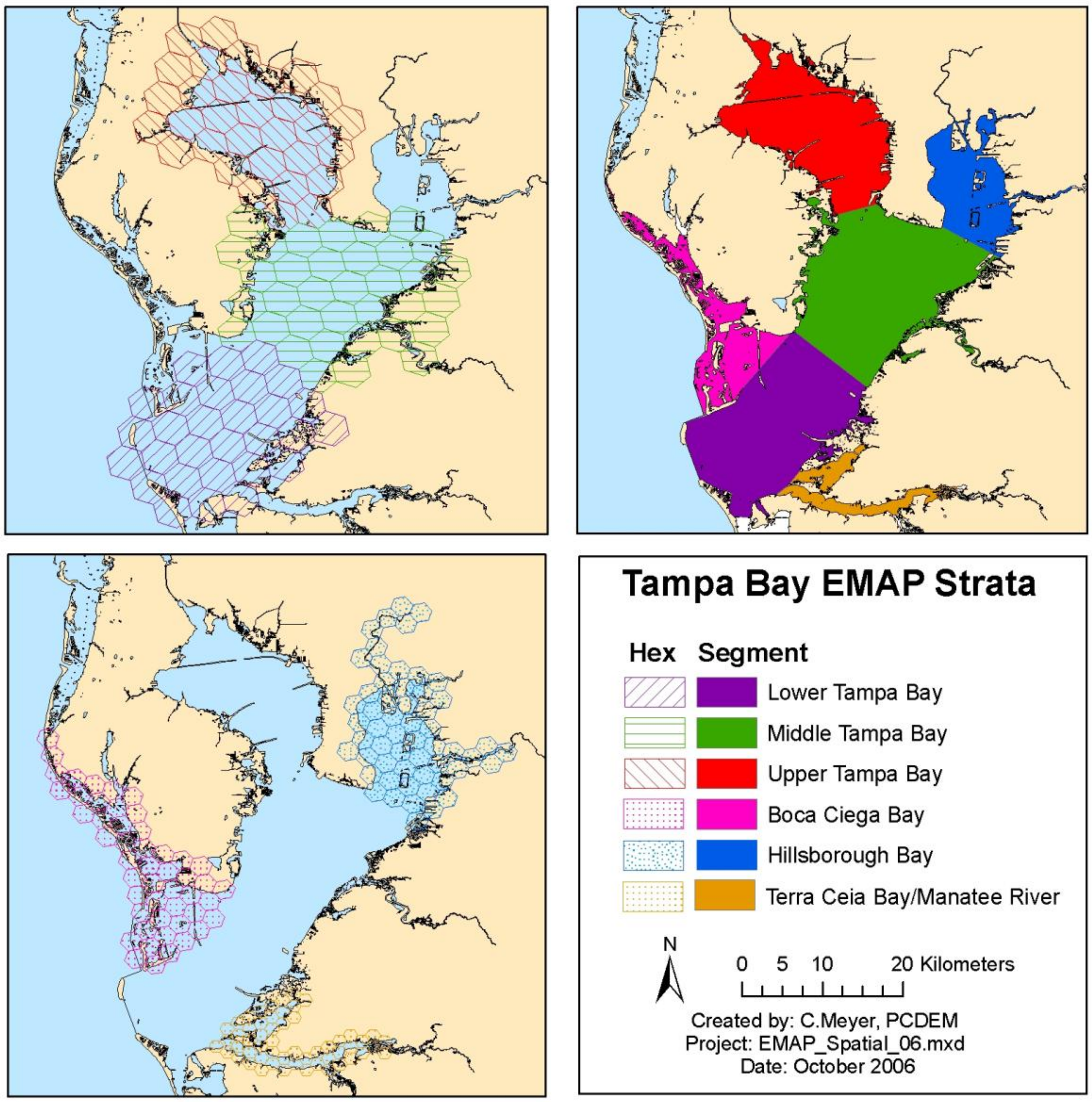

Figure 1. Tampa Bay segments and sampling grids.

Field Collection

Field and laboratory methods were adopted from the EMAP-E Louisianan Province operations manual (Macauley, 1993) and modified for the Tampa Bay monitoring program (Versar, 1993; Courtney et al. 1995). Several modifications to the field sampling routine have been incorporated over the years as equipment has improved in order to stream line the field sampling and increase efficiency. The following is a brief outline of current field procedures.

Hydrographic Measurements: A hydrographic profile was taken at each station using a Hydrolab® multi-probe sonde. Measurements were taken from the surface (0.1 meters) to the bottom at 1 meter intervals for temperature, salinity, pH, and dissolved oxygen.

Benthic Macrofauna: Sediment samples for benthic macrofaunal community analysis were taken at each site using a Young-Modified Van Veen grab sampler. The grab sample was taken to a sediment depth of 15 cm and covered an area of 0.04 m^2. A 60 cc corer was used to take a subsample for Silt+Clay analysis. The sample was emptied into a plastic bag and residual sediment was washed out of the sampler into the bag with squeeze bottles of ambient seawater. An Epsom salt/seawater solution was added to the sample (equivalent to approximately 1/3 of the sample volume) to relax the organisms. An internal station label was added to the sample; the bag was tied and stored on ice. Samples were sieved through a 0.5 mm mesh sieve and the remaining fraction was rinsed into plastic sample jars. Samples were fixed with 10% buffered formalin for a minimum of 72 hours and then transferred into 70% isopropyl alcohol for preservation and storage. Rose Bengal was added to the formalin and isopropyl alcohol solutions to stain the organisms.

Silt+Clay: A 60 cc subsample was removed from the benthic macrofauna sediment grab using a clear plastic syringe corer for Silt+Clay analysis. The apparent Redox Potential Discontinuity (RPD) layer was measured visually with a ruler while the sediment was in the corer. The subsample was then extruded into a HDPE sample jar and stored on ice. An additional sample was taken at 10% of the sites for QA/QC. Samples were stored at 4°C until processing.

Sediment Chemistry: One or more additional sediment grab samples were taken at each site for sediment contaminant analysis depending on the sediment type. The grab sampler and all sampling utensils were field cleaned with Liqui-Nox® detergent (Alconox, Inc. White Plains, NY), rinsed with ambient seawater and decontaminated with 99% pesticide grade isopropyl alcohol (2-Propanol, FisherChemicals, Fisher Scientific Fair Lawn, NJ) prior to sampling and all equipment and samples were handled wearing latex gloves. The top 2 cm layer of sediment was removed from each grab using a stainless steel or Teflon coated spoon and placed in a stainless steel beaker. If more than one grab was taken, the removed layers of sediment were composited in the stainless steel beaker and homogenized by stirring. The homogenized sample was then split, with one fraction being placed in a HDPE sample bottle for metals analysis and the second fraction being placed in a glass sample jar with a Teflon® lined lid for analysis of organic compounds (pesticides, PCBs, PAHs).

Laboratory Procedures

Field data

Hydrographic and other field data were entered into a Microsoft® Access database maintained by the Environmental Protection Commission of Hillsborough County.

Sediment Chemistry

All sediment chemistry samples were analyzed by the EPCHC, except for the initial year of the program (1993). Samples collected that year were analyzed by the Skidaway Institute of Oceanography, Savannah, Georgia. Organic samples were not processed for 1994 due to delays in equipment installation and exceedence of sample holding times.

The sediment metal samples were processed using a total digestion method with hydrofluoric acid using a CEM MARS Xpress microwave digester. Analysis was performed on a Perkin Elmer Optima 2000 Optical Emission Spectrometer according to EPA Method 200.7.

The organic samples were extracted using EPA Method 3545A (Accelerated Solvent Extraction), followed by the cleanup methods, EPA 3630C (Silica gel) and EPA 3660B (copper). Analysis was completed using EPA Method 8081 (organochlorine pesticides) and EPA Method 8082 (PCB congeners) on a gas chromatograph equipped with dual Electron Capture Detectors (ECDs). Polycyclic aromatic hydrocarbons (PAHs) were analyzed using EPA Method 8270c on a mass spectrometer.

Silt+Clay Analysis

The Silt+Clay analysis followed procedures outlined in Versar, 1993. This analysis was conducted by Manatee County Department of Environmental Management for all years except 1994 when it was done by EPCHC.

Benthic Community Analysis

Benthic sorting and identification work was conducted by EPCHC staff for all years with the exceptions of 1993 and 1997. In 1993, the identification work was contracted to Mote Marine Laboratory or subcontracted to the Gulf Coast Research Laboratory (crustaceans). Part of the 1997 sample processing was contracted out to Versar, Inc. Benthic sediment samples were rough sorted under a dissecting microscope into general taxonomic categories (Annelids, Molluscs, Crustaceans, and Miscellaneous Taxa). Resorting was done on 10% of the samples completed by each technician for QA/QC. The sorted animals were identified to the lowest practical taxonomic level (species level when possible) and counted. Taxonomic identifications were conducted using available identification keys and primary scientific literature. All identification and count data were recorded on laboratory bench sheets and entered into a Microsoft Access® database maintained by the EPCHC.

Data Analysis

Data Categorization

A Statistical Analysis Software (SAS) routine (SAS Institute 2003) was used to assign samples to descriptive categories for depth, salinity, dissolved oxygen, sediment type, and Tampa Bay Benthic Index (TBBI) score (Table 1). Cutoff points for depth were based largely on the median and 1st and 3rd quartile values for all sampling sites collected for the bay-wide benthic monitoring program from 1993-2004. The dissolved oxygen cutoffs were based on the state water quality standards and salinity cutoffs were based on the Venice System (Venice Symposium, 1959). Sediment categories were estimated from percent silt+clay measurements and based on the Wentworth size class system (cf. Percival and Lindsay 1997). Sediment grain size (Φ) was determined by regressing percent silt+clay (% SC) vs. mean grain Φ size for Tampa Bay data collected by Long *et al.* (1994) using TableCurve 2D ver. 5.0 software (AISN, 2000). These data were used to develop the following relationship between % SC and mean grain size: % SC= 1/ $(0.0097+1.575*e^{\Phi})$ (Adjusted r^2=0.947). Cutoffs for the Tampa Bay Benthic Index were derived by Janicki Environmental (2005) and Malloy et al. (2007) with the following modifications: Negative TBBI scores were labeled as "Undefined"; depauperate samples were assigned a TBBI score of 0 and labeled as "Empty".

Potential toxicity levels for sediment contaminants followed the sediment quality guidelines established for Florida coastal waters and utilized the Threshold Effects Levels (TELs) and Probable Effects Levels (PELs) established for individual contaminants (MacDonald 1994; MacDonald et al. 1996). The metal:aluminum ratio was used to determine if individual sediment metals were elevated relative to background levels (Schropp et al. 1990).

Univariate Statistical Analysis

Parametric and non-parametric statistical analysis was done initially using SYSTAT® 11 software (SYSTAT Software, Inc. 2004) on the hydrological, sediment chemistry, silt+clay and univariate biological metrics. Analysis was later recalculated using SigmaStat ® 3.5 (SYSTAT Software, Inc. 2006a). Data were log (n+1) or forth root transformed for normality where needed for the parametric tests. All percent silt+clay data were arcsine transformed. Analysis of Variance (ANOVA) with a Bonferroni adjusted pair-wise post hoc test was used to test for differences between years or between bay segments. Where the assumptions of the ANOVA could not be met by the data transformation, a non-parametric Kruskal-Wallis test was used along with a Dunn's Pairwise Multiple Comparison test. Multiple linear regression and Spearman Correlations were calculated to find associations between the biological metrics and physical parameters and sediment contaminants.

Multivariate Statistical Analysis

PRIMER v6 software (PRIMER-E, Ltd. 2006; Clarke and Gorley 2006) was used for all multivariate statistical analysis and for calculating univariate biological metrics (species richness, abundance, and the Shannon Diversity Index). Species richness (*S*) was defined as the total number of taxa, abundance (*N*) as number of individuals per m^2 (calculated as the raw count x 25) and the Shannon diversity index (*H'*) calculations employed the natural logarithm opposed to log base 2 (Clarke and Warwick 2001). Principle Components Analysis (PCA) was done on the hydrographic and silt+clay data to search for patterns in the environmental data (Clarke and Warwick 2001), the data was normalized and log transformed prior to analysis. The zero-adjusted Bray-Curtis similarity (Clarke et al. 2006) was calculated on forth root transformed abundance data and the resulting similarity matrix was used for running Cluster Analysis, Non-metric Multi-Dimensional Scaling (MDS), Similarity Percentage (SIMPER), and Analysis of Similarity (ANOSIM). The BIO-ENV procedure (Clarke and Ainsworth 1993) was used to find correlations between the environmental parameters and benthic community structure.

Spatial and Graphical Analysis

Graphs were generated using SigmaPlot® 10.0 software (Systat Software, Inc. 2006b). Sample location and distributional maps were generated by Pinellas County Department of Environmental Management. Species distributional maps were generated by the Environmental Protection Commission of Hillsborough County using ArcGIS 9.2 (ESRI 2006).

Table 1. Physical and TBBI descriptors and cutoffs.

Depth	
0-0.5 m	Intertidal
>0.5-1.0 m	Shallow subtidal
>1.0-2.0 m	Intermediate Subtidal
>2.0-4.0 m	Deep Subtidal
> 4 m	Deep
Dissolved Oxygen	
0-0.5 ppm	Anoxic
>0.5 – 2.0 ppm	Hypoxic
>2.0-4.0 ppm	Intermediate
> 4.0 ppm	Normoxic
Salinity	
0- 0.5 psu	Tidal Fresh Water
>0.5-5.0 psu	Oligohaline
>5.0-10.0 psu	Low Mesohaline
>10.0 -18.0 psu	High Mesohaline
>18.0-30.0 psu	Polyhaline
> 30.0 psu	Euhaline
Silt+Clay	
0 - 1.70%	Coarse
>1.70-4.51%	Medium
>4.51-11.35%	Fine
>11.35 – 25.95%	Very Fine
> 25.95%	Mud
Tampa Bay Benthic Index	
< 0	Undefined
0	Empty
>0 – 73	Degraded
>73 – 87	Intermediate
≥ 87	Healthy

Results and Discussion

Sampling Locations

A total of 1216 sites were sampled during the 1993-2004 monitoring period (Figure 2). The numbers of sites (n) are given for each sampling year and bay segment in Tables 2 and 3 respectively and illustrated in Figure 2. The number of samples collected per year and bay segment decreased after 2000 due to the program redesign although the original sampling effort was maintained in Hillsborough Bay.

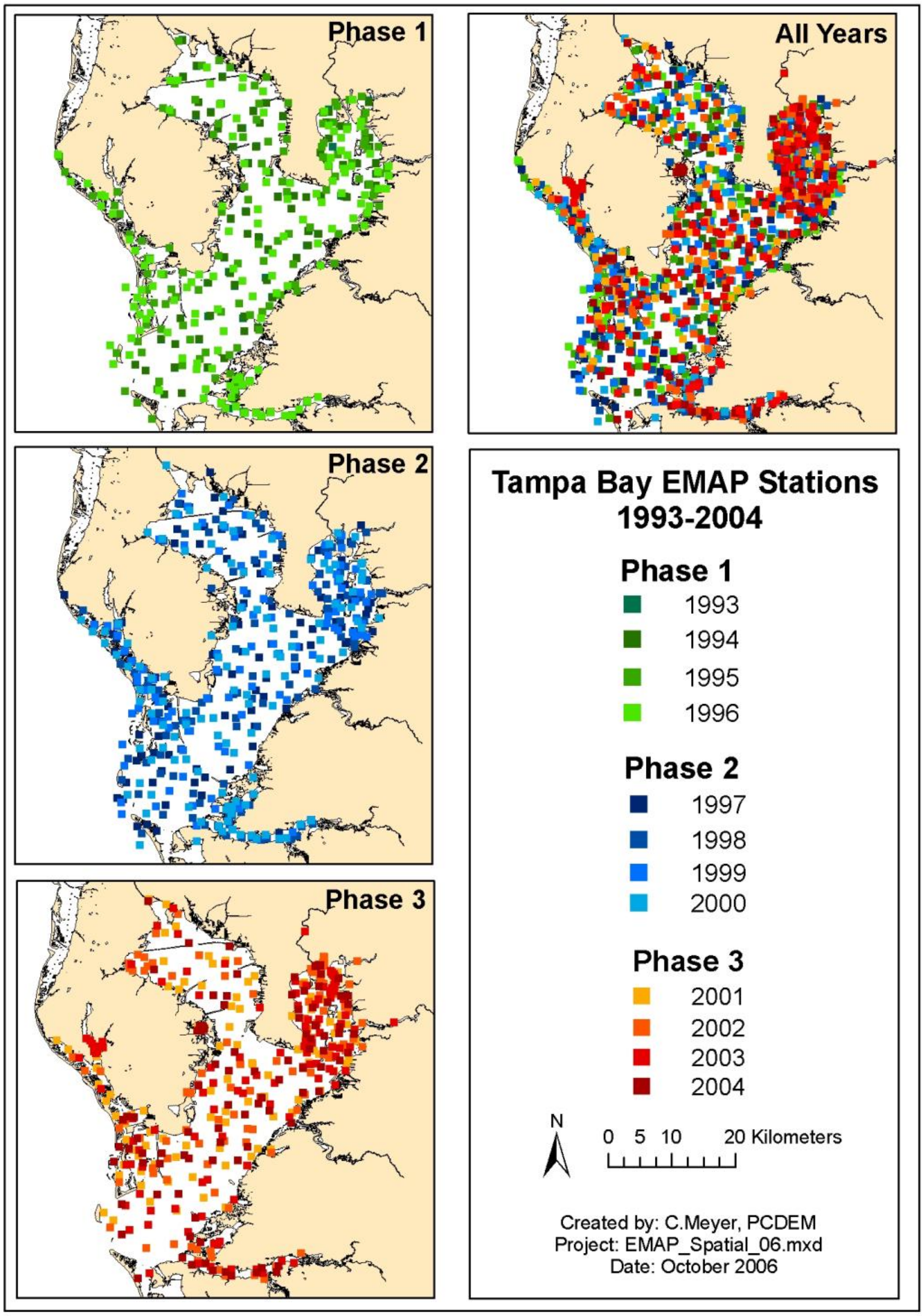

Figure 2. Tampa Bay benthic monitoring sampling sites 1993-2004 by year and four-year sampling phase.

Hydrographic and Sediment Characteristics

Table 2. Bay-wide bottom physical characteristics by year and sampling period.

Year	n	Depth (meters) Median		Temperature (°C) Median		pH Median		Salinity (psu) Median		D.O. (mg/L) Median		Silt+Clay (%) Median	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
1993	**90**	2.80		29.36		7.84		25.60		5.41		3.40	
		0.10	10.00	25.90	31.17	6.54	8.19	4.26	34.20	0.27	10.96	0.00	69.70
1994	**90**	3.00		28.00		7.90		22.80		5.00		2.85	
		1.00	8.00	24.90	30.70	7.10	8.33	7.19	34.80	0.20	10.20	0.00	86.80
1995	**134**	2.00		29.00		8.10		20.00		5.70		3.30	
		0.10	9.00	21.55	33.02	7.06	8.42	4.26	34.10	0.22	11.27	0.20	70.30
1996	**132**	2.85		29.35		7.96		26.05		5.01		4.40	
		0.10	13.20	22.85	39.20	6.90	8.31	7.92	34.50	0.30	9.30	0.80	75.40
Phase 1 1993-1996	**446**	**2.60**		**28.90**		**7.92**		**23.90**		**5.38**		**3.30**	
		0.10	**13.20**	**21.55**	**39.20**	**6.54**	**8.42**	**4.26**	**34.80**	**0.20**	**11.27**	**0.00**	**86.80**
1997	**123**	2.20		28.85		7.97		27.60		5.34		6.60	
		0.10	11.80	23.88	31.19	6.65	8.65	0.00	35.90	0.03	14.00	0.00	81.10
1998	**119**	2.50		28.19		7.96		24.10		5.60		3.75	
		0.10	12.50	25.08	33.40	6.82	8.44	1.80	33.00	0.40	9.49	0.00	39.40
1999	**124**	2.80		27.58		8.05		25.85		5.64		4.20	
		0.10	12.50	25.93	32.00	7.40	8.90	9.00	35.00	1.00	12.84	0.00	82.20
2000	**86**	3.00		28.73		8.00		28.65		5.66		3.60	
		0.50	8.50	26.05	30.90	7.30	8.39	5.30	32.90	0.22	9.07	0.10	91.80
Phase 2 1997-2000	**452**	**2.70**		**28.22**		**8.00**		**27.00**		**5.52**		**5.10**	
		0.10	**12.50**	**23.88**	**33.40**	**6.65**	**8.90**	**0.00**	**35.90**	**0.03**	**14.00**	**0.00**	**91.80**
2001	**80**	3.00		30.24		7.97		27.80		4.12		4.25	
		0.10	11.00	24.44	32.35	7.48	8.40	22.00	34.13	0.35	10.65	1.50	57.80
2002	**83**	3.08		29.52		7.97		27.88		5.10		4.60	
		0.50	11.30	27.93	31.29	6.96	8.90	9.20	34.52	0.26	8.80	0.00	84.94
2003	**78**	3.39		29.18		8.00		19.50		5.20		4.95	
		0.10	9.00	26.30	34.47	7.02	8.63	0.10	33.40	0.18	9.20	1.00	71.10
2004	**77**	3.00		29.65		8.12		22.70		4.99		3.20	
		0.55	11.00	24.00	31.42	7.36	8.62	13.93	33.98	0.11	10.96	0.70	65.70
Phase 3 2001-2004	**318**	**3.09**		**29.69**		**8.00**		**26.30**		**4.89**		**4.30**	
		0.10	**11.30**	**24.00**	**34.47**	**6.96**	**8.90**	**0.10**	**34.52**	**0.11**	**10.96**	**0.00**	**84.94**
Cumulative 1993-2004	**1216**	**2.80**		**28.90**		**7.99**		**26.00**		**5.36**		**4.30**	
		0.10	**13.20**	**21.55**	**39.20**	**6.54**	**8.90**	**0.00**	**35.90**	**0.03**	**14.00**	**0.00**	**91.80**

Table 3. Bottom physical parameters (1993-2004) by bay segment.

Segment	n	Depth (meters) Median		Temperature (°C) Median		pH Median		Salinity (psu) Median		D.O. (mg/L) Median		Silt+Clay (%) Median	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Hillsborough Bay	289	2.85		29.56		7.83		23.70		4.02		6.90	
		0.10	13.20	25.50	34.47	6.82	8.45	0.10	29.24	0.03	10.65	1.00	86.80
Old Tampa Bay	166	2.50		29.09		8.03		22.60		5.53		3.50	
		0.10	7.50	26.03	32.35	6.65	8.63	0.00	28.90	0.20	12.84	0.00	91.80
Middle Tampa Bay	238	4.00		28.80		7.95		26.90		5.34		2.96	
		0.10	11.10	26.00	39.20	7.25	8.62	8.10	32.00	0.28	10.96	0.00	63.00
Lower Tampa Bay	182	4.00		28.00		8.05		30.30		5.85		2.30	
		0.10	12.50	23.88	31.02	7.20	8.39	19.30	35.00	3.63	9.30	0.00	50.70
Manatee River	119	2.00		28.00		7.87		17.38		5.10		6.35	
		0.10	7.00	24.90	33.00	6.54	8.90	0.40	30.00	0.30	9.20	1.20	55.40
Terra Ceia Bay	68	2.00		28.00		8.10		24.00		5.95		4.60	
		0.10	5.00	25.10	32.00	7.54	8.60	10.12	33.00	3.00	8.90	0.00	15.60
Boca Ciega Bay	154	1.60		28.86		8.11		30.80		5.70		6.60	
		0.10	7.36	21.55	32.04	7.36	8.90	20.40	35.90	1.85	14.00	1.10	82.20
Tampa Bay	**1216**	**2.80**		**28.90**		**7.99**		**26.00**		**5.36**		**4.30**	
		0.10	**13.20**	**21.55**	**39.20**	**6.54**	**8.90**	**0.00**	**35.90**	**0.03**	**14.00**	**0.00**	**91.80**

Depth

The median sample depth bay-wide was 2.8 meters with a maximum depth of 13.2 meters near a shipping channel in Hillsborough Bay (Tables 2 and 3). Sample depths varied significantly between years (KW; $p = 0.005$) with median values ranging from 2 meters in 1995 to 3.39 meters in 2003 (Table 2; Figure 3). The lower values observed in 1995 may have been due in part to a sampling bias as there was an increased effort in the field that year to collect shallow sites. Depth between bay segments were also significantly different (KW; $p < 0.001$) with the shallowest median depth in Boca Ciega Bay and the deepest median depths in the Middle and Lower Tampa Bay segments (Table 3; Figure 4). Middle and Lower Tampa Bay were not significantly different from each other but were significantly deeper than the other bay segments. There was a general trend of increasing depth towards the mouth of the bay due to the natural depth contours of the bay as well as to the dredging of shipping channels. Boca Ciega Bay was shallower than all other segments with the exception of Terra Ceia Bay (Dunn's Pairwise Multiple Comparison Test). The majority of the sampling sites fell within the "Deep Subtidal" range (>2.0 – 4.0 meters) baywide and within most bay segments (Table 4). Over half of the sampling sites in the Middle and Lower Tampa Bay segments were categorized as "Deep" with depths exceeding 4 meters (Table 4).

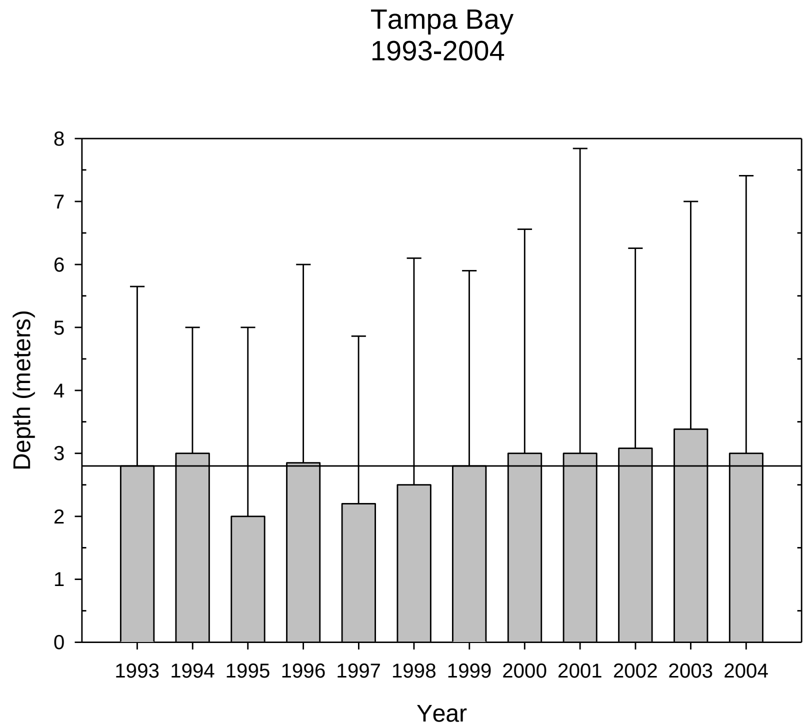

Figure 3. Median sample depth by year. Error bars = 90th percentile, solid line represents bay-wide median value.

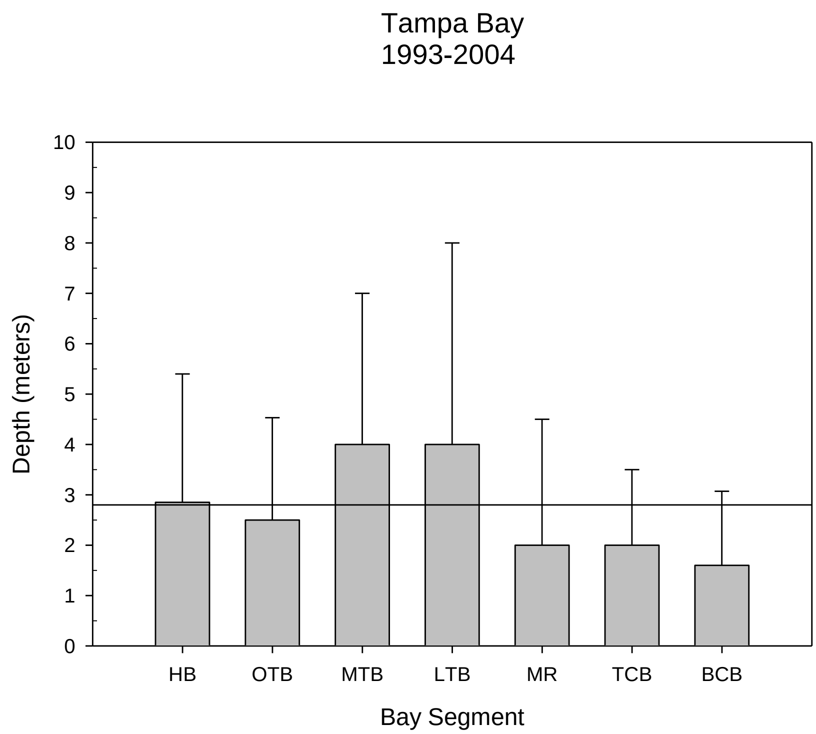

Figure 4. Median sample depth by bay segment. Error bars = 90th percentile, solid line represents bay-wide median value.

Table 4. Percentage of sites within depth categories.

	n	Intertidal	Shallow Subtidal	Intermediate Subtidal	Deep Subtidal	Deep
1993-1996	446	9.42%	4.04%	21.30%	37.00%	28.25%
1997-2000	452	7.30%	5.97%	20.13%	35.62%	30.97%
2001-2004	318	3.77%	10.38%	20.75%	28.30%	36.79%
Hillsborough Bay	289	6.92%	7.27%	21.11%	34.95%	29.76%
Old Tampa Bay	166	9.04%	8.43%	18.67%	42.17%	21.69%
Middle Tampa Bay	238	5.88%	5.04%	13.87%	23.11%	52.10%
Lower Tampa Bay	182	3.30%	2.75%	10.99%	29.67%	53.30%
Manatee River	119	6.72%	1.68%	29.41%	38.66%	23.53%
Terra Ceia Bay	68	4.41%	0.00%	35.29%	54.41%	5.88%
Boca Ciega Bay	154	13.64%	15.58%	31.17%	34.42%	5.19%
Tampa Bay (Total)	1216	7.15%	6.41%	20.72%	34.21%	31.50%

Bottom Temperature

Bottom temperatures ranged from 21.55 to 39.20° C with a median temperature of 28.90° C (Tables 2 and 3). Temperatures varied significantly between years (KW; $p < 0.001$) with the highest median temperature occurring in 2001 (Table 2; Figure 5). Bottom temperatures were also significantly different between bay segments (KW; $p < 0.001$). Hillsborough Bay had the highest median temperature and was significantly higher than the other six segments (Dunn's Pairwise Multiple Comparison test) while the highest recorded temperature was in Middle Tampa Bay in the vicinity of the Big Bend power plant (Table 3). The higher water temperature in Hillsborough Bay may be due to the extensive shallow area and restricted flow in this part of the bay.

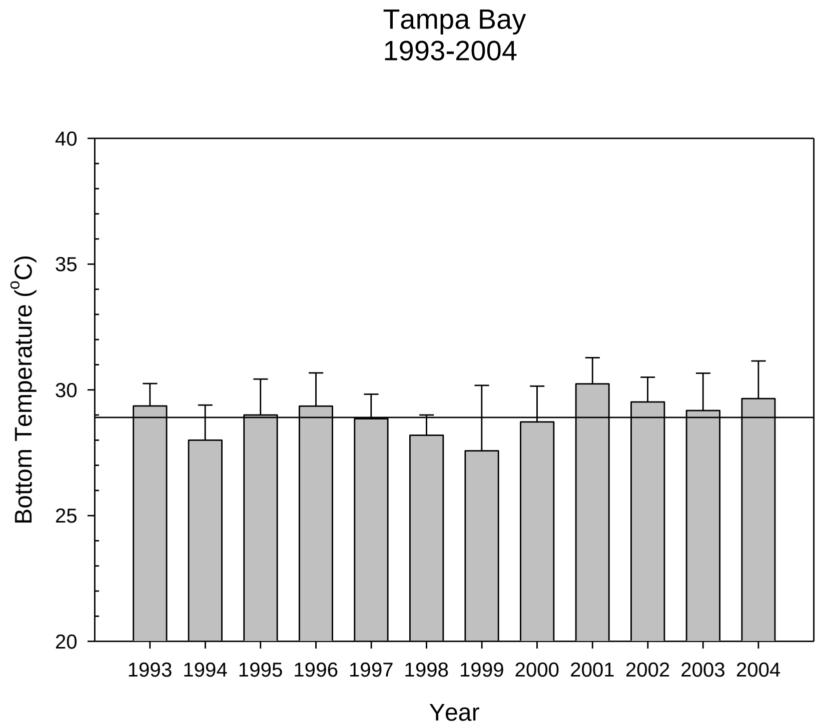

Figure 5. Median bottom temperature by year. Error bars = 90th percentile, solid line represents bay-wide median value.

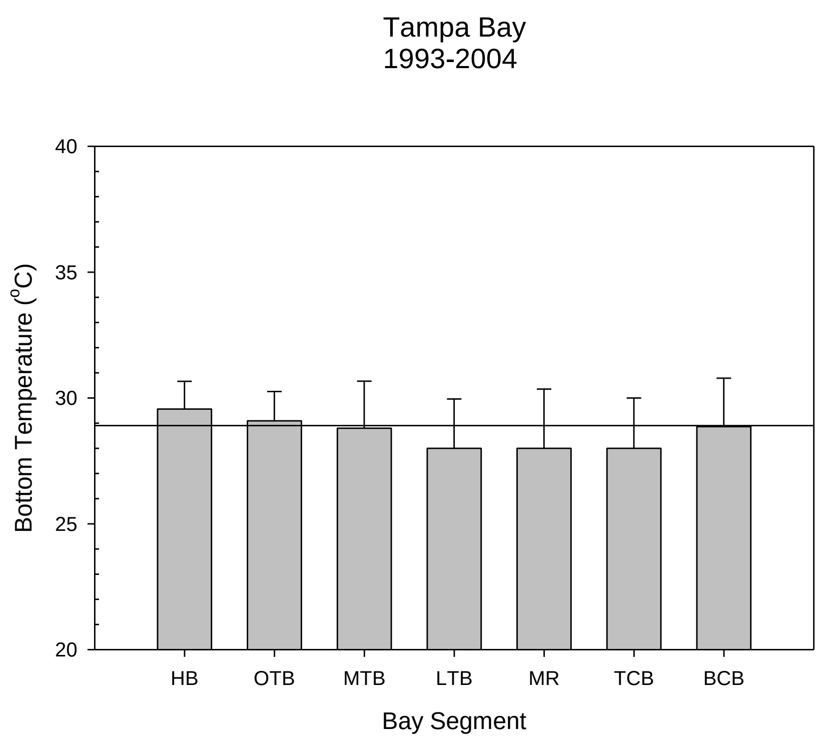

Figure 6. Median bottom temperature by bay segment. Error bars = 90th percentile, solid line represents bay-wide median value.

Bottom pH

The median bottom pH was 7.99 and ranged from 6.54 to 8.90. The lowest recorded value and widest range was in the Manatee River (Table 2 and 3). There were significant differences in pH between years (KW; $p < 0.001$, Figure 7) with 1993 recording the overall minimum and lowest median pH value while the highest median pH was observed in 2004 and the maximum values were recorded in 1999 and 2002 (Table 2). Although there is a positive correlation between pH and salinity, this did not appear to be a factor in the observed temporal trend in pH. The pH between bay segments also varied significantly and was lowest in the Manatee River and Hillsborough Bay (KW; $p < 0.001$, Figure 8). This was probably due to the greater input of freshwater in these systems. Generally lower pH values are associated with lower salinities due to the presence of acidic compounds in freshwater (tannins) and low concentrations of buffering ions.

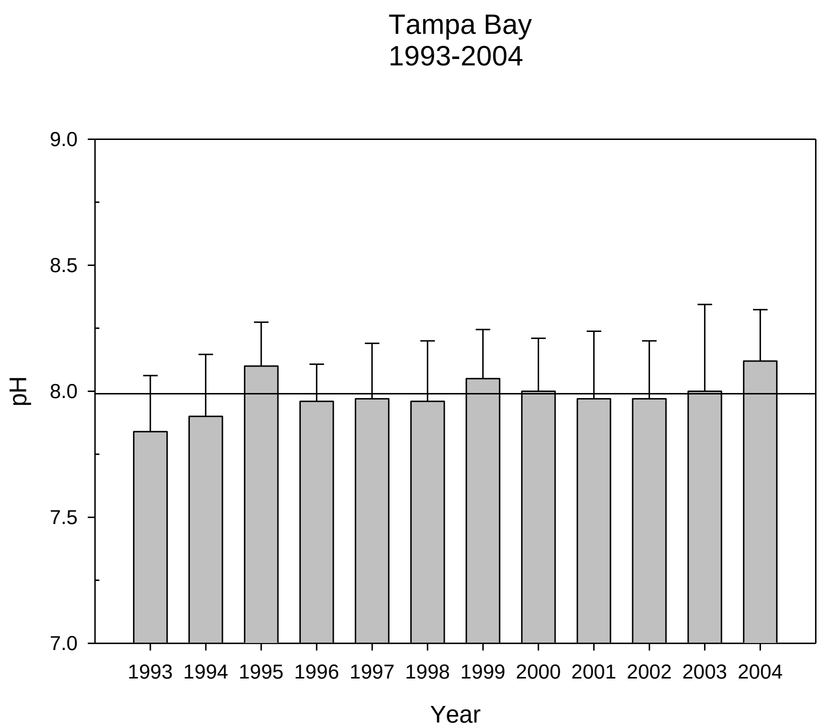

Figure 7. Median bottom pH by year. Error bars = 90th percentile, solid line represents bay-wide median value.

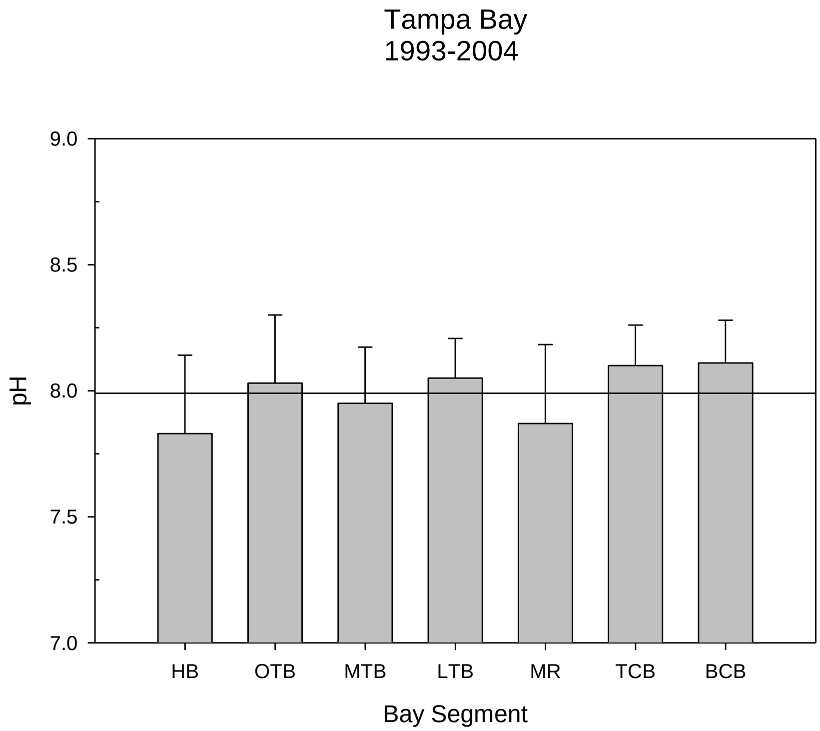

Figure 8. Median bottom pH by bay segment. Error bars = 90th percentile, solid line represents bay-wide median value.

Bottom Salinity

Bottom salinities ranged from 0 to 35.9 psu with a bay-wide median salinity of 26 psu (Tables 2 and 3). Salinities were significantly variable from year to year (KW; $p < 0.001$). The lowest median salinities occurred in 1995 and 2003 and highest in 2000 (Table 2; Figure 9) and temporal trends were associated with rainfall patterns. Salinities were significantly different between bay segments (KW; $p < 0.001$), with the highest salinities being recorded in Boca Ciega Bay and Lower Tampa Bay and the lowest median salinity in the Manatee River (Table 3; Figure 10). Most pairwise comparisons (Dunn's method) between bay segments were significant ($p < 0.05$) however, no differences in bottom salinity were found between Boca Ciega Bay and Lower Tampa Bay or between Hillsborough Bay, Terra Ceia Bay, and Old Tampa Bay (Figure 10). The Manatee River had significantly lower salinities than all of the other bay segments except for Old Tampa Bay. This result may have been due to the high variability in salinity values in those two segments.

Most of the sampling sites fell within the polyhaline salinity range, while only a small percentage of sites were freshwater or oligohaline (Table 5). The Manatee River had the highest percentage of low salinity sites, while the majority of sites within Boca Ciega Bay and Lower Tampa Bay were euhaline (Table 5). The spatial extent of different salinity regimes was variable over time with a slight increase in tidal fresh water sites during the third sampling phase (Table 5; Figure 11).

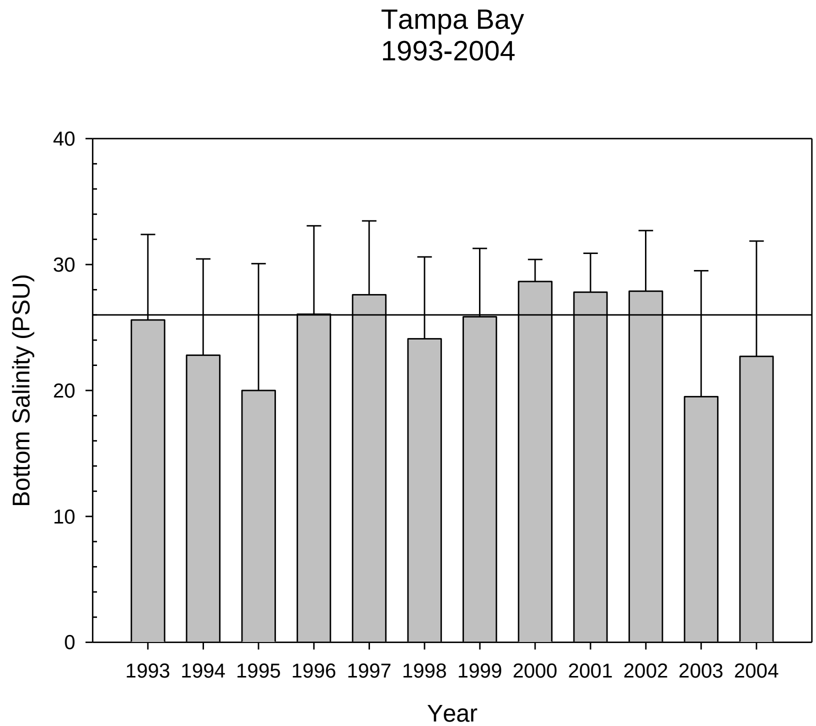

Figure 9. Median bottom salinity by year. Error bars = 90th percentile, solid line represents bay-wide median value.

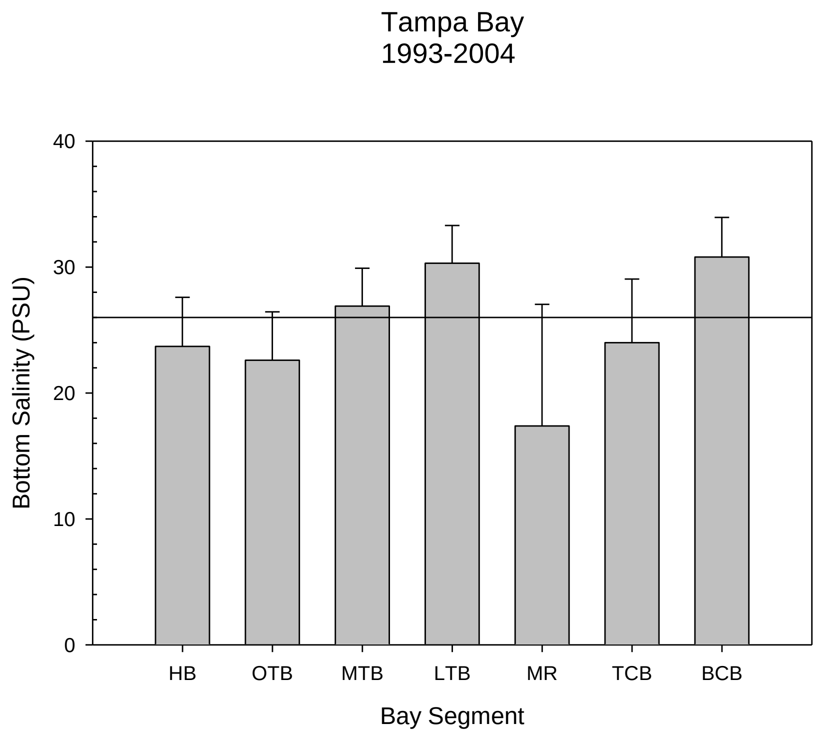

Figure 10. Median bottom salinity by bay segment. Error bars = 90th percentile, solid line represents bay-wide median value.

Table 5. Percentage of samples within salinity categories.

	n	Tidal Freshwater	Oligohaline	Low Mesohaline	High Mesohaline	Polyhaline	Euhaline
1993-1996	440	0.00%	0.45%	2.73%	14.77%	65.00%	17.05%
1997-2000	450	0.22%	0.44%	2.22%	6.67%	68.44%	22.00%
2001-2004	318	0.94%	0.31%	1.89%	8.49%	71.70%	16.67%
Hillsborough Bay	289	0.69%	0.35%	1.04%	14.53%	83.39%	0.00%
Old Tampa Bay	165	0.61%	0.00%	1.21%	13.94%	84.24%	0.00%
Middle Tampa Bay	236	0.00%	0.00%	0.42%	0.85%	89.83%	8.90%
Lower Tampa Bay	181	0.00%	0.00%	0.00%	0.00%	44.20%	55.80%
Manatee River	116	0.86%	3.45%	18.97%	29.31%	46.55%	0.86%
Terra Ceia Bay	68	0.00%	0.00%	0.00%	30.88%	61.76%	7.35%
Boca Ciega Bay	153	0.00%	0.00%	0.00%	0.00%	35.29%	64.71%
Tampa Bay (Total)	1208	0.33%	0.41%	2.32%	10.10%	68.05%	18.79%

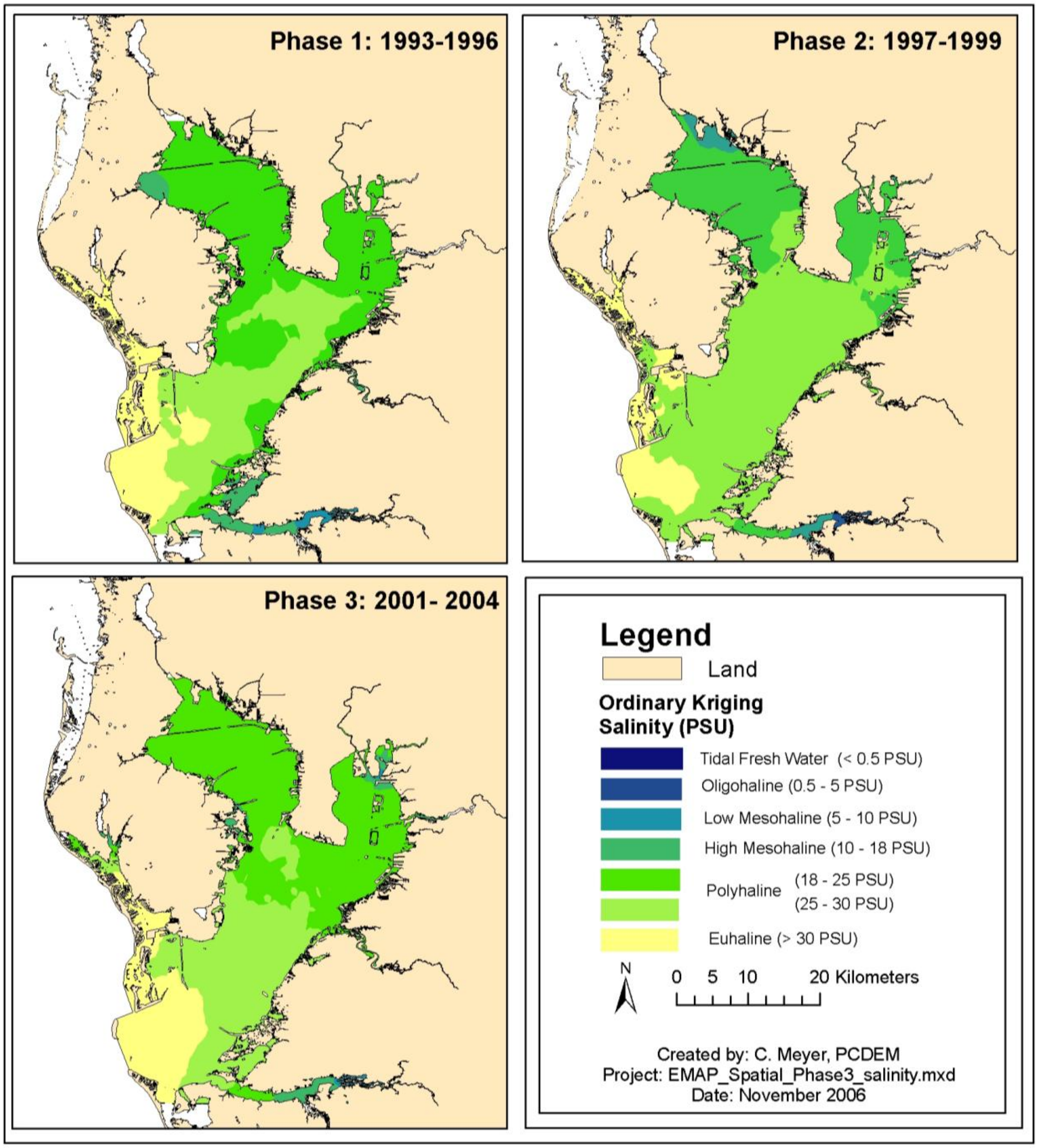

Figure 11. Spatial analysis of bottom salinity by four-year sampling phases.

Bottom Dissolved Oxygen

Bottom dissolved oxygen levels during the monitoring period were generally high, with a bay-wide median of 5.36 mg/L (Table 2). There were significant differences between years (KW; $p < 0.001$) with the lowest median dissolved oxygen in 2001. Bottom dissolved oxygen levels also tended to be lower during the Phase 3 years (Table 2; Figure 12) and showed a negative correlation with water temperature ($\rho_s = -0.207$; $p < 0.001$). Differences between bay segments were also significant (KW; $p < 0.001$). Hillsborough Bay had the lowest median dissolved oxygen while Terra Ceia Bay had the highest (Table 3; Figure 13). Overall, nearly 80% of the sites had bottom dissolve oxygen levels above 4 mg/L (Table 6). Hillsborough Bay had relatively high occurrences of anoxia and hypoxia, while these conditions were nearly absent in the other bay segments (Table 6). The aerial extent of anoxia and hypoxia appeared to increase substantially over time, most notably in Hillsborough Bay (Table 6; Figure 14). Hillsborough Bay in particular has historically been impacted by hypoxia, which has been associated with past die-offs of benthic fauna (Santos and Simon, 1980 a&b).

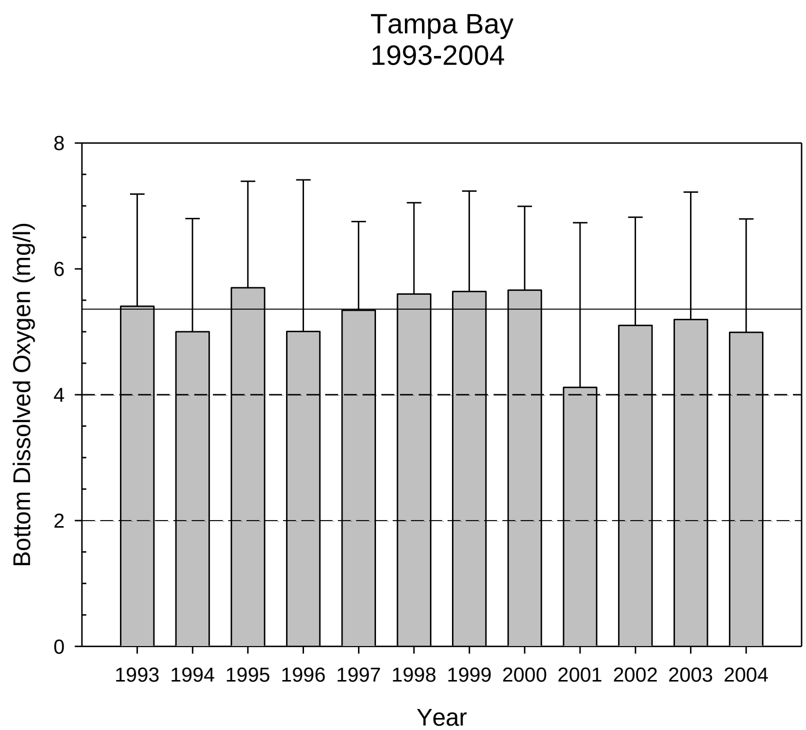

Figure 12. Median bottom dissolved oxygen by year. Error bars = 90th percentile, solid line represents bay-wide median value; dashed lines represent critical values for hypoxic (< 2 mg/l) and normoxic (> 4 mg/l) conditions.

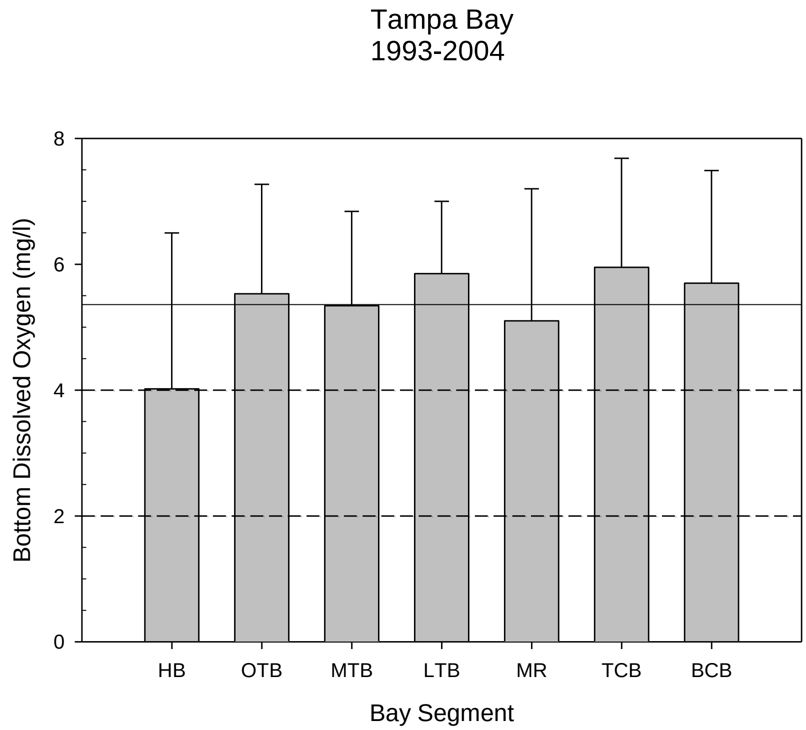

Figure 13. Median bottom dissolved oxygen by bay segment. Error bars = 90th percentile, solid line represents bay-wide median value; dashed lines represent critical values for hypoxic (< 2 mg/l) and normoxic (> 4 mg/l) conditions.

Table 6. Percentage of Dissolved Oxygen Category

	n	Anoxic	Hypoxic	Intermediate	Normoxic
1993-1996	423	2.84%	2.60%	13.48%	81.09%
1997-2000	447	0.67%	2.91%	8.72%	87.70%
2001-2004	318	4.72%	9.43%	18.55%	67.30%
Hillsborough Bay	288	9.03%	17.36%	22.57%	51.04%
Old Tampa Bay	164	0.61%	0.61%	20.12%	78.66%
Middle Tampa Bay	227	0.44%	0.00%	12.33%	87.22%
Lower Tampa Bay	171	0.00%	0.00%	1.17%	98.83%
Manatee River	119	1.68%	1.68%	10.08%	86.55%
Terra Ceia Bay	68	0.00%	0.00%	4.41%	95.59%
Boca Ciega Bay	151	0.00%	0.66%	7.95%	91.39%
Tampa Bay (Total)	1188	2.53%	4.55%	13.05%	79.88%

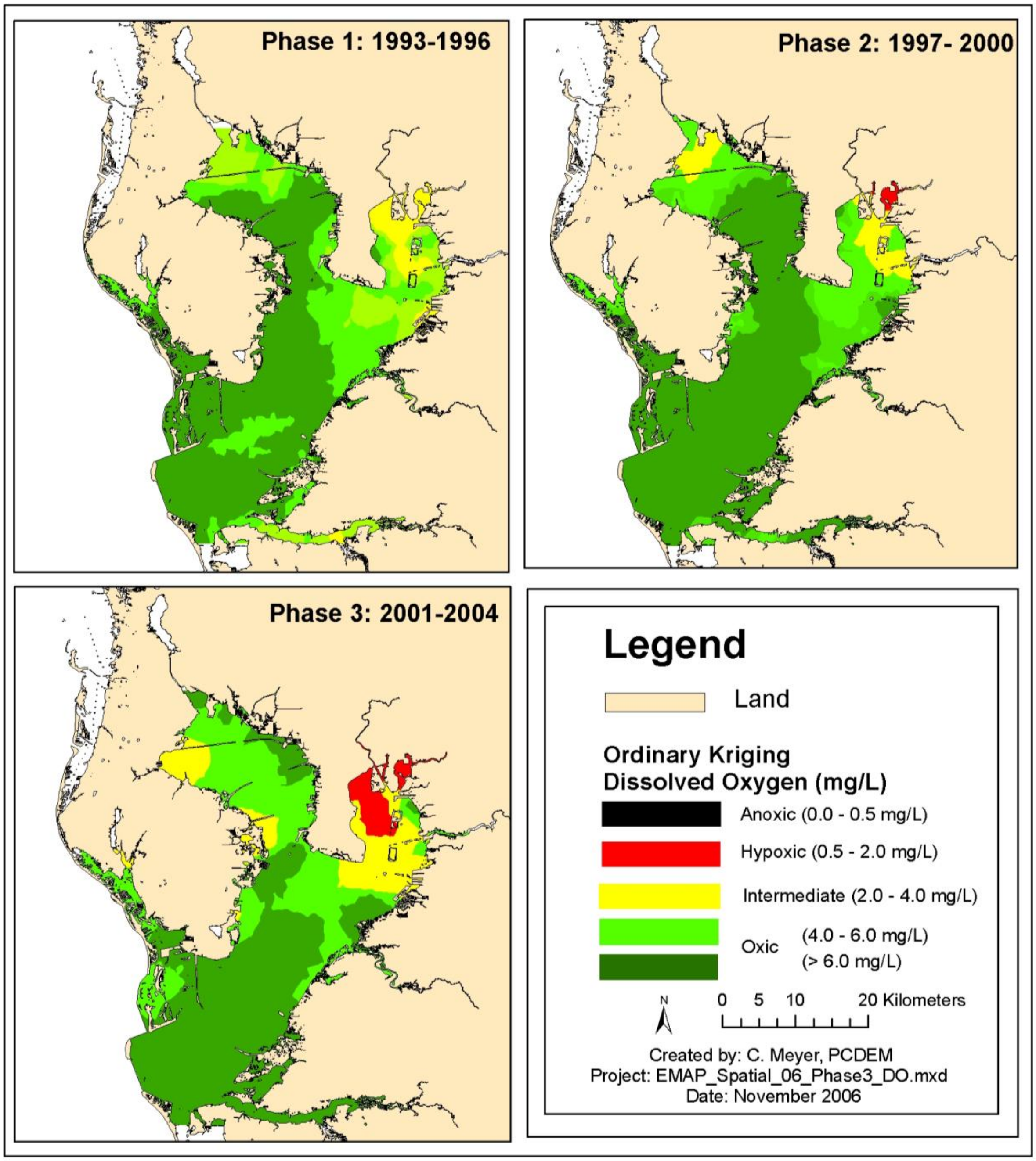

Figure 14. Spatial distribution of Dissolved Oxygen over time.

Sediment Composition (%Silt+Clay)

The median silt+clay in Tampa Bay was 4.3%, falling within the "medium" grain size classification (Tables 2 and 3).There was a significant difference in sediment composition between years (KW; $p < 0.001$) with the highest median silt+clay value being recorded in 1997 (Table 2; Figure 15). Hillsborough Bay had the highest silt+clay values among the bay segments with high measurements also occurring in Boca Ciega Bay and the Manatee River (Table 3; Figure 16). Medium grained sediments predominated in all bay segments but Hillsborough Bay had the highest percentage of muddy and very fine grain sediments (Table 7). The observed distribution of sediments from this monitoring program confirm previous reports (Brooks and Doyle 1991).Several factors contribute to the higher silt+clay in Hillsborough Bay including greater sediment input from tributaries such as the Hillsborough and Alafia Rivers, dredged channels which act as sinks for finer grained sediments, and restricted tidal exchange with the rest of Tampa Bay. There was a general trend of decreasing silt+clay from the upper portions of the bay towards the lower end of the bay (Table 7; Figure 17) due in part to less inflow carrying sediment into the lower bay and greater tidal flow between the bay and the Gulf of Mexico (Brooks and Doyle 1991). Brooks and Doyle (1992) mention fine-grained sediments (< 63μm) as a "parameter of concern" which may be considered a pollutant if they are increased by anthropogenic sources. Fine-grained sediments can have adverse affects by increasing turbidity and reducing light penetration through the water column and by accumulating sediment contaminants (Brooks and Doyle 1991, 1992).

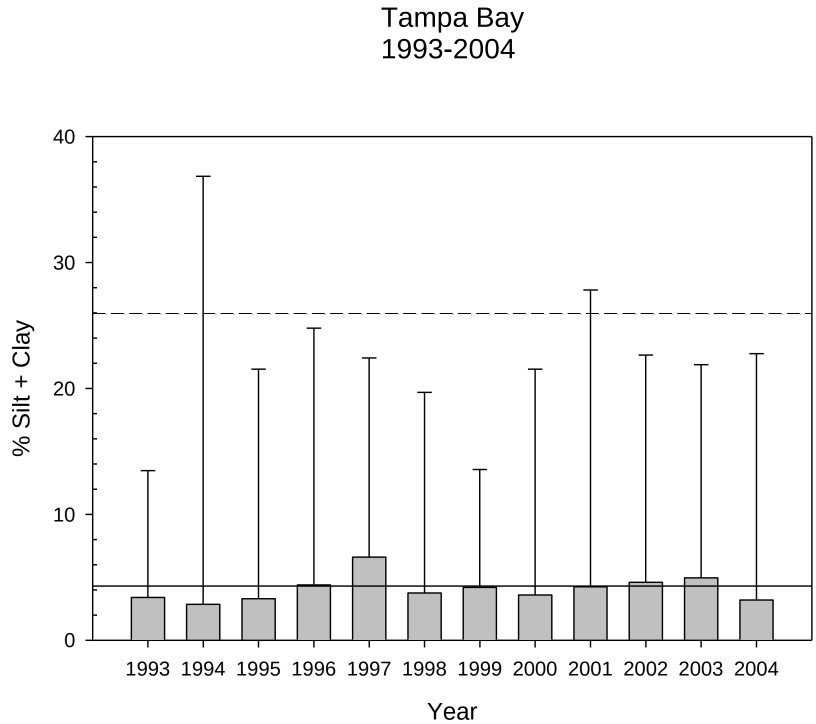

Figure 15. Median percent silt+clay by year. Error bars = 90th percentile, solid line represents bay-wide median value, dashed line represents the critical value for muddy sediments (>25.95% silt+clay).

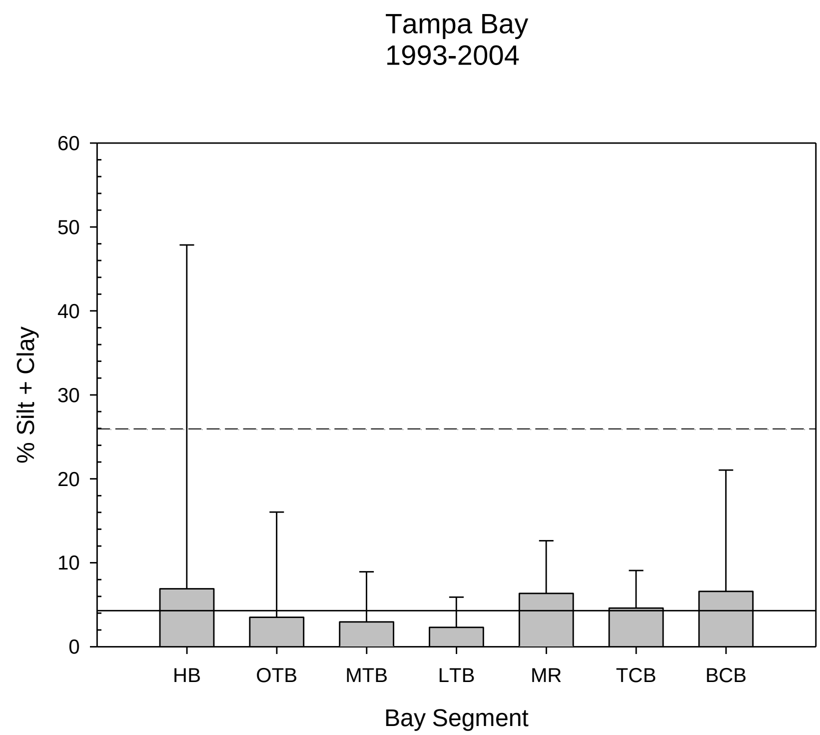

Figure 16. Median percent silt+clay by bay segment. Error bars = 90th percentile, solid line represents bay-wide median value, dashed line represents the critical value for muddy sediments (>25.95% silt+clay).

Table 7. Percent sediment categories.

	n	Coarse	Medium	Fine	Very Fine	Mud
1993-1996	446	19.28%	41.93%	22.87%	7.17%	8.74%
1997-2000	447	9.84%	33.56%	37.81%	12.30%	6.49%
2001-2004	314	10.51%	42.04%	26.11%	13.69%	7.64%
Hillsborough Bay	286	6.29%	29.02%	24.48%	16.78%	23.43%
Old Tampa Bay	165	20.00%	41.82%	22.42%	11.52%	4.24%
Middle Tampa Bay	238	23.11%	44.54%	24.37%	5.88%	2.10%
Lower Tampa Bay	181	24.86%	56.91%	17.13%	0.55%	0.55%
Manatee River	116	6.90%	25.86%	54.31%	10.34%	2.59%
Terra Ceia Bay	67	2.99%	44.78%	49.25%	2.99%	0.00%
Boca Ciega Bay	154	1.30%	31.17%	39.61%	22.08%	5.84%
Tampa Bay (Total)	1207	13.50%	38.86%	29.25%	10.77%	7.62%

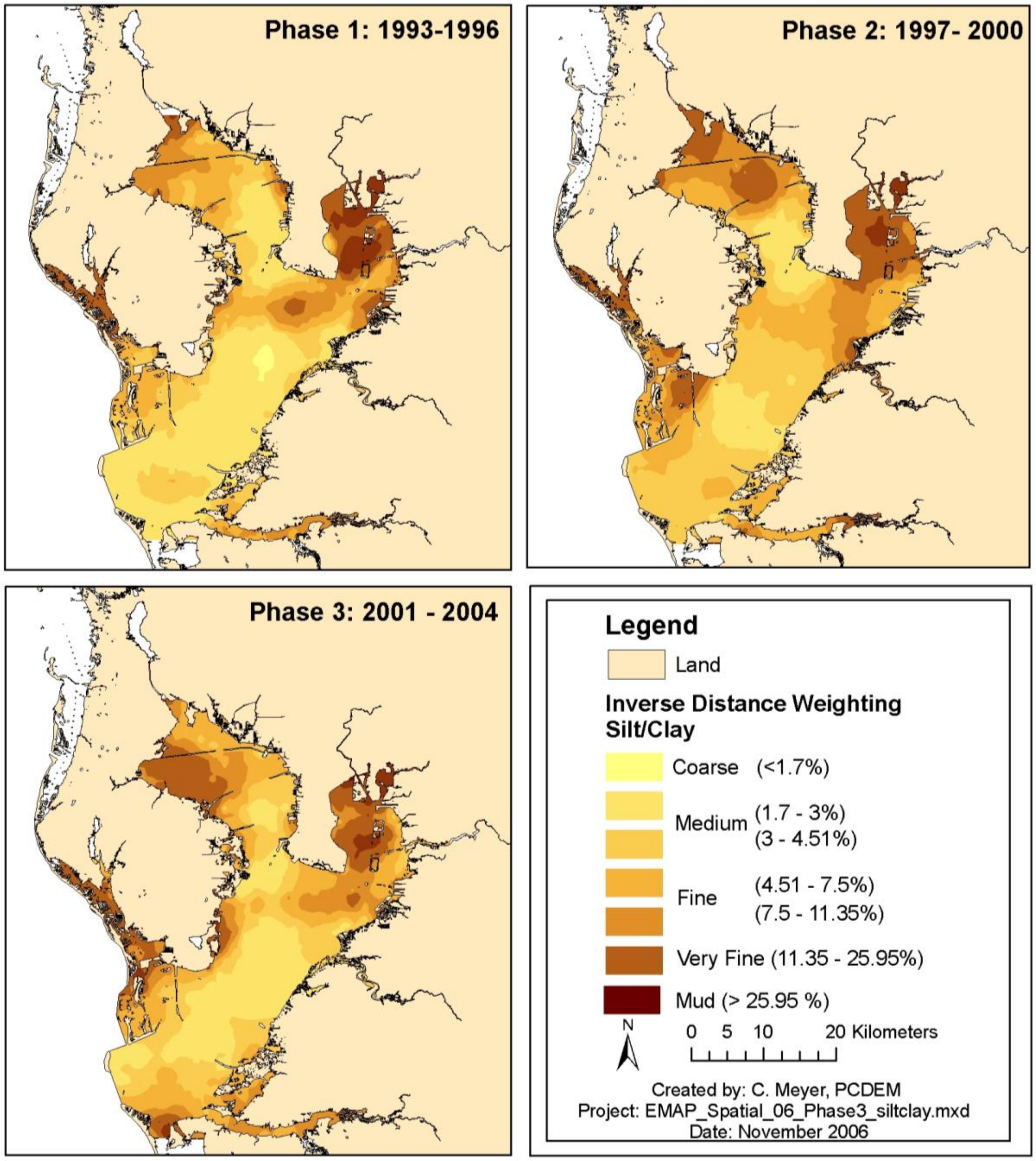

Figure 17. Spatial distribution of sediments in Tampa Bay over time.

Analysis of Environmental Data

Principle Components Analysis (PCA) results show that the individual bay segments are segregated by distinct physical characteristics with overlap between adjacent segments (Figure 18). This pattern is even more apparent when the samples are averaged by year within each segment (Figure 19). The PCA eigenvalues indicate that the first principle component axis (PC1) explains 34.5% of the variation and is weighed largely by dissolved oxygen and pH (Table 9; Figure 20). The second principle component axis (PC2) accounts for 22.9% of the variation (Table 8) and is weighed by depth and salinity (Table 9; Figures 21 & 22).

Table 8. Eigenvalue and percent variation explained by principle component axes.

PC	Eigenvalues	%Variation	Cum.%Variation
1	**2.07**	**34.5**	**34.5**
2	**1.37**	**22.9**	**57.4**
3	**1.03**	**17.2**	**74.6**
4	**0.699**	**11.6**	**86.3**
5	**0.534**	**8.9**	**95.2**

Table 9. Eigenvectors for bottom parameters contributing to principle component axes.

Variable (Bottom values)	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**
Depth	**-0.113**	**0.616**	**0.443**	**0.442**	**0.452**
Temperature	**-0.158**	**0.186**	**-0.877**	**0.328**	**0.218**
Salinity	**0.270**	**0.658**	**-0.093**	**-0.197**	**-0.608**
Dissolved Oxygen	**0.592**	**-0.213**	**0.006**	**-0.093**	**0.372**
pH	**0.562**	**0.256**	**-0.153**	**-0.265**	**0.345**
Silt+clay	**-0.472**	**0.205**	**-0.043**	**-0.761**	**0.348**

The superimposed variable vectors on Figures 18 & 19 indicate that there is an inverse relationship between bottom dissolved oxygen and percent silt+clay. The main bay segments fall along these vectors with the Hillsborough Bay data points grouping at one extreme and being characterized by low dissolved oxygen and high percent silt+clay. The Lower Tampa Bay points group at the opposite extreme with high dissolved oxygen and low percent silt+clay. The other segments fall between these two extremes (Figure 19). The Manatee River data points group at one end of the salinity and depth vectors indicating that low salinity is the primary factor characterizing this bay segment (Figure 19).

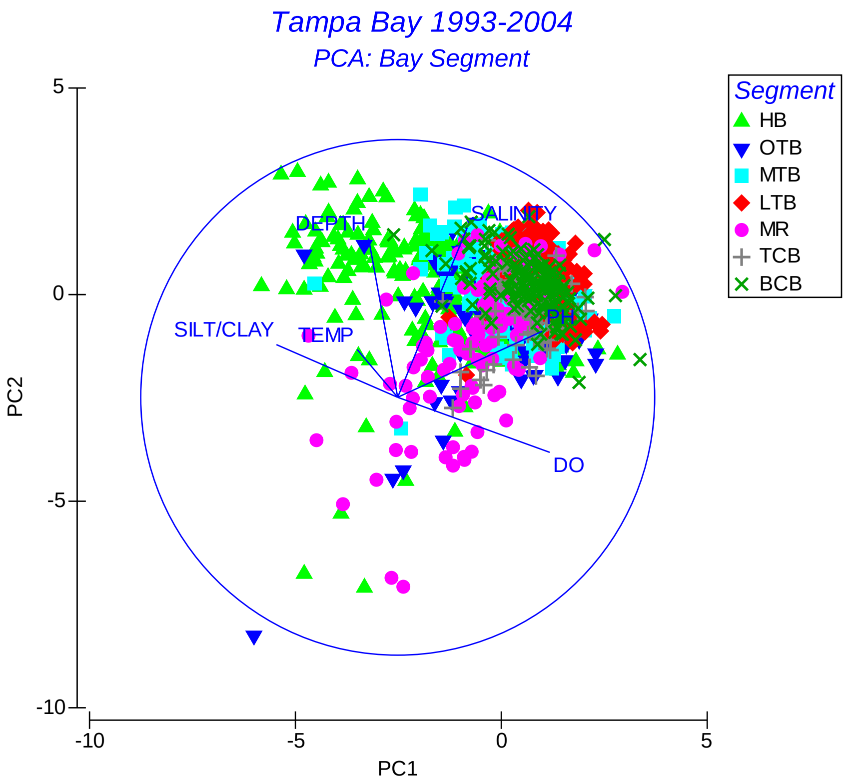

Figure 18. PCA coded by bay segment

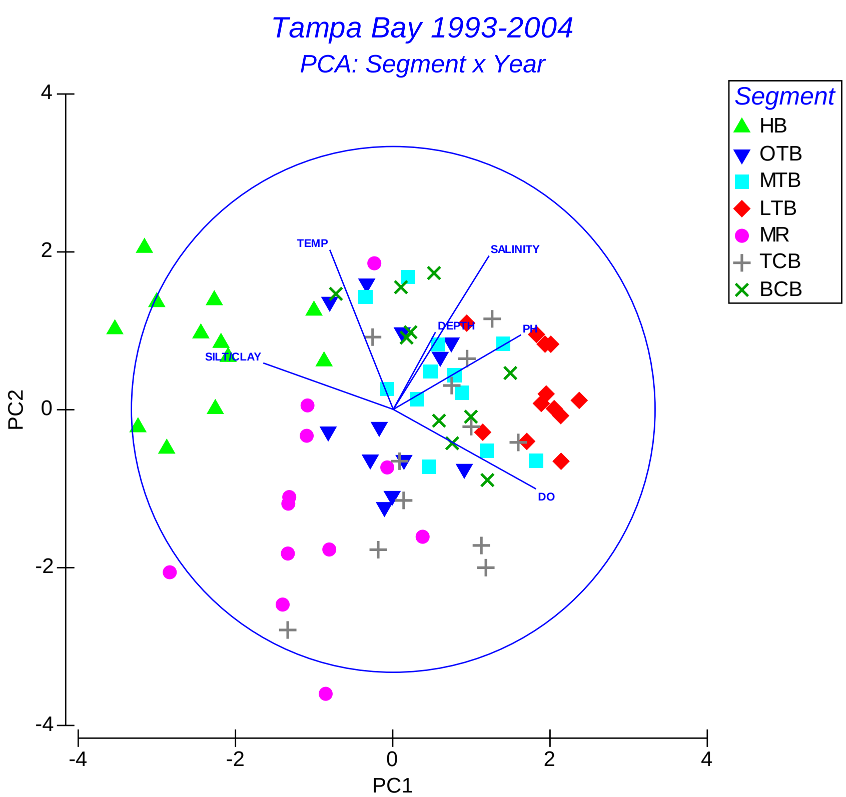

Figure 19. PCA by bay segment, averaged by year.

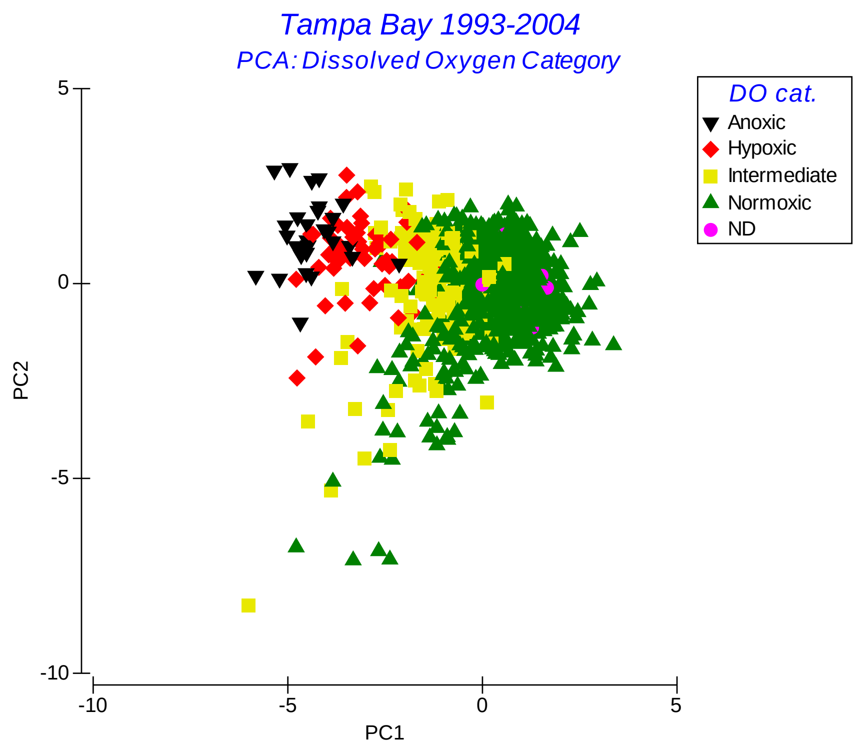

Figure 20. PCA by bottom dissolved oxygen classification.

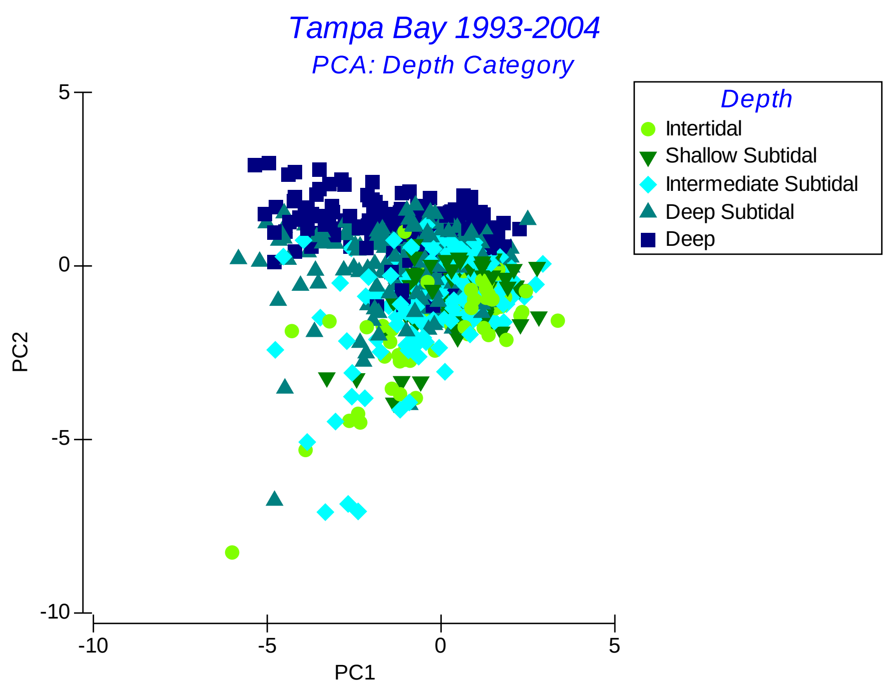

Figure 21. PCA by depth classification.

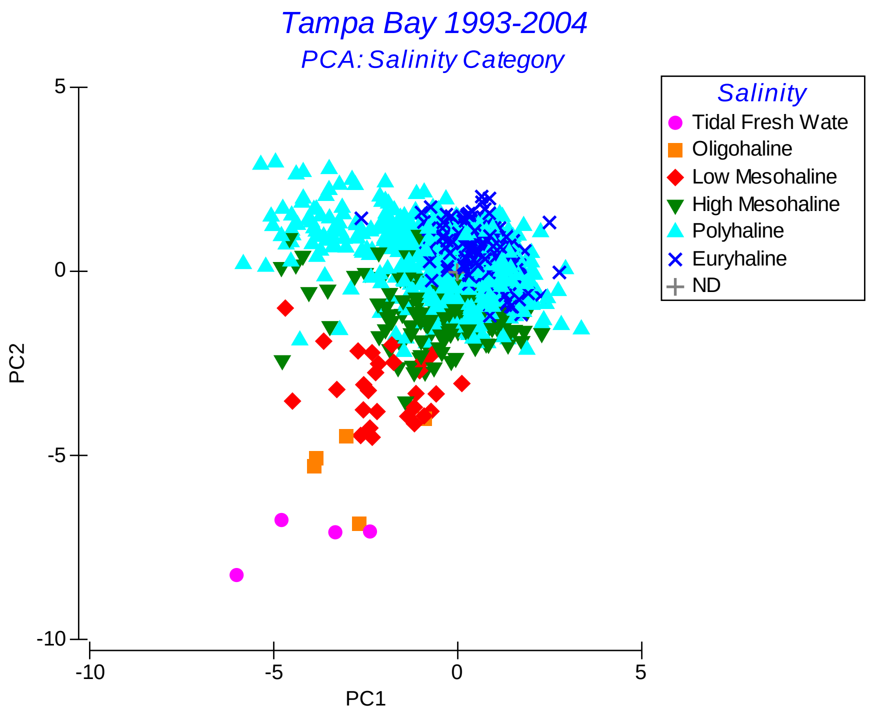

Figure 22. PCA by salinity classification.

Sediment Contaminants

Metals

Bay-wide sediment metal summary statistics and percent of samples exceeding the sediment toxicity Threshold Effects Level (TEL) and Probable Effects Level (PEL) for each metal (MacDonald 1994) are presented in Table 10 for all years combined. Due to the large number of low measurements, the mean rather than median values are presented for between bay segment comparisons.

Silver (Ag) is known to be a highly toxic to aquatic organisms and has a high rate of bioaccumulation (Lee et al. 2004; Luoma et al. 1995). Sediment silver concentrations in Tampa Bay ranged from below detectable limits to 1.48 mg/kg (Table 10). There were few TEL exceedences (2.38% of samples) but all samples were below the PEL. Differences in Ag levels between bay segments were significant (KW; $p = 0.002$), with highest levels occurring in Hillsborough and Boca Ciega Bays (Figure 23). The Ag:Al ratio suggests that a few of the samples above the TEL are due to anthropogenic sources (Figure 24). Most of the potentially contaminated sites were in Hillsborough Bay with scattered sites in the other segments (Figures 25). Brooks and Doyle (1991) found silver present at only 17% of their sites in Tampa Bay concentrated mainly around St. Petersburg and in Hillsborough Bay. Their highest recorded value was 0.5 mg/kg (Brooks and Doyle 1991) which is below the TEL of 0.73 mg/kg established by MacDonald (1994) and a third of the maximum value found in the current monitoring results. Silver has several industrial uses including the production and processing of photographic materials, electrical contacts, soldering, jewelry and silver plating and medical and dental uses (Purcell and Peters 1998; MacDonald 1994). Potential inputs into Tampa Bay include waste incinerators, landfills, waste water treatment plants, and coal combustion (MacDonald 1994)

Arsenic (As) is used in several industrial applications including pesticides and in pressure treated lumber (MacDonald 1994) and possible sources to the environment may include runoff or leaching from treated wood structures. A few samples exceeded the TEL for arsenic but none were above the PEL (Table 10). There were significant differences between bay segments (KW; $p = 0.008$), with highest values in Terra Ceia Bay and Hillsborough Bay (Figure 26). The As:Al ratio indicates that the sites with elevated As levels may be due to anthropogenic sources (Figure 27). Potentially contaminated sites were in Hillsborough Bay and Terra Ceia Bay with scattered sites in Middle and Lower Tampa Bay (Figure 28).

Cadmium (Cd) has many industrial and agricultural sources including electroplating, paints, plastics, batteries, mining, some pesticides and fertilizers and combustion of fossil fuel (MacDonald 1994). Cadmium also is known to be toxic to aquatic organisms (Long et al. 1994; Lee et al. 2004) and can bioaccumulate in the food chain (Kirby et al. 2001; Seebaugh et al. 2006; Ruelas-Inzunza and Páez-Osuna 2008). However, several studies have failed to find evidence of trophic effects (Barwick and Maher 2003) or on the colonization of sediments by benthic infauna (Trannum et al. 2004) from elevated Cd levels in sediment. The toxicity and distribution of Cd in sediments can be affected by physical factors such as pH and sulfides (Di

Toro 1990; MacDonald 1994) and bioturbation of the sediments (Rasmussen et al. 1998; Klerks et al. 2007).

Levels of Cd tended to be high throughout Tampa Bay, with 36% of the samples above the TEL and approximately 2.5% above the PEL (Table 10). There was a significant difference between bay segments (KW; $p < 0.001$); with Hillsborough Bay and the Manatee River having the highest Cd levels (Figure 29). Despite the high percentage of sites with TEL exceedences, the Cd:Al ratio (Figure 30), suggests that the high Cd levels are due largely to natural sources such as weathering of phosphate enriched soils (MacDonald 1994) or from anthropogenic inputs related to phosphate mining. The elevated Cd was apparent throughout Tampa Bay (Figure 31). In contrast to these results, previous surveys (Brooks and Doyle 1992; Long et al. 1994) found Cd:Al ratios in samples from Tampa Bay which indicated anthropogenic enrichment and Long et al. (1994) further found significant correlations between sediment Cd concentrations and toxicity bioassays. Frithsen et al. (1995) estimated an annual loading of around 3,500 kg of cadmium to Tampa Bay with Hillsborough Bay receiving the largest loading (39%) followed by Old Tampa Bay (23%). The main sources of Cd loading were identified as being atmospheric deposition (46%), followed by point sources (32%) and urban runoff (21%) (Frithsen et al. 1995).

Chromium (Cr) is used in the production of chrome plating, the production of chromium metal and chrome alloys, dyes, paints and the production of paper, among other industrial uses (MacDonald, 1994). Chromium is commonly found in two valence states: Cr(III) and Cr(VI). The Cr (III) form adsorbs to organic particles and can co-precipitate with iron and magnesium oxides, accumulating in the sediment (MacDonald 1994). Cr (III) is considered less toxic to aquatic organisms, while the Cr (VI) form is water soluble, more bioavailable and thus has a greater toxicity than Cr (III) (MacDonald 1994; McConnell et al. 1996).

Total Cr levels in Tampa Bay were above the TEL at 7.54% of the sites and exceeded the PEL at 1.2% of the sites (Table 10). There were significant differences between bay segments (KW; $p < 0.001$) with highest concentrations occurring in Hillsborough Bay, Old Tampa Bay and Terra Ceia Bay and lowest levels in Middle and Lower Tampa Bay (Figure 32). Several of sites had Cr:Al ratios which indicated possible contamination (Figure 33). Areas of highest contamination were mainly in Hillsborough Bay and generally associated with the Port of Tampa or the shipping channels (Figure 34). There were additional scattered “hits” at several sites around the periphery of Old Tampa Bay (Figure 34).

Previous surveys have also found high concentrations of Cr in the upper part of Hillsborough Bay (Brooks and Doyle 1992) and it has been identified as a “Chemical of Concern” for this area of the bay (McConnell et al. 1996; McConnell and Brink 1997). Frithsen et al. (1995) estimated Cr loading to Tampa Bay to be approximately 14,600 kg/yr, primarily from urban runoff (57%) and point sources (27%). Hillsborough Bay and Old Tampa bay receive 43.7% and 24% of the total Cr load respectively due to the urban development in these areas (Frithsen et al. 1995).

Copper (Cu) is commonly used in biocides for controlling algae and fungi and in antifouling paints (MacDonald 1994). Industrial sources of Cu in the environment include waste water treatment effluents, runoff of Cu based biocides, corrosion of copper pipes and atmospheric fallout from coal burning facilities such as power plants (MacDonald 1994). In Tampa Bay, the estimated annual loading of Cu is approximately 12,500 kg with major inputs coming from urban runoff (43%), point sources (35%) and atmospheric deposition (18%)(Frithsen et al. 1995). Copper is known to be toxic to aquatic organisms and high levels of Cu can impede the settlement and colonization of sediments by benthic infauna (Olsgard 1999; Trannum et al. 2004). Elevated sediment Cu concentrations can further accumulate in the food chain, particularly in mollusks and crustaceans which utilize Cu as a blood pigment (MacDonald, 1994; Barwick and Maher 2003) and in bottom feeding fishes (Kirby et al. 2001).

Results from the current monitoring found sediment Cu levels exceeded the TEL in 6% of the samples and the PEL in 0.46% of the samples (Table 10). Differences between bay segments were significant (KW; $p < 0.001$). High levels of copper were present in Hillsborough Bay, the Manatee River and Boca Ciega Bay (Figure 35) and the Cu:Al ratios indicated several sites were contaminated (Figure 36). The areas of highest contamination were in Hillsborough Bay in the Port of Tampa and the shipping channels (Figure 37). Previous surveys (Brooks and Doyle 1992) also found enriched levels of copper in 23% of their samples, with the highest measurement (267 mg/kg) at Bayboro Harbor in Middle Tampa Bay and Cu has been identified as a "Chemical of Concern" for upper Hillsborough Bay (McConnell et al. 1996; McConnell and Brink 1997).

Nickel (Ni) is primarily used in the manufacture of stainless steel and nickel plating, as well as being used as a catalyst for other industrial processes and oil refining (MacDonald 1994). Potential sources of Ni pollution include the combustion of fossil fuels, electroplating operations, and wastewater treatment facilities (MacDonald 1994; McConnell and Brink 1997).

Nickel levels were above the TEL at 11.4% of the sites and exceeded the PEL at 0.55%, with a maximum concentration of 481 mg/kg (Table 10). Highest levels were found in Hillsborough Bay (Figures 38), and were significantly higher than in the other bay segments (KW; $p < 0.001$). Only a few sites had Ni:Al ratios which suggested levels were higher than background (Figure 39). The potentially contaminated sites were mainly concentrated in Hillsborough Bay near the Port of Tampa (Figure 40). Brooks and Doyle (1992) found elevated Ni levels at 17% of their sites, with a maximum value of 64.5 mg/kg in Hillsborough Bay. Nickel has been correlated with sediment toxicity (Amezcua-Allieri and Salazar-Coria 2008) although previous sediment toxicity work on Tampa Bay sediments (Long et al. 1994) did not find significant correlations between nickel concentrations and amphipod survival bioassays, however McConnell et al. (1996) identified this metal as a significant environmental risk due to potential bioaccumulation and Ni was identified as a contaminant of concern for upper Hillsborough Bay (McConnell and Brink 1997). Bay-wide loading estimates for Ni were not calculated by Frithsen et al. (1995). McConnell and Brink (1997) calculated a loading of approximately 753 kg/yr Ni for upper Hillsborough Bay from point source discharges, primarily from the Hooker's point WWTP (68%) and the Tampa Electric Gannon power plant (32%).

Lead (Pb) has many industrial uses including the manufacture of batteries and chemical compounds (MacDonald 1994). Lead was also used as a gasoline additive until it was phased out in the mid-1980s. The Pb concentrates in Tampa Bay sediments exceeded the TEL at 5.52% of the sites and was above the PEL at 0.74% (Table 10). The maximum concentration was nearly 638 mg/kg (Table 10). There was a significant difference between bay segments (KW; $p<0.001$) with highest levels occurring in Hillsborough Bay and the Manatee River (Figure 41). The Pb:Al ratio indicated elevated Pb levels were present (Figure 42). The most contaminated sites were in Hillsborough Bay near the Port of Tampa, although there were a few isolated sites in other parts of the bay, including near Egmont Key in Lower Tampa Bay, Bayboro Harbor in Middle Tampa Bay, and on the eastern side of Old Tampa Bay (Figure 43). Brooks and Doyle (1992) detected elevated Pb concentrations at 93% of their sites, with 12% exceeding the PEL of 112 mg/kg as determined by MacDonald (1994). The highest Pb concentration in the Brooks and Doyle survey was 385 mg/kg in MacKay Bay. Sediment Pb levels in Tampa Bay sediments were also found to be significantly correlated with sediment toxicity tests (Long et al. 1994). Frithsen et al. (1995) estimated annual loading of Pb to Tampa Bay at nearly 50,000 kg, primarily from urban runoff (60%), along with atmospheric deposition (20%), point source pollution (11%) and ground water (9%).

Zinc (Zn) levels were above its TEL at 2.67% of the sites and exceeded its PEL at 1.38% (Table 10). Differences between bay segments were significant (KW; $p<0.001$). The highest levels were in Hillsborough Bay, Terra Ceia Bay and the Manatee River (Figure 44) and contaminated sites were evident from elevated Zn:Al ratios (Figure 45). Most of the contaminated sites were in Hillsborough Bay, the Manatee River, and Terra Ceia Bay but there were also several isolated sites with high Zn levels found in Middle Tampa Bay and off of Egmont Key (Figure 46). Brooks and Doyle (1992) found concentrations of zinc as high as 700 mg/kg in McKay Bay, which exceeds the highest value found in our samples (Table 10). Approximately 17% of the sites in the Brooks and Doyle survey exceeded the PEL value for zinc compared to only 1.38% of our monitoring sites. Frithsen et al. (1995) estimated annual loading of zinc to Tampa Bay at 164,000 tons, with 66% of the input coming from urban runoff.

Four additional metals were analyzed: Manganese (Mn), Antimony (Sb), Selenium (Se), and Tin (Sn). MacDonald (1994) did not establish toxicity levels (TELs and PELs) for these metals (Table 10). There were significant differences between segments for Mn, Sb, and Se (KW; $p<0.001$). Manganese levels were higher in Terra Ceia Bay, Lower Tampa Bay, and Hillsborough Bay (Figure 47) with a few sites with high Mn:Al ratios (Figure 48). The mean Sb levels were higher in the Manatee River, Terra Ceia Bay, and Boca Ciega Bay (Figure 49) but all sites were within background levels (Figure 50). Selenium was higher in Boca Ciega Bay and Hillsborough Bay (Figure 51) but the Se:Al ratios did not show any sites to be above background levels (Figure 52). Tin levels were relatively high in Terra Ceia Bay (Figure 53) but there was no significant difference among the bay segments (KW; $p=0.204$). The Sn:Al ratio did indicate that a number of sites were potentially contaminated (Figure 54).

Table 10. Tampa Bay (1993-2004) sediment metals summary statistics and percentage of sites exceeding TEL and PEL values.

mg/kg	AG	AS	CD	CR	CU	NI	PB	ZN	MN	SB	SE	SN
TEL	0.73	7.20	0.68	52.30	18.70	15.90	30.20	124.00	ND	ND	ND	ND
PEL	1.77	41.60	4.20	160.00	108.00	42.80	112.00	271.00	ND	ND	ND	ND
n	1011	1087	1087	1087	1087	1087	1087	1087	503	503	503	1087
Minimum	0.00	0.10	0.00	0.64	0.27	0.20	0.50	0.00	0.00	0.01	0.00	0.00
Maximum	1.48	19.11	14.52	650.70	252.56	481.40	637.71	529.25	162.70	77.08	39.42	34.59
Median	0.18	1.95	0.18	7.24	2.25	4.82	5.23	7.00	11.83	15.27	7.33	1.64
Mean	0.23	2.61	1.01	18.04	6.35	7.21	11.22	23.10	21.39	21.07	8.29	3.13
SD	0.19	1.95	1.34	38.49	17.20	16.15	29.09	54.64	24.23	18.12	7.55	4.89
% >TEL;<PEL	**2.38%**	**3.40%**	**36.00%**	**7.54%**	**6.07%**	**11.41%**	**5.52%**	**2.67%**				
% >PEL	**0.00%**	**0.00%**	**2.49%**	**1.20%**	**0.46%**	**0.55%**	**0.74%**	**1.38%**				

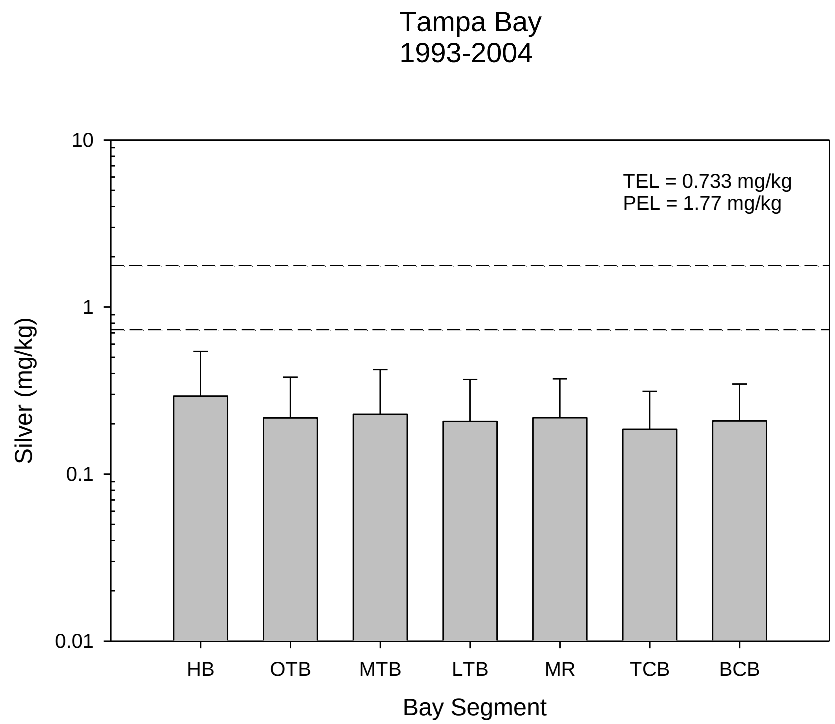

Figure 23. Mean sediment silver levels by bay segment. Error bars = 1 standard deviation, dashed lines represent PEL (upper) and TEL (lower) values.

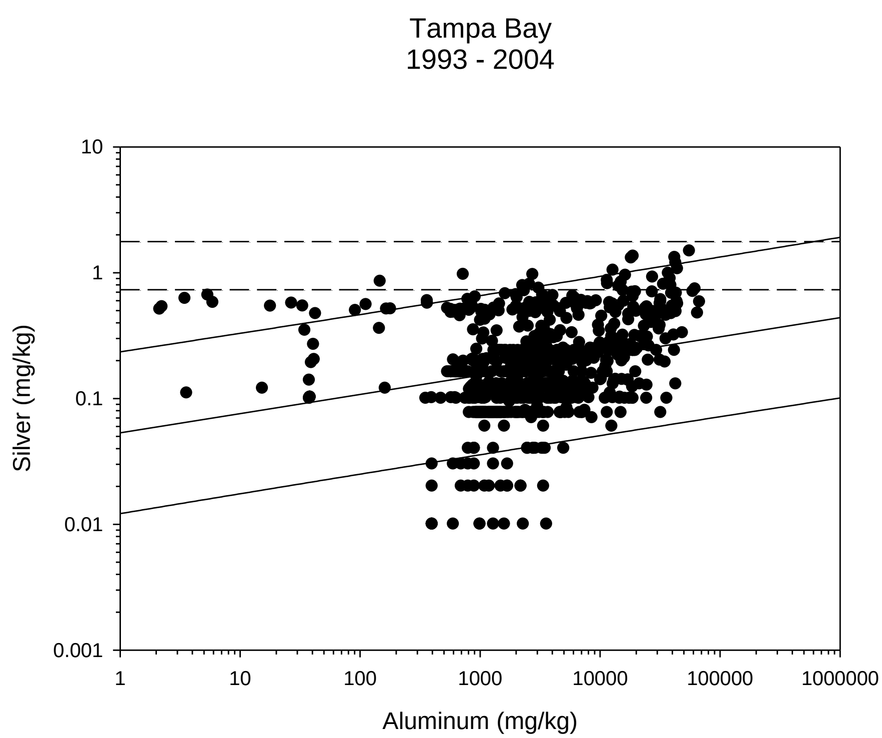

Figure 24. Tampa Bay Ag:Al ratio with 95% prediction intervals (solid lines). Dashed lines represent PEL (upper) and TEL (lower) values.

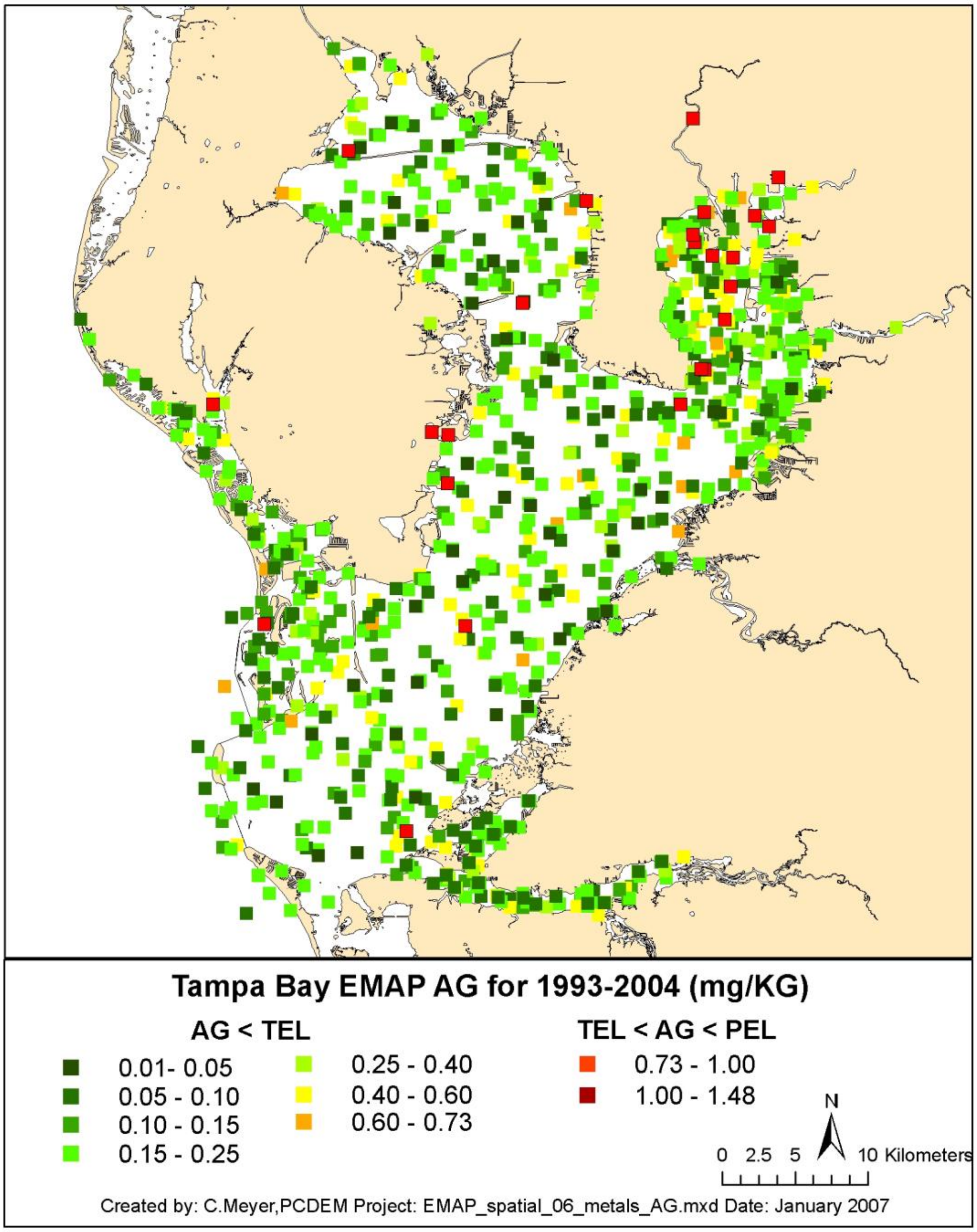

Figure 25. Spatial distribution of silver in Tampa Bay 1993-2004.

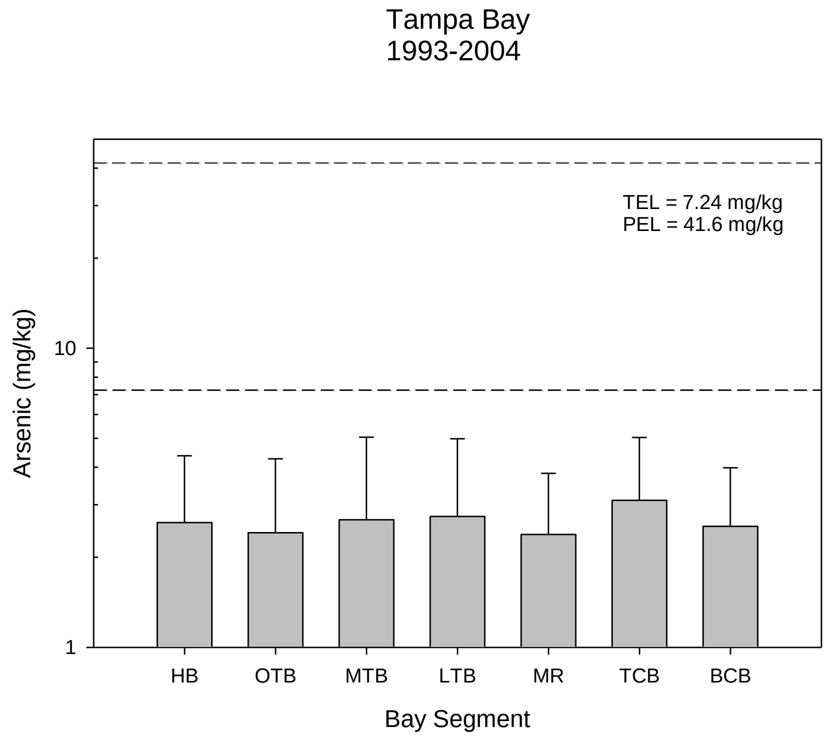

Figure 26. Mean sediment arsenic levels by bay segment. Error bars = 1 standard deviation, dashed lines represent PEL (upper) and TEL (lower) values.

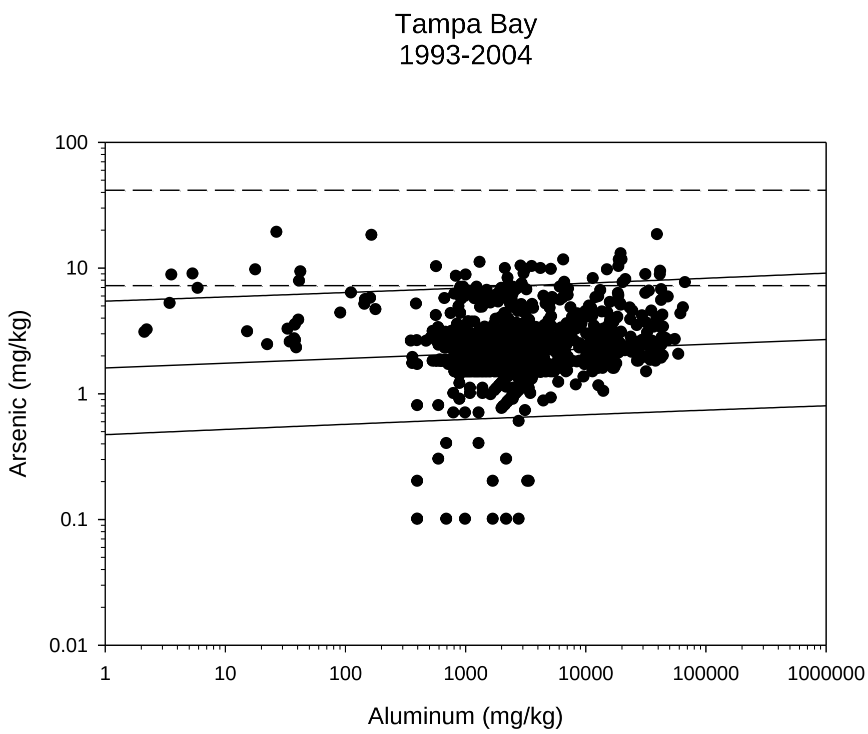

Figure 27. Tampa Bay As:Al ratio with 95% prediction intervals (solid lines). Dashed lines represent PEL (upper) and TEL (lower) values.

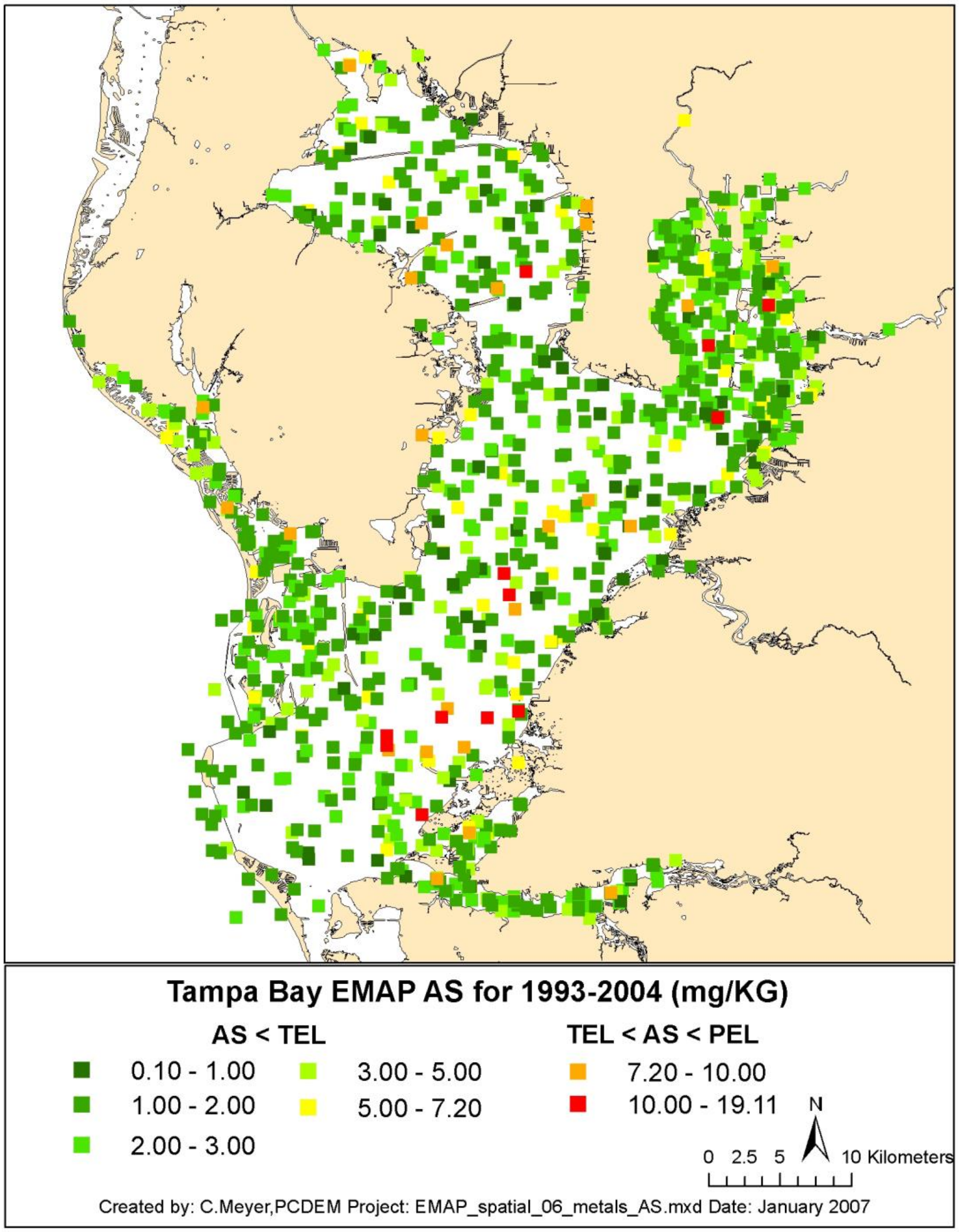

Figure 28. Spatial distribution of arsenic in Tampa Bay 1993-2004.

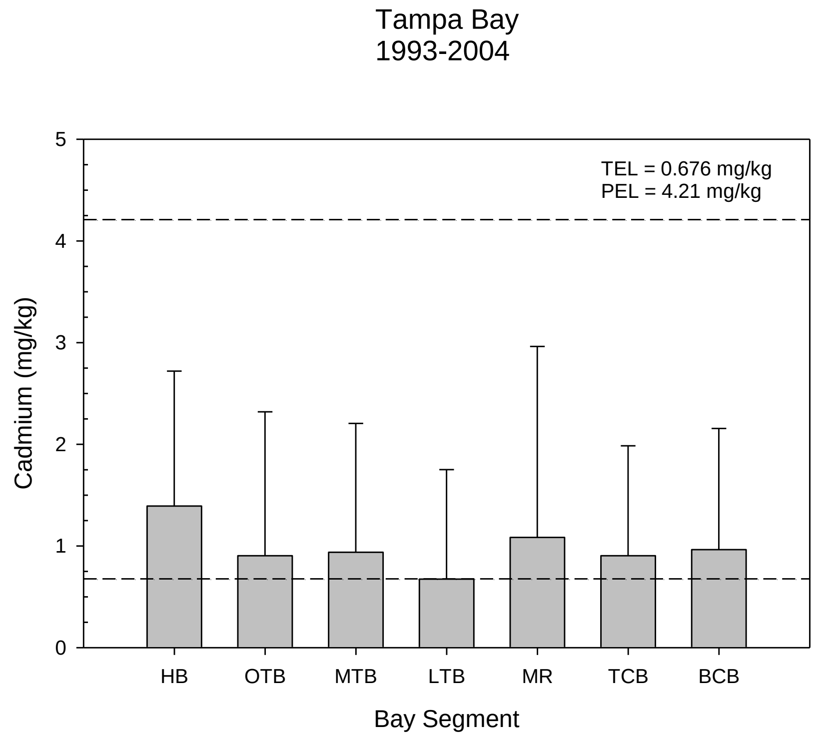

Figure 29. Mean sediment cadmium levels by bay segment. Error bars = 1 standard deviation, dashed lines represent PEL (upper) and TEL (lower) values.

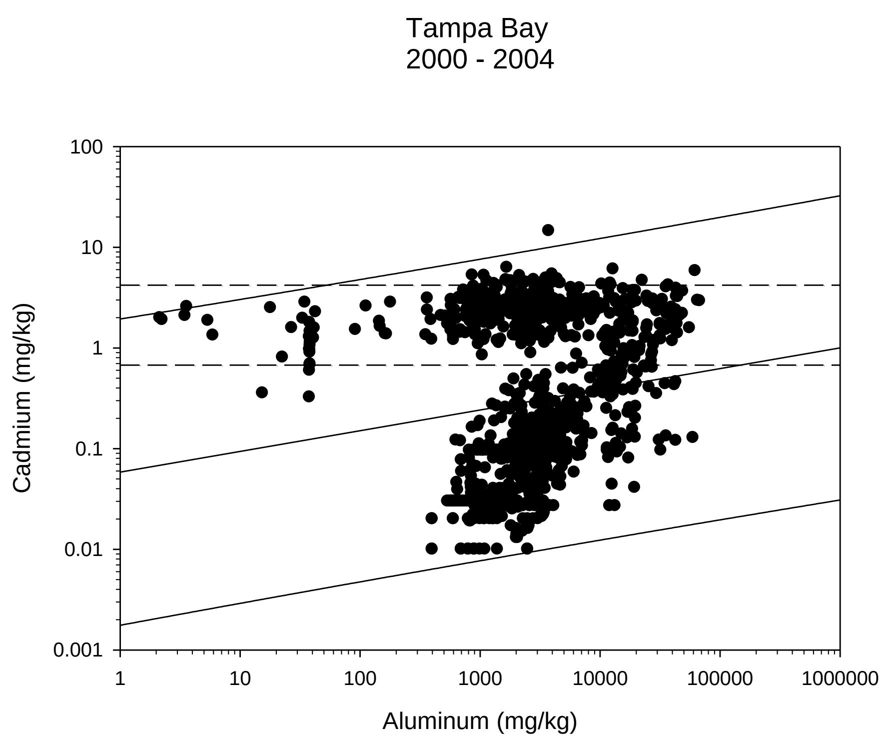

Figure 30. Tampa Bay Cd:Al ratio with 95% prediction intervals (solid lines). Dashed lines represent PEL (upper) and TEL (lower) values.

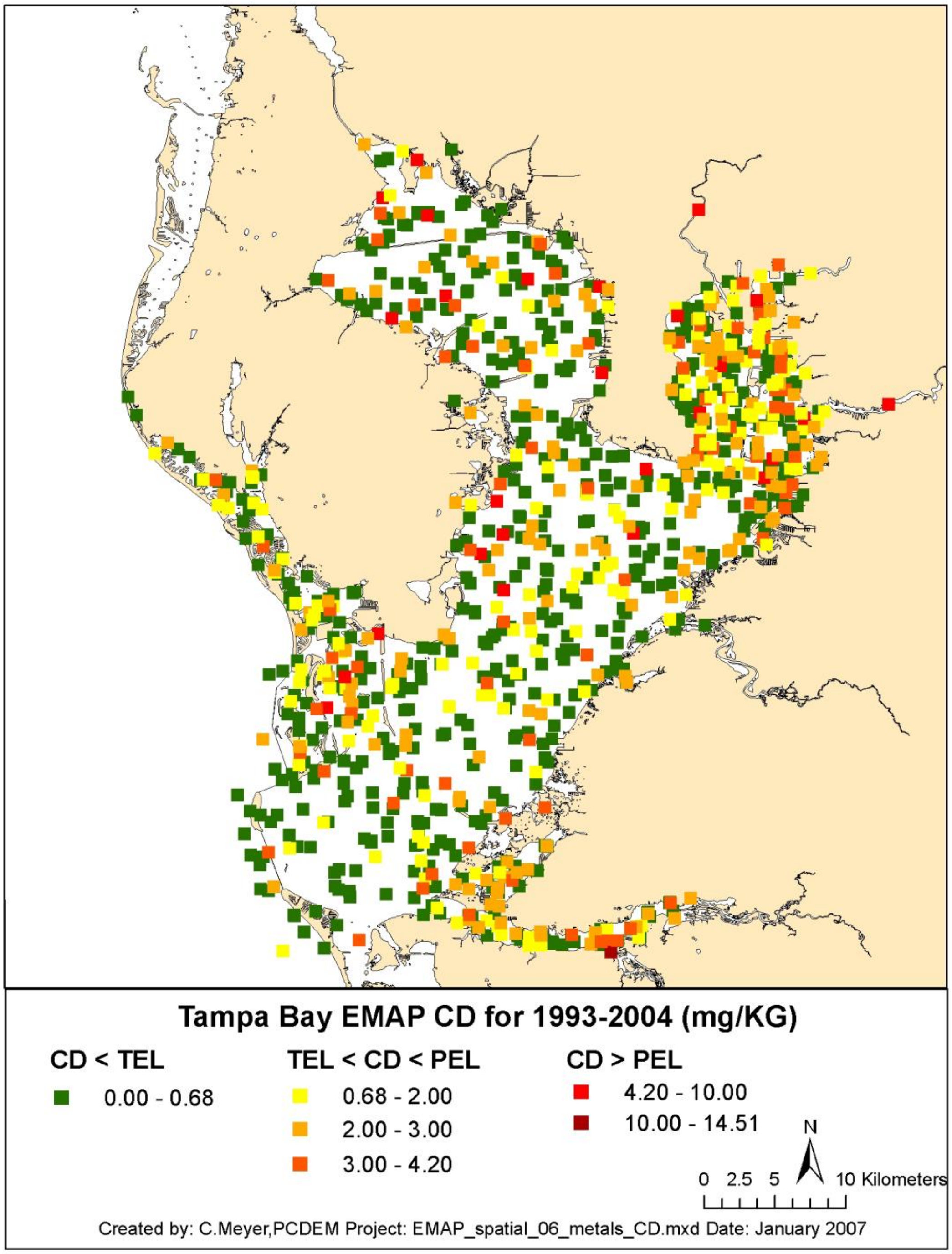

Figure 31. Distribution of cadmium in Tampa Bay 1993-2004.

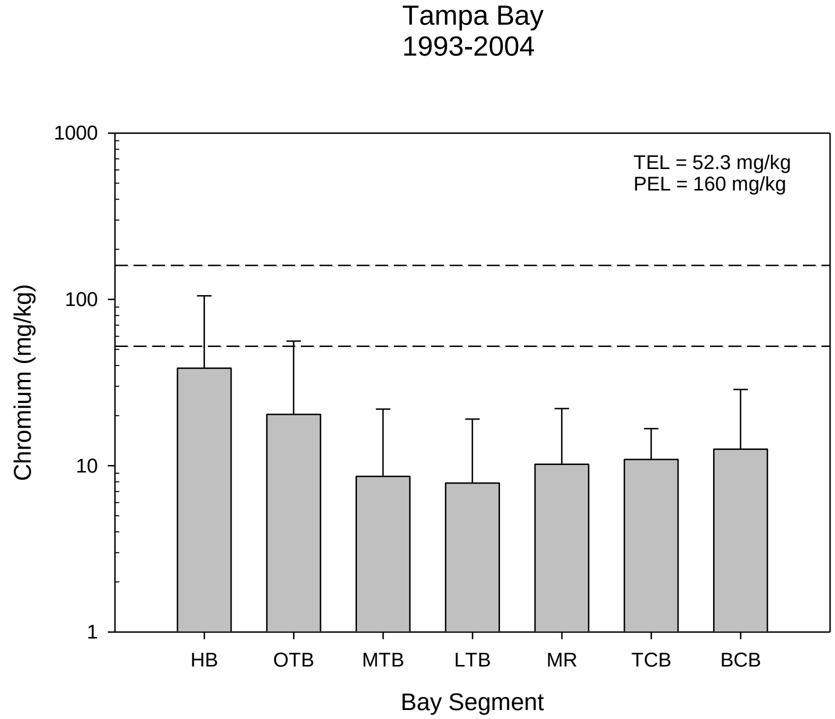

Figure 32. Mean sediment chromium levels by bay segment. Error bars = 1 standard deviation, dashed lines represent PEL (upper) and TEL (lower) values.

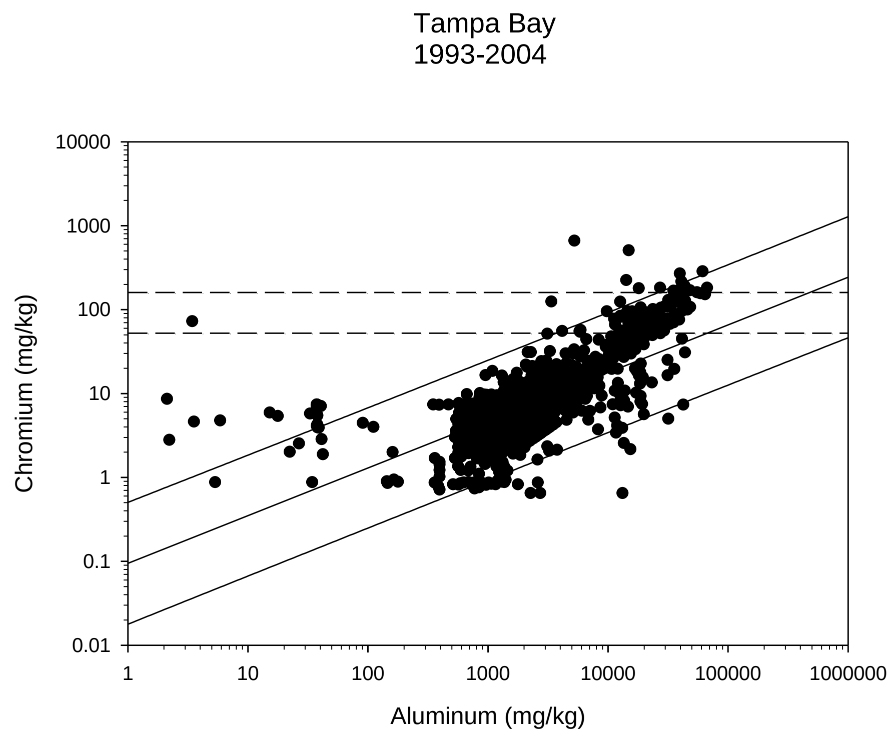

Figure 33. Tampa Bay Cr:Al ratio with 95% prediction intervals (solid lines). Dashed lines represent PEL (upper) and TEL (lower) values.

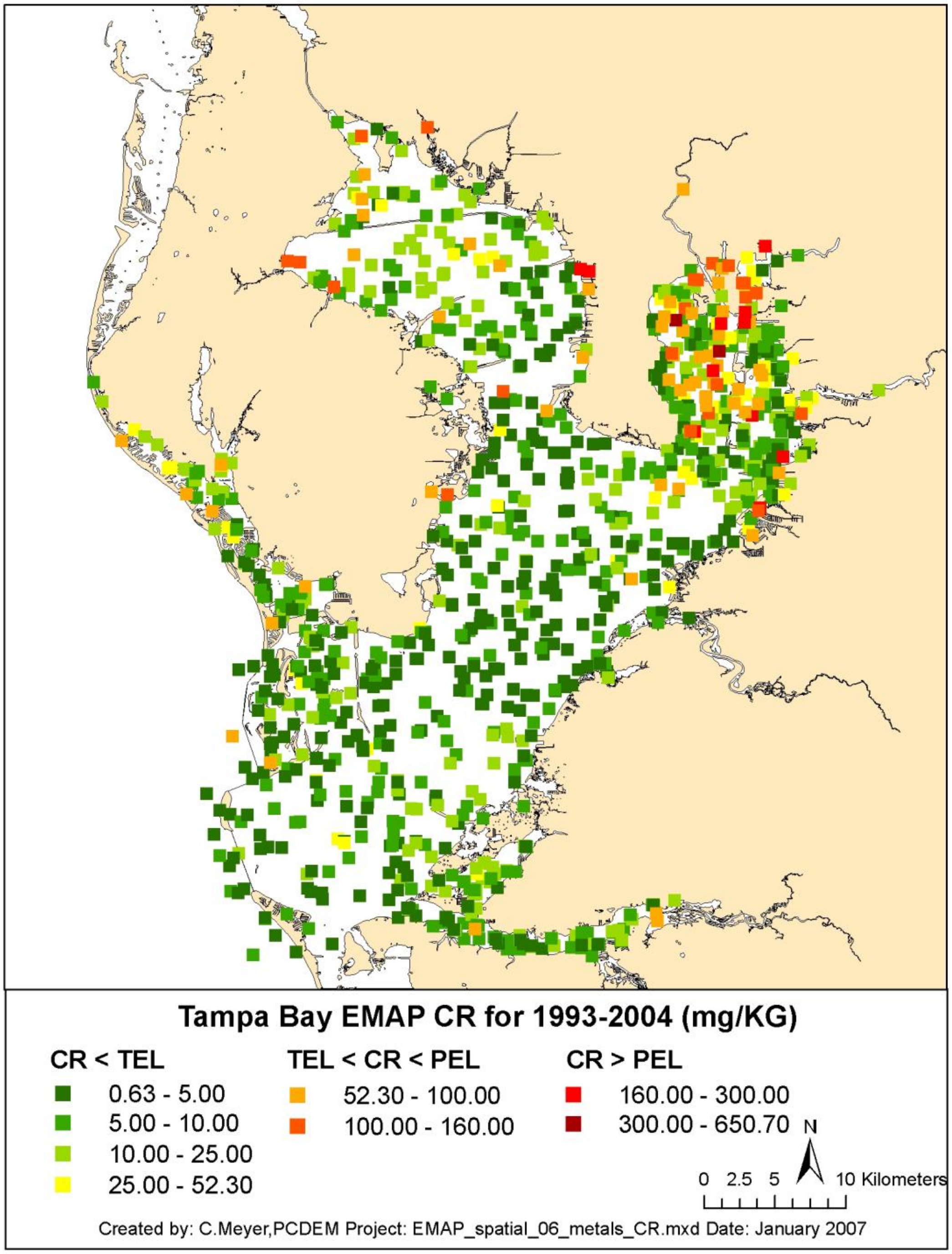

Figure 34. Distribution of chromium in Tampa Bay 1993-2004.

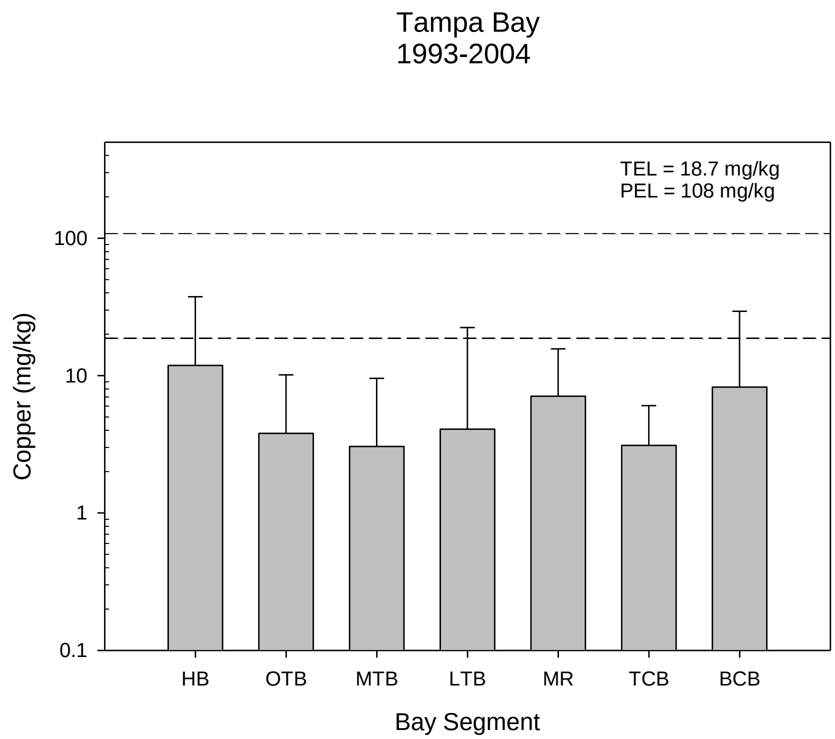

Figure 35. Mean sediment copper levels by bay segment. Error bars = 1 standard deviation, dashed lines represent PEL (upper) and TEL (lower) values.

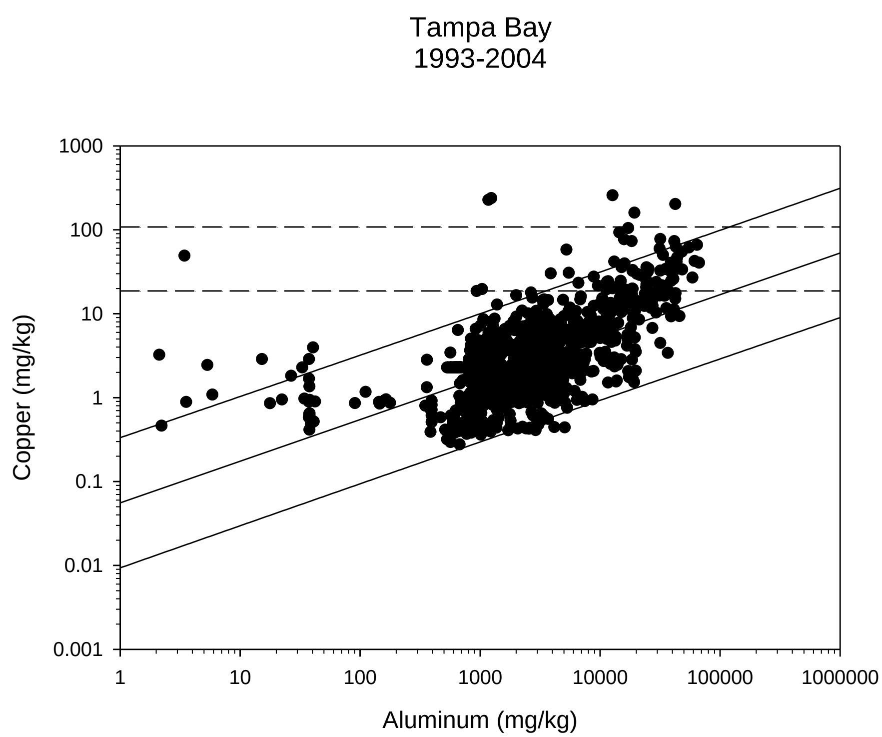

Figure 36. Tampa Bay Cu:Al ratio with 95% prediction intervals (solid lines). Dashed lines represent PEL (upper) and TEL (lower) values.

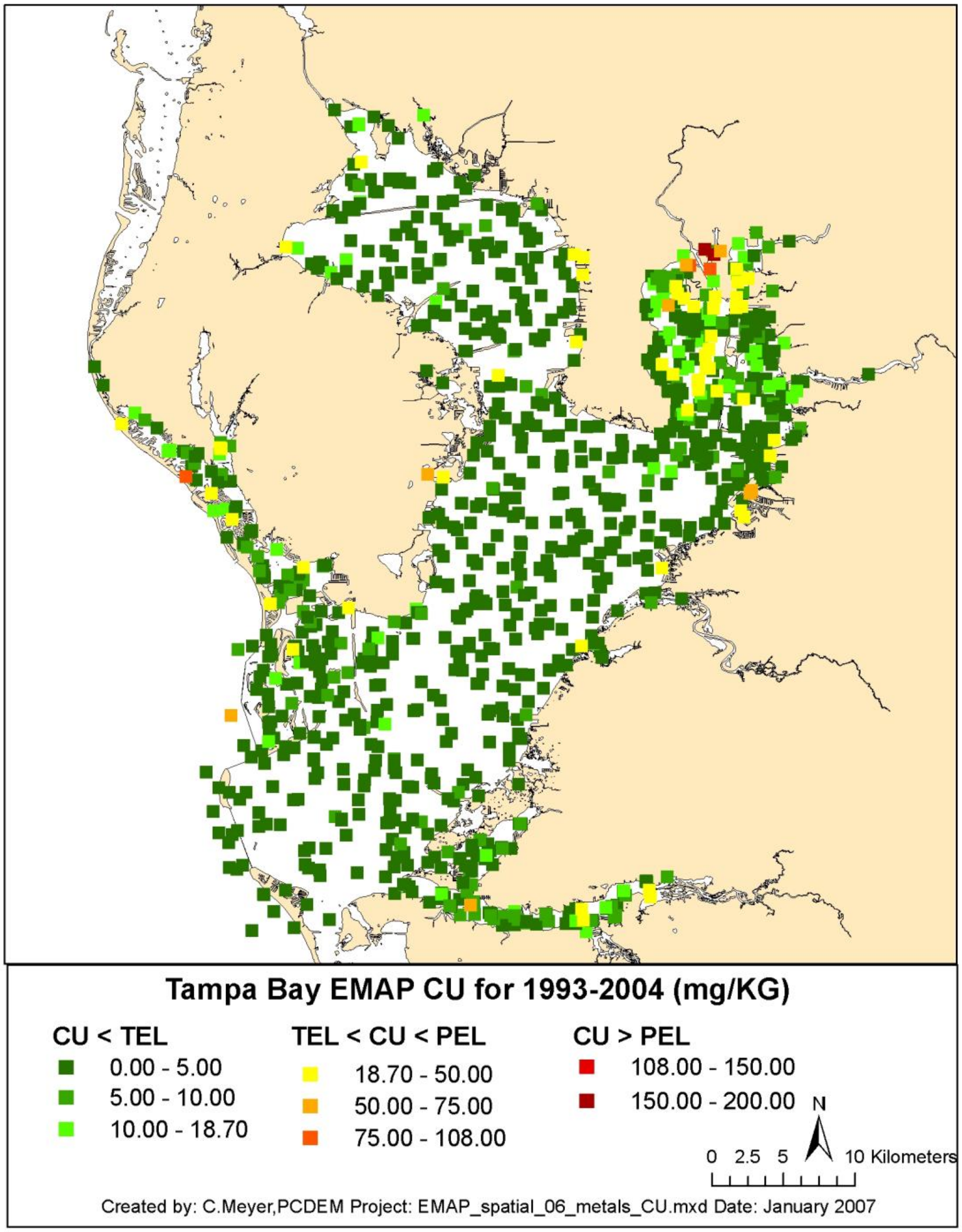

Figure 37. Distribution of copper in Tampa Bay 1993-2004.

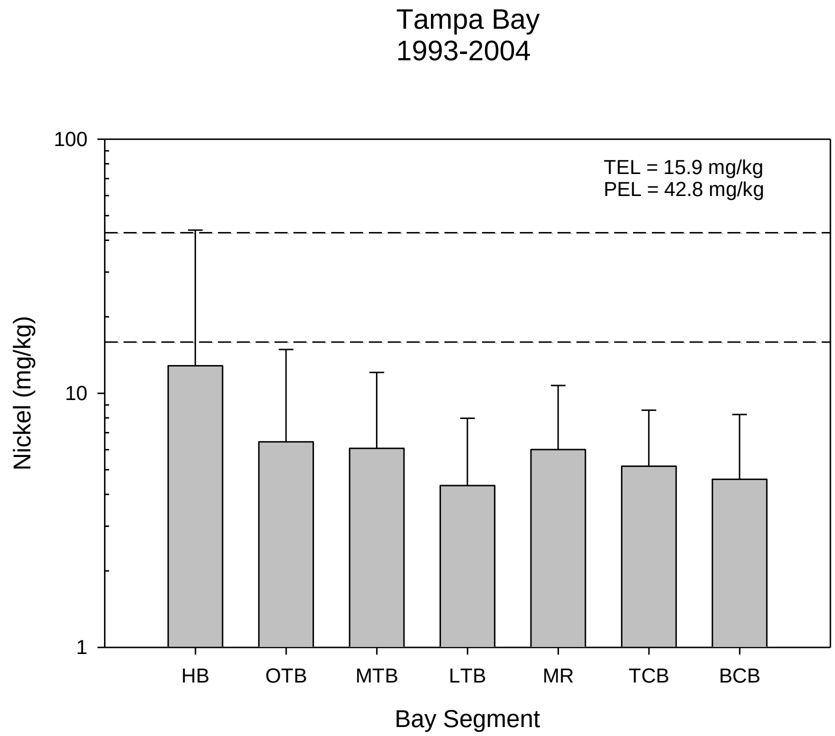

Figure 38. Mean sediment levels of nickel by bay segment. Error bars = 1 standard deviation, dashed lines represent PEL (upper) and TEL (lower) values.

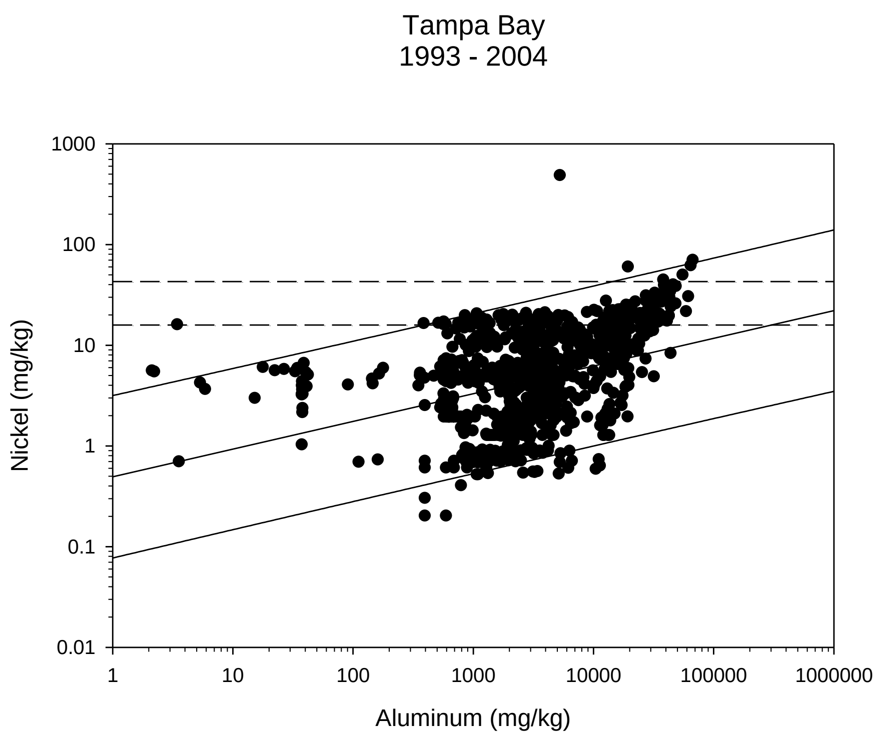

Figure 39. Tampa Bay Ni:Al ratio with 95% prediction intervals (solid lines). Dashed lines represent PEL (upper) and TEL (lower) values.

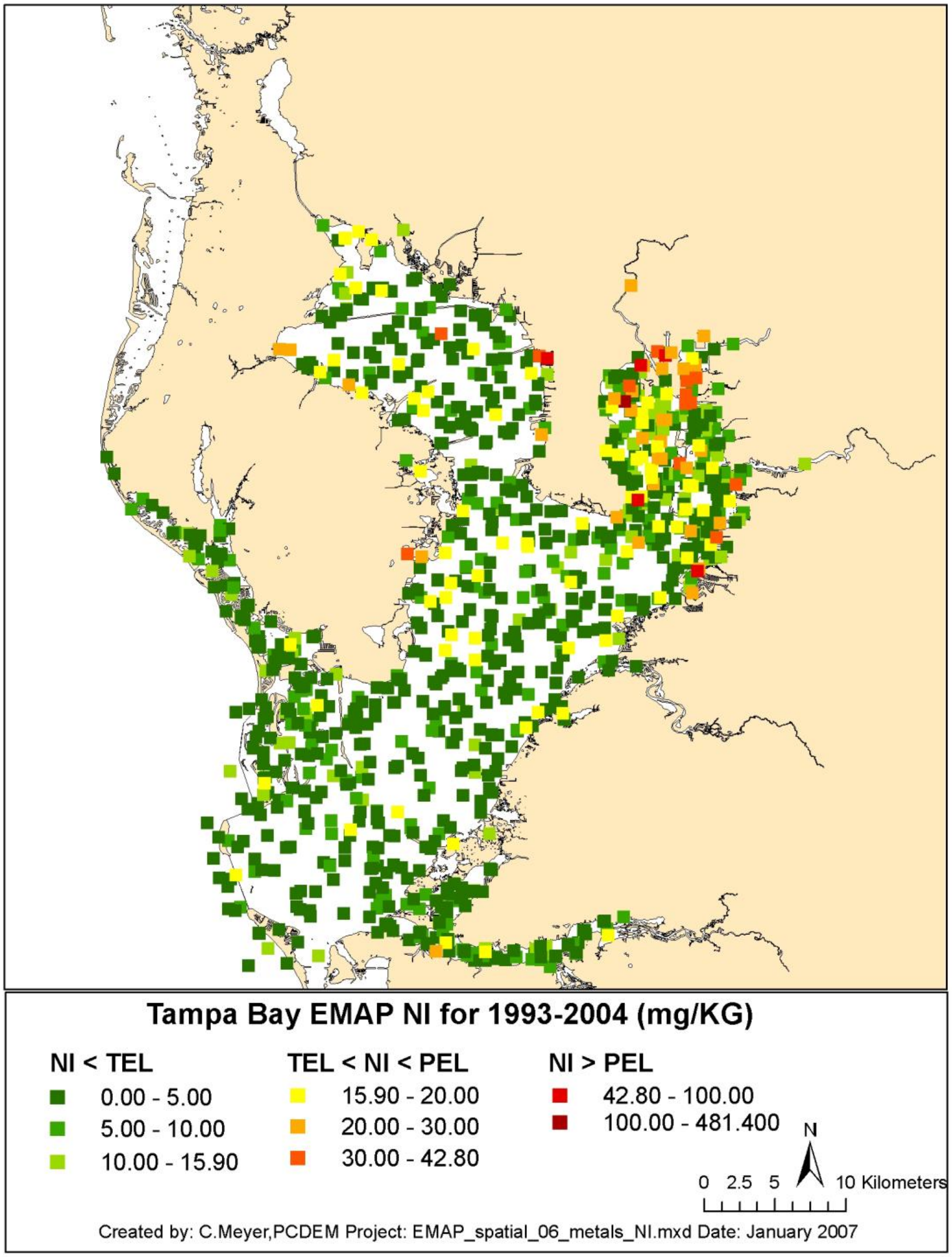

Figure 40. Distribution of nickel in Tampa Bay 1993-2004.

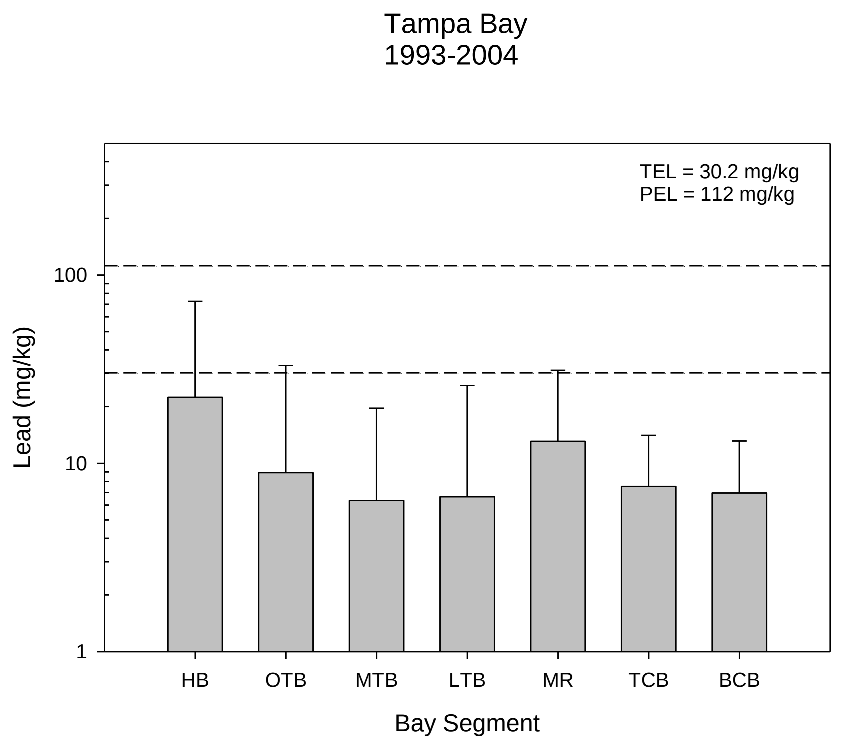

Figure 41. Mean sediment lead levels by bay segment. Error bars = 1 standard deviation, dashed lines represent PEL (upper) and TEL (lower) values.

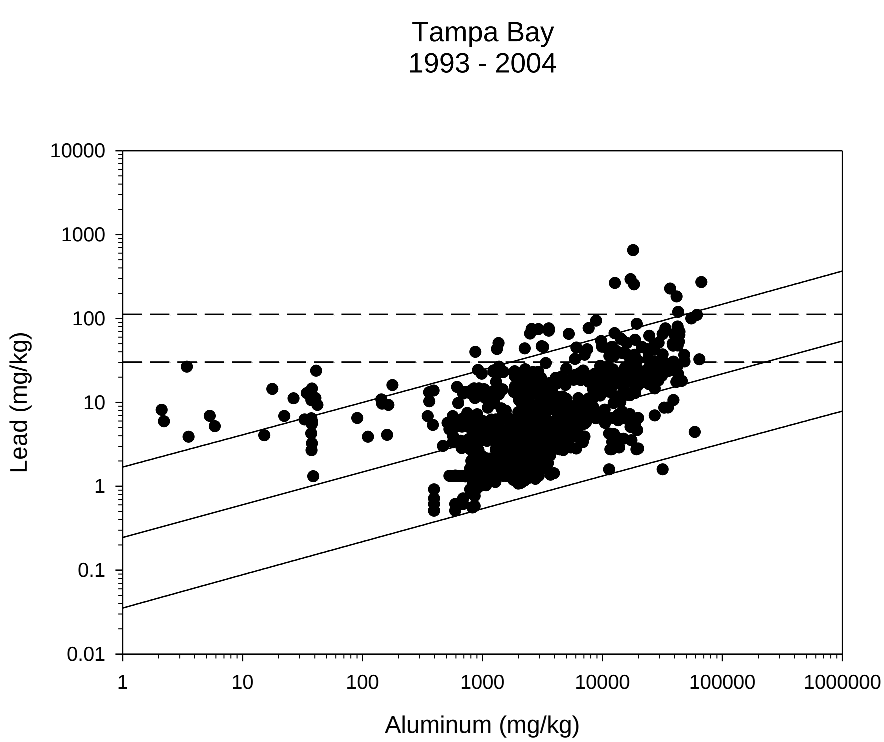

Figure 42. Tampa Bay Pb:Al ratio with 95% prediction intervals (solid lines). Dashed lines represent PEL (upper) and TEL (lower) values.

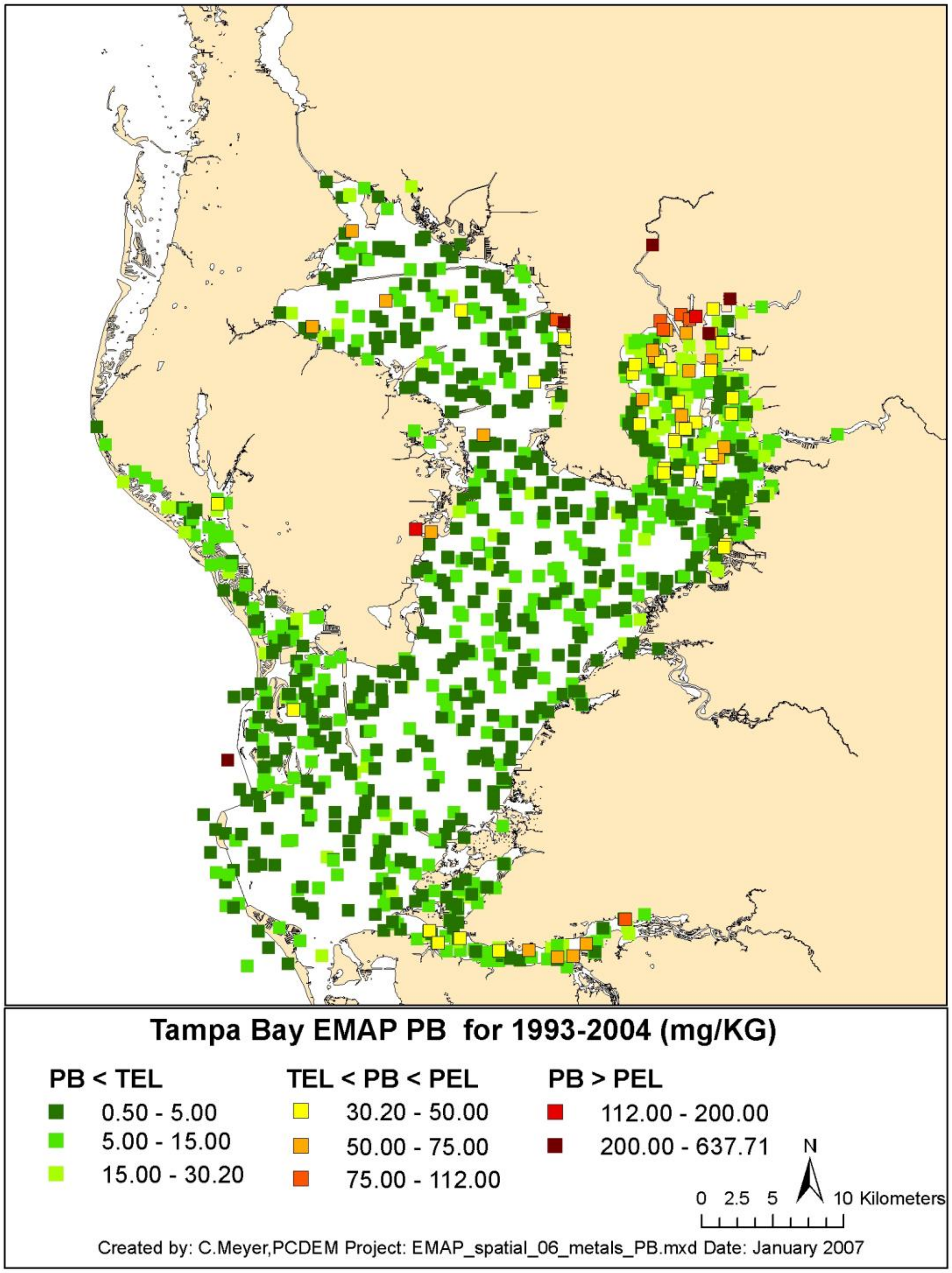

Figure 43. Distribution of lead in Tampa Bay 1993-2004.

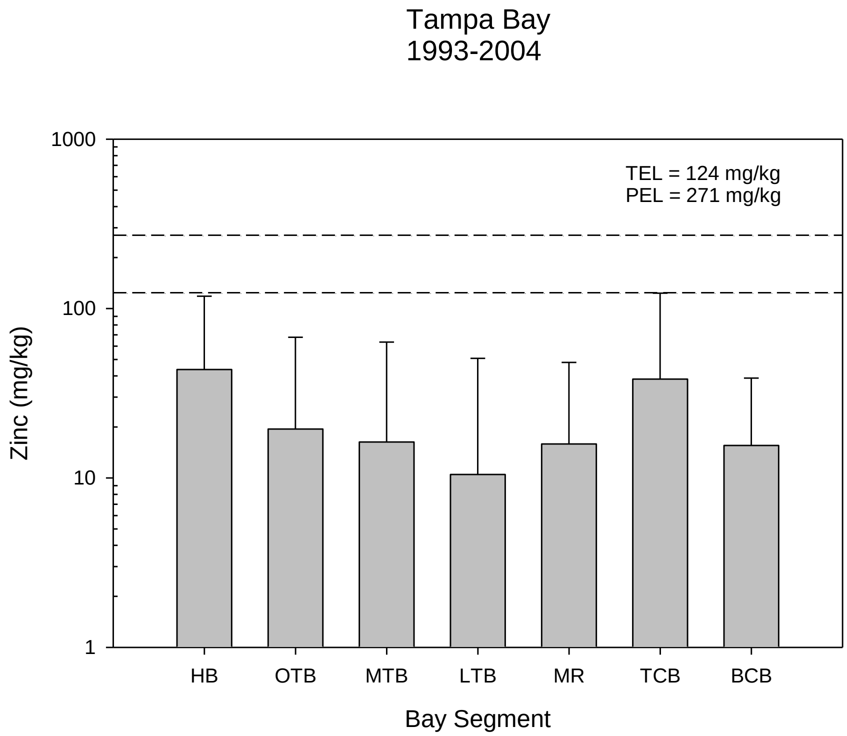

Figure 44. Mean sediment zinc levels by bay segment. Error bars = 1 standard deviation, dashed lines represent PEL (upper) and TEL (lower) values.

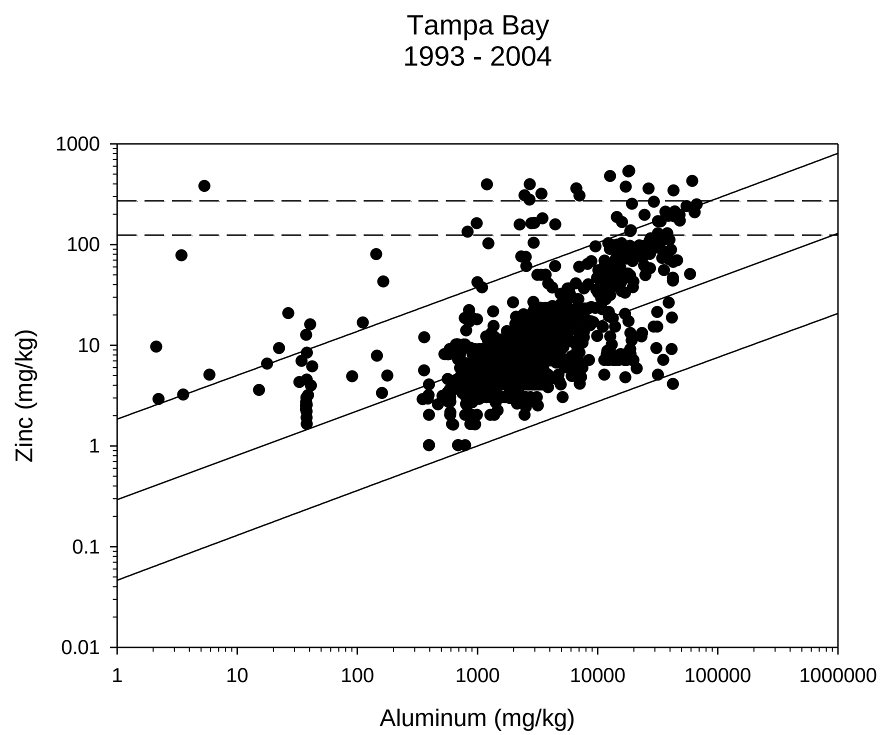

Figure 45. Tampa Bay Zn:Al ratio with 95% prediction intervals (solid lines). Dashed lines represent PEL (upper) and TEL (lower) values.

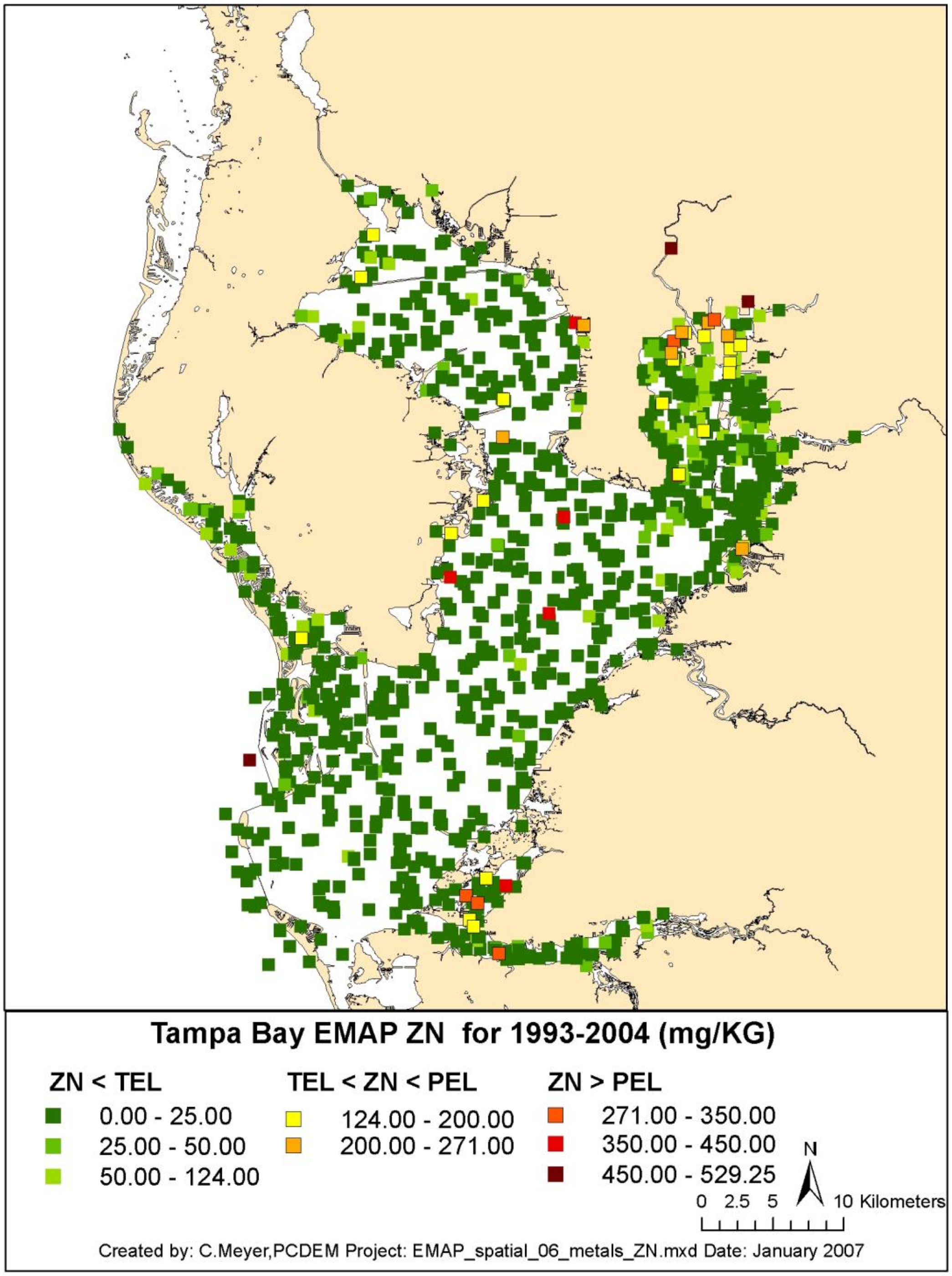

Figure 46. Distribution of Zinc in Tampa Bay 1993-2004.

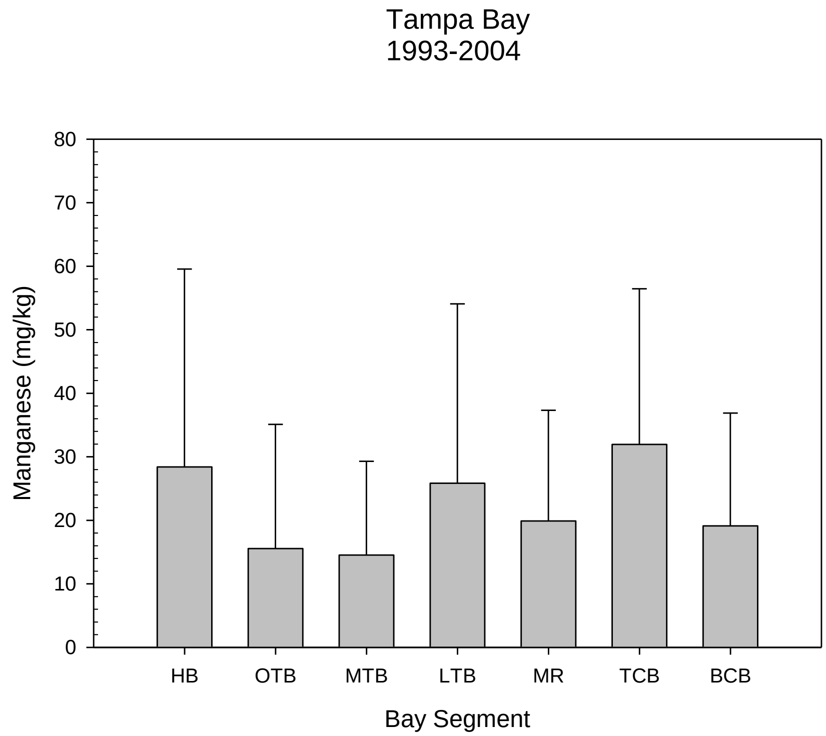

Figure 47. Mean sediment manganese levels by bay segment. Error bars = 1 standard deviation.

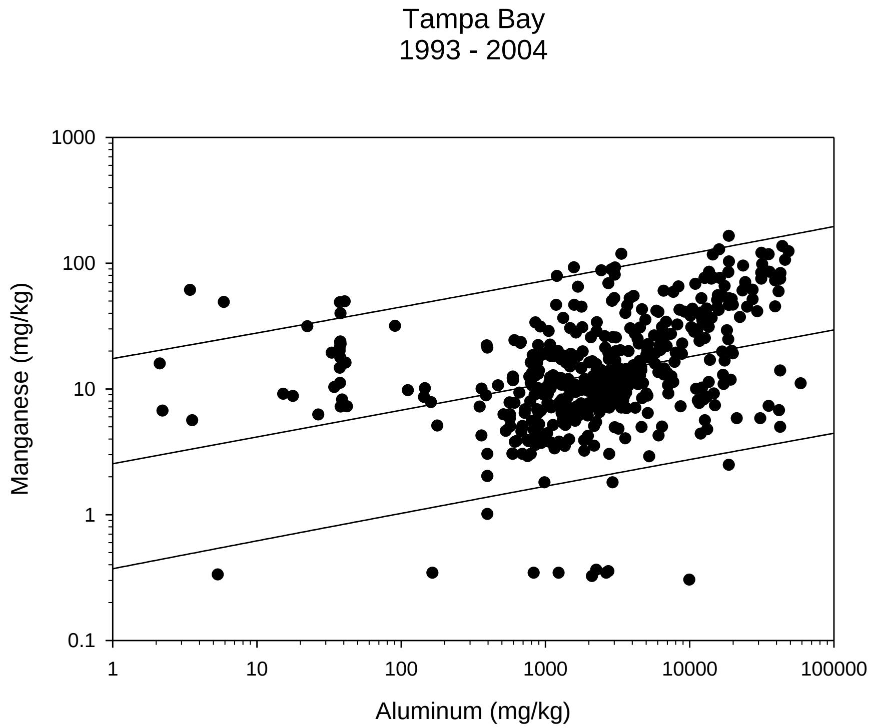

Figure 48. Tampa Bay Mn:Al ratio with 95% prediction intervals (solid lines).

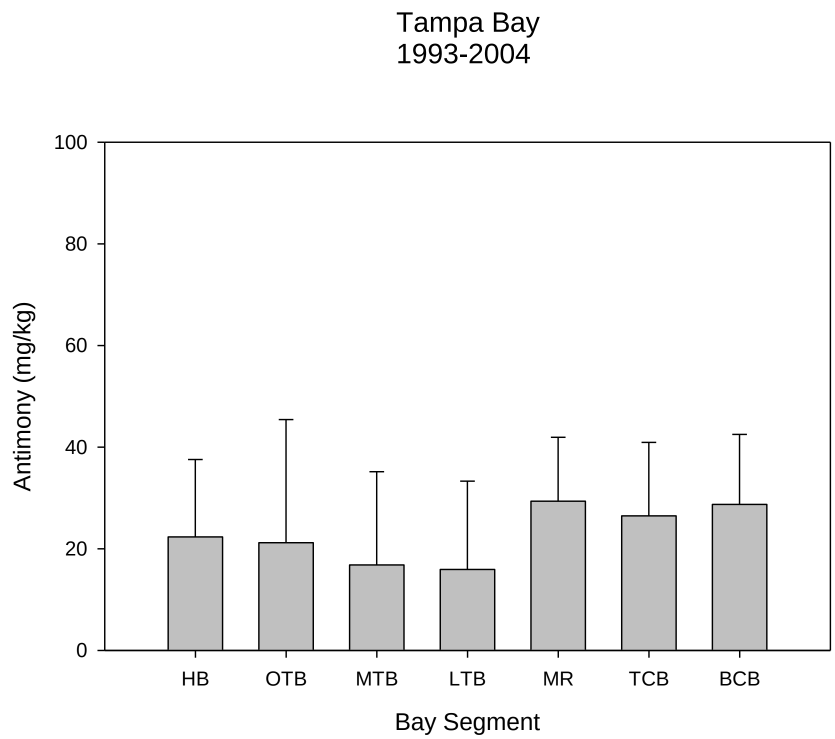

Figure 49. Mean sediment antimony levels by bay segment. Error bars = 1 standard deviation.

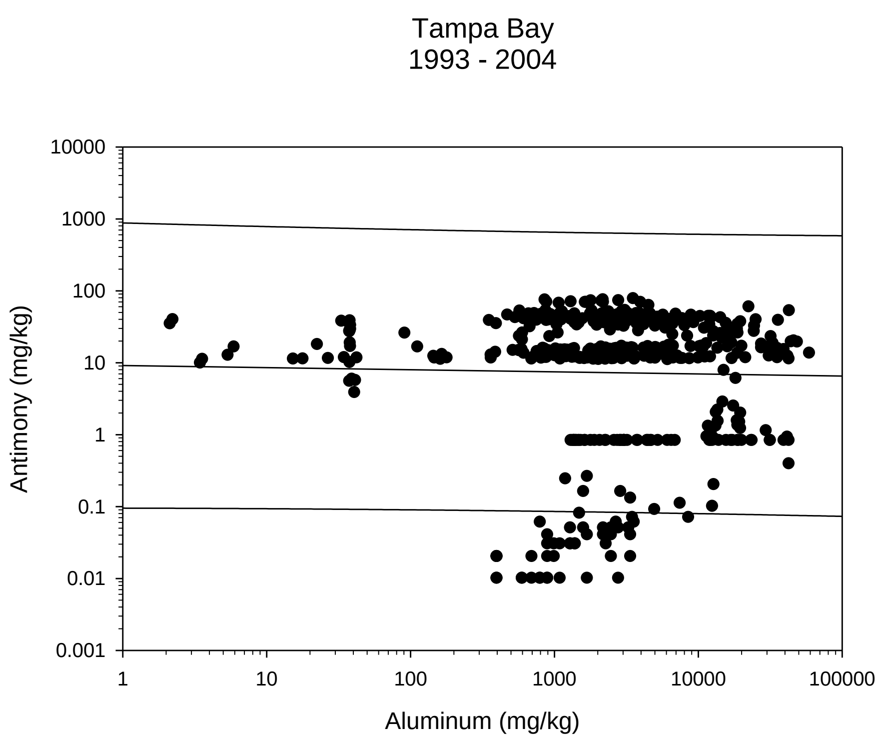

Figure 50. Tampa Bay Sb:Al ratio with 95% prediction intervals (solid lines).

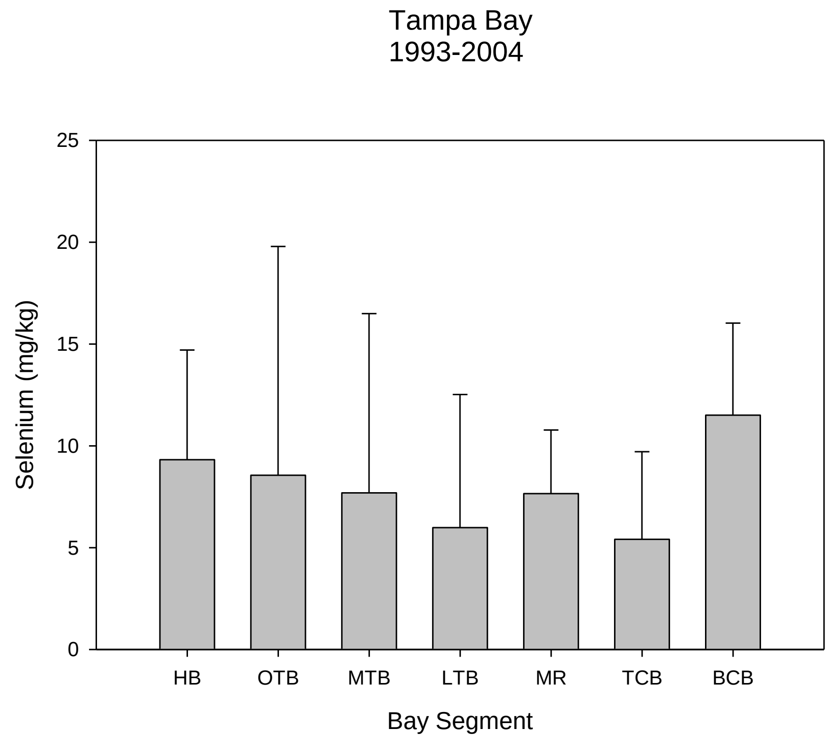

Figure 51. Mean sediment selenium levels by bay segment. Error bars = 1 standard deviation.

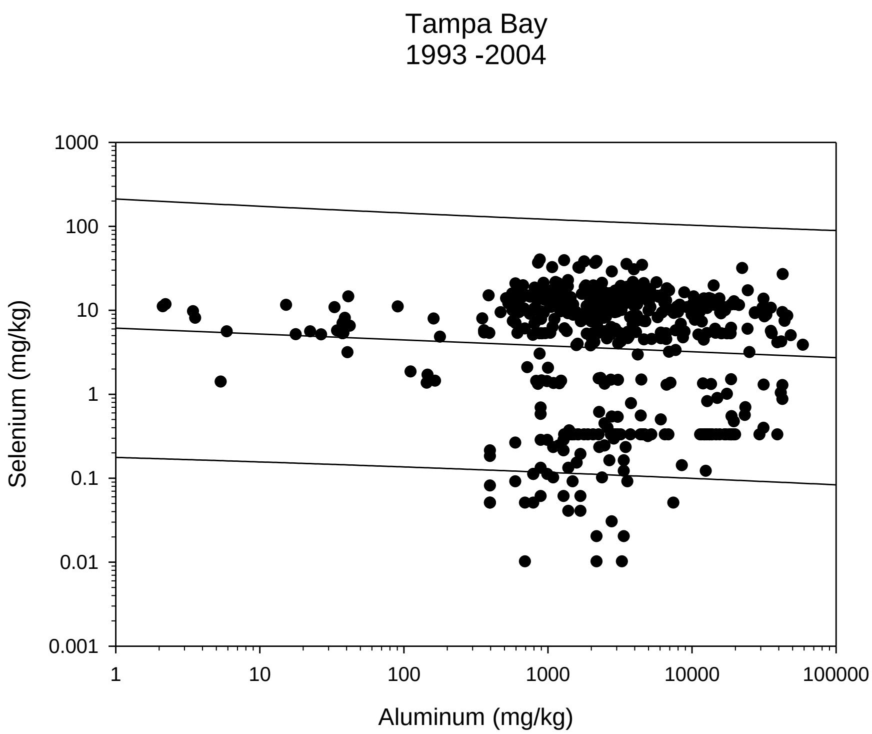

Figure 52. Tampa Bay Se:Al ratio with 95% prediction intervals (solid lines).

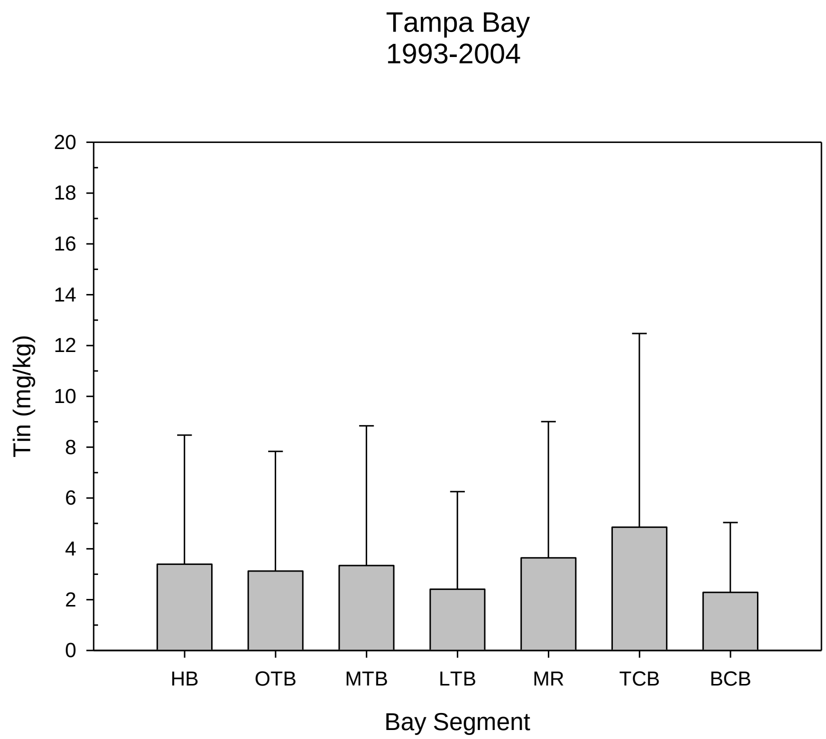

Figure 53. Mean sediment tin levels by bay segment. Error bars = 1 standard deviation.

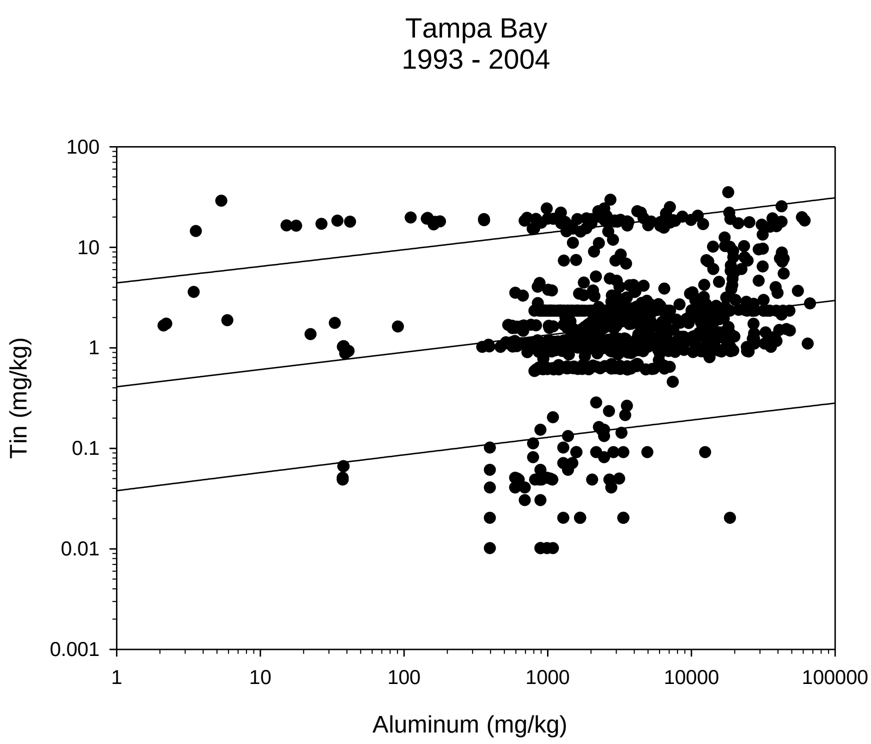

Figure 54. Tampa Bay Sn:Al ratio with 95% prediction intervals (solid lines).

Polycyclic Aromatic Hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons (PAHs) are organic compounds formed from carbon and hydrogen atoms arranged in two or more benzene rings (Kennish 1998). PAHs composed of two to three benzene rings are classified as low molecular weight PAHs (Long et al. 1994). Many of these compounds are known to have acute toxic affects as well as sublethal effects on marine organisms (Long et al. 1994, Kennish 1998). PAHs consisting of four to seven benzene rings are classified as high molecular weight PAHs (Long et al. 1994). These compounds are less toxic to marine organisms but many are known to be cancer causing (carcinogenic), cause genetic mutations (mutagenic) or can cause birth defects (teratogenic) (Long et al. 1994; Kennish 1998).

Natural sources of PAHs include the decomposition or combustion of organic matter and petroleum seeps. PAHs can be introduced into the environment anthropogenically through the combustion of fossil fuels, oil spills, atmospheric deposition and wastewater effluents (MacDonald 1994; Frithsen et al. 1995; Kennish 1998). Stormwater runoff from roads and urban areas is a major route of introduction for PAHs in estuarine systems, with PAH concentrations in water and sediments being highest near roadways and large urban centers (MacDonald 1994; Ngabe et al. 2000; Van Dolah et al. 2005). The primary source of PAHs in Tampa Bay is from the combustion of gasoline via automobile emissions (Grabe and Barron 2002, 2004) which enters the bay through stormwater runoff (McConnell and Brink 1997). Earlier analysis of the sediment chemistry samples collected from the Tampa Bay Benthic monitoring program indicated that areas of PAH contamination were typically restricted to sites with lower salinities and fine sediments, mainly within in the Hillsborough River and the upper reaches of Hillsborough Bay (Grabe and Barron 2002; 2004).

Bay-wide sediment PAH summary statistics and percent of samples exceeding the sediment toxicity TEL and PEL for each constituent PAH (MacDonald 1994) are presented in Tables 11-13 for all years combined. Due to the large number of low measurements, the mean rather than median values are presented for between bay segment comparisons.

Summary statistics and percentage of samples exceeding toxicity cut-offs for low molecular weight PAHs (LMW-PAHs) are presented in Table 11. Total LMW-PAHs were above the TEL at 0.96% of the sites and exceeded the PEL at 0.11% (Table 11). Two constituent LMW-PAHs in particular, acenaphthene and acenaphthylene, had TEL exceedences at 15% and 14% of the sites respectively (Table 11). Long et al. (1994) found a significant correlation between acenaphthylene concentration and amphipod survival in sediment toxicity tests from Tampa Bay sites. There were significant differences between bay segments (KW; $p< 0.001$) with highest levels occurring in Hillsborough Bay, the Manatee River, and Boca Ciega Bay (Figure 55).

The total high molecular weight PAHs (HMW-PAHs) were above the TEL at 2.78% of the sites and exceeded the PEL at 0.32% (Table 12). Dibenzo (a,h) anthracene exhibited the highest levels of contamination exceeding the TEL at nearly 15% of the sites and the PEL at over 1% (Table 12). There was a significant difference in HMW-PAH levels between bay segments with the highest mean values occurring in Hillsborough Bay followed by the Manatee River and Boca Ciega Bay (Figure 56). Total PAHs were above the TEL at 1.7% of the sites, but there were no PEL exceedences recorded (Table 12). Total PAH levels between bay segments were significantly different, with highest mean values recorded in Hillsborough Bay, the Manatee River, and Boca Ciega Bay (Figures 57 & 58). Several additional hydrocarbons that do not have established TEL or PEL values were measured during the course of the monitoring period. Summary statistics for these are presented in Table 13.

Table 11. Tampa Bay (1993-2004) sediment low molecular weight polycyclic aromatic hydrocarbon summary statistics and percentage of sites exceeding TEL and PEL values.

µg/kg	Acenaphthene	Acenaphthylene	Anthracene	Fluorene	Naphthalene	Phenanthrene	Total LMW PAHs
TEL	6.7	5.9	46.9	21.2	34.6	86.7	312.00
PEL	88.9	128	245	144	391	544	1440.00
n	935	935	935	935	935	935	935
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	129.00	414.00	169.00	123.00	358.00	862.93	1928.00
Median	3.00	3.00	3.00	3.00	2.90	3.00	20.00
Mean	4.13	4.14	4.32	4.03	5.40	13.37	35.39
SD	6.50	14.72	12.41	5.76	17.31	60.19	103.02
% >TEL;<PEL	**15.10%**	**14.13%**	**0.96%**	**0.96%**	**1.82%**	**1.71%**	**0.96%**
% >PEL	**0.21%**	**0.21%**	**0.00%**	**0.00%**	**0.00%**	**0.43%**	**0.11%**

Table 12. Tampa Bay (1993-2004) sediment high molecular weight and total polycyclic aromatic hydrocarbon summary statistics and percentage of sites exceeding TEL and PEL values.

µg/kg	Benzo (a) anthracene	Benzo (a) pyrene	Chrysene	Dibenzo(a,h) anthracene	Fluoranthene	Pyrene	Total HMW PAHs	TOTAL PAHs
TEL	74.8	88.8	108	6.2	113	153	655.00	1680.00
PEL	693	763	846	135	1490	1400	6680.00	16800.00
n	935	935	881	935	935	935	935	935
Min.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Max.	1564.00	2103.88	2326.89	830.00	3014.98	4889.99	14455.03	15562.48
Median	3.00	3.00	3.00	3.00	3.00	3.00	18.00	38.00
Mean	17.20	22.99	23.35	9.69	32.31	38.27	142.68	178.08
SD	87.38	121.80	116.73	46.87	176.38	237.70	770.66	863.76
% >TEL;<PEL	**2.89%**	**3.21%**	**2.73%**	**14.78%**	**3.51%**	**2.92%**	**2.78%**	**1.71%**
% >PEL	**0.43%**	**0.43%**	**0.57%**	**1.07%**	**0.34%**	**0.56%**	**0.32%**	**0.00%**

Table 13. Other measured hydrocarbons without established TEL/PELs.

µg/kg	Benzo(b)fluoranthene	Benzo(k)fluoranthene	Indeno(1)pyrene	Benzo(g,h,i)perylene	Retene	Coronene
n	935	935	935	795	288	288
Min.	0.00	0.00	0.00	0.00	0.98	1.02
Max.	3382.50	1808.00	2161.00	2500.01	62.87	1262.48
Median	4.00	3.15	2.00	3.00	5.60	3.40
Mean	32.57	17.92	18.92	22.50	5.76	17.13
SD	185.82	89.33	114.58	131.66	6.97	76.49

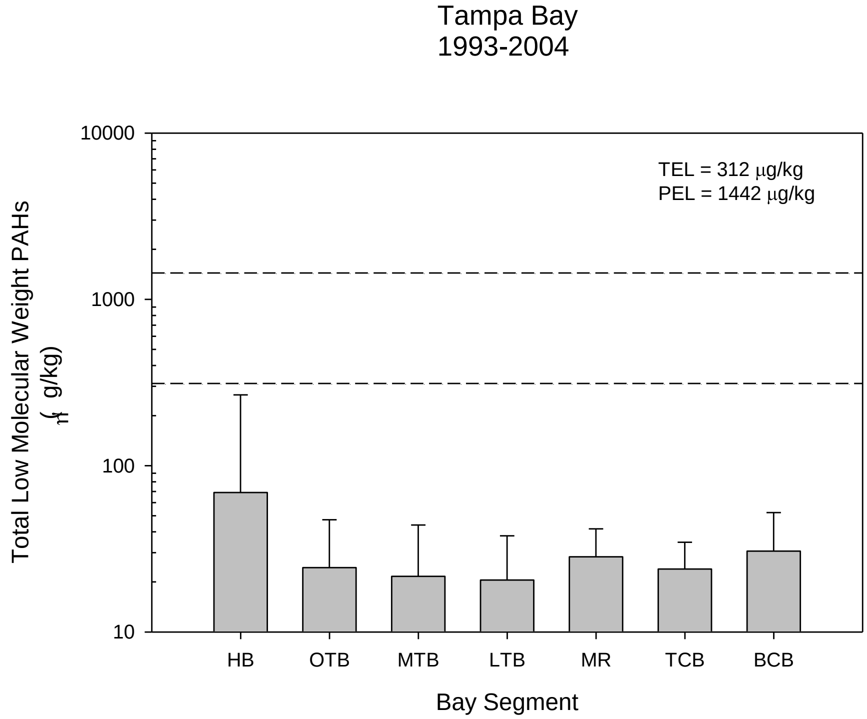

Figure 55. Mean levels for total LMW-PAHs by bay segment. Error bars = 1 standard deviation, dashed lines represent PEL (upper) and TEL (lower) values.

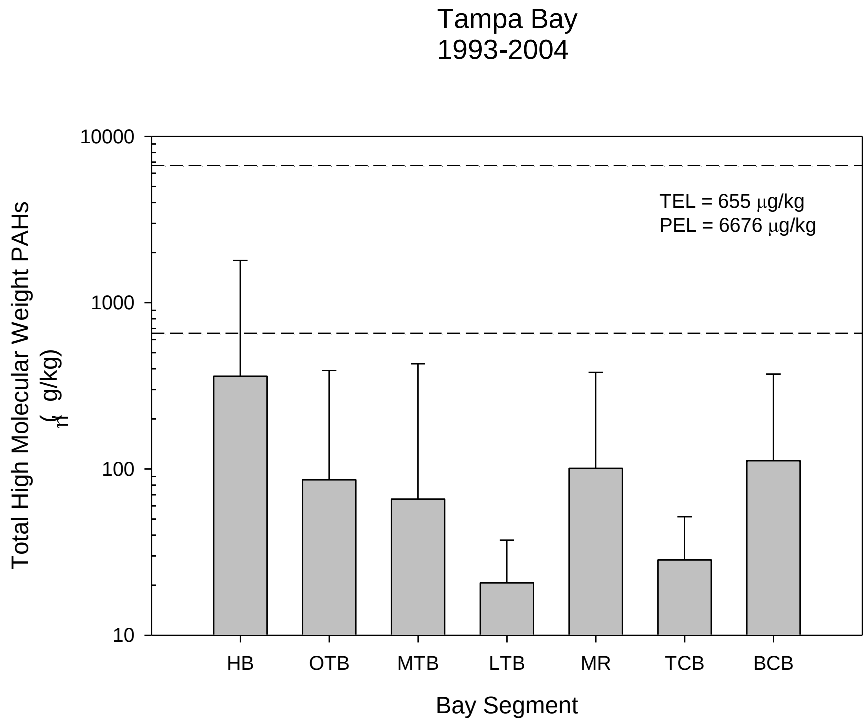

Figure 56. Mean levels for total HMW-PAHs by bay segment. Error bars = 1 standard deviation, dashed lines represent PEL (upper) and TEL (lower) values.

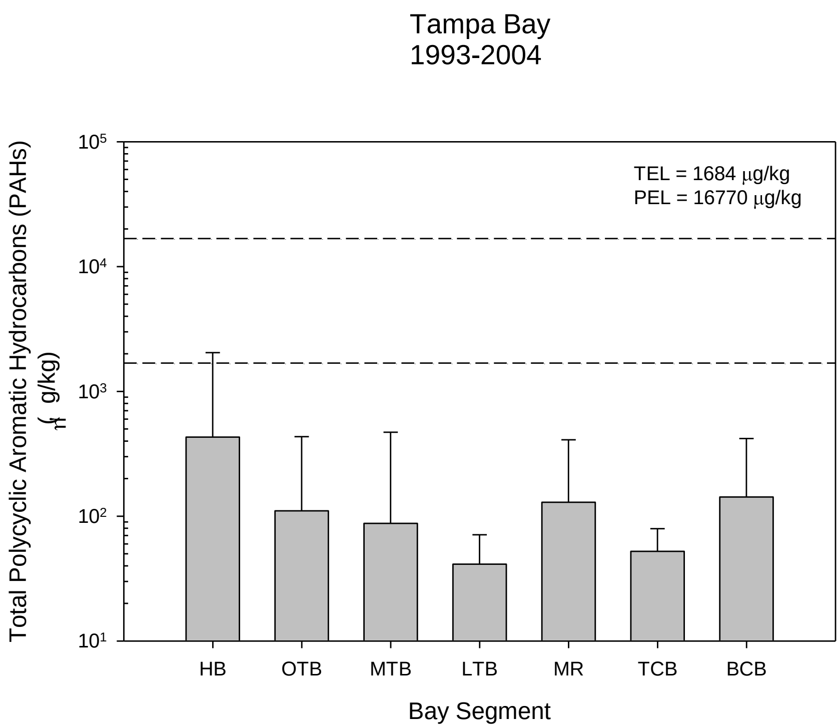

Figure 57. Mean levels for total PAHs by bay segment. Error bars = 1 standard deviation, dashed lines represent PEL (upper) and TEL (lower) values.

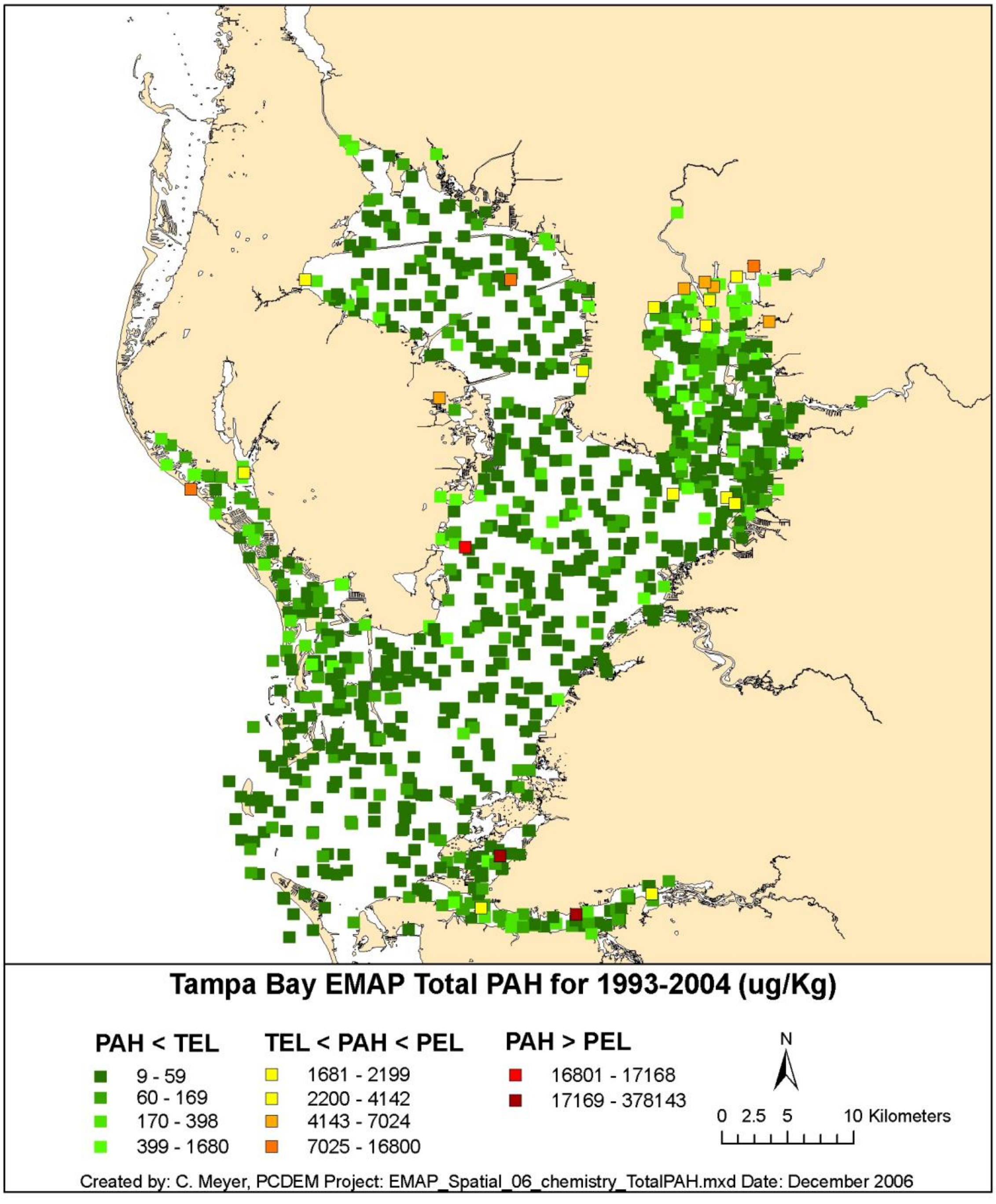

Figure 58. Distribution of total PAH's in Tampa Bay 1993-2004.

Polychlorinated biphenyls (PCBs) and Chlorinated Pesticides

Bay-wide summary statistics for Total PCBs and pesticides are presented in Table 14. Additional pesticides that were measured but which do not have set TEL/PEL cutoffs are summarized in Table 15. Due to the large number of low readings for these contaminants, the mean values are presented for between bay-segment comparisons.

Polychlorinated biphenyls (PCBs) are organic compounds composed of a biphenyl polycyclic aromatic hydrocarbon with one to ten attached chlorine atoms (Frithsen et al. 1995). PCBs can have 209 possible isomers (congeners) which are grouped based on the number of attached chlorine atoms (Frithsen et al. 1995). PCBs were commonly used for numerous industrial applications including as dielectric fluids in transformers and capacitors, lubricants, hydraulic fluids, flame retardants, adhesives, and plasticizers among other uses (MacDonald 1994; Frithsen et al. 1995). The manufacture of PCBs in the United States was banned in 1976, but production in other countries continued through the 1980s (Frithsen et al. 1995). Sources of PCB contaminants in the environment include waste discharges from industry, leaching from disposal sites, leaks and spills of PCB containing products and vaporization from plastics (Frithsen et al. 1995; Kennish 1998). Because PCBs are stable compounds and insoluble in water they tend to accumulate in fine grained sediments with high organic content. PCBs further can accumulate in fat tissues and are known to bioaccumulate in organisms and biomagnify at higher trophic levels in the food web (Kennish 1998); however, recent studies suggest that bioaccumulation of PCBs may be more a factor of size and age of the individual organism rather than its trophic level (Burreau et al. 2006; Magnusson et al. 2006). Levels of PCBs in marine and freshwater organisms have also been shown to be related to sediment concentrations and proximity of known areas of contamination (Kuzyk et al. 2005; Straub et al. 2007).

Bay-wide total PCBs exceeded the TEL in 2.28% of the samples and were significantly different between bay segments (KW; $p<0.001$) with the highest values in Hillsborough Bay (Figure 59). Frithsen et al. (1995) estimated annual loading of PCBs to Tampa Bay at 11 kg/year with the primary input from atmospheric deposition. Grabe and Barron (2002; 2004) found PCB contamination in Tampa Bay was primarily in the tributaries and particularly in the Palm River.

Chlorinated pesticides or organochlorines are composed of one or more hydrocarbon rings with attached chlorine atoms (Kamrin 1997). This group of organic compounds was widely used as pesticides for agriculture and mosquito control, but most uses were reduced or eliminated in the United States since the 1970’s due to their adverse affects on non-target organisms (Kamrin 1997; Kennish 1998). However, these pesticides are still used in other parts of the world. Chlorinated pesticides work by attacking the central nervous system. They affect the sodium/potassium balance along nerves causing continuous transmission of impulses along the nerve fiber which can result in nervousness, tremors, or convulsions and ultimately causing paralysis and death (Kamrin 1997; Kennish 1998). Chlorinated pesticides are lipid soluble and can accumulate in fat tissues as well as adsorb to organic sediments. These compounds also bioaccumulate and highest tissue concentrations are found in predatory species at the top of the food chain (Kamrin 1997; Kennish 1998).

The pesticide lindane (gamma-BHC) has been used as an insecticide on crop and to control insect-borne diseases as well as in shampoo and lotions to control lice in humans (Kamrin 1997). Lindane is highly toxic to aquatic invertebrates and fish (Kamrin 1997) and also affects phytoplankton and zooplankton abundances (Fliedner and Klein 1996). Like other organochlorines, lindane accumulates in organic sediments and bioaccumulates in organisms living and feeding in the sediments. Egeler et al. (1997) found tubificid oligochaetes bioaccumulate lindane from sediments in microcosm studies. In Tampa Bay, lindane was above the TEL concentration in 2.28% of the samples, but only exceeded the PEL in 0.11% of the samples (Table 14). Relatively higher sediment concentrations were found in Lower Tampa Bay despite the lower silt+clay content in that bay segment. The four main bay segments (HB, OTB, MTB, and LTB) also had significantly higher lindane values than the three smaller segments (Figure 60; KW, $p < 0.001$). Frithsen et al. (1995) did not include lindane in their loading estimates for Tampa Bay and the explanation for the distribution of this pesticide in Tampa Bay is not known at this time.

Dieldrin has been used widely to control agricultural pests and is also a breakdown product of aldrin, another pesticide used in agriculture as well as for termite control (MacDonald 1994). Frithsen et al. (1995) estimate annual loading of dieldrin to Tampa Bay at 775 kg, with agricultural runoff accounting for 99% of the input. In Tampa Bay, dieldrin was above the TEL concentration in 1.28% of the samples and exceeded its PEL in only 0.11% of the samples (Table 14). There were significant differences between bay segments for dieldrin, (KW, $p<0.001$) with Hillsborough Bay having the highest mean value while Lower Tampa Bay had the highest median value (Figure 61). Concentrations were significantly higher in the main bay segments relative to the three smaller segments, with the exception of Hillsborough Bay and Boca Ciega Bay.

Dichlorodiphenylethane (DDT) was widely used as an agricultural pesticide and for mosquito control through the 1960s (Kamrin 1997). DDT has been banned in the United States for over 30 years; however, total DDT and it's breakdown compounds p,p'-DDD, p,p'-DDE and p,p'-DDT are still detectable in Tampa Bay sediments (Table 14). Frithsen et al. (1995) estimated annual loadings of DDT to Tampa Bay of approximately 1,660 kg with 95% coming from agricultural runoff. One of the most notorious effects of DDT is the breakdown of the hormones that regulate calcium mobilization and eggshell formation in birds which historically had led to the reproductive failure and population decline of several bird species (Kennish 1998). DDT can also accumulate in aquatic food webs (Wang and Wang 2005) and has been associated with decreasing abundance of amphipods (Swartz et al. 1994) and can have effects on the overall benthic community structure (Ferraro and Cole 1997). Total DDT (Figure 62) was generally highest in Hillsborough Bay. High levels were also recorded in the Manatee River and Boca Ciega Bay. There were significant differences between bay segments for all DDT products with the exception of p,p'-DDT (KW; $p=0.339$). Total DDT and p,p'-DDE exceeded their TELs in just over 2% of the samples (Table 14).

Chlordane was formally used for several applications including as a home and garden pesticide, as a treatment for termites, and as a wood preservative (MacDonald 1994; Frithsen et al. 1995). This pesticide is highly toxic to marine and aquatic organisms, particularly crustaceans and aquatic insects (Kamrin 1997; Moore et al. 1998) and can also accumulate in the fatty tissues of commercially and recreationally important fish and shellfish (Kennish and Ruppel 1996, 1997). The use of chlordane has been banned since 1988 after it was classified as a probable carcinogen by the EPA (Kamrin 1997). Total chlordane is a composite of several isomers primarily consisting of alpha-chlordane and gamma-chlordane (MacDonald 1994). Total chlordane levels were highest in Hillsborough Bay and Old Tampa Bay, while Lower Tampa Bay and Boca Ciega Bay also had slightly elevated levels (Figure 63). Bay-wide, approximately 1% of the samples had total chlordane levels above the TEL and 1% above the PEL (Table 14). Annual inputs of chlordane to Tampa Bay were estimated at 1,050 kg with 77% coming from agricultural runoff and 21% from urban runoff (Frithsen et al. 1995).

Table 14. Total PCBs and Pesticide summary statistics.

µg/kg	Total PCBs	Lindane	Dieldrin	DDD	DDE	DDT	Total DDT	Total Chlordane
TEL	21.60	0.32	0.72	1.2	2.1	1.2	3.89	2.30
PEL	189.00	0.99	4.30	7.8	37.4	4.8	51.70	4.80
n	879	935	935	935	935	935	935	935
Minimum	0.45	0.01	0.01	0.02	0.02	0.02	0.08	0.03
Maximum	199.90	1.62	7.87	29.98	117.35	19.04	166.36	166.75
Median	2.70	0.05	0.05	0.04	0.10	0.10	0.26	0.14
Mean	5.19	0.08	0.10	0.19	0.48	0.18	0.84	0.69
SD	10.75	0.10	0.31	1.17	4.30	0.70	6.01	7.18
% >TEL;<PEL	**2.28%**	**1.82%**	**1.28%**	**0.96%**	**2.14%**	**1.28%**	**2.03%**	**0.96%**
% >PEL	**0.11%**	**0.21%**	**0.11%**	**0.43%**	**0.11%**	**0.21%**	**0.11%**	**0.96%**

Table 15. Other measured pesticides without established TEL/PELs.

µg/kg	Alpha - BHC	Beta- BHC	Delta- BHC	Endosulfan 1	Endosulfan 2	Endosulfate	Endrin	Endrin aldehyde	Endrin keytone
n	935	879	879	935	935	879	935	879	879
Minimum	0.01	0.02	0.01	0.02	0.01	0.01	0.02	0.03	0.02
Maximum	4.61	2.50	2.50	4.90	2.20	5.14	2.84	4.67	5.10
Median	0.05	0.10	0.09	0.14	0.05	0.05	0.05	0.05	0.20
Mean	0.09	0.10	0.09	0.14	0.09	0.09	0.09	0.13	0.16
SD	0.18	0.12	0.16	0.18	0.15	0.20	0.22	0.27	0.22

Table 15. Continued.

µg/kg	Aldrin	Alpha- Chlordane	Gamma- Chlordane	Heptachlor	Heptachlor Epoxide	Methoxychlor	Mirex
n	935	787	787	879	879	879	935
Minimum	0.02	0.01	0.02	0.02	0.03	0.03	0.02
Maximum	1.49	76.35	90.40	1.90	2.10	7.64	1.11
Median	0.10	0.05	0.06	0.10	0.05	0.10	0.10
Mean	0.09	0.23	0.27	0.22	0.14	0.14	0.10
SD	0.10	2.79	3.30	0.21	0.16	0.36	0.10

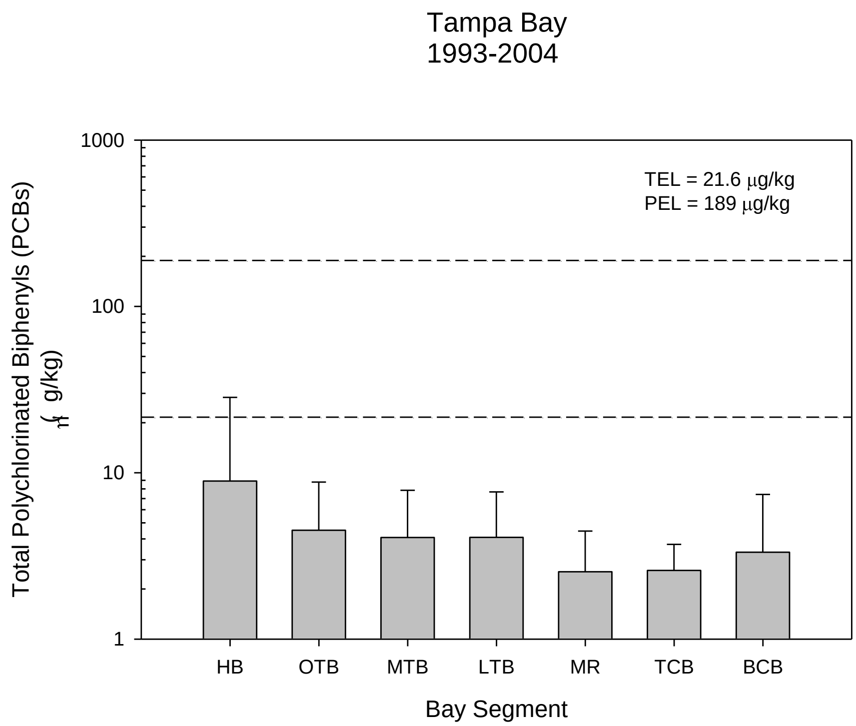

Figure 59. Mean levels for total PCBs by bay segment. Error bars = 1 standard deviation.

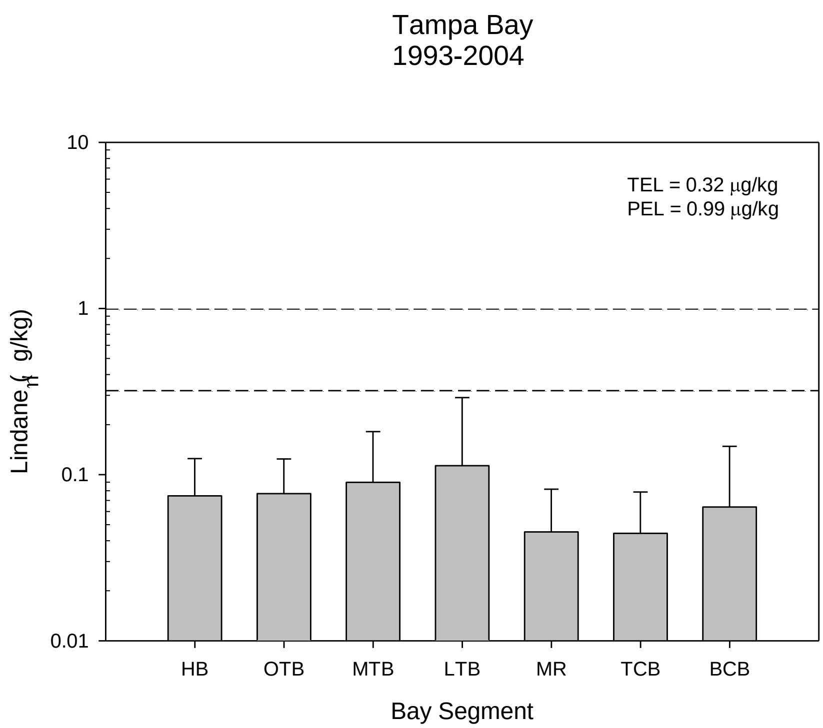

Figure 60. Mean levels for lindane by bay segment. Error bars = 1 standard deviation.

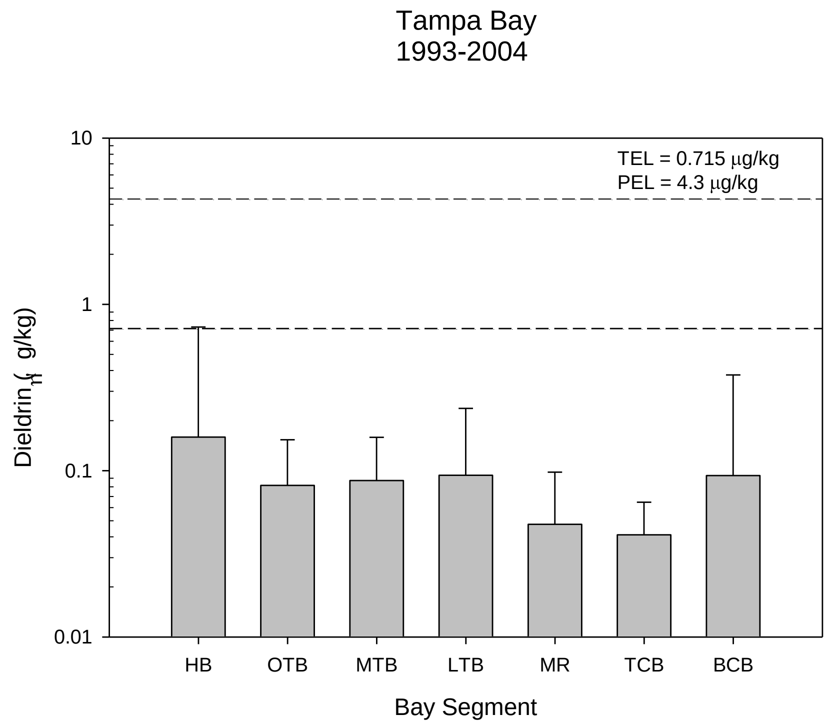

Figure 61. Mean levels of dieldrin by bay segment error bars = 1 standard deviation.

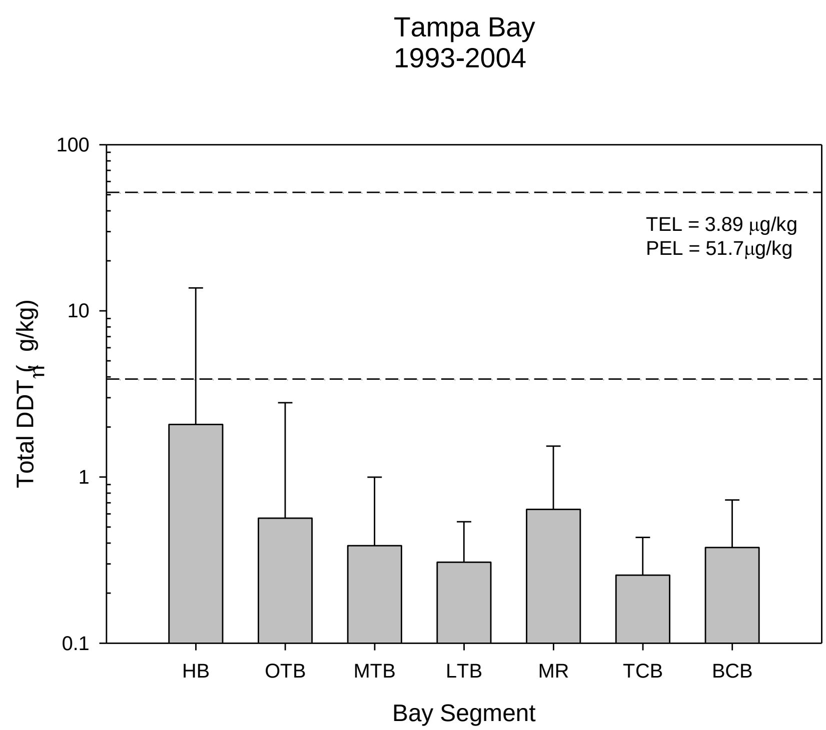

Figure 62. Mean levels of total DDT by bay segment. Error bars = 1 standard deviation.

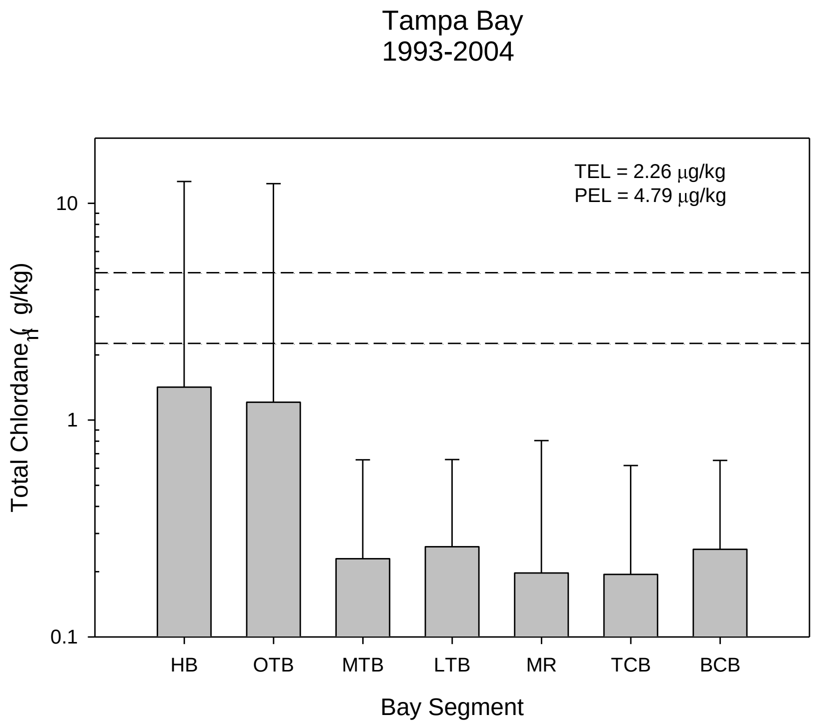

Figure 63. Mean levels of total chlordane by bay segment. Error bars = 1 standard deviation.

Benthic Community Structure

Summary Statistics

Table 16 presents the median, minimum, and maximum recorded values for benthic species richness, abundance, the Shannon Diversity Index, and the Tampa Bay Benthic Index by year and four-year sampling phase. The same summary statistics are presented for each Bay Segment in Table 17.

The overall median number of taxa per sample was 35 and ranged from 0 to 125 (Tables 16 &17). The highest median number of taxa was in 1997, followed by 1993 and 2002. The lowest median numbers of taxa were in 2003 and 1998 (Table 16; Figure 64). There was a significant difference in species richness among years (KW, $p < 0.001$) although most pair-wise comparisons (Dunn's Method) were not significant. Species richness in 1997 was significantly higher relative to 1998, 2003, and 2001; 1993 was higher than 1998 (Dunn's; $p < 0.05$).

There was a general trend of increasing species richness towards the mouth of the bay with the highest median number of taxa being recorded in Lower Tampa Bay and Boca Ciega Bay (Table 17; Figure 65). Overall differences in species richness between bay segments were significant (KW; $p < 0.001$). Lower Tampa Bay, Middle Tampa Bay, and Boca Ciega Bay were not statistically different from each other, and all three had higher numbers of taxa than Hillsborough Bay, Old Tampa Bay, and the Manatee River. Terra Ceia Bay and Old Tampa Bay were not significantly different from each other and were intermediate between the other bay segments. Terra Ceia Bay was not statistically different in number of taxa relative to Lower Tampa Bay, Middle Tampa Bay, and Boca Ciega Bay but was higher than Hillsborough Bay and the Manatee River. Old Tampa Bay had fewer taxa than the lower bay segments but was higher than Hillsborough Bay and the Manatee River. There was no significant difference in the benthic species richness between Hillsborough Bay and the Manatee River.

The abundance of benthic organisms ranged from 0 to 183,400 organisms/m^2 with a median of 5,150 organisms/m^2 (Table 16 & 17). Abundances were variable between sampling years (Figure 66) with significant differences between years overall (KW; $p < 0.001$). Highest abundances were observed in 2004 and 1993 and the lowest in 1998 (Table 16; Figure 66). Among the seven bay segments Middle Tampa Bay and Old Tampa Bay had the highest median abundances while the lowest median abundance was in Terra Ceia Bay (Table 17; Figure 67). The benthic abundances between bay segments was statistically different (KW; $p <0.001$) and was higher in Middle Tampa Bay relative to Hillsborough Bay, the Manatee River, Terra Ceia Bay, and Boca Ciega Bay (Dunn's; $p <0.05$). There was no difference in abundance between Middle Tampa Bay, Lower Tampa Bay, and Old Tampa Bay and between Old Tampa Bay and the Manatee River. Lower Tampa Bay also was not significantly different from Hillsborough Bay, Terra Ceia Bay, or the Manatee River.

The median Shannon Diversity Index was 2.49 and ranged from 0 to 3.94 (Tables 16 & 17). There was no significant difference between sampling years (Figure 68: KW; $p = 0.051$). The diversity increased towards the lower bay (Figure 69) and was highest in Boca Ciega Bay, Terra Ceia Bay, and Lower Tampa Bay with no statistical differences between these segments. The lowest median diversity values were in Hillsborough Bay and the Manatee River (Table 17; Figure 69).

The Tampa Bay Benthic Index (TBBI) had an overall median value of 81.41 which falls within the "Intermediate" category for benthic habitat health (Tables 16 & 17). Yearly median values tended to fall in the "Intermediate" range (Table 16; Figure 70) but there were significant differences between years (KW; $p < 0.001$). The highest median TBBI was in 2004 and lowest median values were in 1994 and 2003 (Table 16; Figure 70). The TBBI scores were significantly different between bay segments (KW; $p < 0.001$) with highest values occurring in Old Tampa Bay, Middle Tampa Bay, and Lower Tampa Bay and lower values in Hillsborough Bay, the Manatee River, Terra Ceia Bay, and Boca Ciega Bay (Table 17; Figure 71). The areal extent of benthic habitat categories based on the TBBI showed apparent shifts over the 12 year monitoring period (Figure 72) with notable increases in "Degraded" habitat particularly in western Old Tampa Bay. Bay-wide 1.48% of the samples had no benthic organisms present (TBBI = 0; "Empty"), 26.8% were classified as "Degraded," 45.6% as "Intermediate," and 26% as

“Healthy” (Table 18). Hillsborough Bay had the highest number of empty samples (4.83%) and one-third of the sites were classified as “Degraded” (Table 18). The Manatee River, Terra Ceia Bay, and Boca Ciega Bay also had a large percentage of “Degraded” sites (38-40%; Table 19). Old Tampa Bay, Middle Tampa Bay and Lower Tampa Bay had few empty (0-0.6%) or “Degraded” (<20%) sites and approximately 35% of the sites in each of these segments was classified as “Healthy” (Table 18).

The National Estuary Program Coastal Condition Report published in 2007 included an evaluation of the estuarine condition in Tampa Bay based on samples collected by the National Coastal Assessment (NCA) monitoring program (USEPA 2007). The NCA collected sediment samples in July 2000 from 25 sites throughout Tampa Bay. These samples were analyzed for benthic invertebrate community structure and the condition of the benthic community was evaluated at each site using the Gulf Coast Benthic Index (GCBI) developed for the Louisianan Provence EMAP program (Engle et al., 1994; Engle and Summers 1999). The condition of the benthic community at each station was rated as “Good” if the GCBI score was ≥ 5.0, “Fair” if the GCBI score was between 3.0 and 5.0, and “Poor” if the GCBI score was < 3.0 (USEPA 2007). The overall benthic community condition for the estuary was rated based on the following criteria: “Good” if < 10% of the sites had a poor benthic index score and >50% had a good benthic index score; “Fair” if 10% to 20% of the sites had a poor benthic index sore or >50% of the sites had a combined poor and fair benthic index score; “Poor” if >20% of the sites had a poor benthic index score. The overall benthic community condition for Tampa Bay based on these criteria was rated as “Poor” with 36% of the NCA sites having poor benthic index scores, 20% rated as “Fair”, and 44% as “Good” (USEPA 2007).

The benthic community condition of the bay-wide monitoring samples was evaluated applying the same criteria for “Good”, “Fair”, and “Poor” as outlined in the Coastal Condition Report (USEPA 2007) but utilizing the Tampa Bay Benthic Index and its scoring criteria for the individual samples. Results from this analysis are presented in Table 19 by year and bay segment. The bay-wide benthic condition was calculated two ways: initially by simply evaluating all of the samples equally and then by proportionally weighing the samples based on their bay segment area in order to compensate for differing sampling densities in the different bay segments. Overall bay-wide results were consistent with the NCA rating of “Poor” for all years with only one individual year (1999) having a rating of “Fair” (Table 19). Weighing the samples proportionally by their segment area did increase the bay-wide rating from “Poor” to “Fair” in just over half of the individual years (7 of 12; Table 19). Hillsborough Bay, Terra Ceia Bay, the Manatee River and Boca Ciega Bay generally had “Poor” benthic community conditions for most years (Table 19). Terra Ceia Bay rated as “Good” in 2004; however this was based on a single sample that was collected that year. Old Tampa Bay, Middle Tampa Bay, and Lower Tampa Bay generally had “Fair” benthic community conditions (Table 19). Both Middle and Lower Tampa Bay rated as “Good” in 2004, while Old Tampa Bay had “Poor” benthic community conditions from 2001 – 2004. There was an apparent trend of degrading benthic condition in Old Tampa Bay over time (Table 19), however this may be a sampling artifact due to reduce sampling intensity during the later years of the study period.

Table 16. Benthic Community Summary Statistics by Year

Year	n	Number of taxa Median	Number of taxa Min	Number of taxa Max	Number per m² Median	Number per m² Min	Number per m² Max	Diversity (H') Median	Diversity (H') Min	Diversity (H') Max	TBBI Median	TBBI Min	TBBI Max
1993	**90**	39	5	86	7763	250	45725	2.64	0.66	3.52	78.67	0.99	93.59
1994	**90**	32	0	74	5638	0	27825	2.51	0.00	3.41	75.65	0.00	93.68
1995	**134**	33	0	99	5475	0	183400	2.49	0.00	3.94	82.12	0.00	97.83
1996	**132**	36	0	74	7250	0	91625	2.42	0.00	3.66	83.14	0.00	96.19
Phase 1 1993-1996	**446**	**35**	**0**	**99**	**6263**	**0**	**183400**	**2.50**	**0.00**	**3.94**	**80.96**	**0.00**	**97.83**
1997	**123**	41	0	92	7175	0	49475	2.54	0.00	3.70	82.68	0.00	97.24
1998	**119**	30	0	89	3264	0	44575	2.55	0.00	3.57	81.31	0.00	96.40
1999	**124**	36	0	120	6450	0	54175	2.47	0.00	3.79	83.41	0.00	98.72
2000	**86**	37	2	86	7663	50	43925	2.64	0.69	3.61	84.39	13.78	92.93
Phase 2 1997-2000	**452**	**35**	**0**	**120**	**6076**	**0**	**54175**	**2.53**	**0.00**	**3.79**	**83.03**	**0.00**	**98.72**
2001	**80**	31	0	88	3750	0	21675	2.53	0.00	3.61	79.77	0.00	93.07
2002	**83**	38	0	125	5850	0	97075	2.54	0.00	3.63	81.75	0.00	94.83
2003	**78**	27	0	86	4113	0	50376	2.40	0.00	3.58	77.71	0.00	96.48
2004	**77**	36	2	101	8725	50	61125	2.33	0.51	3.48	85.55	42.95	97.44
Phase 3 2001-2004	**318**	**33**	**0**	**125**	**4938**	**0**	**97075**	**2.43**	**0.00**	**3.63**	**80.18**	**0.00**	**97.44**
Cumulative 1993-2004	**1216**	**35**	**0**	**125**	**5950**	**0**	**183400**	**2.49**	**0.00**	**3.94**	**81.41**	**0.00**	**98.72**

Table 17. Benthic Community Summary Statistics by Bay Segment.

Segment	n	Number of taxa Median Min Max		Number per m^2 Median Min Max		Diversity (H') Median Min Max		TBBI Median Min Max	
Hillsborough Bay	**289**	25		4750		2.17		78.62	
		0	66	0	53825	0.00	3.25	0.00	97.44
Old Tampa Bay	**166**	35		7575		2.43		84.86	
		0	69	0	183400	0.00	3.44	0.00	96.40
Middle Tampa Bay	**238**	38		7750		2.53		84.82	
		2	125	50	97075	0.22	3.79	7.53	96.36
Lower Tampa Bay	**182**	44		6100		2.85		83.90	
		2	101	50	54175	0.68	3.79	24.51	97.83
Manatee River	**119**	25		5575		2.29		78.15	
		1	74	300	91625	0.00	3.51	5.20	95.89
Terra Ceia Bay	**68**	36		4025		2.93		77.27	
		1	86	25	17525	0.00	3.56	26.60	96.19
Boca Ciega Bay	**154**	42		4563		2.96		75.33	
		0	120	0	61125	0.00	3.94	0.00	98.72
Tampa Bay	**1216**	**35**		**5950**		**2.49**		**81.41**	
		0	**125**	**0**	**183400**	**0.00**	**3.94**	**0.00**	**98.72**

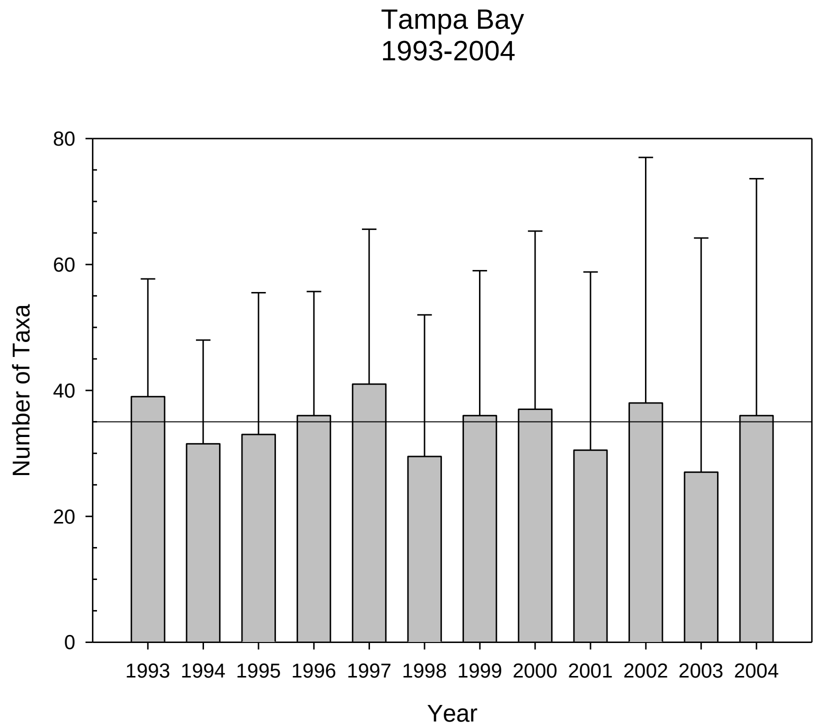

Figure 64. Median number of benthic taxa by year. Error bars = 90th percentile, solid line represents bay-wide median value.

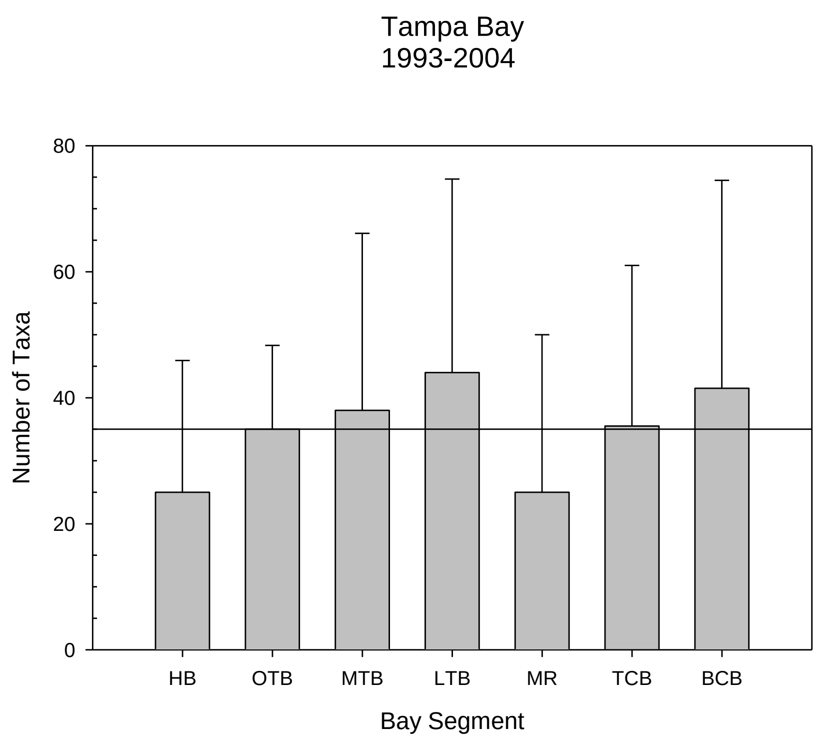

Figure 65. Median number of benthic taxa by bay segment. Error bars = 90th percentile, solid line represents bay-wide median value.

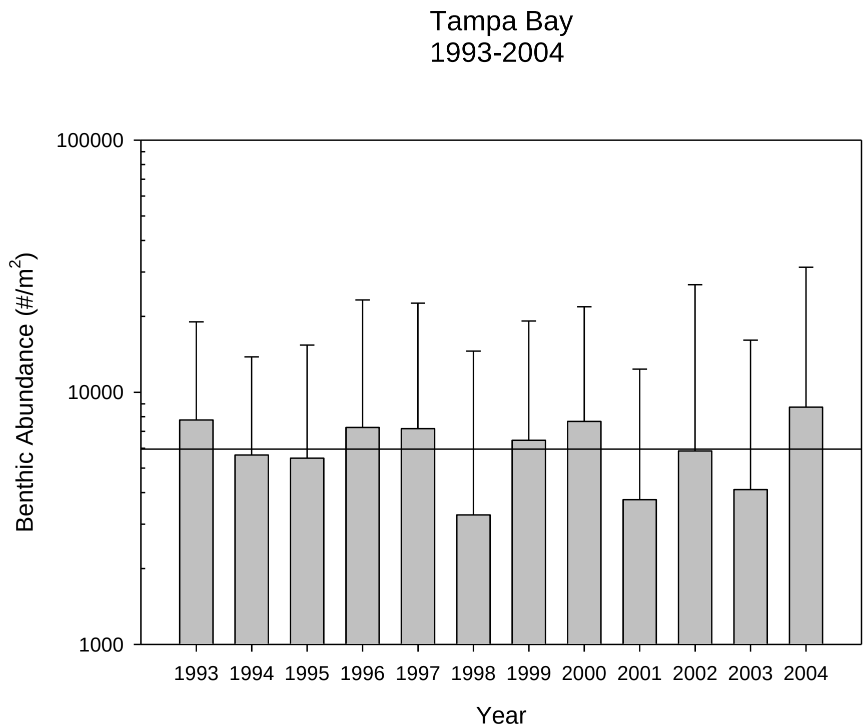

Figure 66. Median benthic abundance by year. Error bars = 90th percentile, solid line represents bay-wide median value.

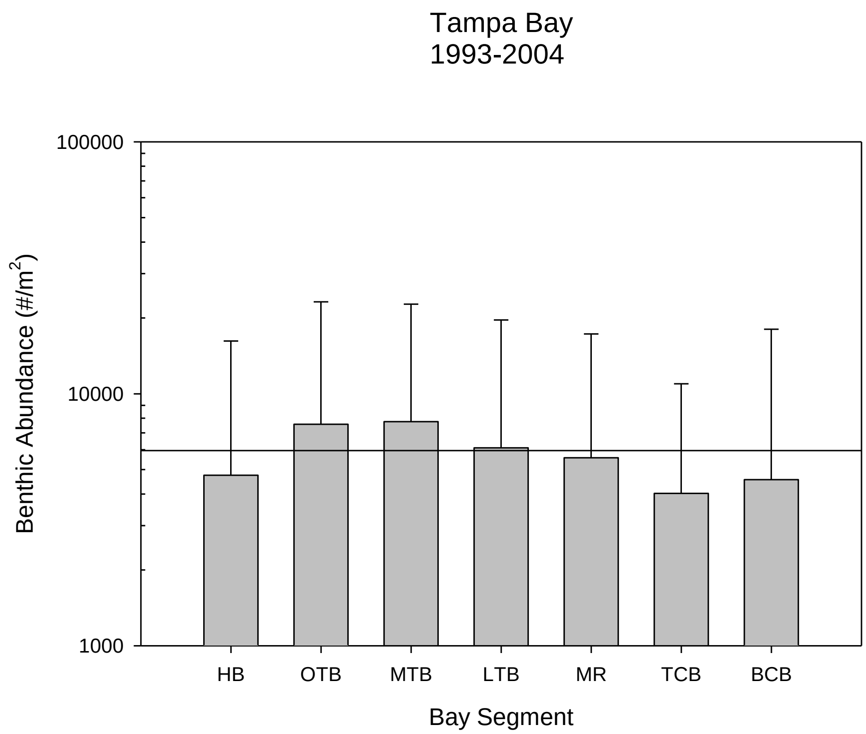

Figure 67. Median benthic abundance by bay segment. Error bars = 90th percentile, solid line represents bay-wide median value.

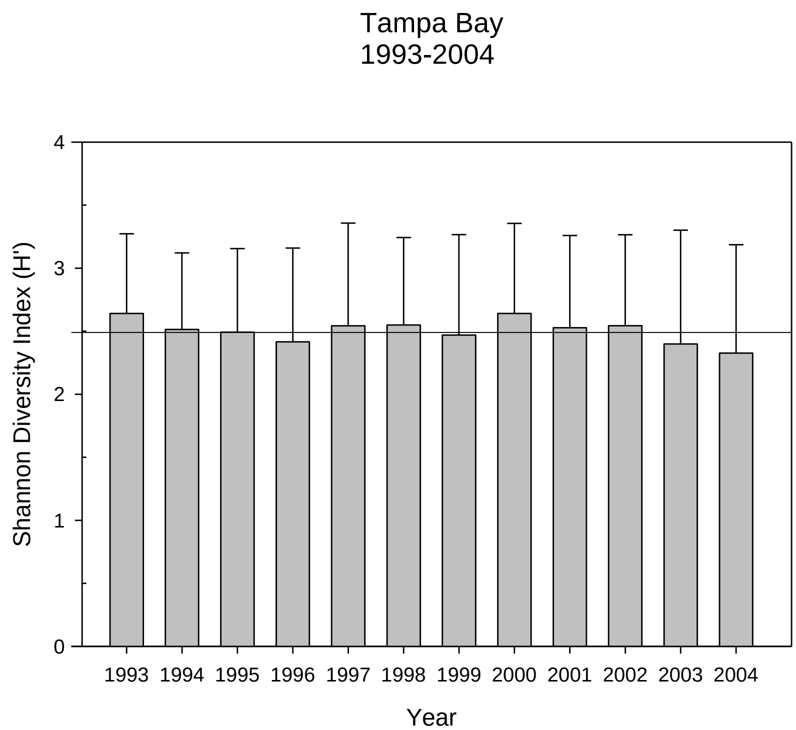

Figure 68. Median Shannon-Wiener Diversity Index ($\log_e$) by year. Error bars = 90^{th} percentile, solid line represents bay-wide median value.

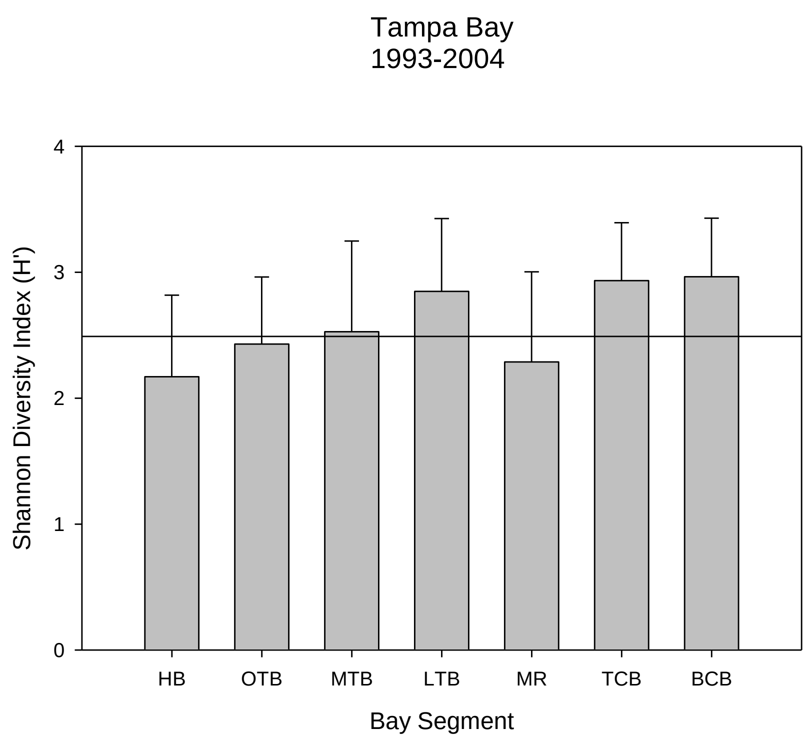

Figure 69. Median Shannon-Wiener Diversity Index ($\log_e$) by bay segment. Error bars = 90^{th} percentile, solid line represents bay-wide median value.

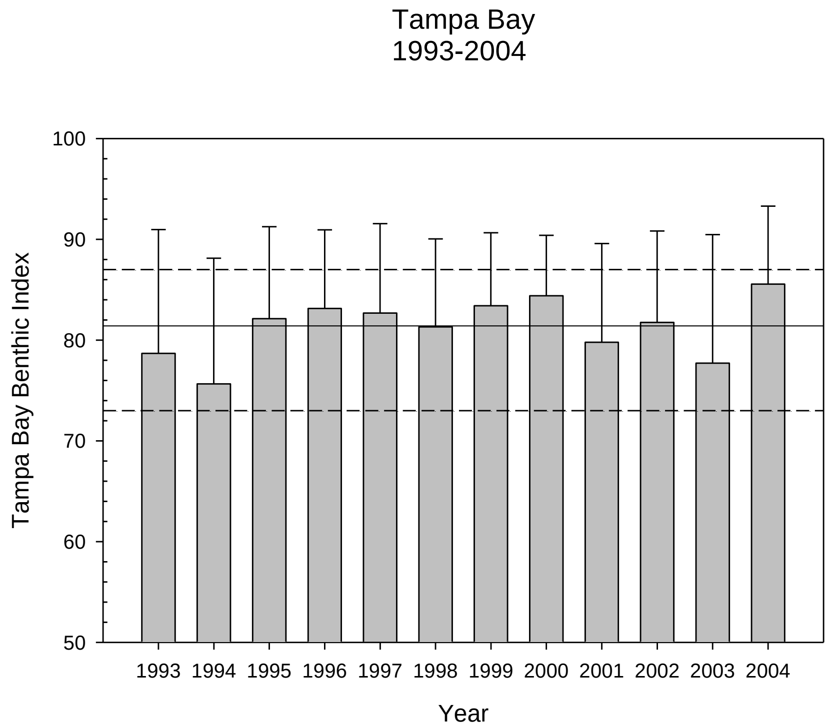

Figure 70. Median Tampa Bay Benthic Index scores by year. Error bars = 90th percentile, solid line represents bay-wide median value, dashed lines indicate cutoffs for "Degraded" (<73) and "Healthy" (>87) benthic habitats.

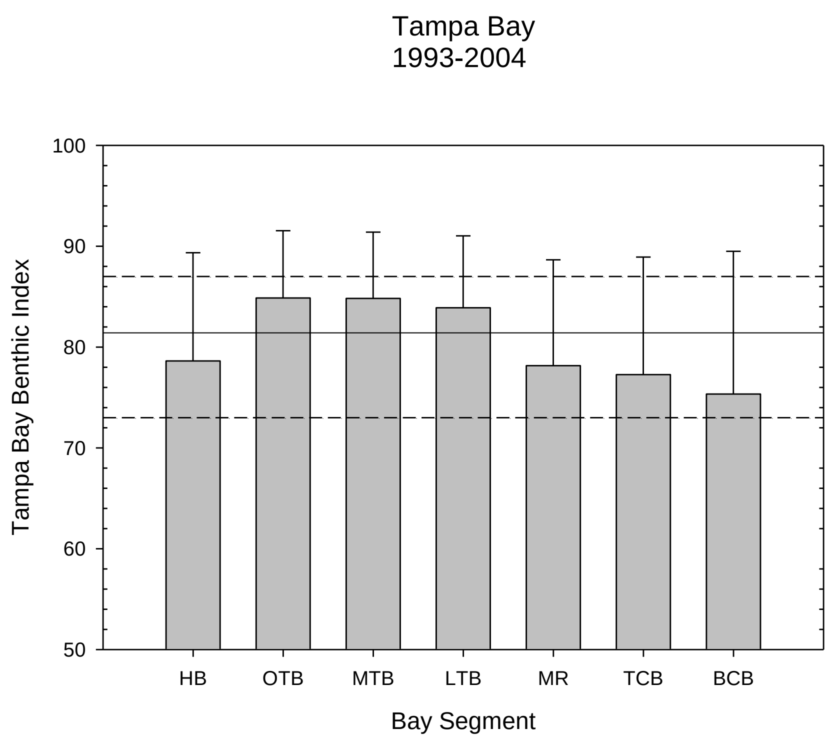

Figure 71. Median Tampa Bay Benthic Index by bay segment. Error bars = 90th percentile, solid line represents bay-wide median value, dashed lines indicate cutoffs for "Degraded" (<73) and "Healthy" (>87) benthic habitats.

Table 18. Percentage of sites within TBBI categories by period, bay segment, and bay-wide.

	n	Undefined	Empty	Degraded	Intermediate	Healthy
1993-1996	446	1.12%	2.02%	30.04%	44.84%	23.09%
1997-2000	453	1.10%	0.88%	21.85%	49.23%	28.04%
2001-2004	318	1.57%	1.57%	29.56%	41.51%	27.36%
Hillsborough Bay	290	1.72%	4.83%	33.10%	41.72%	20.34%
Old Tampa Bay	166	0.00%	0.60%	16.87%	46.99%	35.54%
Middle Tampa Bay	238	1.26%	0.00%	14.71%	49.58%	35.71%
Lower Tampa Bay	182	0.55%	0.00%	18.68%	46.70%	34.62%
Manatee River	119	4.20%	0.00%	38.66%	46.22%	15.13%
Terra Ceia Bay	68	1.47%	0.00%	38.24%	44.12%	17.65%
Boca Ciega Bay	154	0.00%	1.95%	40.26%	44.16%	13.64%
Tampa Bay (Total)	**1217**	**1.23%**	**1.48%**	**26.87%**	**45.60%**	**26.05%**

Table 19. Condition of Tampa Bay benthic communities based on the TBBI using the EPA's National Coastal Assessment program criteria.

Year	Status								
	HB (n)	OTB (n)	MTB (n)	LTB (n)	MR (n)	TCB (n)	BCB (n)	Bay-wide (n)	Weighted Bay-wide*
1993	Poor (19)	Fair (16)	Fair (20)	Poor (17)	Fair (11)	Poor (7)	N/A	Poor (90)	Poor (90)
1994	Poor (19)	Poor (17)	Poor (20)	Poor (16)	Poor (10)	Poor (7)	N/A	Poor (89)	Poor (89)
1995	Poor (29)	Fair (23)	Fair (21)	Fair (22)	Poor (11)	Poor (7)	Fair (21)	Poor (134)	Fair (134)
1996	Poor (27)	Fair (15)	Poor (24)	Poor (24)	Fair (13)	Fair (8)	Poor (21)	Poor (132)	Poor (132)
1997	Poor (22)	Fair (16)	Fair (22)	Fair (21)	Poor (13)	Fair (8)	Poor (21)	Poor (123)	Fair (123)
1998	Poor (26)	Fair (16)	Fair (20)	Fair (17)	Poor (13)	Fair (7)	Poor (21)	Poor (120)	Fair (120)
1999	Fair (23)	Fair (19)	Fair (21)	Good (18)	Fair (13)	Poor (8)	Poor (21)	Fair (123)	Fair (123)
2000	Poor (22)	Fair (11)	Fair (23)	Fair (8)	Poor (9)	Poor (7)	Poor (6)	Poor (86)	Fair (86)
2001	Poor (25)	Poor (7)	Fair (26)	Fair (5)	Fair (2)	Poor (1)	Poor (14)	Poor (80)	Poor (80)
2002	Poor (25)	Poor (8)	Good (21)	Fair (9)	Poor (7)	Poor (4)	Poor (9)	Poor (83)	Fair (83)
2003	Poor (28)	Poor (9)	Fair (9)	Fair (12)	Poor (7)	Poor (3)	Poor (10)	Poor (78)	Poor (78)
2004	Fair (25)	Poor (9)	Good (11)	Good (11)	Poor (10)	Good (1)	Poor (10)	Poor (77)	Fair (77)

*Weighted by Bay Segment Area

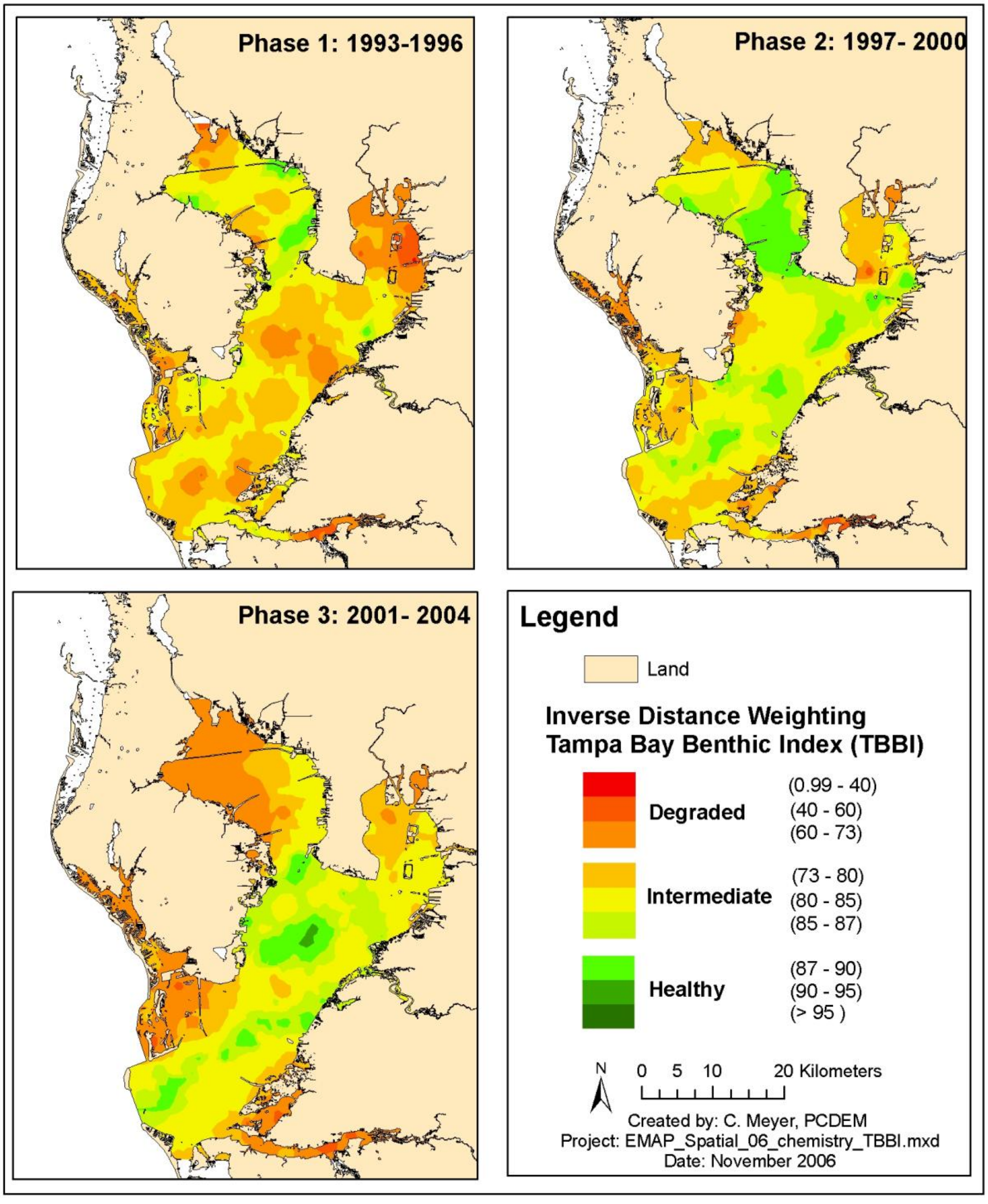

Figure 72. Spatial extent of TBBI scores by four-year sampling phases.

Dominant Taxa

The relative abundance of dominant benthic taxa is presented by sampling year in Table 20 and by Bay Segment in Table 21.

The most abundant species in Tampa Bay was the cephalochordate *Branchiostoma floridae* which accounted for 5.06% of the overall abundance (Table 20). The overall mean abundance was 491 individuals per square meter with a maximum density of 17,775/m^2 (= 711 specimens per grab sample). The maximum density is much higher than reported in previous studies [Stokes, 1996 (1200/m^2)]. *Branchiostoma floridae* was the most abundant species in Lower Tampa Bay and among the most dominant taxa in Old Tampa Bay and Middle Tampa Bay (Table 21; Figure 73). It was also among the numerically dominant taxa in all years except 2003 and was the most abundant taxa in 1993, 1997, and 1998 (Table 20). SIMPER analysis based on salinity, dissolved oxygen, and sediment type indicate that *B. floridae* is found primarily in polyhaline and euhaline salinities, normoxic conditions and in medium to coarse sediments. The preference for higher salinities has also been shown in an earlier study, where a sudden drop in salinity due to heavy rainfall resulted in a mass die off (Dawson 1965). Stokes (1996) looked at the larval recruitment and post-settlement growth of *B. floridae* in Tampa Bay focusing on a sampling site near the Courtney Campbell Causeway in Old Tampa Bay. Stokes found that reproduction occurred from May to September with larval settlement from late-May to mid-October. Several earlier studies reported this species as *Branchiostoma caribaeum* (Dawson 1965; Pierce 1965; Nelson 1969, Bloom et al. 1972, Hall and Saloman 1975).

The second most abundant species was the cirratulid polychaete *Monticellina cf. dorsobranchialis*. This polychaete was initially identified as *Tharyx annulosus* during the first year of the program based on the taxonomic key in Wolf, 1984 and is probably the same as *Tharyx* sp. C of Taylor, 1971 and Hall and Saloman, 1975. Blake (1991) revised the genus *Tharyx* and reinstated the genus *Monticellina* placing several species in this new taxon based on the presence of serrated chaetae. He further synonymized *T. annulosus* with *T. dorsobranchialis* under the new taxon *Monticellina dorsobranchialis*. Blake (1996) further revised this genus, describing several new species from California and mentioned that future revisions were needed. Specifically he mentioned that several taxa he initially synonymized as *Monticellina dorsobranchialis* (including *M. annulosus*) in his 1991 paper were to be reinstated as separate species (Blake 1996). Due to the current revisions of this genus the identity of the *Monticellina* specimens from Tampa Bay is still uncertain. For the purpose of this report we are maintaining the name *Monticellina cf. dorsobranchialis* for the Tampa Bay specimens with the understanding that this designation may change upon future verification of our voucher material. The average density of *M. cf. dorsobranchialis* was 391/m^2 with a maximum of 43,250/m^2. It was among the most abundant taxa during all years with the exception of 1995 with highest relative abundances occurring in 1994 and 1999 (Table 20). It was the most abundant taxon in Hillsborough Bay and Terra Ceia Bay and ranked second in the Manatee River (Table 21; Figure 74). The SIMPER analysis for the different physical parameters found *M. cf. dorsobranchialis* contributed to the similarity between sites with very fine to fine grained sediments, high mesohaline to euhaline salinities, and a wide range for dissolved oxygen (hypoxic to normoxic).

The brachiopod *Glottidia pyramidata* was the third most abundant infaunal organism bay-wide (Table 21) with an average density of 479/m^2 and a maximum density of 94,374/m^2 (primarily as recently settled post-larvae). This average density is lower than previously reported by Culter (1979) who found an average density of 2275/m^2 in Old Tampa Bay near the Courtney Campbell Causeway. The relative abundance of *G. pyramidata* was variable over time and it was not among the top ten dominant taxa during the first four years of the monitoring program or in 1998 and 2000 (Table 20). *G. pyramidata* was the most abundant infaunal organism in 2001 and again in 2002 when it accounted for 39.5% of the total benthic abundance (Table 20). *G. pyramidata* was the most abundant animal in Middle Tampa Bay accounting for over 14% of the benthic abundance and was also among the dominant taxa in Hillsborough Bay and Old Tampa Bay (Table 21; Figure 75). The SIMPER analysis showed that *G. pyramidata* was found at relatively deeper sites (>2 meters) with fine to medium grained sediments, polyhaline salinities, and normoxic bottom dissolved oxygen levels. These findings agree with previous life-history studies. Paine (1963) studying populations of *G. pyramidata* on the west coast of Florida found that this species inhabited salinities ranging from 18 – 35 psu and could tolerate salinities as low 13 psu. Paine also noted that *G. pyramidata* was absent from mud or clay bottoms or from calcareous sediments, preferring sandy habitats. Culter (1979) further showed that *G. pyramidata* is unable to burrow in coarse sediments and burrowing is also inhibited in muddy substrates. Both Paine (1963) and Culter (1979) reported that spawning and recruitment occurred over the summer months and Culter found that highest densities occurred in August, which corresponds closely to the time our samples were collected. Culter and Simon (1987) found that a small percentage of *G. pyramidata* in Tampa Bay (< 1%) were hermaphroditic, particularly in areas of low population density.

Tubificid oligochaetes ranked forth overall in relative abundance making up 3.30%. This group was composed of immature and/or damaged specimens of multiple species which could not be identified below the family level. Tubificid oligochaetes were common across all years and bay segments (Tables 20 & 21).

The gastropod *Caecum strigosum* was the fifth most abundant infaunal animal bay-wide accounting for nearly 3% of the relative abundance (Table 21). This species was recorded in Tampa Bay during the Bureau of Commercial Fisheries survey in the 1960's (Hall and Saloman, 1975) and was initially identified as *Caecum cf. johnsoni* during the early years of the current monitoring program (Mote Marine Laboratory, 1995) as well as in other earlier works (Culter, 1986). *C. strigosum* was among the most abundant taxa during all years except 2003 and 2004 (Table 20) and was particularly abundant in Middle Tampa Bay (7.86% relative abundance) as well as among the top taxa in Old Tampa Bay and Lower Tampa Bay (Table 21; Figure 76). The SIMPER analysis indicated that *C. strigosum* was found at deeper sites (>4 meters) with coarse sediments.

Two congeneric amphipods, *Ampelisca holmesi* and *Ampelisca abdita,* were ranked sixth and ninth respectively in overall abundance (Table 21). *Ampelisca holmesi* was the most abundant species in 2004 (Table 20) and was among the dominant taxa in Hillsborough Bay, the Manatee River, Terra Ceia Bay and Old Tampa Bay (Table 21: Figure 77). The SIMPER analyses showed

A. holmesi had a wide depth distribution (intertidal to deep subtidal), was found in fine to medium sediments, high mesohaline to polyhaline salinities and intermediate to normoxic dissolved oxygen levels. Grabe et al (2006) reported similar habitat preferences for this species calculating an optimum depth of 0.5 meters, silt + clay of 5.5%, salinity of 21.4 psu, and dissolved oxygen of 8.8 mg/l.

Ampelisca abdita was among the top ranked taxa in 1993 and 1996 (Table 20) and was the most abundant species in the Manatee River samples (Table 21; Figure 78). The SIMPER results indicate that *A. abdita* was found at intertidal sites and in low to high mesohaline habitats. Grabe et. al. (2006), calculated an optimal depth of 1.5 meters and salinity of 14.4 psu as well as a relatively high silt + clay content (15.6%) and low dissolved oxygen (2.9 mg/l) for this species. Thoemke (1979) studied the life history and population dynamics of *A. abdita* in Hillsborough Bay over a two year period (July 1975 – July 1977) and found that reproduction occurred year round, but life span of individuals varied seasonally presumably mediated by water temperature. Juvenile *A. abdita* recruited during March – August had shorter life spans (6-8 weeks) and produced a single generation of offspring, while juveniles recruited between September – February were longer lived (10-13 weeks) and produced two generations of offspring (Thoemke 1979). He additionally recorded highest population densities in June/July followed by a decline in late summer, possibly in response to low dissolved oxygen levels (Thoemke 1979).

The small bivalve *Mysella planulata* ranked seventh in abundance bay-wide and was most abundant in the 1996-1998 sampling years (Tables 20 & 21). *M. planulata* was mainly found in Hillsborough Bay and Old Tampa Bay where it ranked second and third in abundance respectively (Table 21; Figure 79). SIMPER results indicate that *M. planulata* has a wide depth distribution (intertidal to deep subtidal), and was found in fine to medium sediments, high mesohaline to polyhaline salinities and intermediate to normoxic dissolved oxygen conditions. *Mysella planulata* is known to be a simultaneous hermaphrodite that can self-fertilize, and has larviparous development where the larvae are brooded within the adult shell during the early larval stages then released into the plankton (Franz 1973).

The eighth most abundant taxa were unidentified, juvenile barnacles (Cirripedia) which were most likely a composite of several species (probably *Balanus* spp.). These were typically epiphytic on seagrass blades or larger shell fragments. Barnacles were particularly abundant in 1995 where they comprised over 16% of the abundance (Table 20) and they were the most abundant taxa in Old Tampa Bay (Table 21).

The bivalve *Mulinia lateralis* ranked tenth overall in abundance and was among the dominant taxa in 1998-2000 (Table 20). *M. lateralis* was particularly abundant in the Manatee River where it ranked third and accounted for nearly 8% of the benthic infauna (Table 21). It was also among the top ranked taxa in Hillsborough Bay and Terra Ceia Bay (Table 21; Figure 80). Bay-wide, the mean density was $145/m^2$ with a maximum record of $24{,}150/m^2$. These densities are lower than some reported in the literature ($63{,}000/m^2$ in Wassaw Sound, GA; Walker and Tenore, 1984). *M. lateralis* densities have been reported to be variable over time, but when occurring in high densities they serve as an important prey item for commercially important species such as blue crabs (Virnstein 1977; Walker and Tenor, 1984). The 1963 survey conducted by the Bureau of Commercial Fisheries found *M. lateralis* to be the most frequently occurring and abundant mollusk in Hillsborough Bay (Taylor et al. 1970). The SIMPER analysis indicated that *M. lateralis* was found in fine sand sediments and high mesohaline salinities which agree with the habitat types reported by Taylor et al. (1970) for this species.

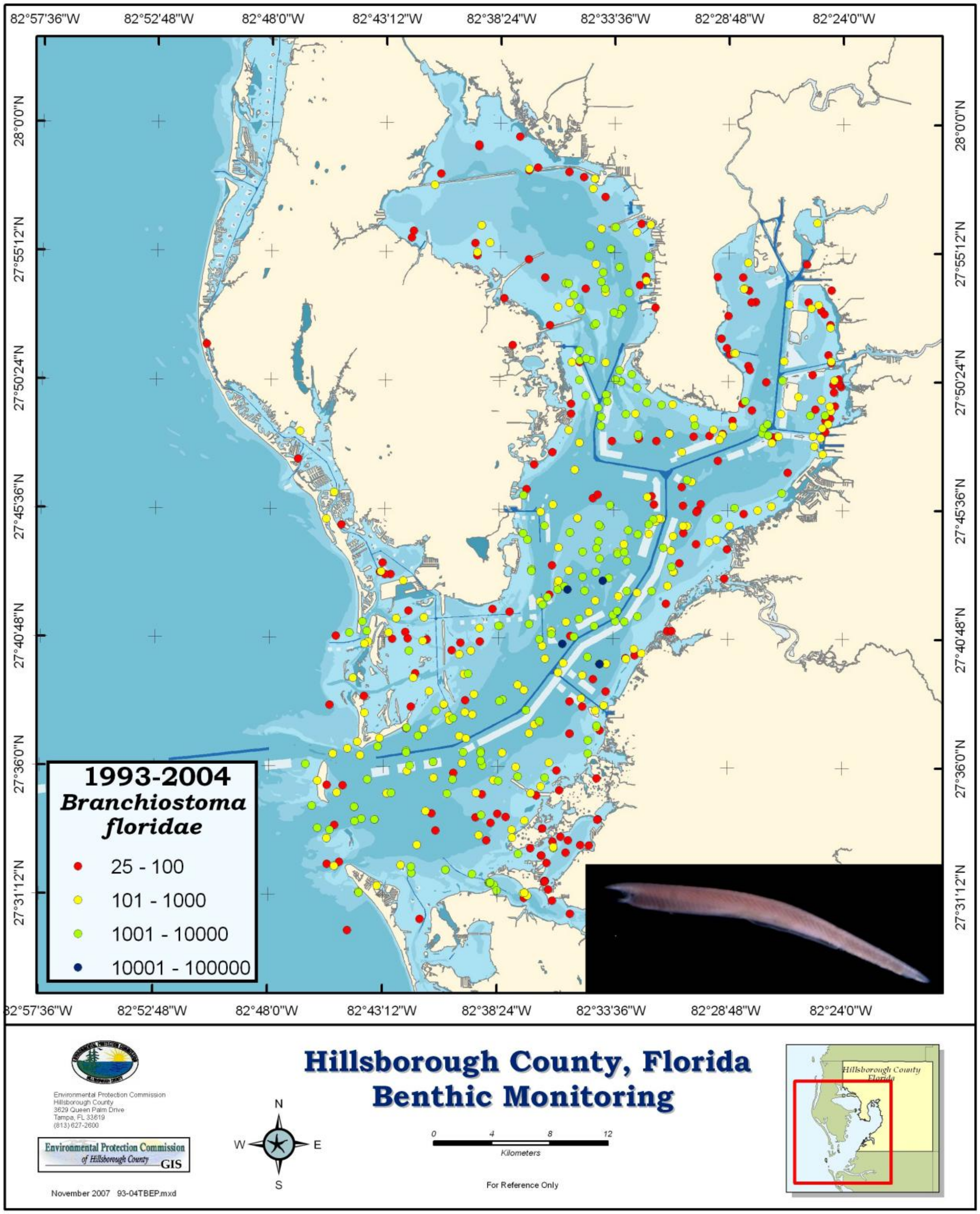

Figure 73. Late-Summer distribution of *Branchiostoma floridae* in Tampa Bay 1993-2004.

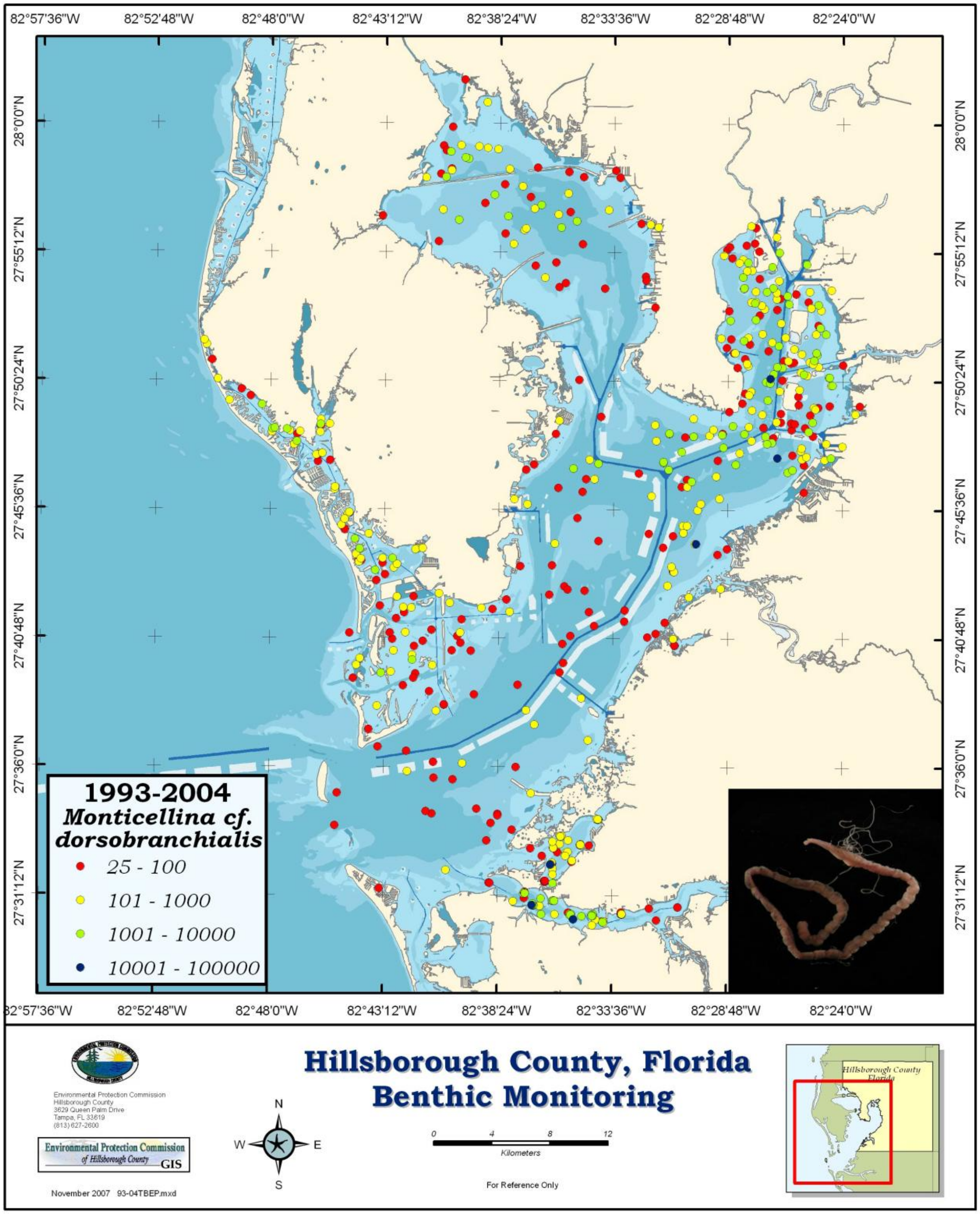

Figure 74. Late-Summer distribution of *Monticellina cf. dorsobranchialis* in Tampa Bay 1993-2004.

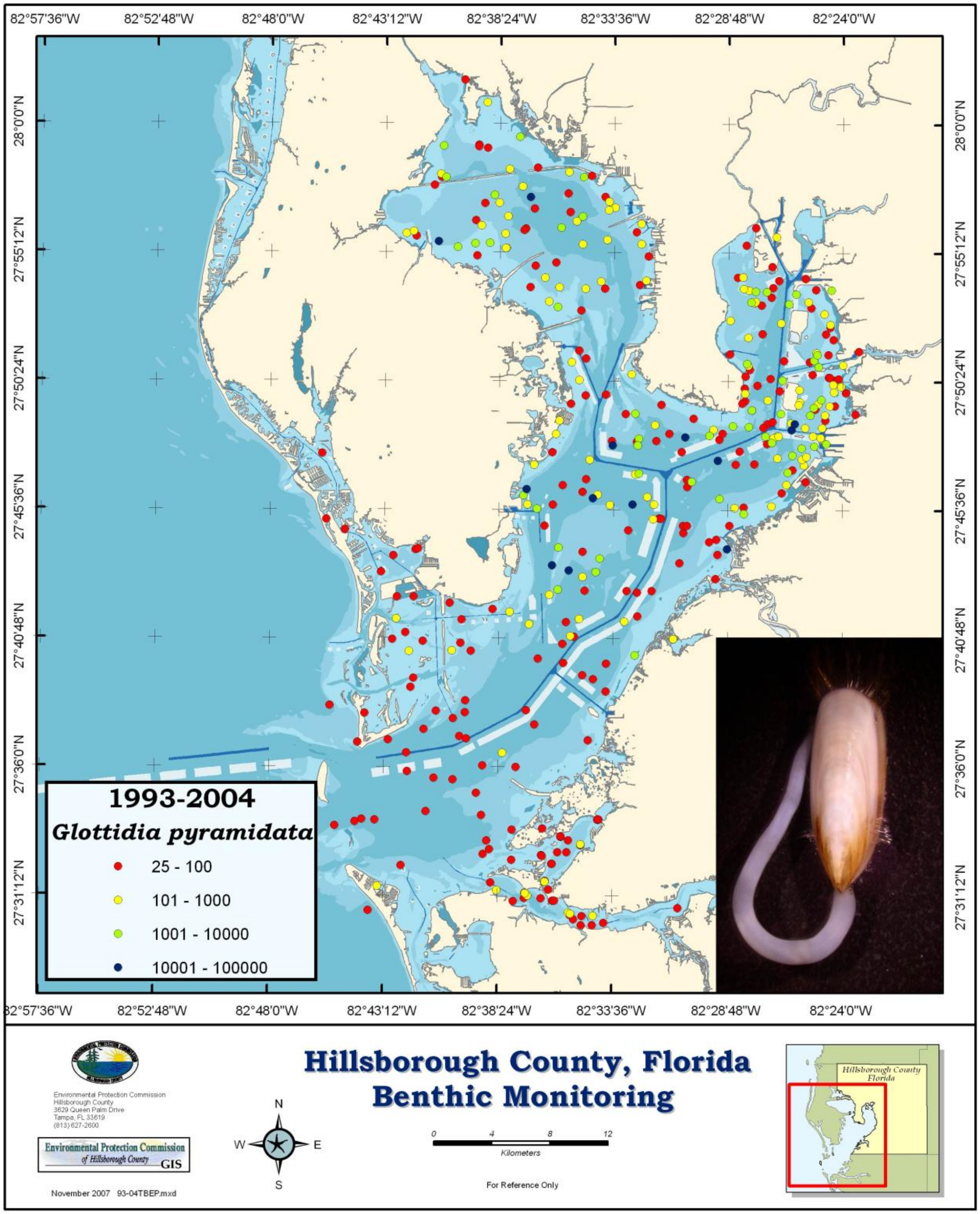

Figure 75. Late-Summer distribution of *Glottidia pyramidata* in Tampa Bay 1993-2004.

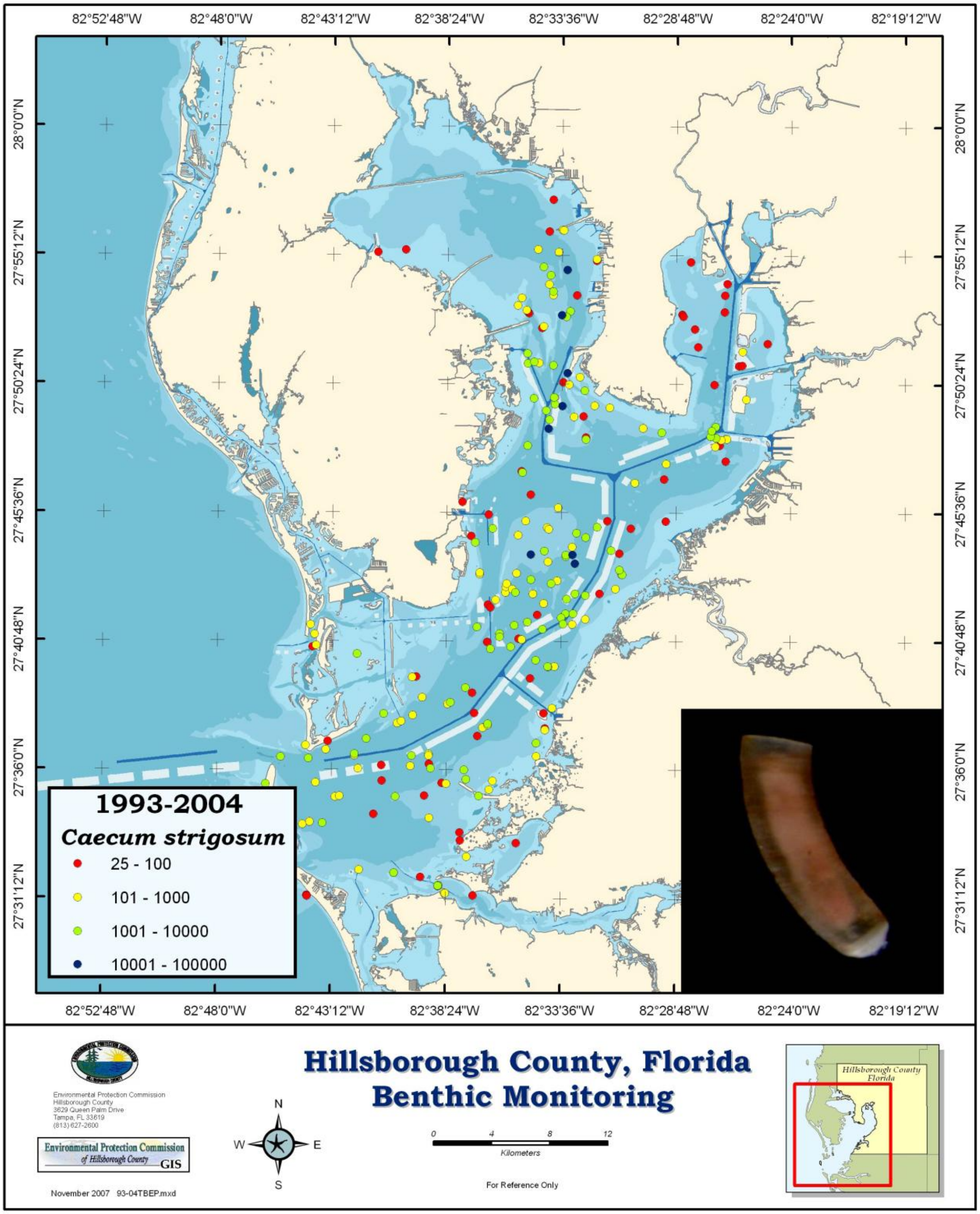

Figure 76. Late-Summer distribution of *Caecum strigosum* in Tampa Bay 1993-2004.

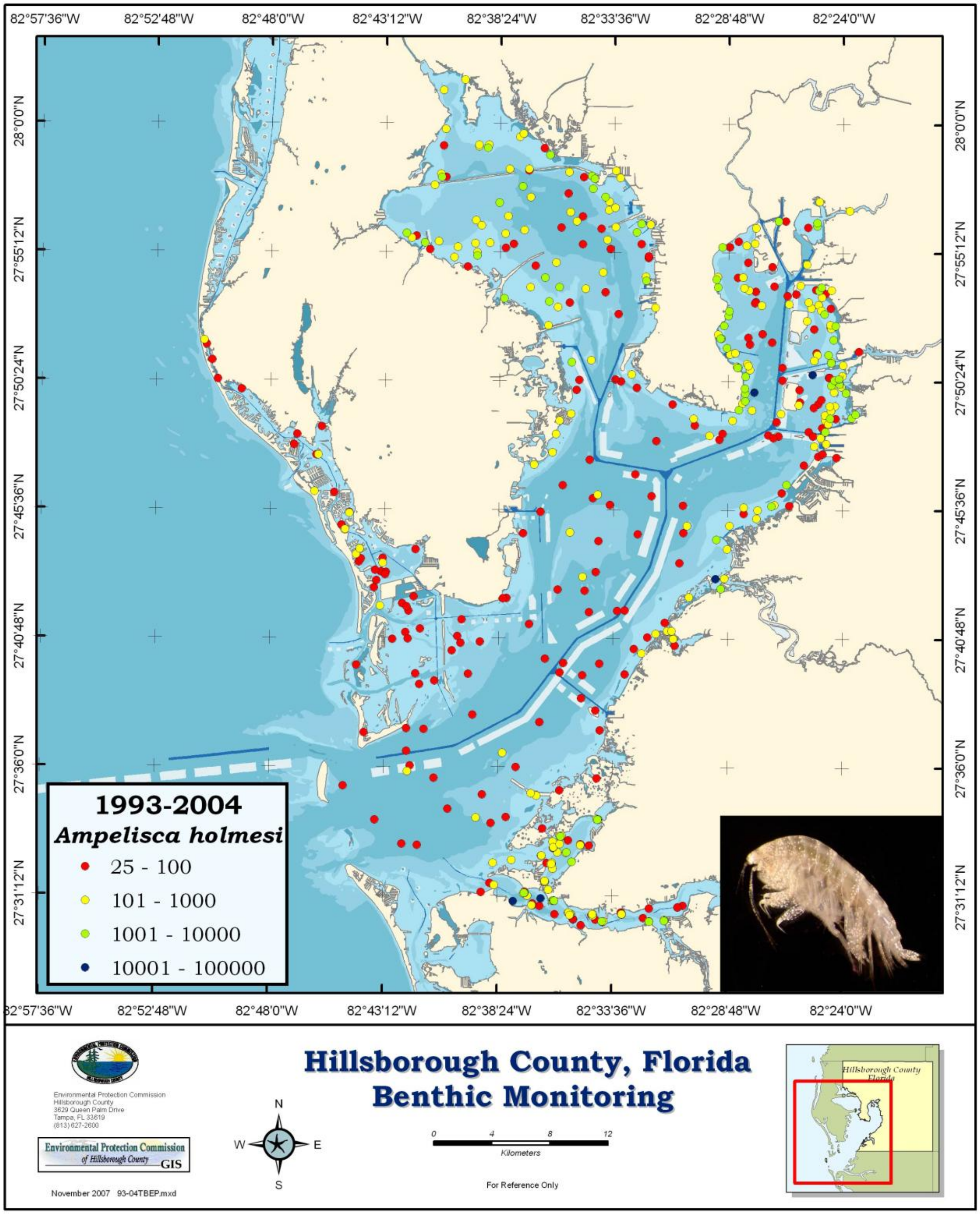

Figure 77. Late-Summer distribution of *Ampelisca holmesi* in Tampa Bay 1993-2004.

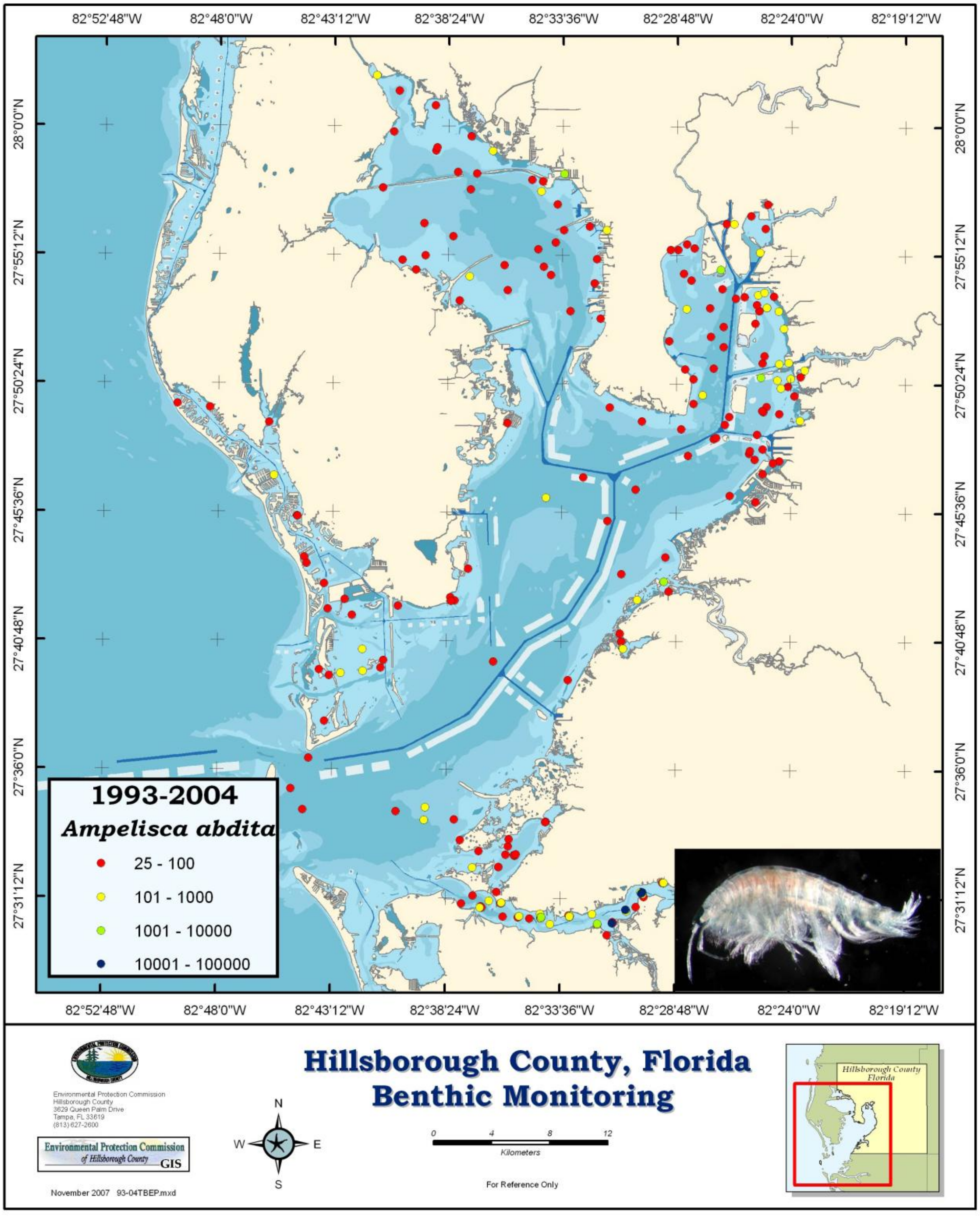

Figure 78. Late-Summer distribution of *Ampelisca abdita* in Tampa Bay 1993-2004.

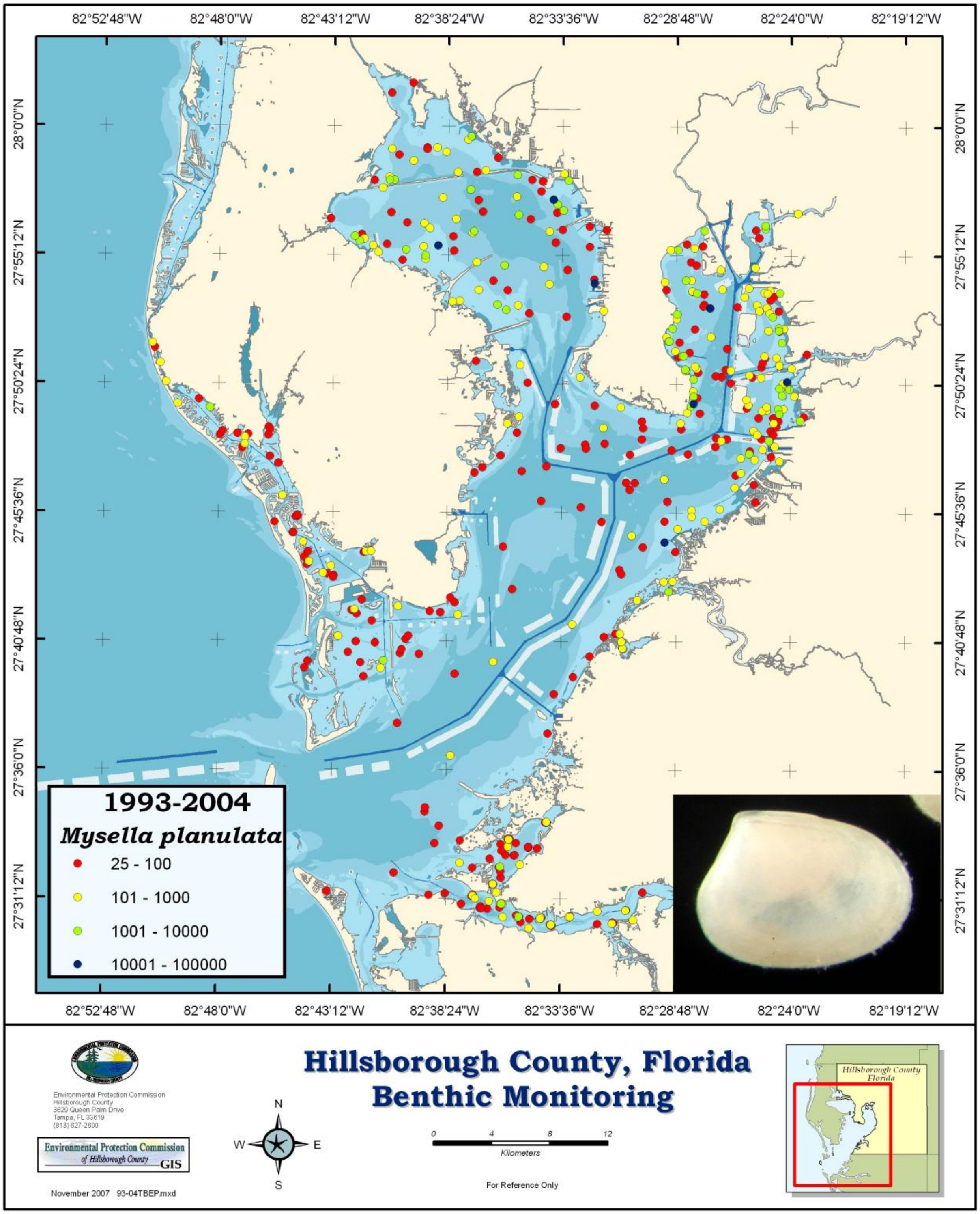

Figure 79. Late-Summer distribution of *Mysella planulata* in Tampa Bay 1993-2004.

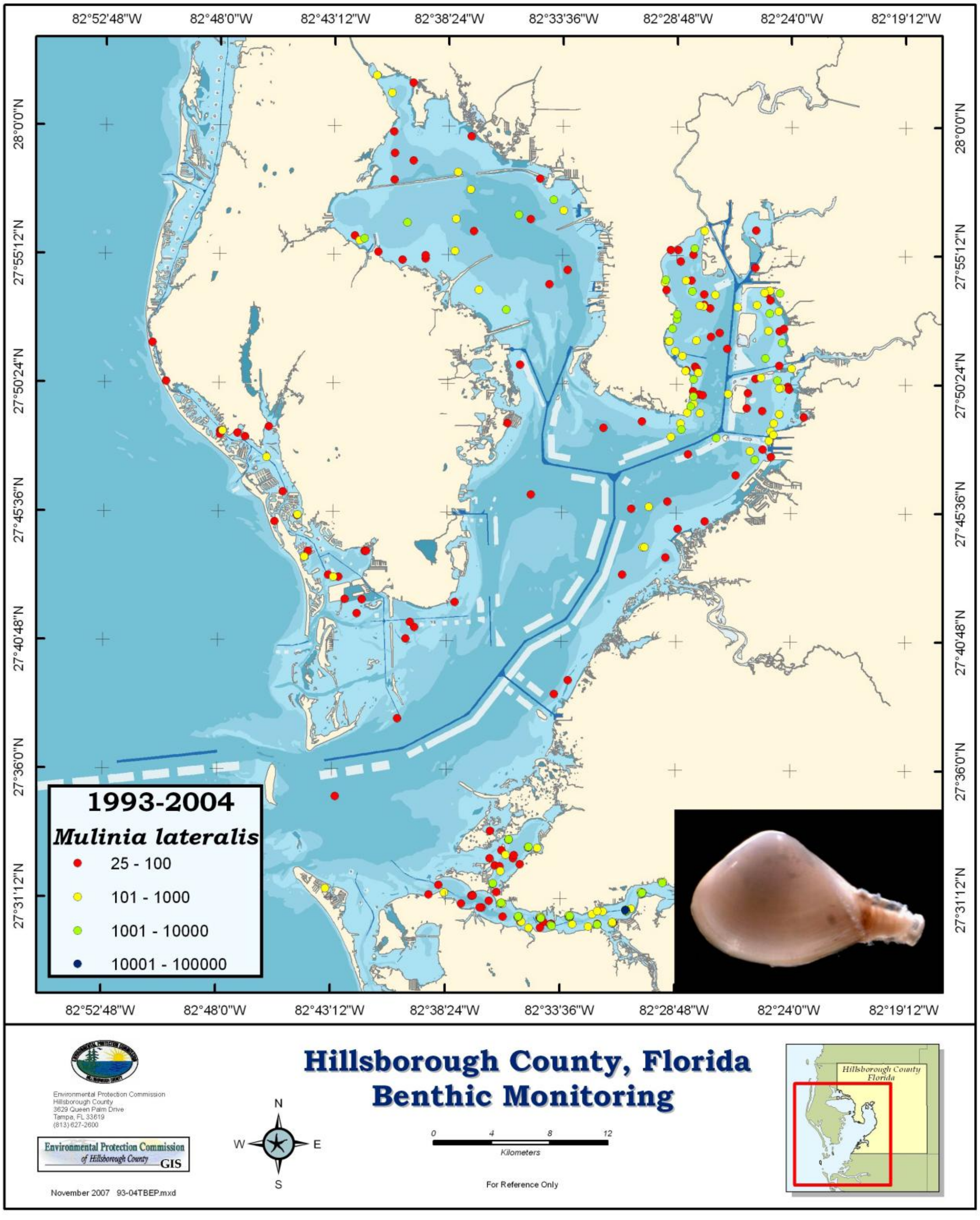

Figure 80. Late-Summer distribution of *Mulinia lateralis* in Tampa Bay 1993-2004.

Table 20. Bay-wide Relative Abundance by year.

1993	%	1994	%	1995	%	1996	%
Branchiostoma floridae (Cephalochordata)	8.77	*Monticellina cf. dorsobranchialis* (Annelida:Polychaeta)	9.60	CIRRIPEDIA (Crustacea:Cirripedia)	16.05	*Mysella planulata* (Mollusca:Bivalvia)	8.92
Mediomastus ambiseta (Annelida:Polychaeta)	4.15	*Branchiostoma floridae* (Cephalochordata)	7.54	*Janua (Dexiospira) steueri* (Annelida:Polychaeta)	9.91	*Ampelisca abdita* (Crustacea:Amphipoda)	8.51
Prionospio perkinsi (Annelida:Polychaeta)	3.92	*Caecum strigosum* (Mollusca:Gastropoda)	6.72	TUBIFICIDAE (Annelida:Oligochaeta)	3.86	*Caecum strigosum* (Mollusca:Gastropoda)	5.31
Carazziella hobsonae (Annelida:Polychaeta) *Ampelisca abdita* (Crustacea:Amphipoda)	3.51	*Prionospio perkinsi* (Annelida:Polychaeta)	4.05	*Pileolaria rosepigmentata* (Annelida:Polychaeta)	2.54	*Monticellina cf. dorsobranchialis* (Annelida:Polychaeta)	3.74
Monticellina cf. dorsobranchialis (Annelida:Polychaeta)	3.32	TUBIFICIDAE (Annelida:Oligochaeta)	3.94	*Branchiostoma floridae* (Cephalochordata)	2.44	*Rudilemboides naglei* (Crustacea:Amphipoda)	3.63
Ampelisca holmesi (Crustacea:Amphipoda)	3.09	*Paraprionospio pinnata* (Annelida:Polychaeta)	2.65	*Bittiolum varium* (Mollusca:Gastropoda)	2.38	*Branchiostoma floridae* (Cephalochordata)	3.36
Rudilemboides naglei (Crustacea:Amphipoda) TUBIFICIDAE (Annelida:Oligochaeta)	2.74	*Mediomastus californiensis* (Annelida:Polychaeta)	2.57	*Tellina spp.* (Mollusca:Bivalvia)	2.24	*Ampelisca holmesi* (Crustacea:Amphipoda)	3.28
Mysella planulata (Mollusca:Bivalvia)	2.48	*Mediomastus ambiseta* (Annelida:Polychaeta)	2.41	*Amygdalum papyrium* (Mollusca:Bivalvia)	2.22	TUBIFICIDAE (Annelida:Oligochaeta)	2.87
Amygdalum papyrium (Mollusca:Bivalvia)	2.45	*Metharpinia floridana* (Crustacea:Amphipoda)	2.37	*Caecum strigosum* (Mollusca:Gastropoda)	2.13	*Axiothella mucosa* (Annelida:Polychaeta)	2.84
Caecum strigosum (Mollusca:Gastropoda)	2.28	*Mysella planulata* (Mollusca:Bivalvia)	2.33	*Ampelisca holmesi* (Crustacea:Amphipoda)	2.12	*Leptochelia sp.* (Crustacea:Tanaidacea)	2.35

Table 20. (Continued). Bay-wide dominant benthic taxa (relative abundance) by year.

1997	%	1998	%	1999	%	2000	%
Branchiostoma floridae (Cephalochordata)	10.19	*Branchiostoma floridae* (Cephalochordata)	9.37	*Monticellina cf. dorsobranchialis* (Annelida:Polychaeta)	7.88	*Rudilemboides naglei* (Crustacea:Amphipoda)	6.25
Mysella planulata (Mollusca:Bivalvia)	4.59	*Mysella planulata* (Mollusca:Bivalvia)	6.03	*Branchiostoma floridae* (Cephalochordata)	6.56	*Mulinia lateralis* (Mollusca:Bivalvia)	5.48
Caecum strigosum (Mollusca:Gastropoda)	4.43	*Caecum strigosum* (Mollusca:Gastropoda)	6.02	*Glottidia pyramidata* (Brachiopoda)	5.36	*Ampelisca holmesi* (Crustacea:Amphipoda) *Monticellina dorsobranchialis* (Annelida:Polychaeta)	4.67
Monticellina cf. dorsobranchialis (Annelida:Polychaeta)	4.01	*Monticellina cf. dorsobranchialis* (Annelida:Polychaeta)	5.90	*Caecum strigosum* (Mollusca:Gastropoda)	4.13	*Cyclaspis cf. varians* (Crustacea:Cumacea)	4.04
Rudilemboides naglei (Crustacea:Amphipoda)	3.52	*Prionospio perkinsi* (Annelida:Polychaeta)	4.76	*Fabricinuda trilobata* (Annelida:Polychaeta)	3.79	*Tubificoides wasselli* (Annelida:Oligochaeta)	3.72
Ampelisca holmesi (Crustacea:Amphipoda)	3.11	*Mulinia lateralis* (Mollusca:Bivalvia)	3.92	*Prionospio perkinsi* (Annelida:Polychaeta)	2.74	*Branchiostoma floridae* (Cephalochordata)	3.02
TUBIFICIDAE (Annelida:Oligochaeta)	2.65	TUBIFICIDAE (Annelida:Oligochaeta)	3.36	*Mulinia lateralis* (Mollusca:Bivalvia)	2.63	*Aricidea philbinae* (Annelida:Polychaeta)	2.81
Glottidia pyramidata (Brachiopoda)	2.13	*Janua (Dexiospira) steueri* (Annelida:Polychaeta)	3.05	TUBIFICIDAE (Annelida:Oligochaeta)	2.27	*Leptochelia sp.* (Crustacea:Tanaidacea)	2.68
Streblospio spp. (Annelida:Polychaeta)	2.01	*Amygdalum papyrium* (Mollusca:Bivalvia)	2.48	*Pinnixa spp.* (Crustacea:Decapoda)	2.06	*Mediomastus spp.* (Annelida:Polychaeta)	2.21
Phascolion cryptum (Sipuncula)	2.00	*Ampelisca holmesi* (Crustacea:Amphipoda)	1.86	*Pomatoceros americanus* (Annelida:Polychaeta)	1.99	*Caecum strigosum* (Mollusca:Gastropoda)	1.95

Table 20. (Continued). Bay-wide dominant benthic taxa (relative abundance) by year.

2001	%	2002	%	2003	%	2004	%
Glottidia pyramidata (Brachiopoda)	9.15	*Glottidia pyramidata* (Brachiopoda)	39.50	*Polydora cornuta* (Annelida:Polychaeta)	7.23	*Ampelisca holmesi* (Crustacea:Amphipoda)	7.45
Monticellina cf. dorsobranchialis (Annelida:Polychaeta)	6.42	*Branchiostoma floridae* (Cephalochordata)	3.24	TUBIFICIDAE (Annelida:Oligochaeta)	5.17	*Branchiostoma floridae* (Cephalochordata)	5.93
TUBIFICIDAE (Annelida:Oligochaeta)	4.98	TUBIFICIDAE (Annelida:Oligochaeta)	2.07	*Amygdalum papyrium* (Mollusca:Bivalvia)	4.92	*Glottidia pyramidata* (Brachiopoda)	3.85
Caecum strigosum (Mollusca:Gastropoda)	4.94	*Caecum strigosum* (Mollusca:Gastropoda)	1.59	*Monticellina cf. dorsobranchialis* (Annelida:Polychaeta)	4.85	TUBIFICIDAE (Annelida:Oligochaeta)	3.74
Ampelisca holmesi (Crustacea:Amphipoda)	4.31	*Prionospio perkinsi* (Annelida:Polychaeta)	1.47	*Paraprionospio pinnata* (Annelida:Polychaeta)	4.22	*Monticellina cf. dorsobranchialis* (Annelida:Polychaeta)	3.64
Branchiostoma floridae (Cephalochordata)	3.44	*Mysella planulata* (Mollusca:Bivalvia)	1.34	*Balanus improvisus* (Crustacea:Cirripedia)	3.70	*Kalliapseudes macsweenyi* (Crustacea:Tanaidacea)	3.23
Tellina spp. (Mollusca:Bivalvia)	2.40	ENTEROPNEUSTA (Hemichordata)	1.29	*Glottidia pyramidata* (Brachiopoda)	2.87	*Parastarte triquetra* (Mollusca:Bivalvia)	3.10
Paraprionospio pinnata (Annelida:Polychaeta)	1.85	CIRRIPEDIA (Crustacea:Cirripedia)	1.26	*Augeneriella hummelincki* (Annelida:Polychaeta)	2.58	*Balanus spp.* (Crustacea:Cirripedia)	2.77
Carazziella hobsonae (Annelida:Polychaeta)	1.67	*Axiothella mucosa* (Annelida:Polychaeta)	1.23	*Streblospio spp.* (Annelida:Polychaeta)	2.09	*Rudilemboides naglei* (Crustacea:Amphipoda)	2.51
Inanidrilus sp. (Annelida:Oligochaeta)	1.42	*Monticellina cf. dorsobranchialis* (Annelida:Polychaeta)	1.10	*Aspidosiphon cf. muelleri* (Sipuncula)	2.00	*Cerapus sp. C (="tubularis")* (Crustacea:Amphipoda)	2.28

Table 21. Dominant benthic taxa (Relative Abundance) by Bay Segment.

Hillsborough Bay	%	Old Tampa Bay	%	Middle Tampa Bay	%	Lower Tampa Bay	%
Monticellina cf. dorsobranchialis (Annelida:Polychaeta)	8.75	CIRRIPEDIA (Crustacea:Cirripedia)	9.72	*Glottidia pyramidata* (Brachiopoda)	14.06	*Branchiostoma floridae* (Cephalochordata)	12.72
Mysella planulata (Mollusca:Bivalvia)	8.06	*Rudilemboides naglei* (Crustacea:Amphipoda)	6.99	*Branchiostoma floridae* (Cephalochordata)	8.69	*Fabricinuda trilobata* (Annelida:Polychaeta)	5.10
Ampelisca holmesi (Crustacea:Amphipoda)	6.87	*Mysella planulata* (Mollusca:Bivalvia)	6.31	*Caecum strigosum* (Mollusca:Gastropoda)	7.86	*Caecum strigosum* (Mollusca:Gastropoda)	4.35
Glottidia pyramidata (Brachiopoda)	6.32	*Branchiostoma floridae* (Cephalochordata)	5.49	*Monticellina cf. dorsobranchialis* (Annelida:Polychaeta)	3.52	TUBIFICIDAE (Annelida:Oligochaeta)	3.02
Carazziella hobsonae (Annelida:Polychaeta) *Prionospio perkinsi* (Annelida:Polychaeta)	3.67	*Caecum strigosum* (Mollusca:Gastropoda)	4.08	TUBIFICIDAE (Annelida:Oligochaeta)	2.34	*Janua (Dexiospira) steueri* (Annelida:Polychaeta)	2.52
TUBIFICIDAE (Annelida:Oligochaeta)	3.45	*Glottidia pyramidata* (Brachiopoda)	3.83	*Prionospio perkinsi* (Annelida:Polychaeta) *Janua (Dexiospira) steueri* (Annelida:Polychaeta)	2.14	*Leptochelia sp.* (Crustacea:Tanaidacea)	2.45
Amygdalum papyrium (Mollusca:Bivalvia)	3.15	*Ampelisca holmesi* (Crustacea:Amphipoda)	3.73	*Rudilemboides naglei* (Crustacea:Amphipoda)	1.92	*Acanthohaustorius uncinus* (Crustacea:Amphipoda)	2.29
Mulinia lateralis (Mollusca:Bivalvia)	2.40	*Tubificoides wasselli* (Annelida:Oligochaeta)	2.56	*Nucula proxima* (Mollusca:Bivalvia)	1.42	*Phascolion cryptum* (Sipuncula)	2.19
Paraprionospio pinnata (Annelida:Polychaeta)	2.35	*Prionospio perkinsi* (Annelida:Polychaeta)	2.36	*Synelmis ewingi* (Annelida:Polychaeta)	1.33	CIRRIPEDIA (Crustacea:Cirripedia)	2.18
Mediomastus ambiseta (Annelida:Polychaeta)	2.19	*Metharpinia floridana* (Crustacea:Amphipoda)	2.28	*Metharpinia floridana* (Crustacea:Amphipoda)	1.27	*Axiothella mucosa* (Annelida:Polychaeta)	2.07

Table 21. Continued.

Manatee River	%	Terra Ceia Bay	%	Boca Ciega Bay	%	Tampa Bay	%
Ampelisca abdita (Crustacea:Amphipoda)	14.71	*Monticellina cf. dorsobranchialis* (Annelida:Polychaeta)	7.51	TUBIFICIDAE (Annelida:Oligochaeta)	7.01	*Branchiostoma floridae* (Cephalochordata)	5.06
Monticellina cf. dorsobranchialis (Annelida:Polychaeta)	9.40	TUBIFICIDAE (Annelida:Oligochaeta)	7.50	*Janua (Dexiospira) steueri* (Annelida:Polychaeta)	6.14	*Monticellina cf. dorsobranchialis* (Annelida:Polychaeta)	4.48
Mulinia lateralis (Mollusca:Bivalvia)	7.98	*Paraprionospio pinnata* (Annelida:Polychaeta)	5.63	*Monticellina cf. dorsobranchialis* (Annelida:Polychaeta)	3.05	*Glottidia pyramidata* (Brachiopoda)	4.18
Ampelisca holmesi (Crustacea:Amphipoda)	5.15	*Ampelisca holmesi* (Crustacea:Amphipoda)	5.04	*Pileolaria rosepigmentata* (Annelida:Polychaeta)	2.78	TUBIFICIDAE (Annelida:Oligochaeta)	3.30
Amygdalum papyrium (Mollusca:Bivalvia)	4.97	*Mulinia lateralis* (Mollusca:Bivalvia)	3.84	*Cymadusa compta* (Crustacea:Amphipoda)	2.48	*Caecum strigosum* (Mollusca:Gastropoda)	2.99
Cyclaspis cf. varians (Crustacea:Cumacea)	4.74	*Mediomastus spp.* (Annelida:Polychaeta)	2.88	*Kalliapseudes macsweenyi* (Crustacea:Tanaidacea)	2.42	*Ampelisca holmesi* (Crustacea:Amphipoda)	2.95
Grandidierella bonnieroides (Crustacea:Amphipoda)	4.52	*Acteocina canaliculata* (Mollusca:Gastropoda)	2.37	*Tellina spp.* (Mollusca:Bivalvia)	2.09	*Mysella planulata* (Mollusca:Bivalvia)	2.81
Mediomastus spp. (Annelida:Polychaeta)	3.22	*Meioceras nitidum* (Mollusca:Gastropoda)	2.15	*Pomatoceros americanus* (Annelida:Polychaeta)	2.01	CIRRIPEDIA (Crustacea:Cirripedia)	2.44
Paraprionospio pinnata (Annelida:Polychaeta)	2.35	*Tubificoides wasselli* (Annelida:Oligochaeta)	2.01	*Exogone dispar* (Annelida:Polychaeta)	1.84	*Ampelisca abdita* (Crustacea:Amphipoda)	2.26
Streblospio spp. (Annelida:Polychaeta)	2.11	*Haminoea succinea* (Mollusca:Gastropoda)	1.85	*Axiothella mucosa* (Annelida:Polychaeta)	1.65	*Mulinia lateralis* (Mollusca:Bivalvia)	2.06

Benthic Community Similarity Analysis

The Cluster Analysis between sampling years indicated that the Tampa Bay benthic community fell into two main temporal groupings: 1993 - 1997 (Group A) and 1998 - 2004 (Group B) (Figure 81). A SIMPER analysis between the Group A and Group B clusters indicated that both groups had an average within group similarity of around 62% and the dissimilarity between A and B was approximately 48% (zero-adjusted Bray-Curtis index). Both Group A and B had many of the same contributing taxa, the main difference between the two groups being higher abundance of *Glottidia pyramidata* in the Group B years. Group A can further be divided into two sub-groupings designated A1 (1993 +1994) and A2 (1995+1996+1997). The similarity profile test (SIMPROF) indicated that there was no significant structure within the A1 group (i.e. the 1993 and 1994 benthic communities were not different from each other - designated by red lines in Figure 81). SIMPER analysis showed that A1 had an average similarity of 64% and was characterized by high abundances of *Branchiostoma floridae*, and *Monticellina cf. dorsobranchialis*. A total of 44 taxa accounted for 50% of the similarity within the A1 group. The three years comprising the A2 group also had an average similarity of around 64% and were characterized by Tubificid oligochaetes, *Caecum strigosum*, *Branchiostoma floridae,* and *Mysella planulata*. A total of 65 taxa accounted for 50% of the similarity within the A2 group. The average dissimilarity between the A1 and A2 groups was 39% with higher abundances of unidentified barnacles (Cirripedia) in the A2 group and of the capitellid polychaete *Mediomastus ambiseta* in the A1 group. A total of 164 taxa contributed to 50% of the dissimilarity between A1 and A2.

Within Group B sampling years 1998, 1999, and 2001 formed a distinct subgroup (designated as B1) as indicated by the SIMPROF test (Figure 81). The years within the B1 group had an average similarity of 68%. A total of 64 taxa contributed to 50% of the similarity within the B1 group, including *Monticellina cf. dorsobranchialis*, *Caecum strigosum*, and *Branchiostoma floridae*. The B1 years had an average dissimilarity of 37.72% with the other Group B years and differed mainly in lower abundances of *Glottidia pyramidata* and the amphipod *Rudilemboides naglei*.

The Cluster Analysis performed on the average species assemblage by bay segment (Figure 82) showed that the Tampa Bay benthic community fell into two main spatial groupings with the lower segments of the bay (Middle Tampa Bay, Lower Tampa Bay, and Boca Ciega Bay) forming one group (Group A) and the upper segments (Hillsborough Bay and Old Tampa Bay) plus Terra Ceia Bay and the Manatee River forming the second group (Group B). A SIMPER analysis between the two groups found that the Group A bay segments had an average Bray-Curtis similarity of 60.43% and were characterized by high abundances of *Branchiostoma floridae*, unidentified tubificid oligochaetes, the spirorbid polychaete *Janua (Dexiospira) steueri,* and the maldanid polychaete (“bamboo worm”) *Axiothella mucosa*. A total of 95 taxa contributed to 50% of the similarity among the Group A bay segments. The Group B segments had an average similarity of 56.55% and a total of 47 taxa contributed to 50% of the similarity among segments. Abundant taxa included *Ampelisca holmesi*, *Monticellina cf. dorsobranchialis*, *Mulinia lateralis*, *Mysella planulata,* and the spionid polychaete *Paraprionospio pinnata.*

A SIMPROF analysis indicated that within Group A the Middle Tampa Bay and Lower Tampa Bay segments formed a distinct subgroup (designated A1 in Figure 82). The A1 subgroup had and average similarity of 66.77% and had high abundances of *Branchiostoma floridae* and *Caecum strigosum*. There was 42.75% dissimilarity between A1 and the Boca Ciega Bay benthic community, with the A1 subgroup having higher abundances of *B. floridae*, *C. strigosum* and *Glottidia pyramidata*, while Boca Ciega Bay had greater abundances of the spirorbid polychaete *Pileolaria rosepigmentata* and the sabellid polychaete *Augeneriella hummelincki*.

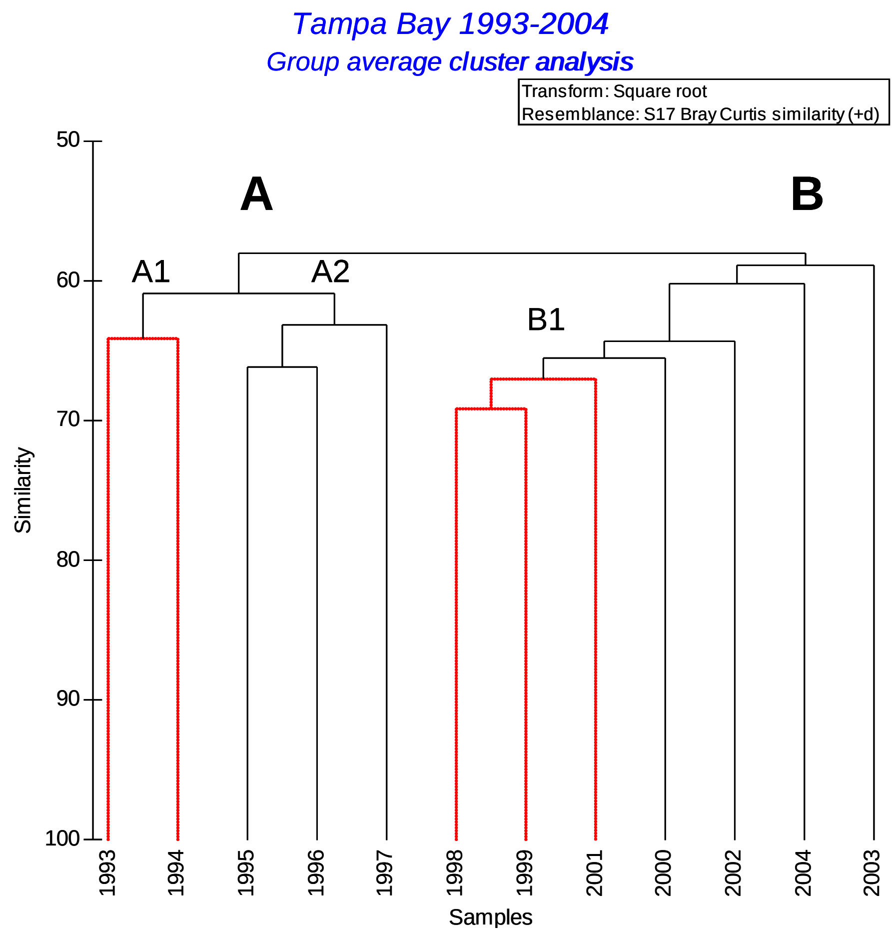

Figure 81. Cluster Analysis by sampling year.

The SIMPROF analysis also indicated two distinct subgroups within Group B, one composed of Terra Ceia Bay and the Manatee River (B1) and one composed of Hillsborough Bay and Old Tampa Bay (B2; Figure 82). The B1 subgroup had an average similarity of 56.79% with 45 taxa accounting for 50% of the similarity. The highest contributing species included *Monticellina cf. dorsobranchialis*, *Ampelisca holmesi*, *Mulinia lateralis*, and *Paraprionospio pinnata*. The B2 subgroup had an average similarity of 62.32% with 40 taxa accounting for 50% of the similarity. The highest contributing species included *Mysella planulata*, *Glottidia pyramidata*, *Ampelisca holmesi*, and the spionid polychaete *Prionospio perkinsi*. The two subgroups had an average dissimilarity of 45.95% with 99 taxa making up 50% of the dissimilarity. The B1 subgroup was characterized by higher abundances of *Ampelisca abdita*, while the B2 subgroup had higher abundances of *Glottidia pyramidata*, barnacles (Cirripedia), the amphipod *Rudilemboides naglei*, and *Mysella planulata*.

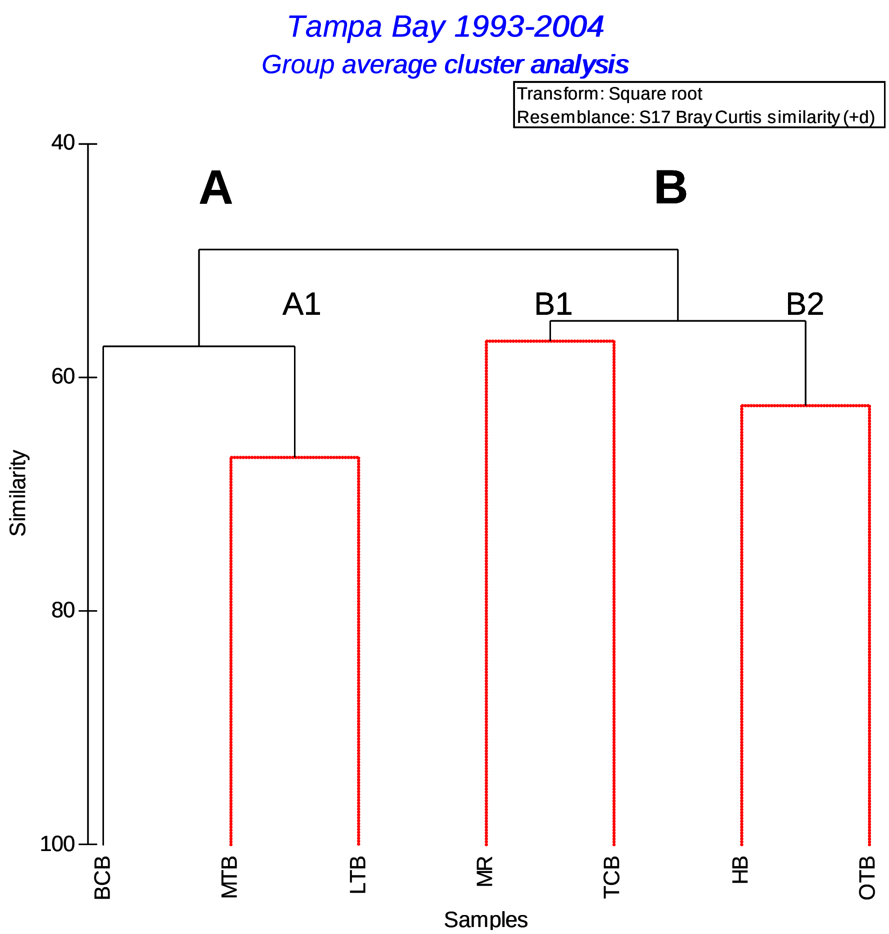

Figure 82. Cluster Analysis by bay segment.

Relating Biological and Environmental data

Multiple linear regression analysis of the benthic community indices versus the six measured hydrographic and sediment parameters are presented in Table 22. All indices showed a positive relationship with dissolved oxygen and a negative relationship with the percent silt+clay with the exception of Pielou's evenness index (*J'*). Salinity was also positively related to most of the indices except for abundance (*N*) and the Tampa Bay Benthic Index (TBBI).

Spearman Rank Order correlations between the benthic community indices and the hydrographic and sediment parameters are presented in Table 23. All of the indices except for evenness were positively correlated with bottom salinity, dissolved oxygen, and pH and negatively correlated with the percent silt+clay. Evenness had a weak positive correlation with both salinity and percent silt+clay. There was also a weak, negative correlation between bottom temperature and the number of taxa (*S*), Shannon diversity index (*H'*), and Tampa Bay Benthic Index. The TBBI also had a positive correlation with depth.

The Spearman correlations between the benthic community indices and sediment metals are summarized in Table 24. The number of taxa, abundance, Shannon diversity index and the Tampa Bay Benthic Index had negative correlations with most of the metals except tin and selenium. Abundance and the TBBI also were not significantly correlated with antimony. Evenness had a weak, positive correlation with half of the analyzed metals, but was not significantly correlated with several of the more frequently encountered contaminants such as arsenic, chromium, copper, or lead.

The number of taxa, abundance, diversity and TBBI were negatively correlated with all of the measured hydrocarbons, with the exception of the TBBI and acenaphthylene (Tables 25 – 27). Evenness was positively correlated with the low molecular weight PAHs fluorine and naphthalene (Table 25) as well as with benzo (G,H,I) perylene, retene, and coronene (Table 27).

The community indices generally had negative, but weaker correlations with the pesticides (Table 28). Total DDT and total PCBs had relatively strong negative correlations with the number of taxa, abundance, diversity. The TBBI was most strongly correlated with Total DDT as well as the DDT breakdown compounds DDD and DDE (Table 28).

Table 22. Multiple linear regression results of benthic community indices vs. physical parameters.

	Adj. R^2	Depth	Temp	Salinity	DO	pH	Silt+Clay
S	**0.423**	**NS (p=0.975)**	**NS (p=0.057)**	**+ (p<0.001)**	**+ (p<0.001)**	**+ (p=0.032)**	**- (p<0.001)**
N	**0.295**	**NS (p=0.739)**	**NS (p=0.768)**	**NS (p=0.413)**	**+ (p<0.001)**	**NS (p=0.192)**	**- (p<0.001)**
H'	**0.285**	**NS (p=0.070)**	**NS (p=0.064)**	**+ (p<0.001)**	**+ (p<0.001)**	**NS (p=0.295)**	**- (p<0.001)**
J'	**0.055**	**- (p=0.025)**	**NS (p=0.361)**	**+ (p=0.005)**	**+ (p<0.001)**	**NS (p=0.262)**	**NS (p=0.145)**
TBBI	**0.165**	**+ (p=0.031)**	**NS (p=0.117)**	**NS (p=0.075)**	**+ (p=0.011)**	**+ (p=0.003)**	**- (p<0.001)**

Table 23. Spearman correlation coefficients for benthic community matrices vs. environmental parameters.

	Depth	**Temp**	**Salinity**	**DO**	**pH**	**Silt+Clay**
S	**0.03 (p=0.284)**	**-0.12 (p=0.000)**	**0.34 (p=0.000)**	**0.34 (p=0.000)**	**0.31 (p=0.000)**	**-0.30 (p=0.000)**
N	**0.00 (p=0.892)**	**-0.03 (p=0.297)**	**0.06 (p=0.042)**	**0.20 (p=0.000)**	**0.16 (p=0.000)**	**-0.27 (p=0.000)**
H'	**-0.03 (p=0.294)**	**-0.12 (p=0.000)**	**0.34 (p=0.000)**	**0.30 (p=0.000)**	**0.26 (p=0.000)**	**-0.22 (p=0.000)**
J'	**-0.02 (p=0.494)**	**-0.02 (p=0.433)**	**0.15 (p=0.000)**	**0.02 (p=0.510)**	**-0.01 (p=0.677)**	**0.10 (p=0.000)**
TBBI	**0.10 (p=0.000)**	**-0.10 (p=0.000)**	**0.08 (p=0.008)**	**0.21 (p=0.000)**	**0.21 (p=0.000)**	**-0.34 (p=0.000)**

Table 24. Spearman Rank Correlations between benthic community indices and sediment metals.

		AG	AS	CD	CR	CU	NI	PB	SN	ZN	MN	SB	SE
S	ρ	-0.23	-0.07	-0.16	-0.35	-0.39	-0.29	-0.26	-0.05	-0.34	-0.19	-0.12	-0.09
	p	0.000	0.017	0.000	0.000	0.000	0.000	0.000	0.128	0.000	0.000	0.006	0.056
N	ρ	-0.25	-0.13	-0.18	-0.26	-0.30	-0.27	-0.22	-0.06	-0.29	-0.27	-0.09	-0.09
	p	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.037	0.000	0.000	0.038	0.035
H’	ρ	-0.13	-0.07	-0.12	-0.30	-0.31	-0.22	-0.24	-0.02	-0.24	-0.14	-0.15	-0.06
	p	0.000	0.016	0.000	0.000	0.000	0.000	0.000	0.509	0.000	0.001	0.001	0.162
J’	ρ	0.11	0.05	0.08	0.04	0.05	0.07	0.05	0.06	0.08	0.10	-0.04	0.00
	p	0.000	0.078	0.012	0.179	0.120	0.023	0.139	0.035	0.011	0.023	0.371	0.979
TBBI	ρ	-0.18	-0.11	-0.13	-0.25	-0.24	-0.17	-0.20	-0.08	-0.26	-0.20	0.02	0.03
	p	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.000	0.000	0.663	0.445

Table 25. Spearman Rank Correlations between benthic community indices and low molecular weight PAHs.

		Acenaphthene	Acenaphthylene	Anthracene	Fluorene	Naphthalene	Phenanthrene	Total LMW PAHs
S	ρ	-0.17	-0.15	-0.18	-0.19	-0.24	-0.26	-0.30
	p	0.000	0.000	0.000	0.000	0.000	0.000	0.000
N	ρ	-0.16	-0.13	-0.12	-0.20	-0.30	-0.18	-0.27
	p	0.000	0.000	0.000	0.000	0.000	0.000	0.000
H’	ρ	-0.09	-0.09	-0.15	-0.09	-0.09	-0.26	-0.21
	p	0.004	0.007	0.000	0.008	0.005	0.000	0.000
J’	ρ	0.04	0.02	-0.02	0.08	0.15	-0.04	0.05
	p	0.194	0.616	0.590	0.020	0.000	0.259	0.156
TBBI	ρ	-0.08	-0.01	-0.08	-0.09	-0.16	-0.18	-0.20
	p	0.014	0.739	0.010	0.006	0.000	0.000	0.000

Table 26. Spearman Rank Correlations between benthic community indices and high molecular weight and total PAHs.

		Benzo (A) Anthracene	Benzo (A) Pyrene	Chrysene	Dibenzo (A,H) Anthracene	Fluoranthene	Pyrene	Total HMW PAHs	Total PAHs
S	ρ	-0.33	-0.32	-0.33	-0.30	-0.32	-0.35	-0.38	-0.38
	p	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
N	ρ	-0.26	-0.27	-0.26	-0.28	-0.28	-0.29	-0.31	-0.33
	p	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
H'	ρ	-0.27	-0.27	-0.28	-0.21	-0.27	-0.31	-0.31	-0.29
	p	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
J'	ρ	0.01	0.01	0.00	0.06	0.01	-0.01	0.01	0.04
	p	0.709	0.790	0.933	0.096	0.836	0.844	0.782	0.276
TBBI	ρ	-0.25	-0.25	-0.29	-0.21	-0.25	-0.27	-0.29	-0.28
	p	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 27. Spearman Rank Correlations between benthic community indices and other measured hydrocarbons.

		Benzo (B) Fluoranthene	Benzo (K) Fluoranthene	Indeno (1,2,3-C,D) Pyrene	Benzo(G,H,I) Perylene	Retene	Coronene
S	ρ	-0.30	-0.31	-0.31	-0.34	-0.30	-0.33
	p	0.000	0.000	0.000	0.000	0.000	0.000
N	ρ	-0.20	-0.29	-0.29	-0.35	-0.30	-0.29
	p	0.000	0.000	0.000	0.000	0.000	0.000
H’	ρ	-0.30	-0.22	-0.24	-0.19	-0.11	-0.17
	p	0.000	0.000	0.000	0.000	0.056	0.004
J’	ρ	-0.04	0.06	0.06	0.12	0.15	0.14
	p	0.253	0.086	0.060	0.000	0.012	0.024
TBBI	ρ	-0.24	-0.22	-0.26	-0.29	-0.29	-0.28
	p	0.000	0.000	0.000	0.000	0.000	0.000

Table 28. Spearman Rank Correlations between benthic community indices and measured pesticides and total PCBs.

		p,p'-DDD	p,p'-DDE	p,p'-DDT	Total DDT	Endrin Aldehyde	Endrin Ketone	Endo SO_4	Methoxychlor	Mirex	Alpha Chlordane	Gamma Chlordane	Total Chlordane
S	ρ	-0.15	-0.17	-0.05	-0.22	-0.01	-0.10	-0.14	-0.09	-0.08	-0.06	-0.07	-0.13
	p	0.000	0.000	0.114	0.000	0.748	0.003	0.000	0.011	0.010	0.078	0.061	0.000
N	ρ	-0.20	-0.09	-0.03	-0.17	-0.01	-0.08	-0.10	-0.08	-0.09	-0.05	0.01	-0.08
	p	0.000	0.004	0.425	0.000	0.830	0.020	0.003	0.016	0.007	0.171	0.886	0.010
H'	ρ	-0.02	-0.16	-0.02	-0.17	0.01	-0.06	-0.11	-0.06	-0.05	-0.05	-0.11	-0.12
	p	0.516	0.000	0.451	0.000	0.752	0.081	0.000	0.057	0.096	0.152	0.003	0.000
J'	ρ	0.14	-0.04	0.01	0.02	0.04	0.00	-0.01	0.01	0.00	0.02	-0.06	-0.01
	p	0.000	0.280	0.801	0.566	0.280	0.915	0.859	0.867	0.986	0.516	0.095	0.679
TBBI	ρ	-0.17	-0.17	-0.06	-0.20	-0.08	-0.07	-0.06	-0.11	-0.08	-0.09	-0.11	-0.12
	p	0.000	0.000	0.065	0.000	0.013	0.038	0.063	0.000	0.019	0.008	0.002	0.000

Table 28. Continued.

		Alpha BHC	Beta BHC	Delta BHC	Lindane	Aldrin	Dieldrin	Endrin	Endosulfan 1	Endosulfan 2	Heptaclor	Heptaclor Epoxide	Total PCB
S	ρ	-0.06	0.03	-0.09	0.03	0.01	-0.04	-0.07	-0.05	-0.03	-0.08	-0.04	-0.21
	p	0.069	0.419	0.010	0.430	0.772	0.266	0.041	0.118	0.310	0.023	0.217	0.000
N	ρ	-0.10	0.10	-0.09	0.06	0.02	-0.02	-0.09	-0.05	-0.07	-0.05	-0.02	-0.16
	p	0.001	0.002	0.009	0.090	0.648	0.480	0.005	0.095	0.034	0.124	0.645	0.000
H'	ρ	-0.01	-0.09	-0.04	-0.01	0.00	-0.04	0.03	-0.03	0.02	-0.07	-0.08	-0.15
	p	0.822	0.009	0.233	0.878	0.975	0.173	0.443	0.310	0.608	0.048	0.025	0.000
J'	ρ	0.06	-0.12	0.03	-0.04	-0.02	-0.02	0.07	0.00	0.06	-0.02	-0.07	0.02
	p	0.064	0.000	0.350	0.232	0.461	0.543	0.048	0.934	0.062	0.516	0.035	0.581
TBBI	ρ	-0.11	-0.03	-0.06	0.00	-0.01	-0.05	-0.13	-0.06	-0.13	-0.06	0.02	-0.09
	p	0.001	0.398	0.081	0.917	0.654	0.134	0.000	0.089	0.000	0.077	0.642	0.005

Non-metric Multi-dimensional Scaling (MDS) indicates that the benthic communities within individual bay segments were relatively distinct and consistent over time (Figure 83). This was most apparent in Lower Tampa Bay and Boca Ciega Bay. There was an apparent gradation in the species composition along the north-south transect of the Bay with little overlap in species composition between Hillsborough Bay and Lower Tampa Bay. Boca Ciega Bay also appeared to have a unique benthic community. The Manatee River and Terra Ceia Bay benthic communities appeared to be more variable which may be a result of the smaller number of samples collected in these two segments.

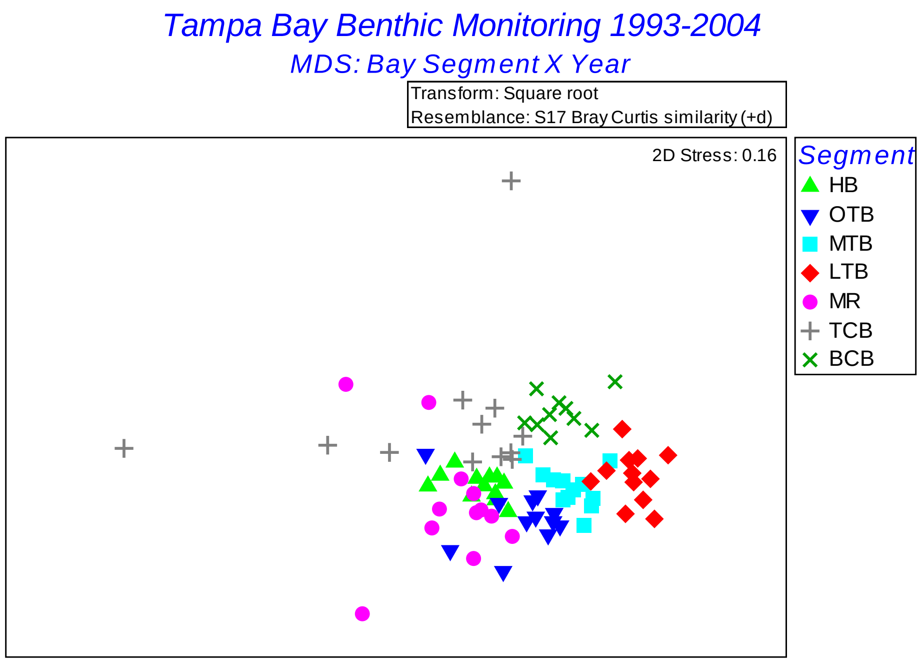

Figure 83. MDS plot of benthic species composition by bay segments, averaged by year.

Coding the sample points for descriptive categories of the different physical parameters illustrates that the benthic community composition is structured in part by depth (Figure 84), salinity (Figure 85), dissolved oxygen (Figure 86), and sediment type (Figure 87). The strong relationship between the percent silt+clay and benthic community composition is further illustrated as a “bubble plot” in figure 88.

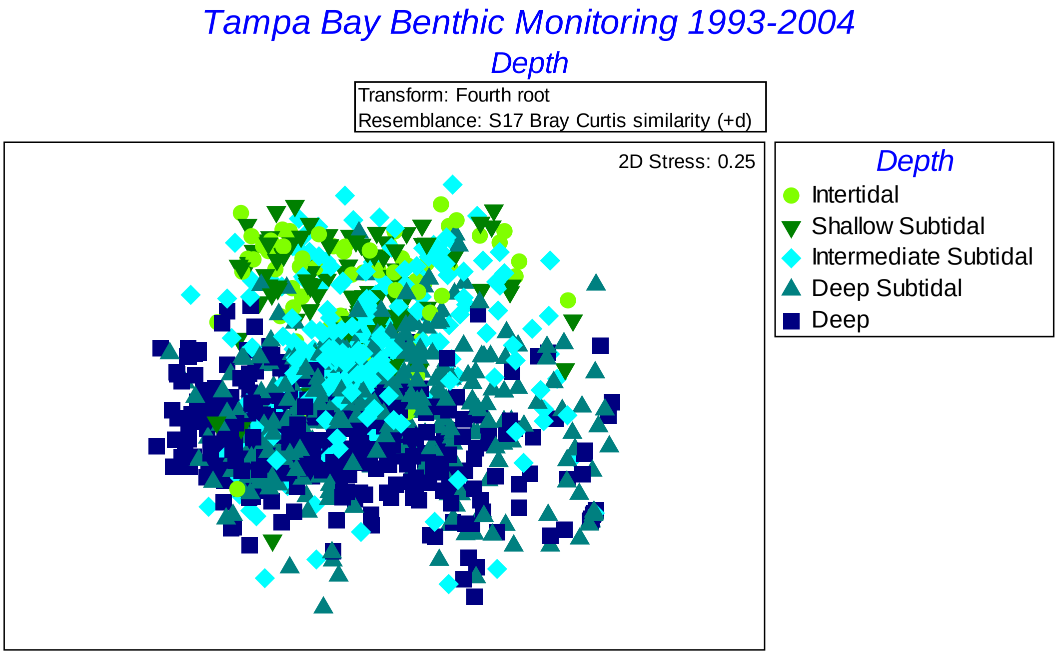

Figure 84. MDS plot data coded by sample depth category - all samples shown.

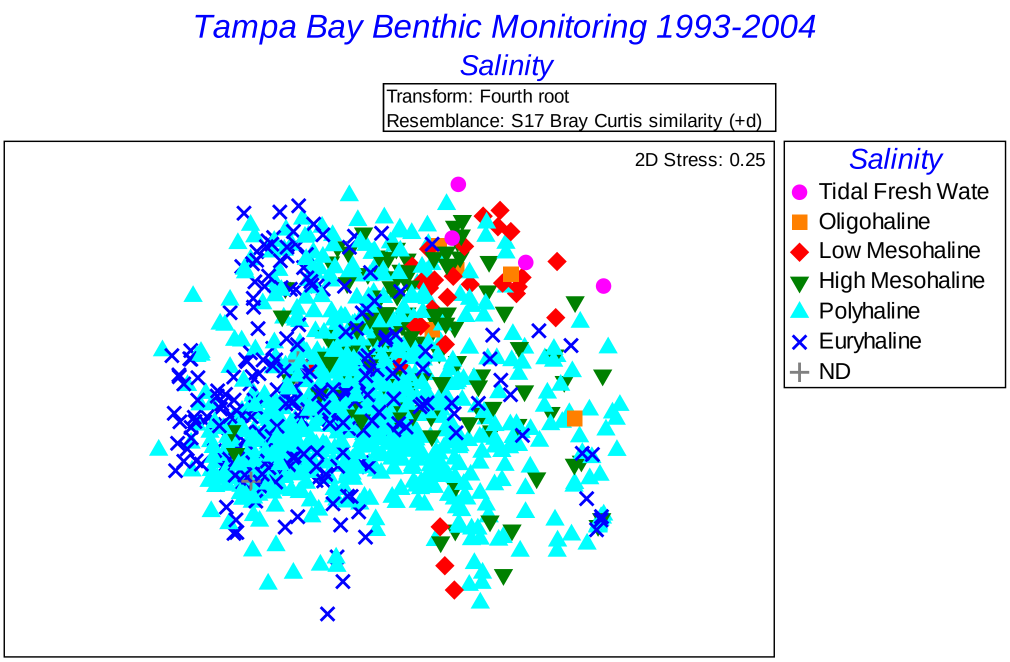

Figure 85. MDS plot data coded by salinity category - all samples shown.

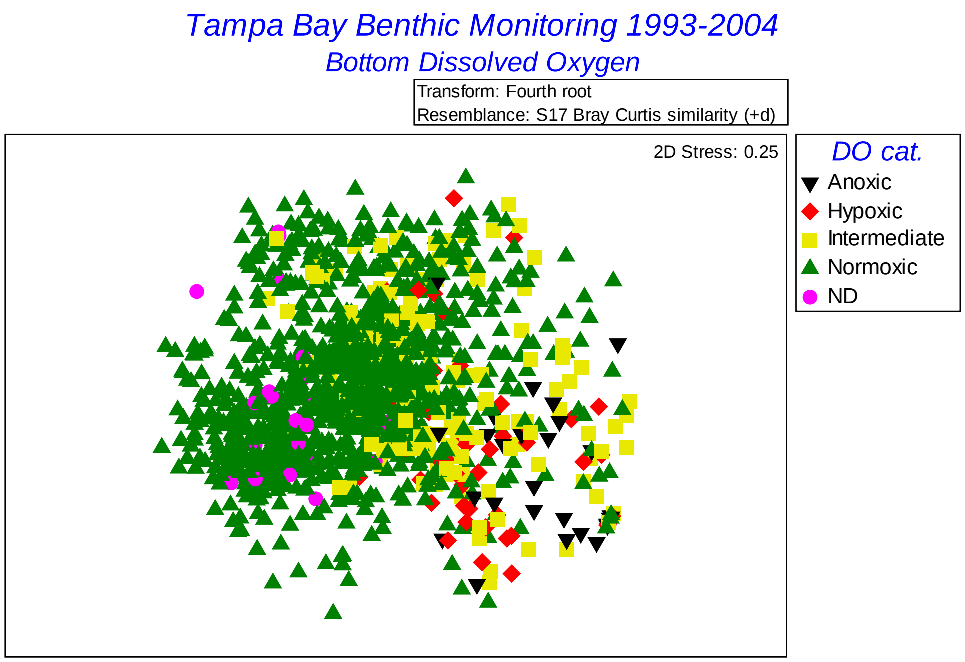

Figure 86. MDS plot data coded by dissolved oxygen category - all samples shown.

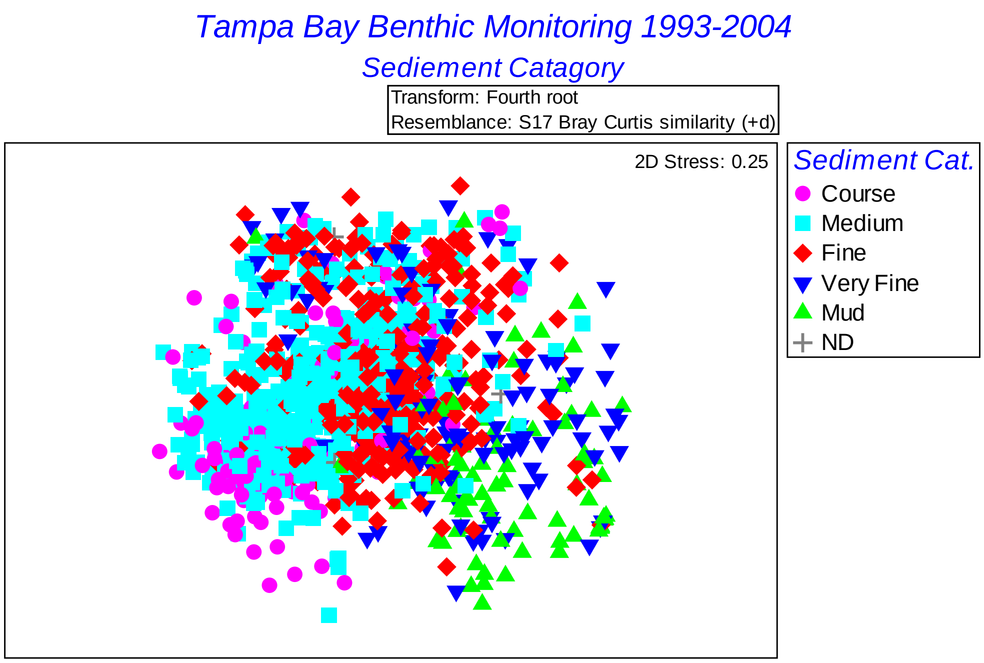

Figure 87. MDS plot data coded by sediment category - all samples shown.

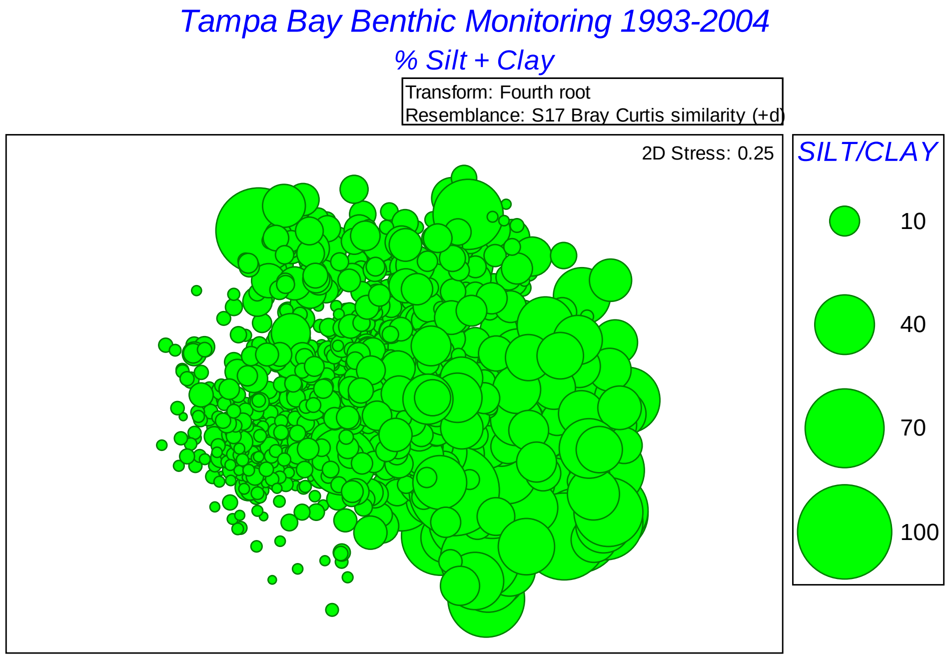

Figure 88. Bubble plot of percent silt+clay values on species similarity MDS plot.

The BIO-ENV analysis between the six environmental factors and the benthic species composition indicated that the strongest correlation was with a combination of depth, bottom salinity, bottom dissolved oxygen, and percent silt+clay (ρ_s = 0.499). The single variable with the highest correlation was percent silt+clay (ρ_s = 0.388) followed by dissolved oxygen (ρ_s = 0.231). The relationship between sediments and benthic infaunal communities over small and large spatial scales has been well established (Zajac 2001). Factors such as sediment grain size and organic content can affect the species present based on their feeding mode (Bloom et al. 1972). Within Tampa Bay, the distribution of dominant taxa is largely influenced by the sediment type as indicated by the high abundances of filter feeding organisms (*Branchiostoma floridae*, *Glottidia pyramidata*) in areas of low percent silt +clay, while deposit feeding species such as *Monticellina cf. dorsobranchialis* dominated in muddier areas.

Dissolved oxygen can affect the benthic community structure by decreasing the abundance and diversity of infaunal organisms during periods of hypoxia (Harper et al. 1981; Gaston 1985) or through the complete defaunation of areas impacted by periods of severe hypoxia or anoxia (Santos and Simon 1980 a&b). Hypoxia can affect individual organisms by decreasing feeding and growth rates and inhibiting their immune systems resulting in higher mortality (Burnett and Stickle 2001). Tolerance for low dissolved oxygen conditions is variable across different taxonomic groups and ecological niches which influences the species composition in habitats impacted by hypoxia. Several studies have shown that crustaceans in particular are more sensitive to hypoxia (Harper et al. 1981; Winn and Knott 1992). Polychaetes tend to dominate under hypoxic conditions with burrowing species being more tolerant than tube dwelling taxa (Harper et al. 1981; Gaston 1985). Some benthic organisms can exhibit physiological adaptations to hypoxic conditions such as increased production of respiratory pigments and switching from aerobic to anaerobic respiration (Burnett and Stickle 2001). Low dissolved oxygen can also cause behavioral responses in infaunal organisms including movement out of burrows or movement closer to the sediment surface, which in turn can result in increased predation by fish (Diaz et al. 1992; Nestlerode and Diaz 1998).

Sediment contaminants can have adverse effects on the structure of benthic infaunal communities. Long et al. (2001) in a review of several data sets found a relationship between increasing sediment toxicity and reduced measures of benthic diversity and abundance, particularly with amphipods. Analysis on the metal sediment contaminant data set showed a combination of chromium and copper had the strongest correlation with the benthic assemblage ($\rho_s = 0.357$) with chromium being the highest ranked single metal ($\rho_s = 0.315$). Analysis on the PAH dataset found the highest correlation with the benthic assemblage was due to a combination of naphthalene, fluoranthene, pyrene and indeno(1,2,3,C,D,) pyrene ($\rho_s = 0.262$) with pyrene having the strongest single correlation ($\rho_s = 0.251$). Total DDT had the highest correlation among the measured pesticides and PCB sediment contaminants ($\rho_s = 0.206$) with the strongest correlation occurring with a combination of Endosulfan 2, DDD, DDE, Total DDT, and total PCBs ($\rho_s = 0.235$).

Conclusions and Recommendations

Tampa Bay has shown tremendous improvements in its water quality over the past 30 years; however, population growth and development continue to strain the environmental resources of the region. Monitoring efforts such as the Bay-wide Benthic Monitoring Program are essential to assess the current environmental conditions in the bay, track long term environmental trends and identify areas in need of remediation. The first twelve years of the Bay-wide Benthic Monitoring Program indicate several trends in the conditions of the benthic environment, sediment chemistry and overall benthic community health.

The hydrographic and sediment parameters collected indicated that Tampa Bay is predominately a shallow estuary with a median depth of 2.8 meters. Overall salinities were in the polyhaline range with a median salinity of 26 psu. Salinities did fluctuate over time due to rainfall patterns and varied spatially due to the inflow from freshwater tributaries. Dissolved oxygen levels were generally high with a bay-wide median of 5.36 mg/L and with nearly 80% of the samples above 4 mg/L. There was however an observed trend of increasing hypoxia in Hillsborough Bay, particularly during the 2001-2004 sampling period. This may be due in-part to a sampling artifact in that the latter samples were collected earlier during the sampling window (August) when water temperatures tended to be higher. This trend in increased hypoxia however, was not as strong in the other bay segments despite the earlier sampling time. Hillsborough Bay also had a much larger percentage of sites which were either anoxic (9.03%) or hypoxic (17.36%) than the other segments of Tampa Bay. The increase in the extent of low dissolved oxygen conditions in Hillsborough Bay and its relationship with other water quality parameters warrants further investigation and it is recommended that historical data collected from other monitoring programs should be analyzed for long term trends in dissolved oxygen conditions.

Sediment contaminant levels were generally low at most sites with higher levels of contamination found at scattered sites and in localized areas, particularly in Hillsborough Bay. Most metals had highest concentrations in Hillsborough Bay. Cadmium had the highest percentage of sites that exceeded the Threshold Effects Level (TEL) and Potential Effects Level (PEL) for sediment toxicity, but the metal: aluminum ratio for cadmium indicated that most sites were not enriched above background levels. All of the metals collected were elevated above their established TELs or PELs as a small percentage of sites. Chromium, copper and zinc had the strongest correlation with benthic community measures and were negatively correlated with the number of taxa and the Tampa Bay Benthic Index. Chromium and copper were also found to be related to the overall benthic species composition, with chromium having the strongest correlation.

Low and high molecular weight PAHs, as well as the overall total PAHs had relatively low concentrations throughout the bay except in isolated sites. Individual hydrocarbons, including acenaphthene, acenaphthylene, and dibenzo (a, h) anthracene however were found at elevated levels (>TEL) in approximately 15% of the samples. The number of taxa had a relatively strong, negative correlation with PAHs, and the high molecular weight PAH pyrene had the strongest correlation with the benthic community structure.

Chlorinated pesticides and PCBs were found at low concentrations throughout the bay, with total PCB's, total DDT and the DDT derivative DDE each having TEL exceedences at over 2% of the sites. Few pesticides had strong or significant correlations with any of the measured benthic community indices with the exception of total DDT and total PCB's which were negatively correlated with the number of taxa. Total DDT also had the strongest correlation with the benthic community composition.

Tampa Bay supports a diverse benthic infaunal community with approximately 1,500 taxa identified from this monitoring program and with a median of 35 taxa per sample. A relatively small number of species however, dominate the overall abundance with only seven taxa accounting for 25% of the relative abundance. The most abundant organism was the cephalochordate *Branchiostoma floridae*, which was found predominantly in coarser grained sediments. The benthic community composition showed some variability over time and spatially between bay segments. Notably, the benthic community composition during the first five years of monitoring (1993-1997) was more similar to each other than the following seven years (1998-2004). Spatially, Boca Ciega Bay, Lower Tampa Bay and Middle Tampa Bay had more similar benthic communities relative to Old Tampa Bay, Hillsborough Bay, Terra Ceia Bay and the Manatee River. Sediment composition had the strongest correlation with the benthic community structure of the physical parameters measured followed by dissolved oxygen. Despite the high diversity of benthic taxa found, trends in the Tampa Bay Benthic Index appear to indicate that the overall condition of the benthic habitat in Tampa Bay is poor. Old Tampa Bay in particular shows a trend in degrading benthic conditions, particularly in the northern and western portions of this bay segment. This downward shift in the benthic habitat also corresponds to an apparent increase in the percent silt+clay in the sediments in that portion of Old Tampa Bay.

The generally "Poor" to "Fair" rating of benthic condition in Tampa Bay, the observed trends towards increased areas of hypoxia in Hillsborough Bay, the increased area of finer grained sediments, and corresponding degraded benthic habitat in parts of Old Tampa Bay emphasize the continued need for benthic monitoring in Tampa Bay. In order to maintain sufficient monitoring efforts to detect changes in the benthic conditions over time while meeting current budgetary constraints, the following recommendations were implemented retroactive to the 2005 sampling year:

- Reduce sampling effort to control increasing monitoring costs.
    - Increase reporting period to five years from current four year reporting period reducing the number of samples collected per year but maintaining long term statistical power.
    - Combine MTB and LTB into a single reporting unit since these two bay segments are the least impacted by sediment contaminants and low dissolved oxygen, have similar benthic species assemblages and are also the most costly samples to process due to the high species diversity in these two segments.

These additional recommendations are proposed for future monitoring of sediments and benthic communities in Tampa Bay:

- Redirect sampling effort to address gaps in the current data and focus on areas of special interest.
    - Continue focus on special study sites – areas of known or suspected environmental degradation or sites with known upcoming impacts such as dredging or proposed mitigation sites.
    - Revisit past special study sites.
    - Increase monitoring efforts in the major river systems (Hillsborough, Palm, Alafia and Little Manatee) and tidal stream areas since few low salinity areas are included in the current database and these systems serve as nursery areas for commercial and recreationally important species. There are also known problems with high sediment contaminants in several rivers, potential impacts due to continued development, and surface water withdrawals for drinking water.

The implementation of these proposed modifications will help to maintain an effective monitoring program to evaluate the long term status of the benthic habitat in Tampa Bay while addressing current budgetary constraints. The program thus far has provided an extensive baseline of the status of benthic habitats and sediment conditions in Tampa Bay which can be utilized to gage future improvements or degradations in the health of the benthic community over the long term. The results presented here indicate that the current status of the benthic community in the upper portions of Tampa Bay is showing an apparent downward trend as indicated by the Tampa Bay Benthic Index, along with trends in increasing hypoxia in Hillsborough Bay and changes in the sediment composition in Old Tampa Bay. These trends emphasize the importance of benthic monitoring as a management tool and the need for long-term monitoring to track changes in environmental conditions and to focus resources for restoration and management.

Literature Cited

AISN Software. 2000. *Table Curve 2D ver.5.0*, SPSS, Chicago, IL.

Amezcua-Allieri, M., and Salazar-Coria, L. 2008. Nickel and vanadium concentrations and its relation with sediment acute toxicity. Bulletin of Environmental Contamination and Toxicology 80(6): 555-560.

Barwick, M., and Maher, W. 2003. Biotransference and biomagnification of selenium, copper, cadmium, zinc, arsenic and lead in a temperate seagrass ecosystem from Lake Macquarie Estuary, NSW, Australia. Marine Environmental Research 56: 471-502.

Burnett, L.E. and Stickle, W.B. 2001. Physiological responses to hypoxia. Chapter 6 pp. 101-114 in N.N. Rabalais and R.E. Turner (eds.) Coastal Hypoxia: Consequences for Living Resources and Ecosystems. American Geophysical Union, Washington D.C.

Blake, J.A. 1991. Revision of some genera and species of Cirratulidae (Polychaeta) from the Western North Atlantic. Ophelia Suppl 5: 17-30.

Blake, J.A. 1996. Chapter 8. Family Cirratulidae Ryckholdt, 1851: Including a revision of the genera and species from the Eastern North Pacific. Pp. 263-384 in J.A. Blake, B. Hilbig and P.H. Scott (eds). Taxonomic Atlas of the benthic fauna of the Santa Maria Basin and the Western Santa Barbara Channel Volume 6: The Annelida Part 3 Polychaeta: Orbiniidae to Cossuridae. Santa Barbara Museum of Natural History, Santa Barbara, CA.

Bloom, S.A., Simon, J.L. and Hunter, V.D. 1972. Animal-sediment relations and community analysis of a Florida estuary. Marine Biology 13: 43-56.

Brooks, G.R. and Doyle, L.J. 1991. Distribution of sediments and sedimentary contaminants in Tampa Bay. In: Treat, S.F. and P.A. Clark (Eds.). Proceedings, Tampa Bay Area Scientific Information Symposium 2 (February 27 – March 1, 1991).TEXT, Tampa, FL.

Brooks, G.R. and Doyle, L.J. 1992. A characterization of Tampa Bay Sediments. Phase III: Distribution of sediments and sedimentary contaminants. Final Report Submitted to SWFWMD.

Burreau, S., Zebühr, Y., Broman, D., and Ishaq, R. 2006. Biomagnification of PBDEs and PCBs in food webs from the Baltic Sea and the northern Atlantic Ocean. Science of the Total Environment 366:659-672.

Clarke, R.K and Ainsworth, M. 1993. A method of linking multivariate community structure to environmental variables. Marine Ecology Progress Series 92: 205-219.

Clarke, K.R. and Gorley, R.N. 2006. PRIMER v6: User Manual/Tutorial. PRIMER-E Ltd. Plymouth, U.K.

Clarke, K.R., and Warwick, R.M. 2001. Change in marine communities: an approach to statistical analysis and interpretation, 2nd edition. PRIMER-E ltd. Plymouth, U.K.

Clarke, K.R., Somerfield, P.J. and Chapman, M.G. 2006. On resemblance measures for ecological studies, including taxonomic dissimilarities and a zero-adjusted Bray-Curtis coefficient for denuded assemblages. Journal of Experimental Marine Biology and Ecology 330: 55-80.

Coastal Environmental, Inc. 1994. A monitoring program to assess environmental changes in Tampa Bay Florida. Prepared for: Tampa Bay National Estuary Program. TBNEP Tech. Pub #02-93.

Courtney, C.M., Grabe, S.A., Karlen, D.J., Brown, R. and Heimbuch, D. 1995. Field operations manual for a synoptic survey of benthic macroinvertebrates of the Tampa Bay estuaries. EPCHC Technical Document. November 1995. 55pp.

Culter, J.K. 1979. A population study of the inarticulate brachiopod *Glottidia pyramidata* (Stimpson). M.A. Thesis, Department of Biology, University of South Florida. Tampa, FL.

Culter, J.K. 1986. Manual for identification of marine invertebrates: A guide to some common estuarine macroinvertebrates of the Big Bend region, Tampa Bay, Florida. USEPA Document EPA/600/4-86/002.

Culter, J.K. and Simon, J.L. 1987. Sex ratios and the occurrence of hermaphrodites in the inarticulate brachiopod, *Glottidia pyramidata* (Stimpson) in Tampa Bay, Florida. Bulletin of Marine Science 40(2): 193-197.

Dawson, C.E. 1965. Rainstorm induced mortality of lancelets, Branchiostoma, in Mississippi Sound. Copeia 1965 (1): 505-506.

Diaz, R.J., Neubauer, R.J., Schaffner, L.C., Pihl, L., and Baden, S.P. 1992. Continuous monitoring of dissolved oxygen in an estuary experiencing periodic hypoxia and the effect of hypoxia on macrobenthos and fish. Science of the Total Environment Suppl. 1992: 1055-1068.

Di Toro, D.M., Mahony, J.D., Hansen, D.J., Scott, K.J., Hicks, M.B., Mayr, S.M. and Redmond, M.S. 1990. Toxicity of cadmium in sediments: the role of acid volatile sulfide. Environmental Toxicity and Chemistry 9: 1487-1502.

Egeler, P., Römbke, J., Meller, M., Knacker, Th., Franke, C., Studinger, G. and Nagel, R. 1997. Bioaccumulation of lindane and hexachlorobenzene by tubificid sludgeworms (Oligochaeta) under standardized laboratory conditions. Chemosphere 35(4): 835-852.

Engle, V.D., and Summers, J.K. 1999. Refinement, validation, and application of a benthic condition index for Northern Gulf of Mexico Estuaries. Estuaries 22(3A): 624-635.

Engle, V.D., Summers, J.K., and Gaston, G.R. 1994. A benthic index of environmental condition of Gulf of Mexico estuaries. Estuaries 17(2): 372-384.

ESRI. (2006) ArcGIS 9.2. Redlands, CA.

Ferraro, S.P., and Cole, F.A. 1997. Effects of DDT sediment contamination on macrofaunal community structure and composition in San Francisco Bay. Marine Biology 130: 323-334.

Fliedner, A., and Klein, W. 1996. Effects of Lindane on the Planktonic Community in Freshwater Microcosms. Ecotoxicology and Environmental Safety 33: 228–235.

Franz, D.R. 1973. The ecology and reproduction of a marine bivalve, *Mysella planulata* (Erycinacea). Biological Bulletin 144: 93-106.

Frithsen, J.B., Schreiner, S.P., Strebel, D.E., Lalijani, R.M., Logan, D.T., and Zarbock, H.W. 1995. Chemical contaminants in the Tampa Bay Estuary: A summary of distributions and inputs. TBNEP Tech. Pub. #01-95.

Gaston, G.R. 1985. Effects of hypoxia on macrobenthos of the inner shelf off Cameron, Louisiana. Estuarine, Coastal and Shelf Science 20: 603-613.

Grabe, S.A., and Barron, J. 2002. Status of Tampa Bay sediments: Polycyclic aromatic hydrocarbons, organochlorine pesticides, and polychlorinated biphenyls (1993 and 1995-1999). Environmental Protection Commission of Hillsborough County Technical Report.

Grabe, S.A. and Barron, J. 2004. Sediment contamination, by habitat, in the Tampa Bay estuarine system (1993-1999): PAHs, Pesticides and PCBs. Environmental Monitoring and Assessment 91: 105-144.

Grabe, S.A., Courtney, C.M., Lin, Z., Alberdi, D., Wilson, H.T., and Blanchard, G. 1996. Environmental Monitoring and Assessment Program – Estuaries West Indian Province 1993 Sampling Volume III Technical Report: A synoptic survey of the benthic macroinvertebrates and demersal fishes of the Tampa Bay estuarine system. TBNEP Tech. Pub. #95-12.

Grabe, S.A., Karlen, D.J., Holden, C.M., Goetting, B.K., Markham, S.E. and Dix, T.L. 2006. Gammaridean Amphipoda of Tampa Bay, Florida (Gulf of Mexico): Distribution and association with abiotic variables. EPCHC Technical Report prepared for the Tampa Bay Estuary Program.

Hall, J.R., and Saloman, C.H. 1975. Distribution and abundance of macroinvertebrate species of six phyla in Tampa Bay, Florida, 1963-64 and 1969. NMFS Data Report 100. USDOC/NOAA/NMFS Seattle WA. 505pp.

Harper, D.E. Jr., McKinney, L.D., Salzer, R.R., and Case, R.J. 1981. The occurrence of hypoxic bottom water off the upper Texas coast and its effects on the benthic biota. Contributions in Marine Science 24: 53-79.

Hochberg, R.J., Weisberg, S.B., Frithsen, J.B., Janicki, A.J., Heimbuch, D.H., and Wilson, H.T. 1992. Design of a basin wide monitoring program for the Tampa Bay estuary. TBNEP Technical Publication #09-92.

Janicki Environmental, Inc. 2003. Tampa Bay Benthic Monitoring Program redesign assessment Final Report. TBEP Tech. Pub #06-03.

Janicki Environmental, Inc. 2005. Development of a benthic index to establish sediment quality targets for the Tampa Bay estuary. Final Report. TBEP Tech. Pub. #01-06.

Kamrin, M.A. (ed.). 1997. Pesticide profiles: toxicity, environmental impact and fate. CRC Press. Boca Raton. 676pp.

Kennish, M.J. 1998. Pollution impacts on marine biotic communities. CRC Press, Boca Raton. 310 pp.

Kennish, M.J., and Ruppel, B.F. 1996. Chlordane contamination in selected estuarine and coastal marine finfish and shellfish of New Jersey, USA. Environmental Pollution 94(1): 75-81.

Kennish, M.J., and Ruppel, B.F. 1997. Chlordane contamination in selected freshwater finfish of New Jersey. Bulletin of Environmental Contamination and Toxicology 58: 142-149.

Kirby, J., Maher, W., and Krikowa, F. 2001. Selenium, cadmium, copper, and zinc concentrations in sediments and mullet (*Mugil cephalus*) from the Southern Basin of Lake Macquarie, NSW, Australia. Archives of Environmental Contamination and Toxicology 40: 246-256.

Klerks, P.L., Felder, D.L., Strasser, K., and Swarzenski, P.W. 2007. Effects of ghost shrimp on zinc and cadmium in sediments from Tampa Bay, FL. Marine Chemistry 104: 17-26.

Kuzyk, Z.A., Stow, J.P., Burgesss, N.M., Solomon, S.M., and Reimer, K.J. 2005. PCBs in sediments and the coastal food web near a local contaminant source in Saglek Bay, Labrador. Science of the Total Environment 351-352: 264-284.

Lee, C.-H., Ryu, T.-K., Chang, M., and Choi, J.-W. 2004. Effect of silver, cadmium, chromium, copper, and zinc on the fertilization of the Northern Pacific asteroid, *Asterias amurensis*. Bulletin of Environmental Contamination and Toxicology 73: 613-619.

Lewis, R.R., and Whitman, R.L. 1985. A new geographic description of the boundaries and subdivisions of Tampa Bay. In: Treat, S.F., Simon, J.L., Lewis, R.R., Whitman, R.L. (Eds.). Proceedings, Tampa Bay Area Scientific Information Symposium (May 1982). Burgess Publishing Co., Inc., Minneapolis, MN.

Lewis, R.R., III, and Estevez, E.D. 1988. The ecology of Tampa Bay, Florida: an estuarine profile. U.S. Fish and Wildlife Service Biological Report 85(7.18), 132 pp.

Long, E.R., Hong, C.B., and Severn, CG. 2001. Relationships between acute sediment toxicity in laboratory tests and abundance and diversity of benthic Infauna in marine sediments: A review. Environmental Toxicology and Chemistry 20(1): 46-60.

Long, E.R., Wolfe, D.A., Carr, R.S., Scott, K.J., Thursby, G.A., Windom, H.L., Lee, R., Calder, F.D. Slone, G.M. and Seal, T. 1994. Magnitude and Extent of Sediment Toxicity in Tampa Bay, Florida. NOAA Tech. Mem. NOS ORCA 78. NOAA Silver Spring, MD.

Luoma, S.N., Ho, Y.B, and Bryan, G.W. 1995. Fate, bioavailability and toxicity of silver in estuarine environments. Marine Pollution Bulletin 31(1-3): 44-54.

Macauley, J.M. 1993. Environmental Monitoring and Assessment Program Estuaries – Louisianian Province: 1993 Sampling. Field Operations Manual. United States Environmental Protection Agency ERL/GB NO SR119. [DRAFT 4/22/93].

MacDonald, D.D. 1994. Approach to the Assessment of Sediment Quality in Florida Coastal Waters Volume 1 - Development and Evaluation of Sediment Quality Assessment Guidelines. Florida Department of Environmental Protection. 124pp.

MacDonald, D.D., Carr, R.S., Calder, F.D., Long, E.R., and Ingersoll, C.G. 1996. Development and evaluation of sediment quality guidelines for Florida coastal waters. Ecotoxicology 5: 253-278.

MacDonald, D.D., Carr, R.S., Eckenrod, D., Greening, H., Grabe, S., Ingersoll, C.G., Janicki, S., Janicki, T., Lindskoog, R.A., Long, E.R., Pribble, R., Sloane, G., and Smorong, D.E. 2004. Development, evaluation and application of sediment quality targets for assessing and managing contaminated sediments in Tampa Bay, Florida. Archives of Environmental Contamination and Toxicology. 46: 147-161.

Magnusson, K., Ekelund, R., Grabic, R. and Bergqvist, P.-A. 2006. Bioaccumulation of PCB congeners in marine benthic infauna. Marine Environmental Research 61: 379-395.

Malloy, K.J., Wade, D. Janicki, A. Grabe, S.A., and Nijbroek, R. 2007. Development of a benthic index to assess sediment quality in the Tampa Bay Estuary. Marine Pollution Bulletin 54: 22-31.

McConnell, R., and Brink, T. 1997. Toxic contamination assessment: sources of sediment contaminants of concern and recommendations for prioritization of Hillsborough and Boca Ciega sub-basins. TBNEP Tech. Pub. #03-97.

McConnell, R., DeMott, R., and Schulten, J. 1996. Toxic contamination sources assessment: risk assessment for chemicals of potential concern and methods for identification of specific sources. TBNEP Tech. Pub. #09-96.

Moore, M.T., Huggett, D.B., Gillspie W.B. Jr., Rodgers, J.H. Jr, and Cooper, C.M. 1998. Comparative toxicity of chlordane, chlorpyrifos, and aldicarb to four aquatic testing organisms. Archives of Environmental Contamination and Toxicology 34: 152-157.

Mote Marine Laboratory. 1995. Benthic Infauna of Tampa Bay Summer 1993. TBEP Tech. Pub. #02-95.

Nelson, G.E. 1969. Amphioxus in Old Tampa Bay, Florida. Quarterly Journal of the Florida Academy of Sciences 31:93-100.

Nestlerode, J.A. and Diaz, R.J. 1998. Effects of periodic environmental hypoxia on predation of a tethered polychaete, *Glycera americana*: implications fro trophic dynamics. Marine Ecology Progress Series 172: 185-195.

Ngabe, B., Bidleman, T.F., and Scott, G.I. 2000. Polycyclic aromatic hydrocarbons in storm runoff from urban and coastal South Carolina. The Science of the Total Environment 255: 1-9.

Olsgard, F. 1999. Effects of copper contamination on recolonization of subtidal marine soft sediments – an experimental field study. Marine Pollution Bulletin 38(6): 448-462.

Paine, R.T. 1963. Ecology of the brachiopod *Glottidia pyramidata.* Ecological Monographs 33(3): 187-213.

Percival, J. B. and Lindsay, P. J. 1997, 'Measurement of physical properties of sediments', in A. Mudroch, J. M. Azcue and P. Mudroch (eds), *Manual of Physico-chemical Analysis of Aquatic Sediments*, Lewis Publ. Boca Raton, pp. 7-46.

Pierce, E. L. 1965. The distribution of lancelets (Amphioxi) along the coasts of Florida. Bulletin of Marine Science 15 (2): 480-494.

PRIMER-E Ltd. 2006. PRIMER v6. Plymouth, U.K.

Purcell, T.W. and Peters, J.J. 1998. Sources of silver in the environment. Environmental Toxicology and Chemistry 17(4): 539-546.

Rasmussen, A.D., Banta, G.T., and Andersen, O. 1998. Effects of Bioturbation by the lugworm *Arenicola marina* on cadmium uptake and distribution in sandy sediments. Marine Ecology Progress Series 164: 179-188.

Ruelas-Inzunza, J., and Páez-Osuna, F. 2008. Trophic distribution of Cd, Pb, and Zn in a food web from Altata-Ensenada del Pabellón subtropical lagoon, SE Gulf of California. Archives of Environmental Contamination and Toxicology 54: 584-596.

Santos, S.L. and Simon, J.L. 1980a. Marine soft-bottom community establishment following annual defaunation: larval or adult recruitment? Marine Ecology Progress Series 2: 235 – 241.

Santos, S.L. and Simon, J.L. 1980b. Response of soft-bottom benthos to annual catastrophic disturbance in a South Florida estuary. Marine Ecology Progress Series 3: 347 – 355.

SAS Institute, Inc. 2003. Statistical Analysis Software v. 9.1.3 Service Pack 4. Cary, NC.

Schropp, S.J., Lewis, F.G., Windom, H.L., Ryan, J.D., Calder, F.D., and Burney, L.C. 1990. Interpretation of metal concentrations in estuarine sediments of Florida using aluminum as a reference element. Estuaries 13: 227-235.

Seebaugh, D.R., Estephan, A., and Wallace, W.G. 2006. Relationship between dietary cadmium adsorption by grass shrimp (*Palaemonetes pugio*) and trophically available cadmium in amphipod (*Gammarus lawrencianus*) prey. Bulletin of Environmental Contamination and Toxicology 76: 16-23.

Stokes, M.D. 1996. Larval settlement, post-settlement growth and secondary production of the Florida lancelet (= amphioxus) *Branchiostoma floridae*. Marine Ecology Progress Series 130: 71-84.

Straub, C.L., Maul, J.D., Halbrook, R.S., Spears, B. and Lydy, M.J. 2007. Trophic transfer of polychlorinated biphenyls in great blue heron (*Ardea herodias*) at Crab Orchard National Wildlife Refuge, Illinois, United States. Archives of Environmental Contamination and Toxicology 52: 572-579.

Swartz, R.C., Cole, F.A., Lamberson, J.O., Ferraro, S.P., Schults, D.W., DeBen, W.A., Lee, H. II, and Ozretich, R.J. 1994. Sediment toxicity, contamination and amphipod abundance at a ddt- and dieldrin-contaminated site in San Francisco Bay. Environmental Toxicology and Chemistry 13(6): 949-962.

SYSTAT Software, Inc. 2004. SYSTAT® 11. Richmond, CA.

SYSTAT Software, Inc. 2006a. SigmaStat® 3.5. Richmond, CA.

SYSTAT Software, Inc. 2006b. SigmaPlot 10.0. Richmond CA.

Taylor, J.L. 1971. Polychaetous annelids and benthic environments in Tampa Bay, Florida. Doctoral Dissertation. University of Florida, Gainesville FL. Facsimile copy, UMI Dissertation Services Ann Arbor, MI.

Taylor, J.L., Hall, J.R. and Saloman, C.H. 1970. Mollusks and benthic environments in Hillsborough Bay, Florida. Fishery Bulletin 68 (2): 191-202.

Thoemke, K.W. 1979. The life histories and population dynamics of four subtidal amphipods from Tampa Bay, Florida. Doctoral Dissertation. University of South Florida, Tampa, FL. Facsimile copy, UMI Dissertation Services Ann Arbor, MI.

TBNEP 1996. Charting the course: The Comprehensive Conservation and Management Plan for Tampa Bay.

Trannum, H.C., Olsgard, F., Skei, J.M., Indrehus, J., Øverås, and Eriksen, J. 2004. Effects of copper, cadmium, and contaminated harbour sediments on recolonization of soft-bottom communities. Journal of Experimental Marine Biology and Ecology 310: 87-114.

U.S. Census Bureau (2007) **http://quickfacts.census.gov/qfd/states/12/12057.html**

U.S. Environmental Protection Agency. 2007. National Estuary Program Coastal Condition Report. http://www.epa.gov/owow/oceans/nepccr/index.html

Van Dolah, R.F, Riekerk, G.H.M., Levisen, M.V., Scott, G.I., Fulton, M.H., Bearden, D., Sivertsen, S., Chung, K.W., and Sanger, D.M. 2005. An evaluation of polycyclic aromatic hydrocarbon (PAH) runoff from highways into estuarine wetlads of South Carolina. Archives of Envrionmental Contamination and Toxicology. 49: 362-370.

Venice Symposium. 1959. Final Resolution: The Venice System for the Classification of Marine Waters According to Salinity. Archivio di Oceanografia e Limnologia 11 (Suppl): 243-248.

Versar, Inc. 1993. Tampa Bay National Estuary Program Benthic Project Field and Laboratory Methods manual. Technical Document prepared for TBNEP March 1993. 32pp.

Virnstein, R.W. 1977. The importance of predation by crabs and fishes on benthic infauna in Chesapeake Bay. Ecology 58(6): 1199-1217.

Walker, R.L. and Tenore, K.R. 1984. Growth and production of the Dwarf Surf Clam Mulinia lateralis (Say 1822) in a Georgia Estuary. Gulf Research Reports 7(4): 357-363.

Wang, X. and Wang, W.-X. 2005. Uptake, absorption efficiency and elimination of DDT in marine phytoplankton, copepods and fish. Environmental Pollution 136(3): 453-464.

Winn, R.N., and Knott, D.M. 1992. An evaluation of the survival of experimental populations exposed to hypoxia in the Savannah River estuary. Marine Ecology Progress Series 88: 161-179.

Wolf, P.S. 1984. Chapter 12. Family Cirratulidae Carus, 1863. pp 12.1-12.30 in J.M. Uebelacker and P.G. Johnson (eds): Taxonomic Guide to the Polychaetes of the Northern Gulf of Mexico Vol. II. Final Report to the Minerals Management Service, Contract No 14-12-001-29091.

Zajac, R.N. 2001. Organism-sediment relations at multiple spatial scales: implications for community structure and successional dynamics. pp. 119-139 in J.Y. Aller, S.A. Woodin, and R.C. Aller (eds.) Organism-sediment Interactions. University of South Carolina Press Columbia SC.