Twenty-year Trends in the Benthic Community and Sediment Quality of Tampa Bay 1993 - 2012

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Tampa Bay Estuary Program

Manatee County FLORIDA

ENVIRONMENTAL PROTECTION COMMISSION HILLSBOROUGH COUNTY

Pinellas County

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 twenty years of monitoring data (1993-2012). A total of 1,572 sites were sampled and analyzed for environmental characteristics, sediment chemistry, and benthic community composition.

The median baywide sample depth was 2.7 meters (range 0 – 13.3 meters) with bottom salinities ranging from 0 to 36.3 psu. The baywide median salinity was 26 psu and over 66% 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 salinities in 2007. 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 baywide with a median value of 5.24 mg/L and over 78% of the sampled locations had values ≥ 4.0 mg/L. Several areas of hypoxia were found, typically in Hillsborough Bay and Old Tampa Bay. 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 over time; however, this may reflect changes in the sampling design and reduction of the sampling effort in Middle Tampa Bay and Lower Tampa Bay since 2005.

Results from the sediment contaminant analysis found that cadmium (Cd) concentrations tended to be high throughout Tampa Bay with 42% of the samples exceeding the Threshold Effects Level (TEL) and 1.7% of the samples 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 had elevated concentrations at a small number of sites primarily in Hillsborough Bay and the Manatee River.

Polycyclic aromatic hydrocarbons (PAHs) concentrations were generally low with no observed PEL exceedences and only 1.78% of 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 4.84% and 4.21% of the sites, respectively. Other low molecular weight PAHs exceeded their TELs at 1 – 2% of the sites. PEL's for acenaphthene, acenaphthylene, phenanthrene and total low molecular weight PAHs were exceeded at <1% of the sites. Elevated concentrations of Dibenzo (a,h) anthracene were found at nearly 13% of the sites and it exceeded its PEL at 1.5% of the sites. All of the measured high molecular weight PAHs exceeded their TELs at 3-5% of the sites and had PEL exceedences

at 0.4- 1.5% of the sites. Total high molecular weight PAHs were above the TEL at 1.78% of the sites. The highest concentrations of PAHs were observed in Hillsborough Bay followed by the Manatee River and Boca Ciega Bay.

Total Polychlorinated Biphenyls (PCBs) exceeded its TEL in 1.84% of the samples with highest values in Hillsborough Bay. Most of the measured pesticides values were low but all had TEL and PEL exceedences at a few sites. Lindane and the DDT derivative DDE exceeded their respective TELs in approximately 2% of the samples. Lindane TEL and PEL exceedences occurred at scattered sites throughout the bay while DDE concentrations were highest in Hillsborough Bay and the Manatee River.

Analysis of the benthic community identified around 1,500 taxa during the first twenty years of monitoring. The overall median number of taxa per sample was 35 and ranged from 0 to 136 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 median abundance of benthic organisms was 5,813 organisms/m^2 and ranged from 0 to 183,400 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 accounted for 25% of the overall benthic abundance: the brachiopod *Glottidia pyramidata* (5.08%) the cephalochordate *Branchiostoma floridae* (4.86%), the polychaete *Monticellina cf. dorsobranchialis* (4.13%), the bivalve *Mysella planulata* (3.48%), unidentified Tubificinae oligochaetes (3.36%), the amphipod *Ampelisca holmesi* (2.96%), and the gastropod *Caecum strigosum* (2.93%). The Shannon Diversity Index increased towards the lower bay and was highest in Boca Ciega Bay, Terra Ceia Bay and Lower Tampa Bay with the lowest median diversity values in Hillsborough Bay and the Manatee River.

The benthic community similarity between sampling years indicated that the Tampa Bay benthic community fell into five temporal groupings: 1993 – 1997; 1998 – 2002+2004; 2006-2009; 2003+2005; and 2010-2012. The 1993-1997 group was characterized by high abundances of *Branchiostoma floridae*, *Monticellina cf. dorsobranchialis* and *Caecum strigosum*. The 1998-2002+2004 group had a similar suite of dominant taxa, but higher abundances of *Glottidia pyramidata*. The 2006-2009 group was characterized by Tubificinae oligochaetes, the polychaete *Fabricinuda trilobata* and the bivalve *Mysella planulata*. The 2003+2005 group was characterized by the mussel *Amygdalum papyrium* and the 2010-2012 group was characterized by Tubificinae, *Monticellina cf. dorsobranchialis* and the gastropod *Bittiolum varium.* 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*, Tubificidnae oligochaetes, the spirorbid polychaete *Janua steueri*, the maldanid polychaete ("bamboo worm") *Clymenella mucosa* and the sabellid polychaete *Fabricinuda trilobata*. 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, copper and zinc had the strongest correlations among the measured metal sediment contaminants, while pyrene had the highest correlation among the measured PAHs. Total DDT had the highest correlation among the measured pesticides and PCBs

The Tampa Bay Benthic Index (TBBI) was developed to measure 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 1993-2012 sampling period had a median value of 84.10 which falls within the "Intermediate" category. The highest TBBI values were in Old Tampa Bay, Middle Tampa Bay, and Lower Tampa Bay. Lower TBBI 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 (4.97%) and one-third of the sites were classified as "Degraded." Manatee River, Terra Ceia Bay and Boca Ciega Bay also had a large percentage of "Degraded" sites (20-30%). Old Tampa Bay, Middle Tampa Bay and Lower Tampa Bay had a low number of empty sites (0-1.7%) and <20% of the sites in each segment were classified as "Degraded," while > 45% of the sites in each of these segments were classified as "Healthy." Baywide, 20.93% of the samples were classified as "Degraded," (including 1.72% as "Empty"), 41.79% as "Intermediate," and 37.28% as "Healthy."

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 Province 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 baywide 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 baywide condition. The baywide 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, baywide results were consistent with the NCA rating of “Poor” for 12 of the 20 years with the remaining 8 years rating as “Fair.” For all years, 22.26% of the samples rated as “Degraded”, 40.46% as “Intermediate” and 37.28% as “Healthy.” Weighting the samples proportionally by their bay segment area did increase the baywide rating from “Poor” to “Fair” in just over half of the individual years (7of 12) and 2005 increased from “Fair” to “Good.” The overall baywide weighted rating for the 20 year monitoring period was “Fair” with 18.66% of the weighted samples rating as “Degraded,” 39.17% as “Intermediate” and 42.17% as “Healthy.” 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. Terra Ceia Bay was also borderline “Fair/Good” in 1996, 1997 and 2010. Middle Tampa Bay and Lower Tampa Bay had “Good” benthic community conditions for at least 10 of the 20 years and rated as “Good” overall. The individual segment ratings for both Middle and Lower Tampa Bay were lower in the last few years of the monitoring period, possibly due to the reduced sampling effort in these segments after the most recent program redesign. Old Tampa Bay generally had “Fair” to “Good” ratings with an overall “Fair” rating for the 20 year monitoring period.

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

Year	HB	OTB	MTB	LTB	MR	TCB	BCB	Baywide	Weighted Baywide*
1993	Poor (19)	Poor (17)	Fair (20)	Poor (17)	Fair (11)	Fair (7)		Poor (91)	Poor (91)
1994	Poor (19)	Poor (17)	Poor (20)	Poor (17)	Poor (10)	Poor (7)		Poor (90)	Poor (90)
1995	Poor (29)	Good (23)	Good (21)	Good (22)	Fair (11)	Poor (7)	Fair (21)	Fair (134)	Fair (134)
1996	Poor (27)	Good (15)	Fair (24)	Good (24)	Fair (13)	Fair/Good* (8)	Poor (21)	Fair (132)	Fair (132)
1997	Poor (22)	Fair/Good* (16)	Good (22)	Good (21)	Poor (13)	Fair/Good* (8)	Poor (21)	Fair (123)	Fair (123)
1998	Poor (26)	Fair (16)	Fair (20)	Good (17)	Poor (13)	Fair (7)	Poor (21)	Poor (120)	Fair (120)
1999	Fair (23)	Fair (19)	Good (21)	Fair (19)	Fair (13)	Poor (8)	Fair (21)	Fair (124)	Fair (124)
2000	Poor (22)	Good (11)	Fair (23)	Fair (8)	Poor (9)	Fair (7)	Fair (6)	Fair (86)	Fair (86)
2001	Poor (25)	Poor (7)	Fair/Good* (26)	Good (5)	Fair (2)	Poor (1)	Poor (14)	Poor (80)	Fair (80)
2002	Poor (25)	Fair (8)	Good (21)	Fair (9)	Poor (7)	Poor (4)	Poor (9)	Poor (83)	Fair (83)
2003	Poor (28)	Poor (9)	Good (9)	Good (12)	Poor (7)	Poor (3)	Poor (10)	Poor (78)	Poor (78)
2004	Fair (25)	Poor (9)	Good (11)	Good (11)	Poor (10)	Good (1)	Fair (10)	Fair (77)	Fair (77)
2005	Poor (9)	Good (3)	Good (3)	Good (6)	Fair (5)	Fair (3)	Fair/Good* (6)	Fair (35)	Good (35)
2006	Poor (9)	Good (8)	Good (4)	Fair (3)	Poor (4)	Fair (5)	Poor (8)	Poor (41)	Fair (41)
2007	Poor (9)	Good (7)	Good (7)	Fair (1)	Poor (5)	Poor (4)	Fair (10)	Poor (43)	Fair (43)
2008	Poor (9)	Fair (7)	Good (5)	Good (3)	Fair (6)	Poor (3)	Fair (11)	Fair (44)	Fair (44)
2009	Poor (9)	Fair (7)	Good (6)	Fair/Good* (2)	Fair (5)	Poor (4)	Poor (11)	Poor (44)	Fair (44)
2010	Fair (9)	Poor (22)	Poor (5)	Good (3)	Fair (5)	Fair/Good* (4)	Good (11)	Poor (59)	Poor (59)
2011	Poor (9)	Poor (7)	Fair (5)	Poor (3)	Poor (7)	Fair (2)	Fair (11)	Poor (44)	Poor (44)
2012	Poor (9)	Good (7)	Fair (5)	Poor (3)	Poor (7)	Poor (2)	Fair (11)	Poor (44)	Fair (44)

*Weighted by Bay Segment Area

Condition of Tampa Bay benthic communities 1993-2012 based on the TBBI using the EPA's National Coastal Assessment program criteria by year and combined segments and reporting periods (4 or 5-year running average).

Year	HB	OTB	MTB	LTB	MR	TCB	BCB	BayWide	Weighted Baywide*
1993	Poor (19)	Poor (17)	Fair (20)	Poor (17)	Fair (11)	Fair (7)		Poor (91)	Poor (91)
1994	Poor (19)	Poor (17)	Poor (20)	Poor (17)	Poor (10)	Poor (7)		Poor (90)	Poor (90)
1995	Poor (29)	Good (23)	Good (21)	Good (22)	Fair (11)	Poor (7)	Fair (21)	Fair (134)	Fair (134)
1996	Poor (27)	Good (15)	Fair (24)	Good (24)	Fair (13)	Fair/Good* (8)	Poor (21)	Fair (132)	Fair (132)
1997	Poor (22)	Fair/Good* (16)	Good (22)	Good (21)	Poor (13)	Fair/Good* (8)	Poor (21)	Fair (123)	Fair (123)
1998	Poor (26)	Fair (16)	Fair (20)	Good (17)	Poor (13)	Fair (7)	Poor (21)	Poor (120)	Fair (120)
1999	Fair (23)	Fair (19)	Good (21)	Fair (19)	Fair (13)	Poor (8)	Fair (21)	Fair (124)	Fair (124)
2000-2003	Poor (100)	Poor (35)	Good (79)	Good (34)	Poor (40)		Poor (39)	Poor (327)	Fair (327)
2001-2004	Poor (103)	Poor (33)	Good (67)	Good (37)	Poor (35)		Poor (43)	Poor (318)	Fair (318)
2002-2005	Poor (87)	Poor (29)	Good (82)		Poor (40)		Poor (35)	Poor (273)	Fair (273)
2003-2006	Poor (71)	Poor (29)	Good (59)		Poor (38)		Poor (34)	Poor (231)	Fair (231)
2004-2007	Poor (52)	Fair (27)	Good (46)		Poor (37)		Poor (34)	Fair (196)	Good (196)
2005-2009	Poor (45)	Good (32)	Good (40)		Poor (44)		Poor (46)	Poor (207)	Fair (207)
2006-2010	Poor (45)	Fair (51)	Good (39)		Poor (45)		Poor (51)	Poor (231)	Fair (231)
2007-2011	Poor (45)	Poor (50)	Good (40)		Poor (45)		Poor (54)	Poor (234)	Fair (234)
2008-2012	Poor (45)	Poor (50)	Fair (40)		Poor (45)		Fair (55)	Poor (235)	Fair (235)

Condition of Tampa Bay benthic communities 1993-2012 based on the TBBI using the EPA's National Coastal Assessment program criteria by five year periods, cumulative total and combined segments.

Phase	HB	OTB	MTB/LTB	MR/TCB	BCB	Baywide	Weighted Baywide*
1993-1997	Poor (116)	Good (88)	Fair (208)	Poor (95)	Poor (63)	Poor (570)	Fair (570)
1998-2002	Poor (121)	Fair (61)	Good (169)	Poor (71)	Poor (71)	Fair (493)	Fair (493)
2003-2007	Poor (80)	Poor (36)	Good (67)	Poor (47)	Poor (44)	Poor (274)	Fair/Good* (274)
2008-2012	Poor (45)	Poor (50)	Fair (40)	Poor (45)	Fair (55)	Poor (235)	Fair (235)
Cumulative 1993-2012	Poor (362)	Fair (235)	Good (484)	Poor (258)	Poor (233)	Poor (1572)	Fair (1572)

The overall “Fair” to “Poor” rating for the benthic community emphasizes the continued need for benthic monitoring in Tampa Bay. The last Benthic Monitoring Report (Karlen et al. 2008) made several recommendations that were intended to control increasing monitoring costs while maintaining the integrity of the program, as follows: 1) reduce the overall annual sampling effort to a total of 44 baywide samples plus 20 additional samples directed towards selected “Special Study” sites, 2) combine Middle Tampa Bay and Lower Tampa Bay into a single reporting unit, and 3) increase the reporting period from four to five years in order to maintain long-term statistical power. These recommendations were adopted by the Tampa Bay Estuary Program retroactively to include the 2005 samples. The recommendation of this report is to maintain the current sampling design that has been in place since 2005 with the possibility of increasing the number of “Special Study” sites above the current 20 samples per year as needed to evaluate areas and issues of special concern to the Tampa Bay Estuary Program and regional bay managers (provided additional funding is available). Maintaining the current sampling design 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.

Recommendations for additional future monitoring of sediments and benthic communities in Tampa Bay:

- Continue to focus on special study sites (i.e., areas of known or suspected environmental degradation or sites with anticipated future impacts, such as dredging or proposed mitigation sites). Also, consider revisiting past special study sites to assess any changes to conditions. These sites may include:
    - Port Tampa Bay (Ybor/Sparkman Channels, Garrison Channel; East Bay)
    - Clam Bayou
    - Bayboro Harbor
- Consider expanding laboratory analyses of sediment contaminants to include new or emerging contaminant concerns, for example:
    - Microplastics
    - PBDEs
    - Nanomaterials
    - Pharmaceuticals
    - Mercury
- Increase monitoring effort in the major river systems (Hillsborough, Palm, Alafia and Little Manatee Rivers) and minor tidal tributary systems since few low salinity areas are included in the current baywide database and these systems serve as important 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 any of these recommendations would be contingent on the availability of additional funding to support the additional analysis and necessary staffing to expand the current monitoring 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 2,562,732 people (U.S. Census Bureau 2015; estimated population for 2013) and includes 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 established 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 re-evaluate 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 baywide 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 re-evaluated in 2003 (Janicki Environmental, 2003). As a result of this assessment, the reporting period was increased from one year to four years, the number of samples collected annually was cut in half (from 124 to 64 samples per year), and the Manatee River and Terra Ceia Bay were combined into a single sampling stratum. 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.

The program was again redesigned in 2007 due to budget constraints. The second redesign maintained a total of 64 samples per year divided between 44 samples collected for the bay-wide monitoring design and 20 samples designated for special study sites. The Manatee River and Terra Ceia Bay were maintained as a single sampling stratum and additionally Middle Tampa Bay and Lower Tampa Bay were combined into a single stratum and the reporting period was increased from four to five years. These changes were made retroactive to 2005. The redesign still allows for the detection of changes baywide on an annual basis and within strata between five year reporting periods.

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.

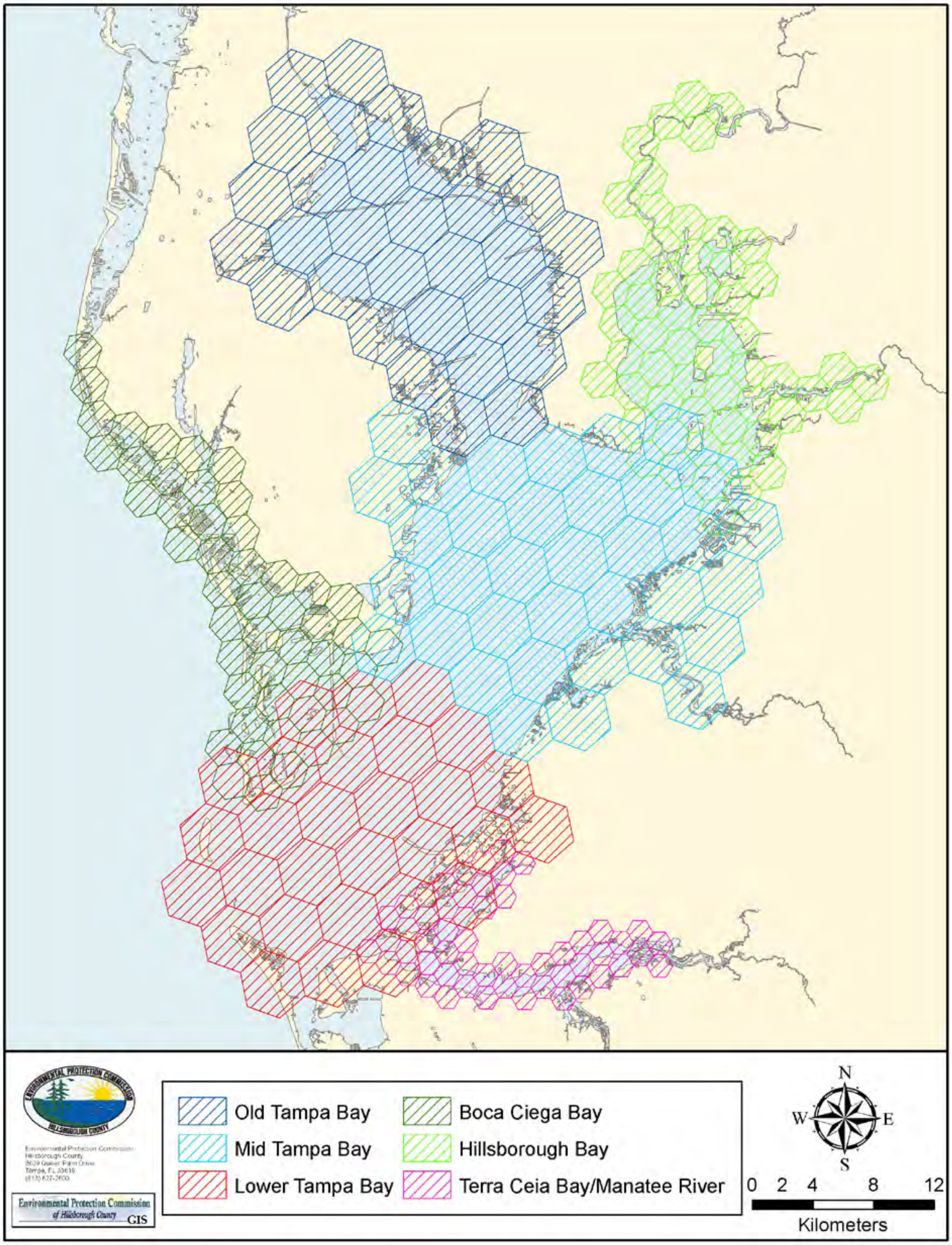


Figure 1. Tampa Bay segments and sampling grids.

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 streamline 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) and bottom 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, and then 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. Prior to 2012, samples were fixed with 10% buffered formalin for a minimum of 72 hours and then transferred into 70% isopropyl alcohol for preservation and storage. Since 2012 samples have been fixed and stored in NOTOXhisto (Scientific Device Laboratory, Inc.). Rose Bengal was added to the formalin, isopropyl alcohol and NOTOXhisto 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 through 2007 except 1994 and earlier Special Study sites which were done by EPCHC. EPCHC has conducted all Silt+Clay analysis since 2008.

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). Re-sorting 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:

Samples were assigned to descriptive categories for depth, salinity, dissolved oxygen, sediment type, and the 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 baywide benthic monitoring program from 1993-2012. 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 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 (Grabe and Barron, 2004): $\% SC = 1/(0.0097+1.575*e^{\Phi})$ (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" and depauperate samples were assigned a TBBI score of 0 and labeled as "Empty." Both of these categories fall under the "Degraded" classification in the final analysis.

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 performed on the hydrological, sediment chemistry, silt+clay and univariate biological metrics using SigmaStat® 3.5 (SYSTAT Software, Inc. 2006a). Data were log (n+1) or square root transformed for normality where needed for the parametric tests. All percent silt+clay data were arcsine transformed. Analysis of Variance (ANOVA) with a Holm-Sidak 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 (PRIMER-E, Ltd. 2006; Clarke and Gorley 2006) and PERMANOVA+ for PRIMER v6 (Anderson et al. 2008) were used for all multivariate statistical analysis and for calculating univariate biological metrics (species richness, abundance, Shannon Diversity Index, Pielou's evenness). 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). Principal Components Analysis (PCA) and Principal Coordinates Analysis (PCO) were performed on the hydrographic and silt+clay data to search for patterns in the environmental data (Clarke and Warwick 2001; Anderson et al. 2008). The data were 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) tests. 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 the Environmental Protection Commission of Hillsborough County using ArcGIS 10.1 (ESRI, 2012).

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	Low
> 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 1,572 sites were sampled during the 1993-2012 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. The number of samples was further reduced in 2005 across all bay segments as indicated in Figure 2 and Tables 2 and 3. The current sampling scheme includes approximately 44 baywide samples collected across 5 strata: Hillsborough Bay, Old Tampa Bay, Middle + Lower Tampa Bay, Manatee River + Terra Ceia Bay, and Boca Ciega Bay. Approximately 20 additional samples are collected across designated special study sites each year to focus sampling efforts in areas of special interest. The allotted special study samples for 2010 were collected in Old Tampa Bay which are included with the 2010 OTB baywide samples in the analysis.

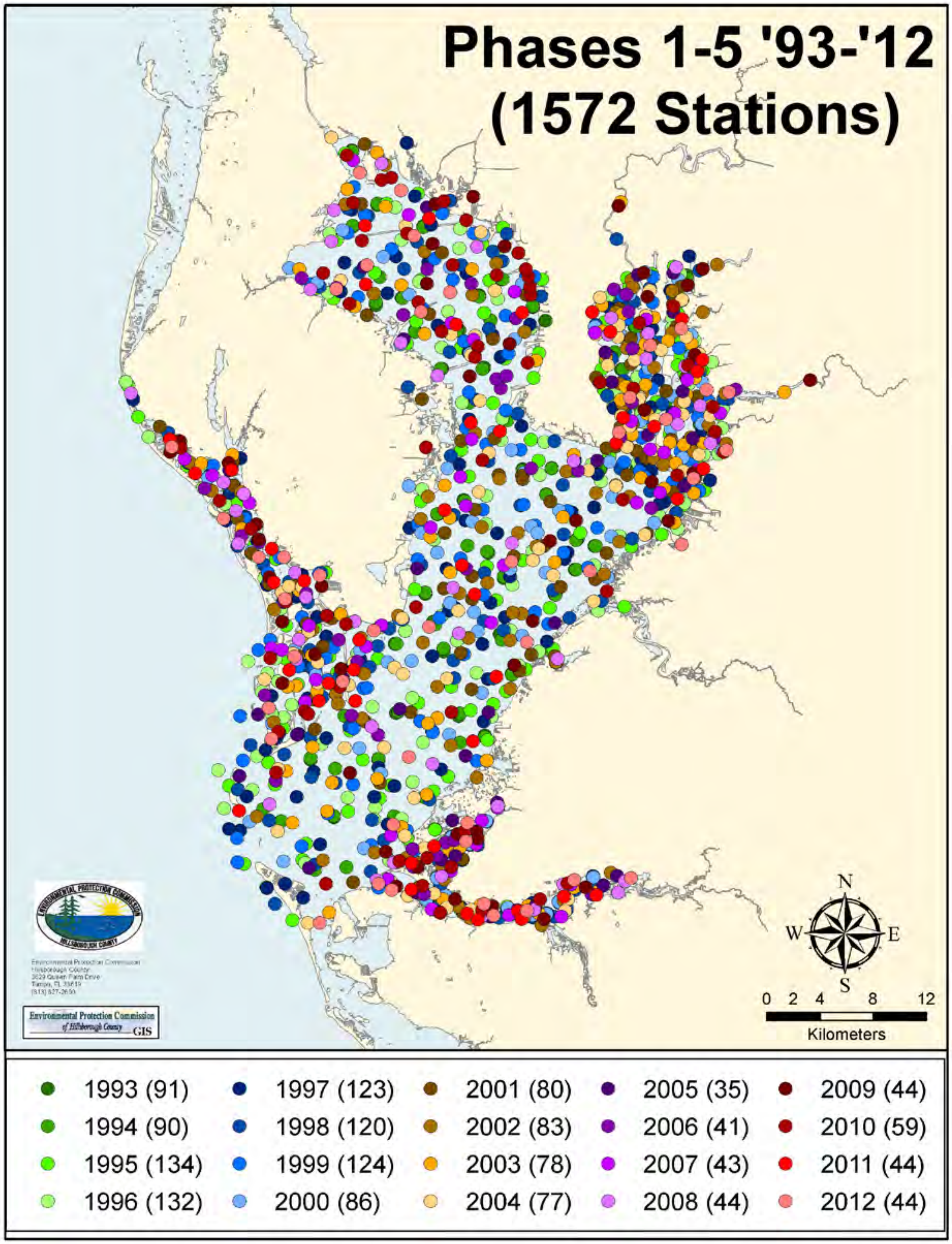


Figure 2. Tampa Bay benthic monitoring sampling sites 1993-2012 by year. Cumulative total = 1572 sampling sites. Number of sites by year in parentheses.

Hydrographic and Sediment Characteristics

Depth

The median sample depth baywide was 2.7 meters (mean = 3.0 meters; Figures 3 & 4) with a maximum depth of 13.3 meters near a shipping channel in Hillsborough Bay (Tables 2 and 3). Sample depths varied significantly between years (KW; $p = 0.006$) with median values ranging from 2 meters in 1995 to 3.4 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. There was an apparent decrease in the average sample depth since 2005 (Figure 3). This can be attributed to fewer samples being collected in the Middle and Lower Tampa Bay segments and an overall decrease in the number of samples collected.

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). Boca Ciega Bay was shallower than all other segments with the exception of Terra Ceia Bay and the Manatee River (Dunn's Pairwise Multiple Comparison Test). 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, although the deepest sample was in Hillsborough Bay. The majority of the sampling sites fell within the "Deep Subtidal" (>2.0 – 4.0 meters) and "Deep" (>4) range, 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" (Table 4).

Table 2. **Baywide bottom physical characteristics by year (1993-2012) and five-year cumulative periods. Top values are medians, lower left= minimum, lower right = maximum. For TOC, n = 147.**

Year	n	Depth (meters)		Temperature (°C)		Salinity (psu)		D.O. (mg/L)		D.O. (% Sat.)		pH		Silt+Clay (%)		TOC (%)	
1993	91	2.8		29.4		25.6		5.4		81.2		7.8		3.4		ND	
		0.1	10.0	25.9	31.2	4.3	34.2	0.3	11.0	4.1	166.5	6.5	8.2	0.0	69.7	ND	ND
1994	90	3.0		28.0		22.7		5.0		74.6		7.9		2.9		ND	
		1.0	8.0	24.9	30.7	7.2	34.8	0.2	10.2	3.0	150.8	7.1	8.3	0.0	86.8	ND	ND
1995	134	2.0		29.0		20.1		5.7		82.7		8.1		3.3		ND	
		0.1	9.0	21.6	33.0	4.3	34.1	0.2	11.3	3.2	157.1	7.1	8.5	0.2	70.3	ND	ND
1996	132	2.9		29.4		26.1		5.0		76.9		8.0		4.4		ND	
		0.1	13.2	22.9	39.2	7.9	34.5	0.3	9.3	4.1	144.1	6.9	8.3	0.8	75.4	ND	ND
1997	123	2.2		28.9		27.6		5.3		80.3		8.0		6.6		ND	
		0.1	11.8	23.9	31.2	0.0	35.9	0.0	14.0	0.5	220.7	6.7	8.7	0.0	81.1	ND	ND
1993 - 1997	570	2.5		28.9		25.2		5.4		80.0		7.9		4.4		ND	
		0.1	13.2	21.6	39.2	0.0	35.9	0.0	14.0	0.5	220.7	6.5	8.7	0.0	86.8	ND	ND
1998	120	2.5		28.2		24.1		5.6		81.7		8.0		3.9		ND	
		0.1	12.5	25.1	33.4	1.8	33.0	0.4	9.5	5.8	135.0	6.8	8.4	1.0	39.4	ND	ND
1999	124	2.8		27.6		25.9		5.6		82.4		8.1		4.3		ND	
		0.1	12.5	25.9	32.0	9.0	35.0	1.0	12.8	15.3	190.5	7.4	8.9	0.8	82.2	ND	ND
2000	86	3.0		28.7		28.7		5.7		84.1		8.0		4.4		ND	
		0.5	8.5	26.1	30.9	5.3	32.9	0.2	9.1	3.4	140.6	7.3	8.4	0.1	91.8	ND	ND
2001	80	3.0		30.2		27.8		4.1		64.9		8.0		4.1		ND	
		0.1	11.0	24.4	32.4	22.0	34.1	0.4	10.7	5.3	162.7	7.5	8.4	1.5	57.8	ND	ND
2002	83	3.1		29.5		27.9		5.1		77.5		8.0		4.6		ND	
		0.5	11.3	27.9	31.3	9.2	34.5	0.3	8.8	4.1	132.2	7.0	8.9	0.0	84.9	ND	ND
1998 - 2002	493	2.9		28.7		27.2		5.5		81.3		8.0		4.3		ND	
		0.1	12.5	24.4	33.4	1.8	35.0	0.2	12.8	3.4	190.5	6.8	8.9	0.0	91.8	ND	ND
2003	78	3.4		29.2		19.5		5.2		73.0		8.0		5.0		ND	
		0.1	9.0	26.3	34.5	0.1	33.4	0.2	9.2	2.7	137.6	7.0	8.6	1.0	71.1	ND	ND
2004	77	3.0		29.7		22.7		5.0		74.5		8.1		3.2		ND	
		0.6	13.0	24.0	31.4	13.9	34.0	0.1	11.0	1.6	165.3	7.4	8.6	0.7	65.7	ND	ND
2005	35	2.2		30.0		23.9		5.3		77.4		8.1		3.6		ND	
		0.5	13.3	27.8	34.2	17.9	34.6	0.1	6.7	1.8	104.4	7.2	8.8	1.1	32.9	ND	ND
2006	41	2.4		29.9		25.6		5.1		77.7		8.1		3.3		ND	
		0.1	7.7	27.2	31.6	1.4	35.4	0.1	7.8	1.8	118.5	7.5	8.4	0.7	94.3	ND	ND
2007	43	3.1		30.7		29.7		4.7		74.5		8.1		4.8		ND	
		0.3	11.7	27.7	33.5	18.3	35.6	0.9	10.8	14.8	181.6	7.5	8.6	1.0	25.1	ND	ND
2003 - 2007	274	3.0		29.9		24.2		4.9		75.2		8.1		3.9		ND	
		0.1	13.3	24.0	34.5	0.1	35.6	0.1	11.0	1.6	181.6	7.0	8.8	0.7	94.3	ND	ND
2008	44	2.4		29.1		27.3		5.2		79.3		7.8		4.8		ND	
		0.3	8.3	27.2	31.8	15.7	36.3	2.8	9.2	41.0	136.0	7.2	8.2	1.4	64.1	ND	ND
2009	44	2.5		29.7		26.9		4.7		73.1		7.8		5.1		ND	
		0.2	11.0	28.2	33.3	1.9	35.4	0.4	10.1	6.6	166.2	7.0	8.2	1.4	96.0	ND	ND
2010	59	2.1		29.2		21.1		5.0		74.9		8.4		4.1		0.4	
		0.1	10.9	26.4	33.1	8.0	34.2	0.2	8.7	2.6	125.0	7.0	9.4	0.9	74.7	0.3	3.8
2011	44	2.2		30.8		26.5		4.8		76.3		8.3		5.8		0.5	
		0.5	11.2	21.3	33.6	13.7	34.2	0.1	8.5	1.7	114.8	7.0	8.8	1.1	48.6	0.3	6.8
2012	44	2.8		30.1		23.0		4.8		73.6		7.9		5.7		0.4	
		0.3	10.6	28.6	33.3	3.4	34.6	0.5	7.6	7.5	115.5	7.2	8.3	1.0	60.3	0.3	2.9
2008 - 2012	235	2.3		29.7		25.9		4.9		75.0		8.0		4.9		0.4	
		0.1	11.2	21.3	33.6	1.9	36.3	0.1	10.1	1.7	166.2	7.0	9.4	0.9	96.0	0.3	6.8
Cumulative 1993-2012	1572	2.7		29.1		26		5.2		78.6		8		4.4		0.4	
		0.1	13.3	21.3	39.2	0	36.3	0	14	0.5	220.7	6.5	9.4	0	96	0.3	6.8

Table 3. **Bottom physical parameters by bay segment (1993-2012). Top values are medians, lower left= minimum, lower right = maximum. For TOC, cumulative n = 147.**

Segment	n	Depth (meters)		Temperature (°C)		Salinity (psu)		D.O. (mg/L)		D.O. (% Sat.)		pH		Silt+Clay (%)		TOC (%)	
Hillsborough Bay	**362**	2.8		29.6		23.5		3.7		54.6		7.8		7.3		0.5	
		0.1	13.3	25.5	34.5	0.1	30.1	0.0	10.7	0.5	162.7	6.8	8.6	1.0	96.0	0.3	3.8
Old Tampa Bay	**235**	2.5		29.1		22.3		5.5		80.3		8.1		3.4		0.3	
		0.1	7.5	26.0	32.4	0.0	29.4	0.1	12.8	1.7	190.5	6.7	9.4	0.0	91.8	0.3	2.6
Middle Tampa Bay	**278**	4.0		29.1		26.9		5.2		79.4		8.0		3.1		0.3	
		0.1	11.1	26.0	39.2	8.1	32.4	0.3	11.0	4.3	165.3	7.0	9.0	0.0	63.0	0.3	2.9
Lower Tampa Bay	**206**	4.0		28.3		30.5		5.9		88.4		8.1		2.4		0.3	
		0.1	13.0	23.9	31.0	19.3	35.0	3.6	9.3	53.1	137.2	7.2	8.8	0.0	50.7	0.3	0.7
Manatee River	**163**	2.0		29.0		18.2		5.2		74.2		7.8		5.8		0.9	
		0.1	7.0	22.1	33.0	0.4	31.0	0.3	9.2	4.1	132.2	6.5	8.9	0.7	55.4	0.3	6.8
Terra Ceia Bay	**95**	2.0		28.2		25.6		6.0		88.0		8.1		4.6		0.6	
		0.1	5.0	21.3	33.3	10.1	33.0	2.8	10.1	41.0	166.2	7.4	8.6	0.0	25.4	0.4	1.4
Boca Ciega Bay	**233**	1.9		29.4		32.4		5.5		84.8		8.1		6.6		0.5	
		0.1	7.4	21.6	33.5	20.4	36.3	0.9	14.0	15.1	220.7	7.4	8.9	1.1	94.3	0.3	3.1
Cumulative 1993-2012	**1572**	**2.7**		**29.1**		**26.0**		**5.2**		**78.6**		**8.0**		**4.4**		**0.4**	
		0.1	**13.3**	**21.3**	**39.2**	**0.0**	**36.3**	**0.0**	**14.0**	**0.5**	**220.7**	**6.5**	**9.4**	**0.0**	**96.0**	**0.3**	**6.8**

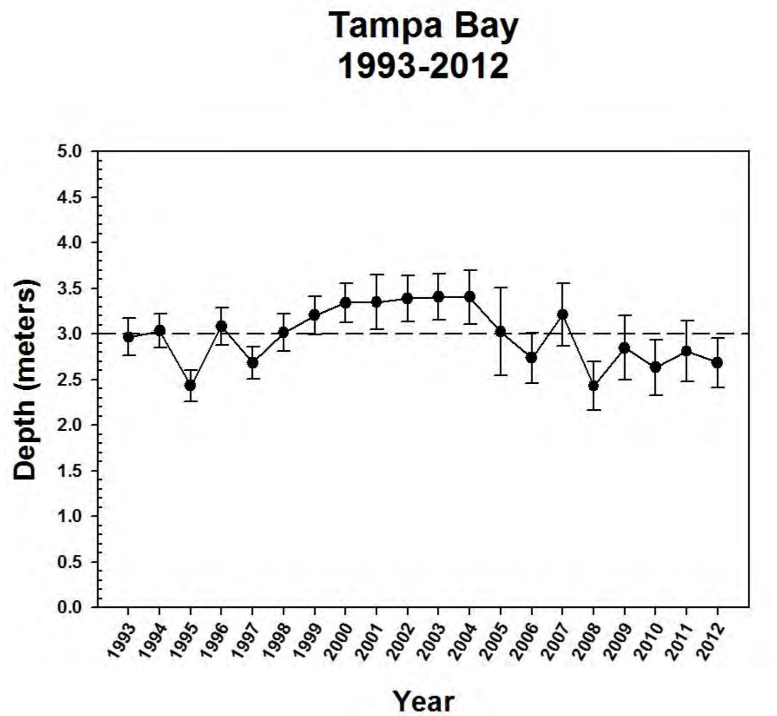


Figure 3. **Mean sample depth by year. Error bars = 1 standard error, dashed line represents baywide mean.**

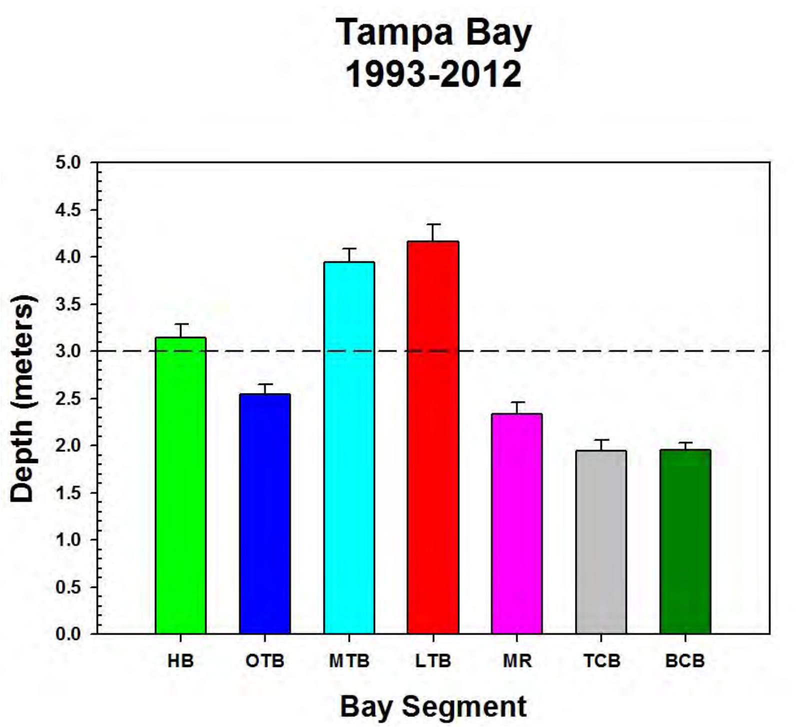


Figure 4. **Mean sample depth by bay segment. Error bars = 1 standard error, dashed line represents baywide mean value.**

Table 4. Percentage of sites within depth categories.

	n	Intertidal	Shallow Subtidal	Intermediate Subtidal	Deep Subtidal	Deep
Hillsborough Bay	362	5.52%	10.77%	20.17%	33.98%	29.56%
Old Tampa Bay	235	7.66%	11.06%	17.02%	43.83%	20.43%
Middle Tampa Bay	278	3.24%	8.63%	13.31%	23.38%	51.44%
Lower Tampa Bay	206	2.43%	3.88%	11.65%	30.58%	51.46%
Manatee River	163	4.91%	6.13%	31.29%	36.20%	21.47%
Terra Ceia Bay	95	3.16%	9.47%	35.79%	47.37%	4.21%
Boca Ciega Bay	233	8.58%	14.16%	30.90%	41.20%	5.15%
Tampa Bay (Total)	1572	5.28%	9.48%	21.06%	35.24%	28.94%

Bottom Temperature

Bottom temperatures ranged from 21.3 to 39.2°C with a median temperature of 29.1°C and mean of 29.0 °C (Tables 2 and 3). Temperatures varied significantly between years (KW; $p < 0.001$) with the highest median temperature occurring in 2011, while the highest mean temperature was in 2007 (Table 2; Figure 5). There was an apparent trend of increasing temperatures over the 1993 – 2012 monitoring period; however, this may be a sampling artifact as the sample collections shifted from September/October to August/September time period over the course of the program.

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 segments except Boca Ciega Bay (Dunn's Pairwise Multiple Comparison test). The higher water temperature in Hillsborough Bay may be due to the extensive shallow area and restricted flow in this part of the bay. The highest temperature (39.2°C) was recorded in Middle Tampa Bay in 1996 near the discharge of the Big Bend power plant (Table 3). The lowest temperature (21.3 °C) was recorded in Terra Ceia Bay in 2011. This segment was sampled in mid-October that year which accounts for the lower observed water temperatures relative to the other bay segments and the wider standard error among the data for that year (Figure 5).

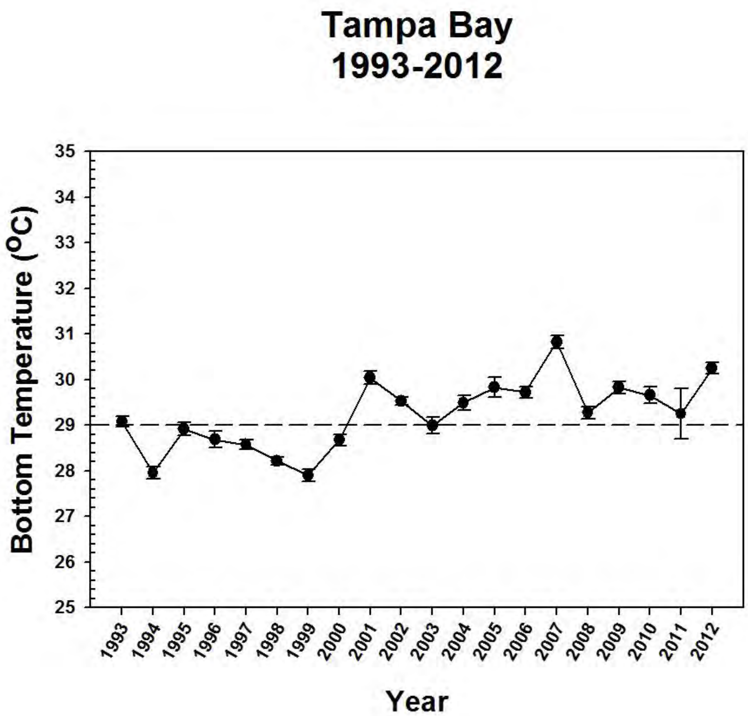


Figure 5. **Mean bottom temperature by year. Error bars = 1 standard error, dashed line represents baywide mean value.**

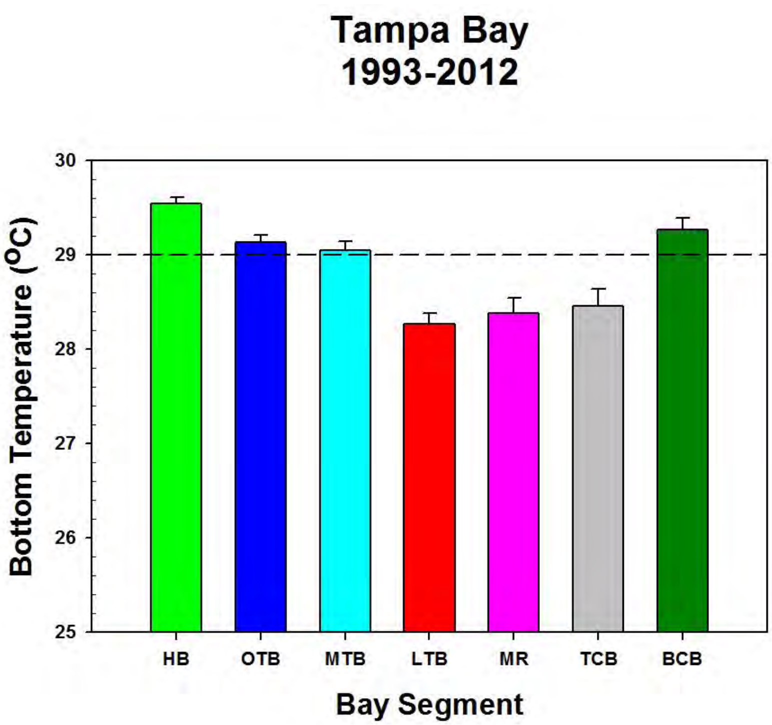


Figure 6. **Mean bottom temperature by bay segment. Error bars = 1 standard error, dashed line represents baywide mean value.**

Bottom pH

The median bottom pH was 8.0 and ranged from 6.5 to 9.4. The lowest recorded value and widest range was in the Manatee River (Table 2 and 3). The highest recorded pH values were in Old Tampa Bay in 2010 due to a bloom of the dinoflagellate *Pyrodinium bahamense* during that year (Karlen 2014). There were significant differences in pH between years (KW; $p < 0.001$, Figure 7) with 1993 recording the overall minimum value. Lowest median pH values (7.8) were observed in 1993, 2008, and 2009 while the highest median pH was observed in 2010 (Table 2). 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 (Bearman, 1989). This did not appear to be a factor in the observed temporal trend in pH (Figure 7) but was more apparent between bay segments (Figure 8). Bottom pH 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. Higher pH values were observed in Boca Cieaga Bay, Terra Ceia Bay and Lower Tampa Bay due in part to higher salinities and possibly to higher seagrass productivity since elevated levels of photosysnthesis can increase pH through the removal of dissolved CO_2 (Parsons et al., 1984). The elevated pH in Old Tampa Bay similarly was due to the 2010 *Pyrodinium bahamense* bloom event.

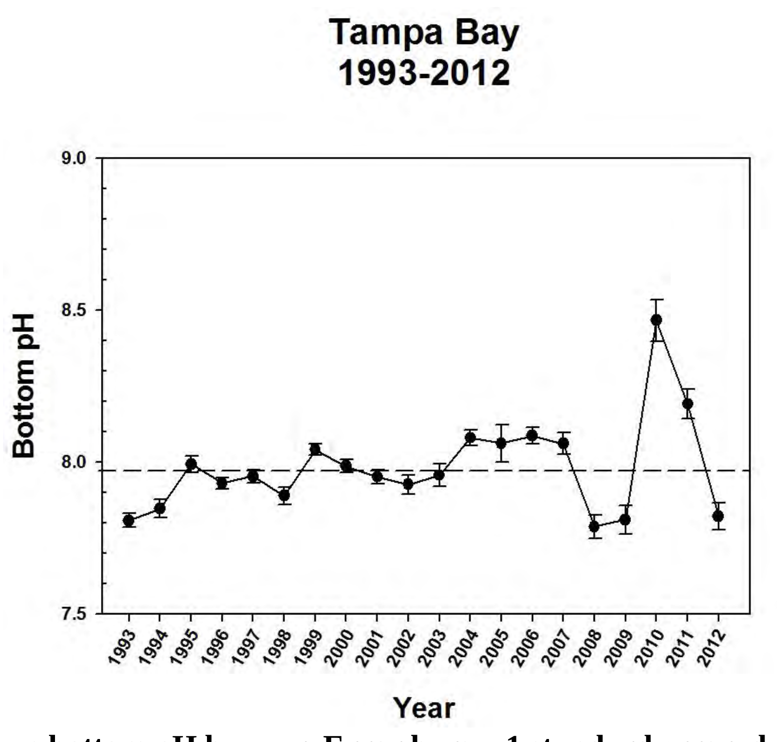


Figure 7. Mean bottom pH by year. Error bars = 1 standard error, dashed line represents baywide mean value.

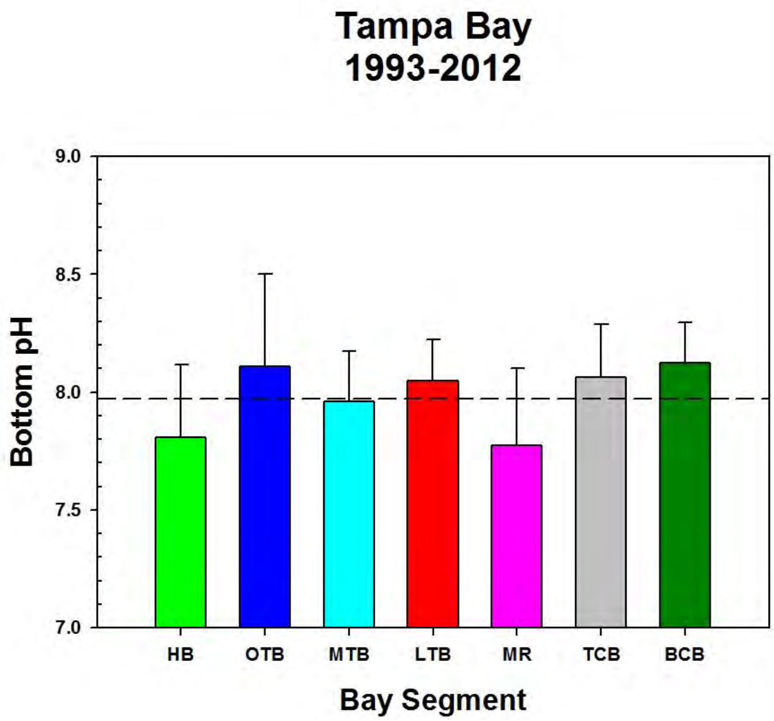


Figure 8. **Mean bottom pH by bay segment. Error bars = 1 standard error, dashed line represents baywide mean value.**

Bottom Salinity

Bottom salinities ranged from 0 to 36.3 psu with a baywide median salinity of 26 psu and a mean of 25 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 2007 (Table 2; Figure 9). Temporal trends generally correspond with rainfall patterns with lower salinities observed during years with higher average precipitation and higher salinities observed during periods of drought. 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 ($p < 0.05$). Boca Ciega Bay had significantly higher salinity than all other bay segments, while the Manatee River has significantly lower salinities than the other bay segments except for Old Tampa Bay

Most of the sampling sites fell within the polyhaline salinity range, while less than 1% 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). In general lower salinities were observed in the upper portions of the bay and in the Manatee River with increasing salinities towards Lower Tampa Bay and Boca Ciega Bay (Table 5; Figures 10 and 11).

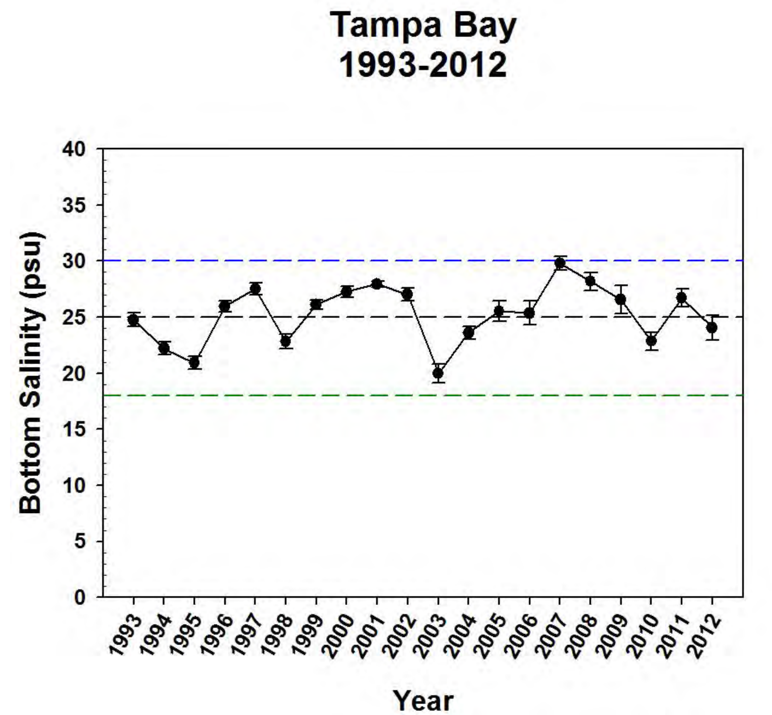


Figure 9. **Mean bottom salinity by year. Error bars = 1 standard error; middle dashed line represents baywide mean value; lower and upper dashed lines denote boundaries of high mesohaline/polyhaline (18 psu) and polyhaline/euhaline (30 psu) salinity categories.**

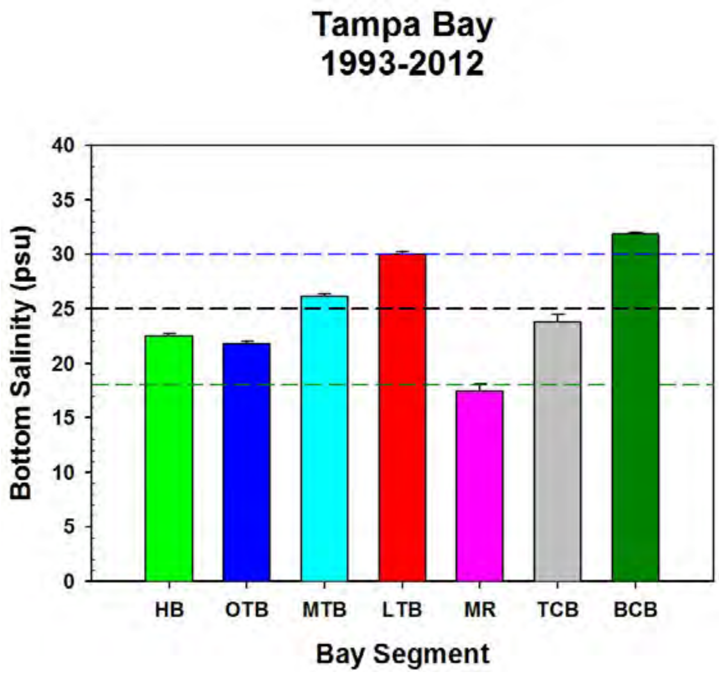


Figure 10. **Mean bottom salinity by bay segment. Error bars = 1 standard error; middle dashed line represents baywide mean value; lower and upper dashed lines denote boundaries of high mesohaline/polyhaline (18 psu) and polyhaline/euhaline (30 psu) salinity categories.**

Table 5. **Percentage of samples within salinity categories 1993-2012.**

	n	Tidal Freshwater	Oligohaline	Low Mesohaline	High Mesohaline	Polyhaline	Euhaline
Hillsborough Bay	362	0.55%	0.83%	0.83%	12.71%	84.81%	0.28%
Old Tampa Bay	235	0.43%	0.00%	0.85%	14.47%	84.26%	0.00%
Middle Tampa Bay	278	0.00%	0.00%	0.36%	1.08%	89.93%	8.63%
Lower Tampa Bay	206	0.00%	0.00%	0.00%	0.00%	42.72%	57.28%
Manatee River	163	0.61%	4.29%	15.95%	26.99%	50.31%	1.84%
Terra Ceia Bay	95	0.00%	0.00%	0.00%	22.11%	64.21%	13.68%
Boca Ciega Bay	233	0.00%	0.00%	0.00%	0.00%	23.61%	76.39%
Tampa Bay (Total)	1572	0.25%	0.64%	2.04%	9.41%	66.22%	21.44%

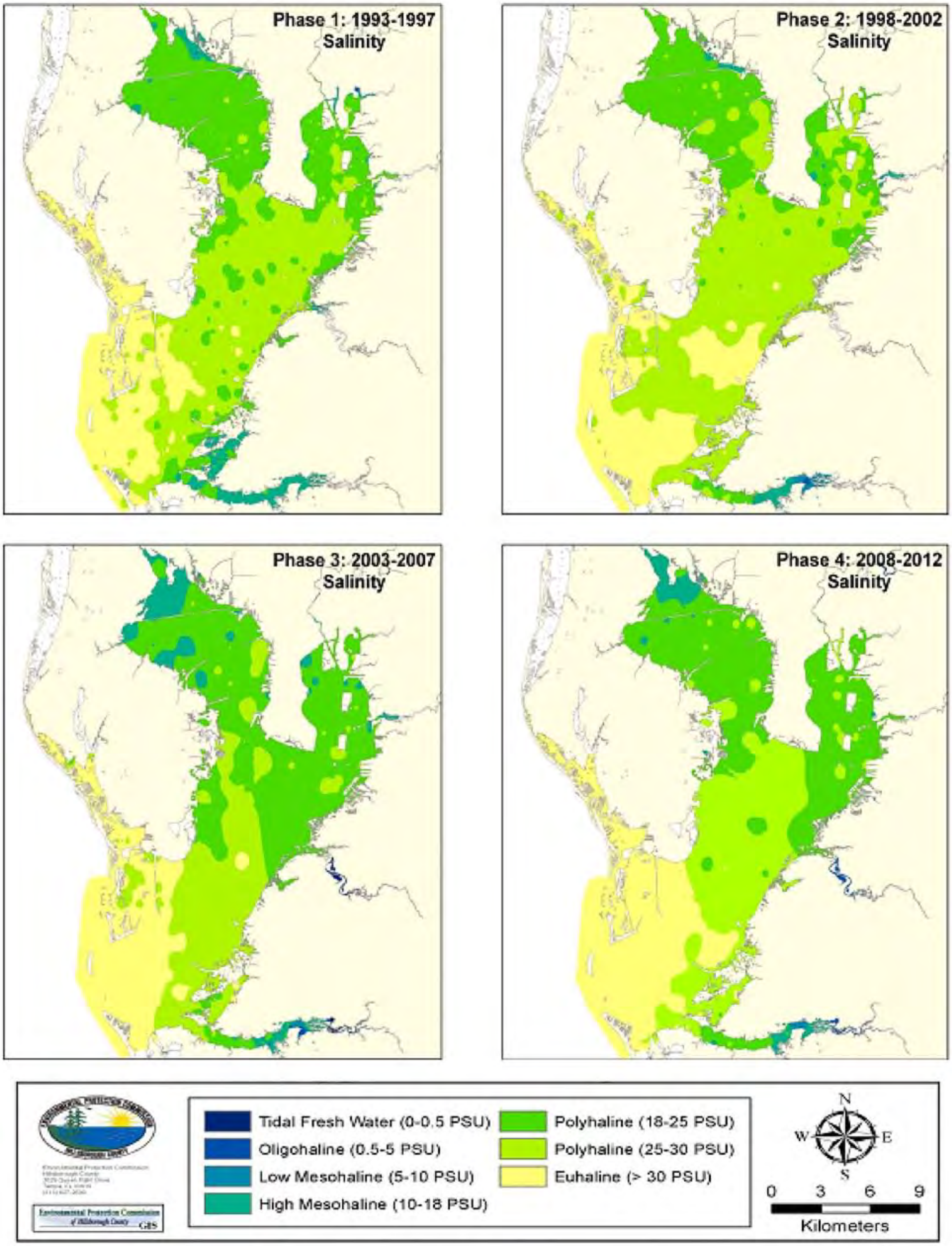


Figure 11. Spatial analysis of bottom salinity (1993-2012).

Bottom Dissolved Oxygen

The amount of oxygen that can be dissolved in water is a function of the water temperature and salinity. Dissolved oxygen can also be expressed as the percent saturation at a given temperature and salinity. Recent changes in 2014 of the state water quality criteria are based on the percent saturation rather than the concentration (mg/L) of dissolved oxygen; however, since the data presented in this report were collected prior to this change, all reported results are based on the concentrations. The percent saturations were back calculated from the dissolved oxygen concentrations and corresponding temperature and salinities at each sampling site and the annual mean percent saturation are presented in Figure 12 for comparison.

Bottom dissolved oxygen levels during the monitoring period were generally high with a baywide median of 5.24 mg/L and a mean of 5.05 mg/L (Tables 2 and 3; Figure 12). There were significant differences in the bottom dissolved oxygen levels between years (KW; $p < 0.001$) with the lowest median dissolved oxygen in 2001 and highest in 1999. The maximum dissolved oxygen recorded was in excess of 14 mg/L (>220% saturation) in 1997 at a site in Boca Ciega Bay (Tables 2 and 3). This site (97BCB50) was shallow (0.5 m) and had seagrasses present, so the high measurement may have been due to these factors. The lower dissolved oxygen levels in 2001 were likely due to a shift in the start of the annual sampling season towards early to mid-August when water temperatures tended to be higher, resulting in lower dissolved oxygen. Mean dissolved oxygen concentrations were generally lower in subsequent years and below the 20 year mean (Figure 12).

Differences between bay segments were also significant (KW; $p < 0.001$). Hillsborough Bay had the lowest median dissolved oxygen and was significantly lower than all the other bay segments. Terra Ceia Bay had the highest median dissolved oxygen but was not significantly different from Boca Ciega Bay or Lower Tampa Bay (Table 3; Figure 13). Nearly 80% of the sites had bottom dissolved oxygen levels within the normoxic range 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 were greatest in Hillsborough Bay and in the upper portion of Old Tampa Bay (Table 6; Figure 14). Hillsborough Bay in particular has historically been impacted by hypoxia. Santos and Simon (1980 a&b) documented annual late summer defaunations of the benthic community in Hillsborough Bay from 1975 – 1977 associated with low bottom dissolved oxygen concentrations (< 1 mg/L).

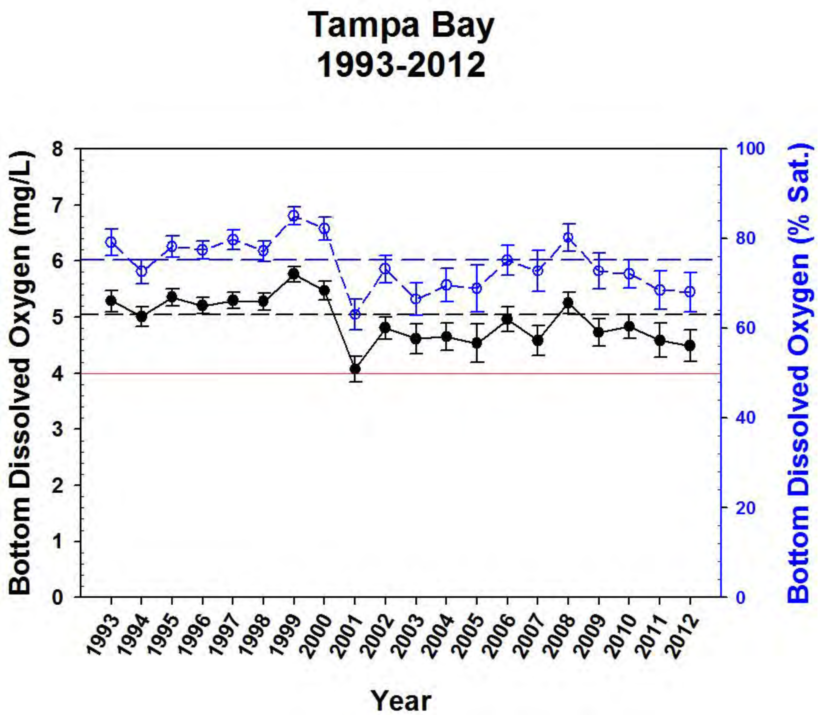


Figure 12. **Mean bottom dissolved oxygen by year in mg/L (black closed circles, solid line; left axis) and as % saturation (blue open circles, dashed line; right axis). Error bars = 1 standard error, black dashed line represents bay-wide mean concentration, blue dash line represents baywide mean saturation value; bottom solid red line represent critical value for normoxic (> 4 mg/l) conditions.**

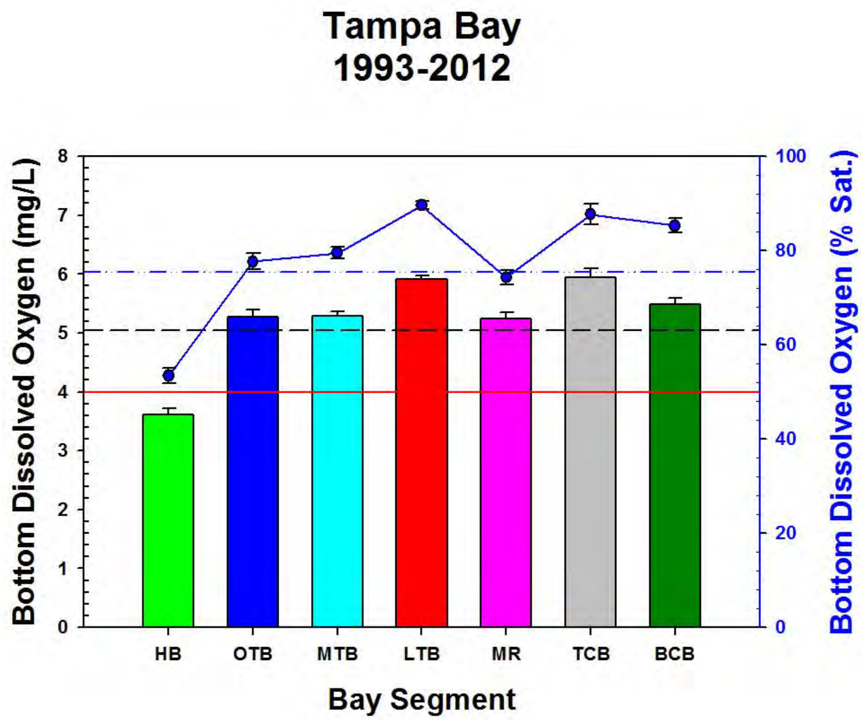


Figure 13. **Mean bottom dissolved oxygen by bay segment in mg/L (bar graph; left axis) and as % saturation (line graph; right axis). Error bars = 1 standard error, black dashed line represents bay-wide mean concentration, blue dash-dot-dot line represents baywide mean saturation value; bottom solid red line represent critical value for normoxic (> 4 mg/l) conditions.**

Table 6. **Percentage of sample sites within dissolved oxygen categories by bay segment.**

	n	Anoxic	Hypoxic	Low	Normoxic
Hillsborough Bay	362	9.39%	17.68%	26.24%	46.69%
Old Tampa Bay	235	1.28%	1.70%	17.45%	79.57%
Middle Tampa Bay	278	0.36%	0.00%	12.95%	86.69%
Lower Tampa Bay	206	0.00%	0.00%	0.97%	99.03%
Manatee River	163	0.61%	1.84%	9.82%	87.73%
Terra Ceia Bay	95	0.00%	0.00%	7.37%	92.63%
Boca Ciega Bay	233	0.00%	1.29%	11.16%	87.55%
Tampa Bay (Total)	1572	2.48%	4.71%	14.19%	78.63%

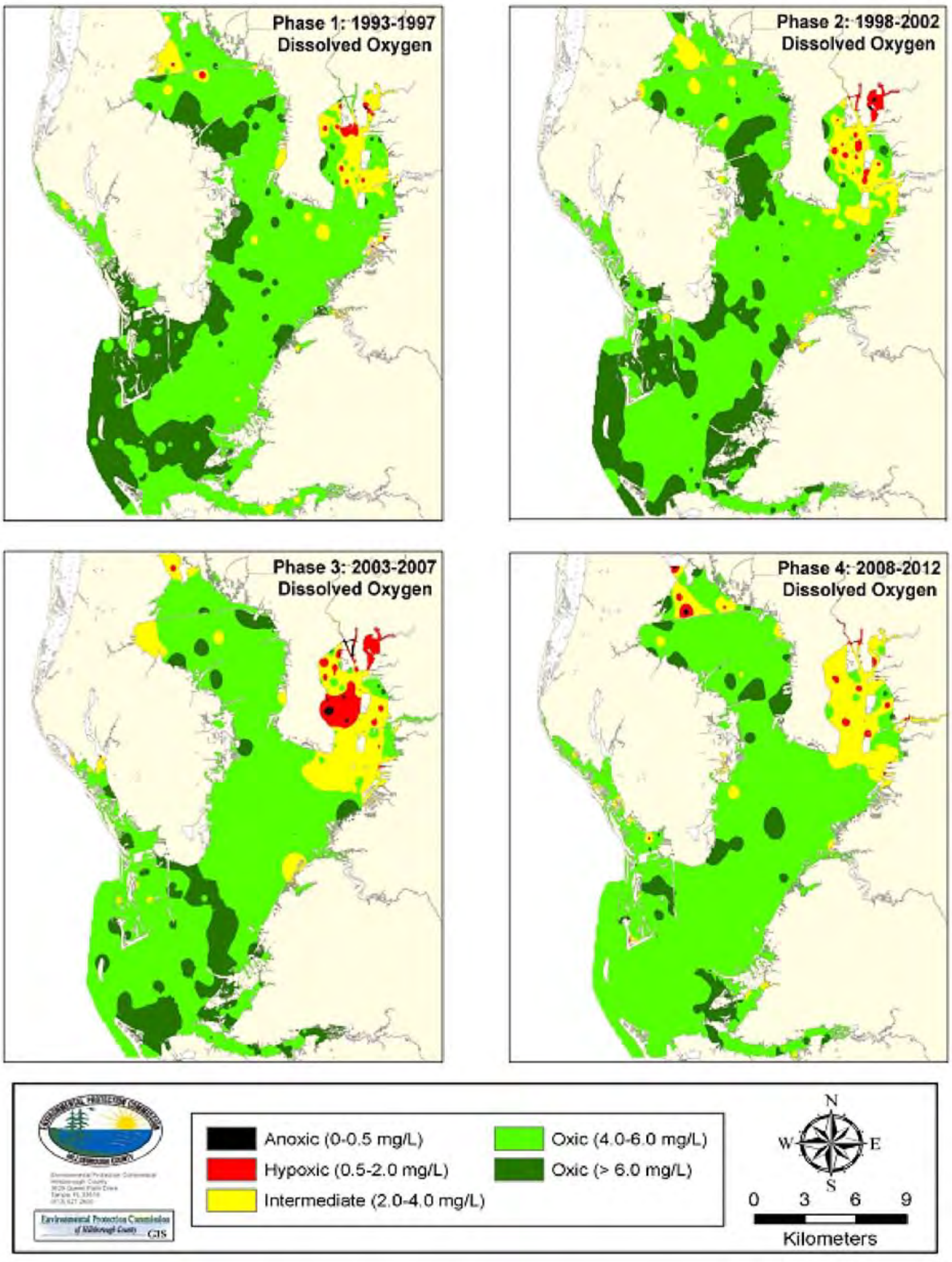


Figure 14. Spatial distribution of dissolved oxygen over time (1993-2012).

Sediment Composition (%Silt+Clay)

The median silt+clay in Tampa Bay was 4.4%, falling within the "medium" grain size classification (Tables 2 and 3), while the mean value was 8.9%. The maximum recorded % silt+clay measurement was 96% in 2009 from a sample in Hillsborough Bay (09HB15). This site was located in Seddon Channel and was 11 meters deep. 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), while higher mean values were recorded in 2009 and 2011 (Figure 15). The higher mean % silt+clay values and greater standard errors observed since 2008 can be attributed to a reduction in the number of samples collected each year, and particularly in the Lower and Middle Tampa Bay segments which tend to have lower % silt+clay values.

Hillsborough Bay had the highest % silt+clay values among all the bay segments. High measurements also occurred in Boca Ciega Bay and the Manatee River (Table 3; Figure 16). Medium grained sediments predominated in Old, Middle and Lower Tampa Bay (Table 7). Hillsborough Bay had the highest percentage of muddy and very fine grain sediments (Table 7). Terra Ceia Bay, Boca Ciega Bay and the Manatee River were predominately medium to fine grained sediments (Table 7). The observed distribution of sediments from this monitoring program confirms previous reports (Brooks and Doyle 1991) who also reported muddier sediments in Hillsborough Bay and coarser sediments towards Lower 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). 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. 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 which reduces light penetration through the water column and by accumulating sediment contaminants (Brooks and Doyle 1991, 1992). The accumulation of fine grained sediments can also impact benthic infaunal communities through burial and smothering (Manning et al., 2014).

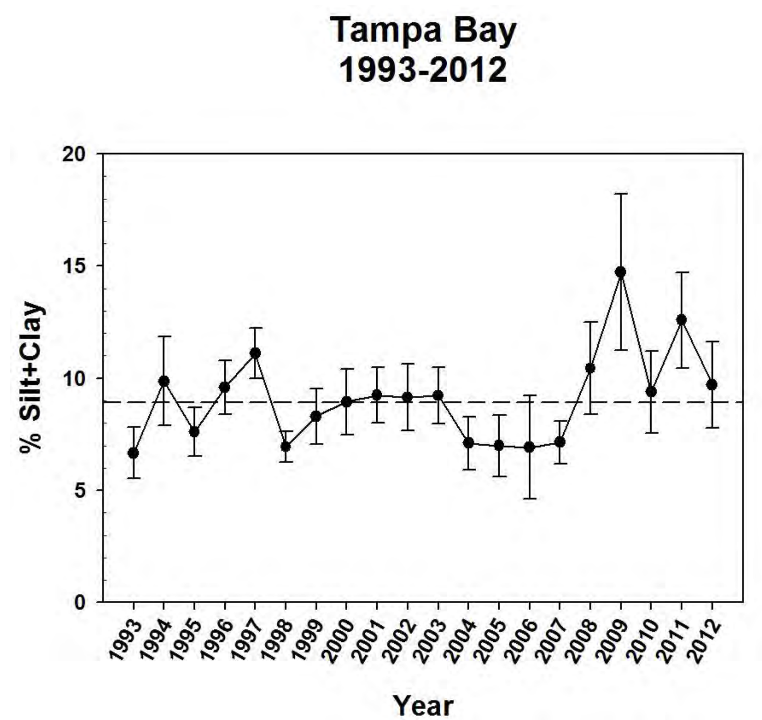


Figure 15. **Mean percent silt+clay by year. Error bars = 1 standard error, dashed line represents baywide mean value.**

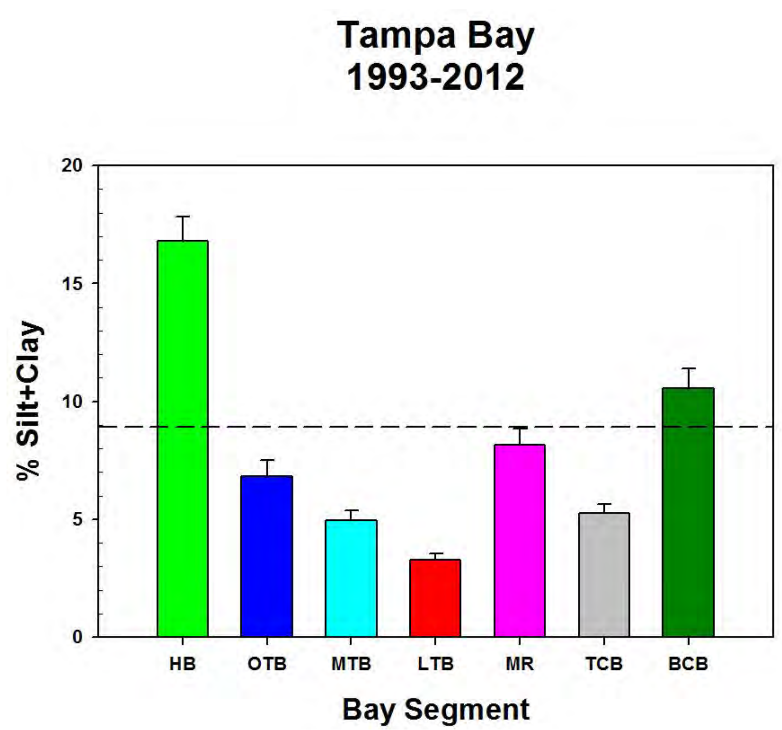


Figure 16. **Mean percent silt+clay by bay segment. Error bars = 1 standard error, dashed line represents baywide mean value.**

Table 7. Percent sediment categories by bay segment (1993-2012).

	n	Coarse	Medium	Fine	Very Fine	Mud
Hillsborough Bay	362	4.97%	29.56%	24.59%	19.06%	21.82%
Old Tampa Bay	235	14.04%	46.81%	25.11%	8.94%	5.11%
Middle Tampa Bay	278	17.99%	50.72%	23.38%	5.76%	2.16%
Lower Tampa Bay	206	20.87%	61.65%	16.02%	0.97%	0.49%
Manatee River	163	6.75%	29.45%	47.85%	11.04%	4.91%
Terra Ceia Bay	95	4.21%	45.26%	45.26%	5.26%	0.00%
Boca Ciega Bay	233	3.43%	30.04%	39.91%	18.88%	7.73%
Tampa Bay (Total)	1572	10.62%	41.09%	29.26%	11.13%	7.89%

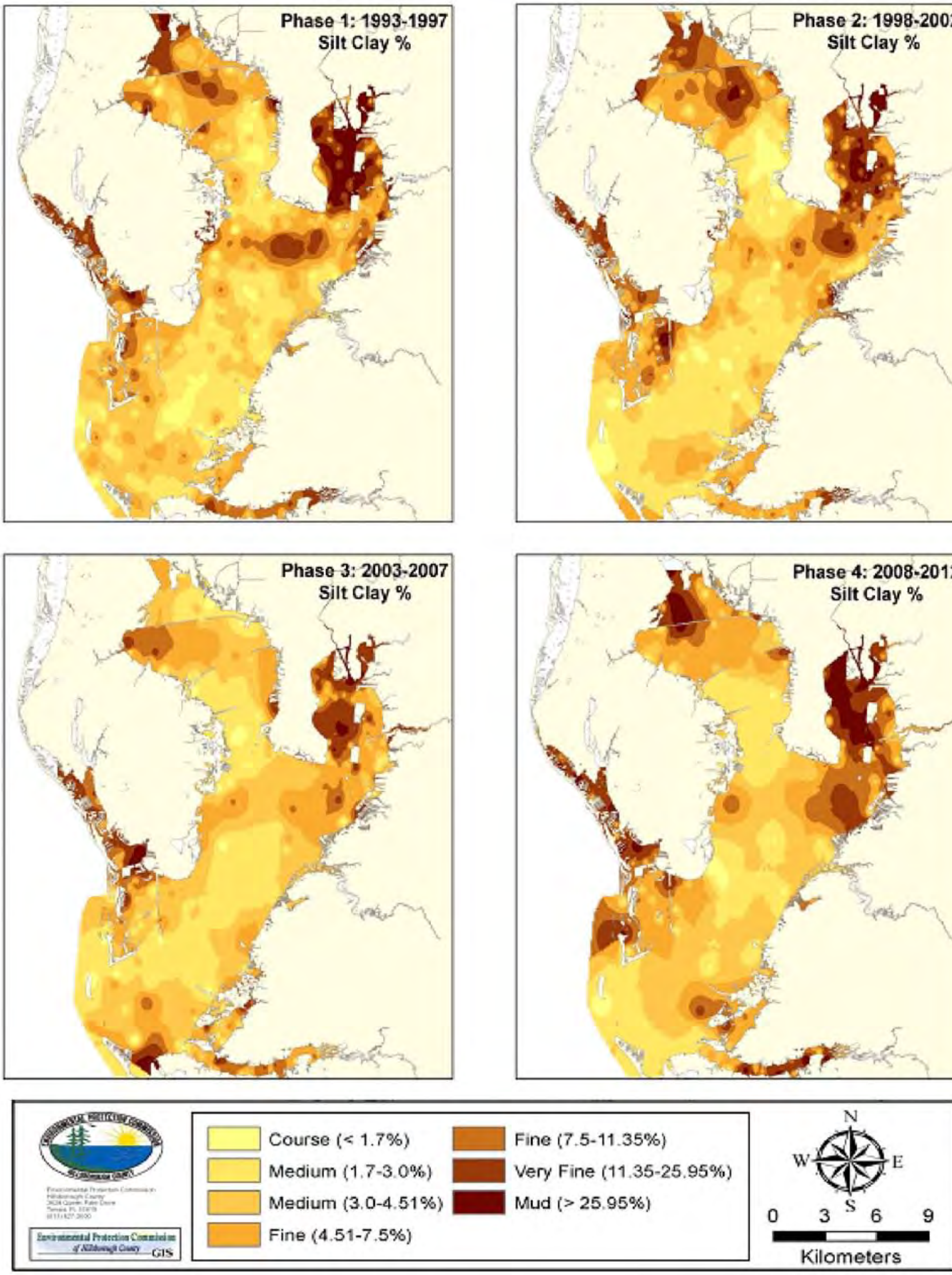


Figure 17. Spatial distribution of sediments in Tampa Bay over time.

Total Organic Carbon (TOC)

Total organic carbon (TOC) was incorporated as an additional sediment parameter starting in 2010. A total of 147 TOC samples were collected during the 2010-2012 monitoring period. Sources of organic carbon to the bottom sediments include deposition from the water column from plankton blooms (Lesen, 2006) and from tributary and terrestrial runoff. Organics in the sediment can serve as a food source for deposit feeding benthic fauna and is an important parameter in structuring benthic communities (Magni et al., 2009).

The median TOC was 0.4% with a mean value of 0.78% and ranging from 0.3 – 6.8%. The highest TOC value was recorded at a Manatee River site in 2011 (11MR43). This single measurement accounted for the overall higher mean TOC value in 2011 (Figure 18). There was no significant difference in the % TOC among years (KW; $p = 0.75$). There was a significant difference between bay segments (KW; $p = 0.015$) with the Manatee River sites having a higher TOC content relative to Old Tampa Bay, Middle Tampa Bay and Lower Tampa Bay (Figure 19). There was a decreasing trend in the sediment TOC content towards the mouth of the bay following a similar trend as percent silt+clay values.

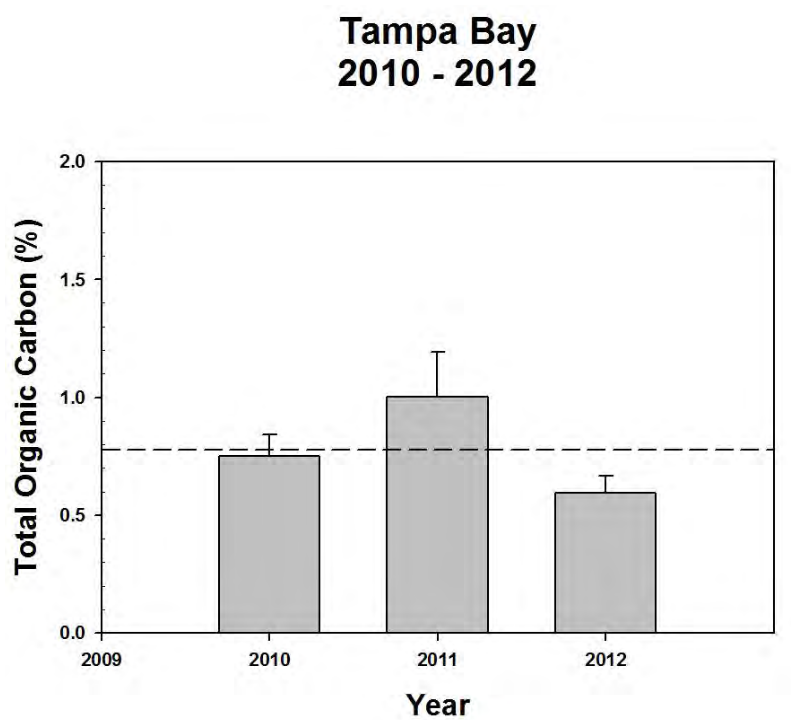


Figure 18. **Mean total organic carbon by year. Error bars = 1 standard error, dashed line represents baywide mean.**

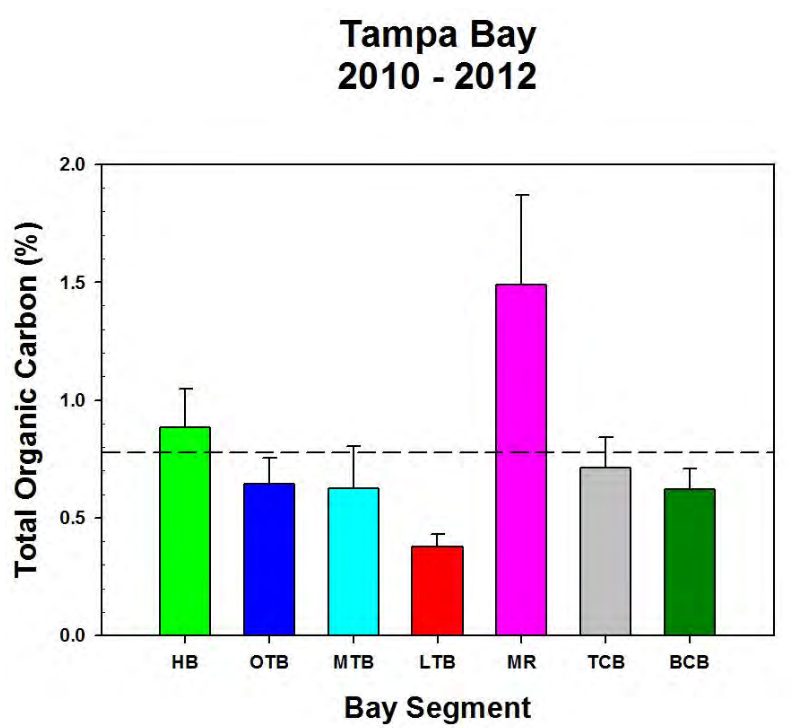


Figure 19. **Mean total organic carbon by bay segment. Error bars = 1 standard error, dashed line represents baywide mean.**

Analysis of Environmental Data

Principal coordinates analysis (PCO) results show that the individual bay segments are segregated by distinct physical characteristics with overlap between adjacent segments (Figure 20). This pattern is even more apparent when the samples are averaged by using the centroid points calculated from the year and segment factors (Figure 21). The first principal coordinate (PCO1) explained 32.4% of the total variation (Table 8) and was positively correlated with dissolved oxygen and pH, and it was negatively correlated with % silt+clay (Table 9; Figures 22 & 23). The second principal coordinate (PCO2) accounts for 23.1% of the total variation (Table 8) and was positively correlated with salinity and depth (Table 9; Figures 24 & 25).

Table 8. Percent of total variation explained by principal coordinates.

PCO	% of Total Variation	% Cumulative Variation
1	32.4%	32.4%
2	23.1%	55.5%
3	17.5%	73.0%
4	11.6%	84.6%
5	9.2%	93.8%
6	6.2%	100.0%

Table 9. Multiple correlations of bottom parameters contributing to principle coordinates.

Parameter	PCO 1	PCO 2	PCO 3	PCO 4	PCO 5	PCO 6
Depth	-0.16	**0.58**	-0.47	-0.47	-0.40	-0.19
Temperature	-0.13	0.24	**0.87**	-0.25	-0.21	-0.24
Dissolved Oxygen	**0.61**	-0.17	-0.08	0.10	-0.16	**-0.74**
pH	**0.53**	0.32	0.10	0.33	**-0.50**	**0.50**
Salinity	0.23	**0.67**	0.03	0.15	**0.68**	-0.09
% Silt+Clay	**-0.50**	0.19	-0.04	**0.76**	-0.22	-0.30

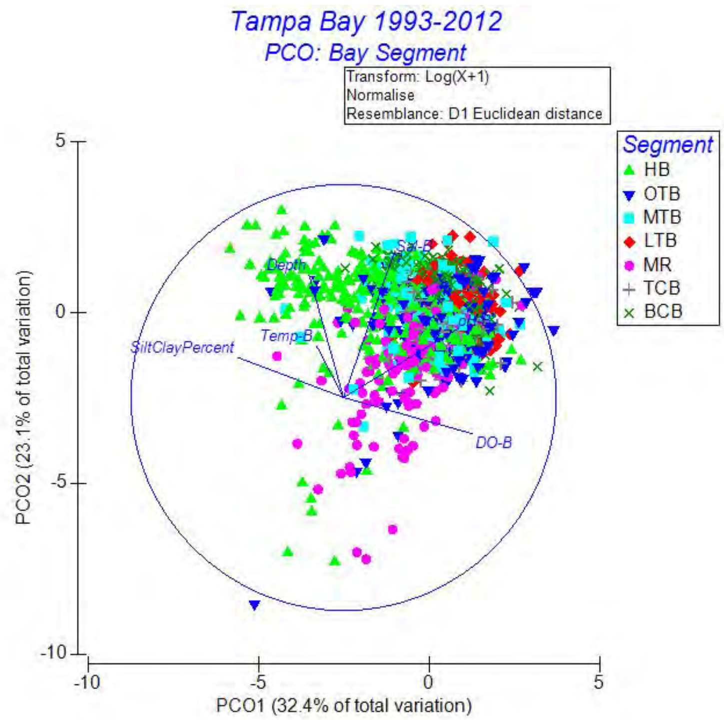


Figure 20. **Principal coordinates coded by bay segment.**

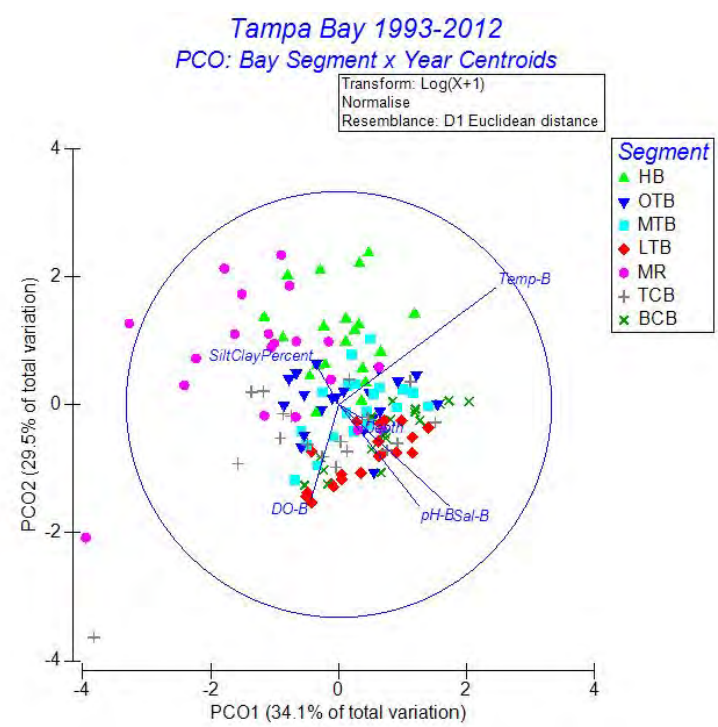


Figure 21. **Principal coordinates by bay segment and year centroids.**

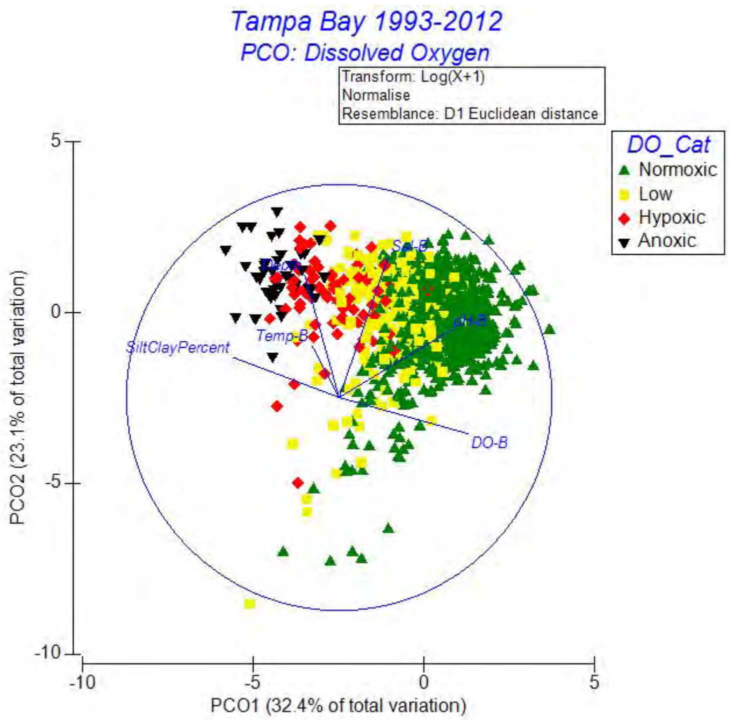


Figure 22. **Principal coordinates by bottom dissolved oxygen classification.**

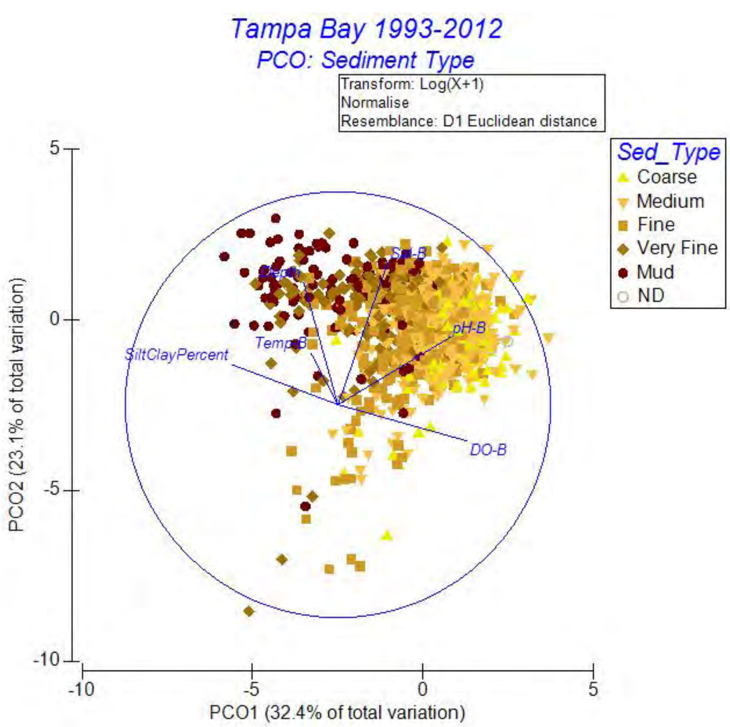


Figure 23. **Principal coordinates by sediment type.**

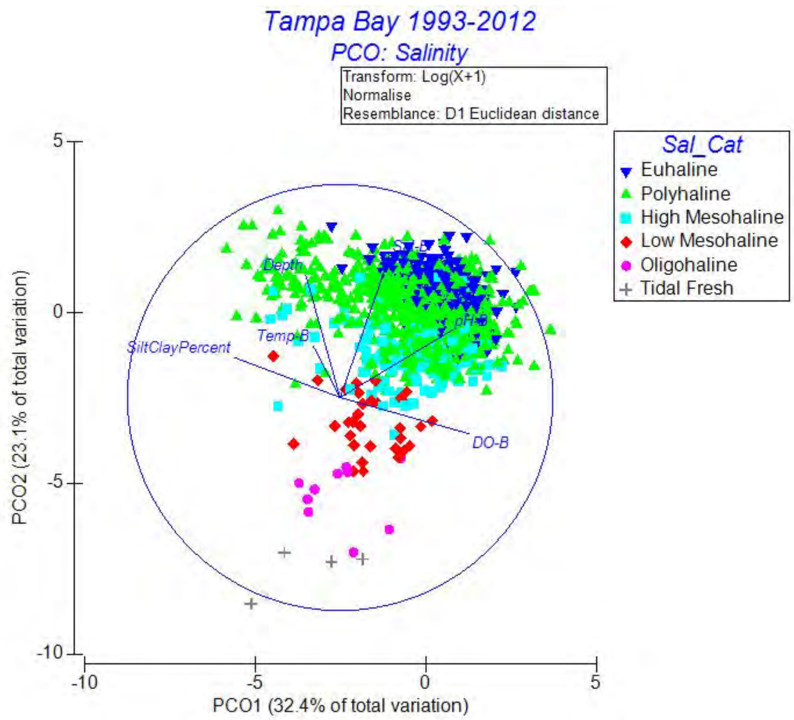


Figure 24. **Principal coordinates by salinity classification.**

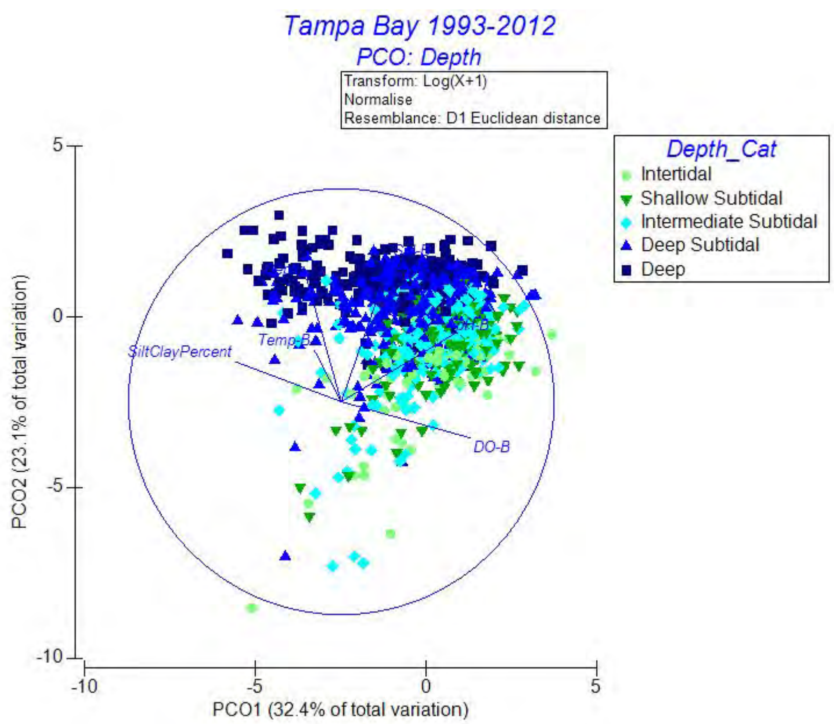


Figure 25. **Principal coordinates by depth classification.**

Sediment Contaminants

Metals

Baywide 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.

Aluminum (Al): Aluminum is among the most common elements in the Earth's crust and is widely used in many industrial and commercial applications. The concentration of other metals is proportional to aluminum in crustal minerals, the metal:aluminum ratio has often been used to normalize metals data and is used for detecting elevated concentrations of a metal above expected background levels (Din, 1992; Pardue et al., 1992; Schropp et al., 1990).

Sediment concentrations of aluminum were highest in Hillsborough Bay and showed a decreasing trend towards Lower Tampa Bay (Figure 26). This reflects the greater input of terrestrial sediments in Hillsborough Bay relative to the other bay segments.

Iron (Fe): Iron is also among the most common elements found in crustal rocks and terrestrial soils and can also be used as a normalizing factor for measuring enrichment of other metals in marine sediments (Schiff and Weisberg, 1999). Iron has many industrial uses such as in the manufacture of steel products, but Fe is also an important micronutrient for organisms. Iron is used by phytoplankton in the production of chlorophyll and in many metabolic pathways involved with photosynthesis and respiration (Street and Paytan, 2005).

Iron concentrations for Tampa Bay sediment ranged from under 4 to over 29,500 mg/kg (Table 10) and were highest in Hillsborough Bay, decreasing towards Lower Tampa Bay (Figure 27). The iron concentrations corresponded with higher percent silt+clay content and as with aluminum, reflects greater terrestrial inputs from runoff.

Antimony (Sb): Antimony is commonly found in two valance states in the environment; Sb (III) under reducing conditions and Sb (V) under oxiding conditions (Chen et al., 2003) and is often associated with arsenic compounds (ATSDR, 1992: Filella et al. 2002). Sb (III) is the more soluble and bioavailable form but can be bound to iron sulfides in the sediment under anoxic conditions (Chen et al. 2003). Sb (V) binds with iron or manganese oxyhydroxides under oxic conditions (Chen et al. 2003). Industrial uses of Sb include antimony oxide which is used as a fire retardant in fabrics and plastics, and alloys with lead and zinc used in batteries, ammunition, pewter, solder and other metal products (Filella et al. 2002). Sources of antimony to the environment include smelting plants, sewage and fertilizer facilities (Filella et al. 2002).

Antimony concentrations for Tampa Bay sediment during the 1993-2012 monitoring period ranged from <MDL (Method Detection Limit) to over 146 mg/kg (Table 10). The median antimony concentration was highest in the Manatee River and lowest in Old Tampa Bay. There

was a significant difference in Sb concentrations between bay segments (KW; $p<0.001$) with Old Tampa Bay being lower than Hillsborough Bay, the Manatee River, and Boca Ciega Bay (Figure 28). The Sb:Al ratios indicated a few Hillsborough Bay sites may be enriched for antimony above background levels (Figure 29).

Arsenic (As): Arsenic typically exists in two inorganic forms in the environment, the trivalent form As (III), which is more soluble and bioavailable and the pentavalent form, As (V), which is often bound with iron compounds in the sediments (Bauer and Blodau, 2006; Guo et al., 1997; Hatje et al., 2010; Masscheleyn et al., 1991). Arsenic is known to be toxic and can accumulate in benthic infauna and transferred to other organisms which feed on them (Barwick and Maher, 2003; Fattorini et al., 2005; Hatje et al., 2010; Neff, 1997; Price et al., 2013; Rainbow et al., 2011). Arsenic is used in several industrial applications including pesticides and as a preservative in pressure treated lumber (ATSDR 2007a; MacDonald 1994). Possible sources to the environment may include runoff of pesticides (Pichler et al., 2008; Whitmore et al., 2008) or leaching from treated wood structures such as docks and pilings (Weis et al., 1993).

The baywide mean concentration for arsenic was 2.54 mg/kg with a maximum of over 22 mg/kg (Table 10). There were no PEL exceedences for As; however, a few samples (5.46%) exceeded the TEL (Table 10). There was a significant differences between bay segments (KW; $p = 0.026$) with highest median values in Terra Ceia Bay and Boca Ciega (Figure 30). The As:Al ratio indicates that the sites with elevated As levels may be due to anthropogenic sources (Figure 31). Potentially contaminated sites were scattered in portions of Old, Middle and Lower Tampa Bay (Figure 32).

Cadmium (Cd): Cadmium has many industrial and agricultural sources including electroplating, paints, plastics, batteries, mining, some pesticides and fertilizers, and combustion of fossil fuel (MacDonald 1994). Cadmium 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). 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 over 42% of the samples above the TEL and approximately 1.7% above the PEL (Table 10; Figure 35). There was a significant difference between bay segments (KW; $p < 0.001$) with Hillsborough Bay and Boca Ciega Bay having the highest Cd levels (Figure 33). Despite the high percentage of sites above the TEL, the Cd:Al ratio (Figure 34), suggests that the high Cd levels are not enriched above background concentrations and may be due to natural souces such as weathering of phosphate enriched soils or from anthropogenic inputs related to phosphate mining (MacDonald 1994). 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) 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): Chromium is used in the production of chrome plating, chromium metal and chrome alloys, dyes, paints, paper, and 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 greater toxicity (MacDonald 1994; McConnell et al. 1996).

Total Cr levels in Tampa Bay were above the TEL at 6.36% of the sites and exceeded the PEL at 0.83% of the sites (Table 10). There were significant differences between bay segments (KW; $p < 0.001$) with highest concentrations occurring in Hillsborough Bay and elevated levels in Old Tampa Bay, the Manatee River and Terra Ceia Bay (Figure 36). Several sites had Cr:Al ratios which indicated possible contamination, particularly in Hillsborough Bay (Figure 37). Areas of highest contamination were mainly in Hillsborough Bay (Figure 38). The highest recorded Cr concentration (15,320 mg/kg) was found at a Hillsborough Bay site in 1996 near the mouth of Bullfrog Creek (96HB46). There were additional sites above the TEL sites around the periphery of Old Tampa Bay as well as a few isolated sites in Middle Tampa Bay, Boca Ciega Bay and the Manatee River (Figure 38).

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 (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 urban development in these areas (Frithsen et al. 1995).

Copper (Cu): Copper is commonly used in biocides for controlling algae and fungi and found in antifouling paints (ATSDR 2004, 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 (ATSDR 2004, MacDonald 1994). The estimated annual loading of Cu in Tampa Bay is approximately 12,500 kg per yearwith 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 Cu concentrations in the sediment can 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).

Cu levels found in Tampa Bay sediments exceeded the TEL in 5.25% of the samples and the PEL in 0.48% 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 39) and the Cu:Al ratios indicated several sites were enriched above background levels (Figure 40). The areas of highest contamination were primarily in Hillsborough Bay, in the Port of Tampa and the shipping channels, and in the Manatee River and Boca Ciega Bay (Figure 41). 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 St. Petersburg, and Cu has been identified as a "Chemical of Concern" for upper Hillsborough Bay (McConnell et al. 1996; McConnell and Brink 1997).

Lead (Pb): Lead has many industrial uses including the manufacture of lead batteries and chemical compounds, solder, lead based paints and ammunition (ATSDR 2007b, MacDonald 1994). Lead was used as a gasoline additive until it was phased out in the 1970s which resulted in a measurable decrease of lead in the environment (Trefry et al., 1985). Lead pipes were historically used for plumbing and transporting potable water dating back to the Roman period (Delile et al., 2014). Sources of lead in the environment include atmospheric deposition and runoff from contaminated soils (ATSDR 2007b). Lead emissions from automobiles have been known to cause soil contamination along roadways (Hafen, 1996; Newsome, 1997). Legacy contamination from lead based paints can linger in soils and sediments (Brinkmann, 1994; Rees et al., 2014). Lead bullets and shot have also been responsible for elevated lead levels in soils at shooting ranges which can leach into the surrounding environment (Bannon et al., 2009; Butkus and Johnson, 2011; Cao et al., 2003; Clausen et al., 2011; Labare et al., 2004).

Lead exposure can affect neurological development in children, affect cognitive functions in adults and causes many other health effects such as cardiovascular disorders and impaired kidney functions (ATSDR 2007b).

Lead concentrates in Tampa Bay sediments exceeded the TEL at 4% of the sites and were above the PEL at 0.55% of the samples (Table 10). The maximum concentration was 638 mg/kg at a site in McKay Bay (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 particularly in Hillsborough Bay (Figure 42). The most contaminated Hillsborough Bay sites were in the upper arm of McKay Bay, in the Hillsborough River and near the Port of Tampa (Figure 43). Other isolated sites with high levels of lead include 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 (PEL value determined by MacDonald, 1994). MacKay Bay had the highest Pb concentration (385 mg/kg) in the Brooks and Doyle (1992) survey. Lead levels in Tampa Bay sediments were 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 per year primarily from urban runoff (60%), along with atmospheric deposition (20%), point source pollution (11%) and ground water (9%).

Manganese (Mn): Manganese is found naturally in the environment and an essential nutrient for plants and animals in low concentrations (ATSDR, 2012). High concentrations of Mn, however, can impact brain development in children and result in behavioral changes and affect memory (ATSDR 2012). The primary industrial use of Mn is in steel production where it is added to increase hardness and strength (ATSDR 2012). Other commercial uses include food additives, nutritional supplements, fertilizers, cosmetics, dry-cell batteries, fireworks, paints and as an additive to gasoline (ATSDR 2012).

MacDonald (1994) did not establish sediment quality guidelines (SQGLs) for manganese. Manganese concentrations in Tampa Bay ranged from below MDLs to 162.7 mg/kg with a median of 11.53 mg/kg (Table 10). The highest value was at a LTB site in 1994 (94LTB25) near Port Manatee. Manganese levels were high at a few sites in Terra Ceia Bay, Lower Tampa Bay, and Hillsborough Bay (Figure 45) with high Mn:Al ratios (Figure 46). Old Tampa Bay had significantly lower concentrations of Mn relative to Lower Tampa Bay, Hillsborough Bay and Terra Ceia Bay (KW; $p<0.001$).

Mercury (Hg): Mercury is a liquid metal at room temperature and can also be found in inorganic compounds such as mercuric sulfide (cinnabar), mercuric chloride, and in organic compounds such as methylmercury (ATSDR 1999). Mercury is used in electric switches, thermometers, thermostats, fluorescent light bulbs, and as a fungicide and dental amalgam fillings (ATSDR 1999). Anthropogenic sources of mercury are primarily from atmospheric deposition which includes the combustion of coal and other fossil fuels and the incineration of municipal waste (ATSDR 1999). Approximately 70% of atmospheric deposition in Florida is estimated to come from the combustion of coal, while 30% is from natural sources such as volcanoes and forest fires (FDEP 2013). Other potential sources include cement and fertilizer production facilities (ATSDR 1999; Mirlean, 2008). Mercury and especially methylmercury can accumulate in sediments and be taken up by deposit feeding infauna (Sizmur, 2013) and bioaccumulate in fish and birds at higher trophic levels (Adams and Onorato, 2005; Beyer et al., 1997; Cleckner et al., 1998; Julian, 2013).

Sediment samples were only analyzed for mercury in 1993 for the four main bay segments. All samples were below the 0.13 mg/kg TEL threshold for Hg (MacDonald 1994; Figure 47) and the Al:Hg ratios did not indicate that samples were higher than background concentrations (Figure 48). The highest Hg concentration (0.1 mg/kg) was found in Safety Harbor in the northern part of Old Tampa Bay. The Florida Department of Environmental Protection in 2013 established a state wide Total Maximum Daily Load (TMDL) for mercury. Florida Department of Health's thresholds for mercury concentrations are based upon the health hazard of human consumption of fish tissues (FDEP 2013). The entire Tampa Bay watershed is listed as impaired for Hg using the criteria developed by the Florida Department of Environmental Protection (FDEP, 2012).

Nickel (Ni): Nickel is primarily used in the manufacture of stainless steel, nickel plating, 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 (ATSDR 2005a; MacDonald 1994; McConnell and Brink 1997).

Nickel levels were above the TEL at 8.71% of the sites and exceeded the PEL at 0.48% of the sites with a maximum concentration of 10,030 mg/kg (Table 10). Highest levels were found in Hillsborough Bay (Figures 49) and were significantly higher than the other bay segments (KW; $p < 0.001$). Only a few sites had Ni:Al ratios that were higher than background levels (Figure 50). These sites were mainly concentrated in Hillsborough Bay near the Port of Tampa (Figure 51) and the highest Ni concentration was recorded at the mouth of Bull Frog creek in 1996 (site 96HB46). This site also had the highest record for chromium and high concentrations for copper and zinc. 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 Long et al. 1994 did not find significant correlations between nickel concentrations and amphipod survival in Tampa Bay. 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). Baywide 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%).

Selenium (Se): Selenium is an essential nutrient in low quantities and is used as a nutritional supplement in animal feed (ATSDR 2003). High doses can lead to severe health effects including pulmonary edema or selenosis (selenium poisoning) characterized by a loss of feeling and control of the victims arms and legs (ATSDR 2003). High levels of Se can be naturally occurring in soils which can be taken up by agricultural crops and potentially reach toxic concentrations (ATSDR 2003). Selenium is used commercially in paints, plastics, glass, nutritional supplements, as an active ingredient in fungicides and anti-dandruff shampoos (ATSDR 2003). Selenium from anthropogenic sources can enter the environment through the combustion of coal, disposal of products containing Se, and agricultural runoff (ATSDR, 2003; Malloy et al. 1999). Selenium in marine and freshwater sediments can be taken up by benthic organisms and accumulate at higher trophic levels (Barwick and Maher, 2003; Krby et al., 2001; Malloy et al., 1999).

Selenium concentrations in Tampa Bay sediments ranged from below its MDL to a maximum of 109 mg/kg with a mean value of 8.18 mg/kg (Table 10). The highest measurement was recorded in 2007 near the south dredge spoil island in Hillsborough Bay. There was a significant difference in the levels of Se among bay segments (KW, $p<0.001$); however, a pairwise comparisons between segments found no significant differences between individual segments. Selenium was high in Boca Ciega Bay and Hillsborough Bay (Figure 52) and the lowest concentration was in Lower Tampa Bay (Figure 52). The Se:Al ratios indicated a few Hillsborough Bay sites were above background levels (Figure 53).

MacDonald (1994) did not develop SQGLs for selenium in Florida coastal sediments. Selenium sediment toxicity thresholds for freshwater streams in the western United States have been proposed with 2.5 µg/g for predicted effects and 4 µg/g for toxicity on fish and wildlife (Van Derveer and Canton, 1997). The median Se concentration in Tampa Bay was 7.15 mg/kg which is above these thresholds; however, other factors such as sediment organic content, pH and sediment redox potential can affect its bioavailability (Masscheleyn et al., 1990; Van Derveer and Canton, 1997) .

Silver (Ag): Silver is known to be a highly toxic to aquatic organisms and bioaccumulates at a high rate (Lee et al. 2004; Luoma et al. 1995). Silver has several industrial uses including the production and processing of photographic materials, electrical contacts, soldering, jewelry and silver plating, in medicine as an antimicrobial and dental fillings (ATSDR, 1990; Purcell and Peters 1998; MacDonald 1994). Nanoparticles of silver have increasingly been used in consumer products such as clothing and cosmetics to inhibit bacterial growth (Mühling et al., 2009). Potential sources of silver to the environment include waste incinerators, landfills, waste water treatment plants, and coal combustion (ATSDR 1990; MacDonald 1994).

Silver concentrations in Tampa Bay sediment ranged from below detectable limits to 1.48 mg/kg (Table 10). The highest concentration was found on the west side of Davis Island in Hillsborough Bay (95HB18). There were no sites above the PEL, while 1.8% of the sites were above the TEL (Table 10). Silver levels had significant differences (KW; $p < 0.001$) between bay segments with highest levels occurring in Hillsborough and Boca Ciega Bays (Figure 54). A few of the sites had Ag:Al ratios indicative of anthropogenic sources (Figure 55). Most of these sites were in Hillsborough Bay with scattered sites in the other segments (Figures 56). 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. The highest value recorded by Brooks and Doyle (1991) was 0.5 mg/kg which is below the TEL of 0.73 mg/kg established by MacDonald (1994) and below the maximum value found in the current monitoring results.

Tin (Sn): Tin has many industrial and commercial applications (ATSDR, 2005b). Inorganic tin is used in tin-plated food containers and aerosol cans, electroplating, solder, glass production, as an additive to perfumes and soaps, as a food preservative, in metal alloys such as bronze and pewter, and tin(II) fluoride (SnF_2) is added to toothpaste as an anti-cavity ingredient (ATSDR, 2005b). Organic tin compounds are used commercially as heat stabilizers for polyvinyl chlorides (PVCs), in the manufacture of polyurethane foam, as biocides, agrichemicals, wood preservatives and in antifouling paints (ATSDR, 2005b). Tributyltin (TBT) was used in antifouling paints and has been a major source of contamination in the marine environment (ATSDR, 2005b). Sediments contaminated by TBT has cause reproductive deformities in gastropods (Balckmore, 2000; Terlizzi et al., 1999) and negatively impacts the benthic community structure by reducing species richness and composition (Austen and McEvoy, 1997; Dahllof et al., 2001). Ttributyltin in antifouling paints has been restricted since 1988 by the Organotin Antifouling Paints Control Act, which limits the types of vessels that can use TBT paints (ATSDR, 2005b).

Tin in Tampa Bay sediments ranged from below its MDL to 34.59 mg/kg with a mean of 2.31 mg/kg (Table 10). The highest tin concentration was found in McKay Bay in 1997 (97HB10), a site which also had high levels of several other metals. There was a significant difference among the bay segments (KW; $p<0.001$) with tin concentrations being lower in Lower Tampa Bay (Figure 57). The Sn:Al ratio did indicate that a number of sites were potentially enriched above background levels (Figure 58). MacDonald (1994) did not establish SQGLs for tin in Florida coastal sediments.

Zinc (Zn): Zinc is a common naturally occurring element and an essential nutrient. Zinc deficiencies in the diet can result in decreased immune function and for pregnant women an increased risk of birth defects (ATSDR 2005c). High doses of Zn can cause anemia and damage to the pancreas (ATSDR 2005c). Zinc has many industrial uses, including galvanization of steel and other metals to prevent corrosion, making alloys such as brass and bronze and in dry cell batteries (ATSDR 2005c). Zinc compounds are used in ceramics, rubber production, in wood preservatives, dietary suppliments, cosmetics, sunscreen and paints (ATSDR 2005c). Nanoparticles of zinc oxides are used in many products including sunscreens, cosmetics and in marine antifouling paints (Schultz et al., 2014).

Anthropogenic sources of zinc in the environment include industrial discharges from steel production and electroplating facilities, domestic wastewater treatment plants, atmospheric deposition and stormwater runoff (ATSDR, 2005c). Sources of zinc in urban runoff include roofs and siding materials from buildings and dust and particles from rubber tire wear along roadways (Davis et al., 2001). Leaching of zinc from antifouling paints can cause contamination in water and sediments (Singh and Turner, 2009a, b; Turner et al., 2009) and antifouling paints used on nets can increase zinc concentrations in farmed fish tissues (Nikolaou et al., 2014). High zinc concentrations can impair growth and fertility in amphipods(Conradi and Depledge, 1999), cause mouthpart deformities in freshwater chironomid larvae (Martinez et al., 2001) and impact recruitment of benthic organisms (Watzin and Roscigno, 1997). Zinc assimilation is high in some invertebrates such as barnacles (Rainbow and Wang, 2001; Wang and Rainbow, 2000) which can be further transferred up the food chain (Blackmore, 2000). In contrast, Barwick and Maher (2003) did not find evidence of biomagnifications of Zn at higher trophic levels in a seagrass ecosystem.

Zinc concentrations in Tampa Bay sediments ranged from 0.27 – 522 mg/kg with a mean value of 17.62 mg/kg and median of 5.15 mg/kg (Table 10). Zinc levels were above its TEL at 1.87% of the sites and exceeded its PEL at 0.69% of the sites (Table 10). Zinc levels had significant differences (KW; $p<0.001$) between bay segments. . The highest zinc levels were in Hillsborough Bay and the Manatee River (Figure 59). Contaminated sites were evident from elevated Zn:Al ratios particularly in Hillsborough Bay (Figure 60). Most of these contaminated sites were in Hillsborough River, McKay Bay, around the Port of Tampa and at the mouth of Bullfrog Creek (Figure 61). Brooks and Doyle (1992) found concentrations of zinc as high as 700 mg/kg in McKay Bay which exceeds the highest value (522 mg/kg) found in this study (Table 10). Approximately 17% of the sites in the Brooks and Doyle (1992) exceeded the PEL value for zinc compared to only 0.69% in this study. Frithsen et al. (1995) estimated annual loading of zinc to Tampa Bay at 164,000 tons per year with 66% of the input coming from urban runoff.

Table 10. Tampa Bay sediment metals summary statistics and percentage of sites exceeding TEL and PEL values (1993-2012).

mg/kg	Aluminum Al	Antimony Sb	Arsenic As	Cadmium Cd	Chromium Cr	Copper Cu	Iron Fe	Lead Pb	Manganese Mn	Mercury Hg	Nickel Ni	Selenium Se	Silver Ag	Tin Sn	Zinc Zn
TEL	ND	ND	7.2	0.68	52.3	18.7	ND	30.2	ND	0.13	15.9	ND	0.73	ND	124
PEL	ND	ND	41.6	4.2	160	108	ND	112	ND	0.696	42.8	ND	1.77	ND	271
n	1447	857	1447	1406	1447	1447	857	1447	857	57	1447	857	1330	1447	1447
Minimum	1.13	0.01	0.05	0.01	0.32	0.11	3.98	0.29	0.16	0.01	0.20	0.01	0.01	0.01	0.27
Maximum	59,540.00	146.83	22.19	14.52	15320.00	729.10	29,508.94	637.71	162.70	0.10	10030.00	109.21	1.48	34.59	522.00
Median	1826.11	7.73	1.31	0.45	7.05	1.81	1180.17	4.26	11.53	0.01	3.34	7.15	0.11	1.15	5.15
Mean	4836.63	15.17	2.54	1.00	26.55	6.14	2758.98	10.38	19.40	0.01	12.93	8.18	0.21	2.31	17.62
SD	7914.04	17.84	2.46	1.20	403.70	25.43	4462.71	25.05	22.48	0.02	263.90	8.34	0.21	4.06	42.89
% >TEL;<PEL			**5.46%**	**42.46%**	**6.36%**	**5.25%**		**4.01%**		**0.00%**	**8.71%**		**1.80%**		**1.87%**
% >PEL			**0.00%**	**1.71%**	**0.83%**	**0.48%**		**0.55%**		**0.00%**	**0.48%**		**0.00%**		**0.69%**

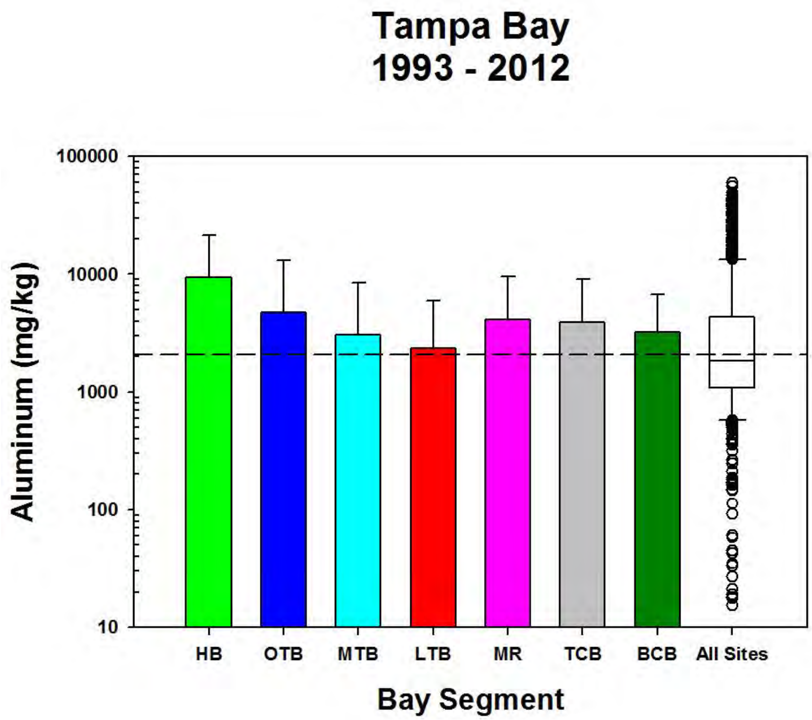


Figure 26. Mean sediment aluminum concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents bay-wide mean.

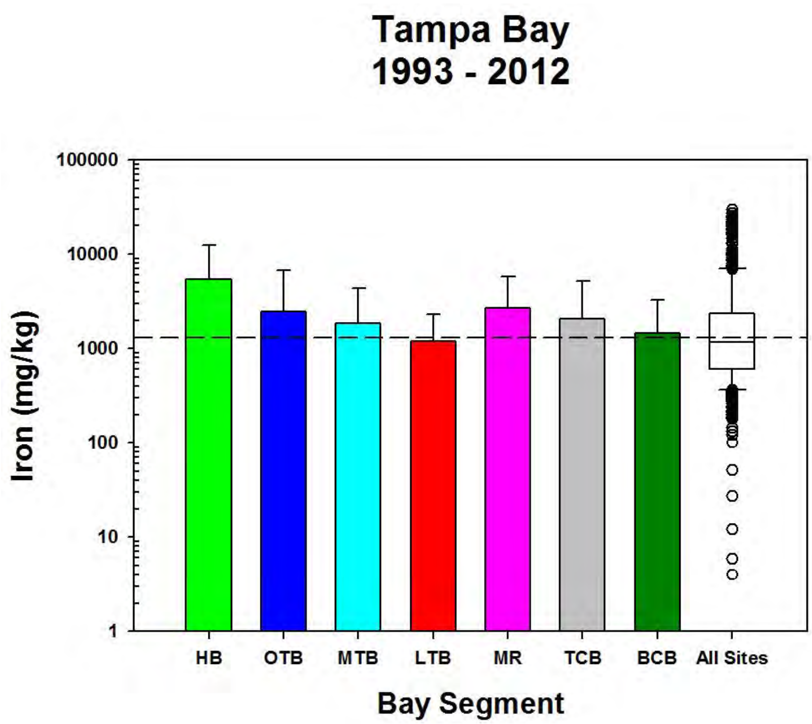


Figure 27. Mean sediment iron concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents bay-wide mean.

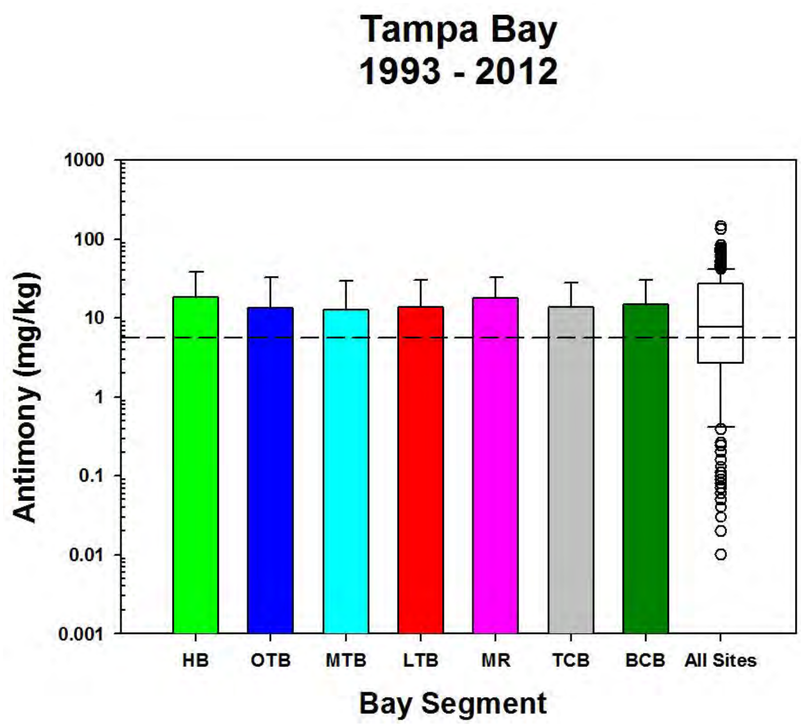


Figure 28. **Mean sediment antimony concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents bay-wide mean.**

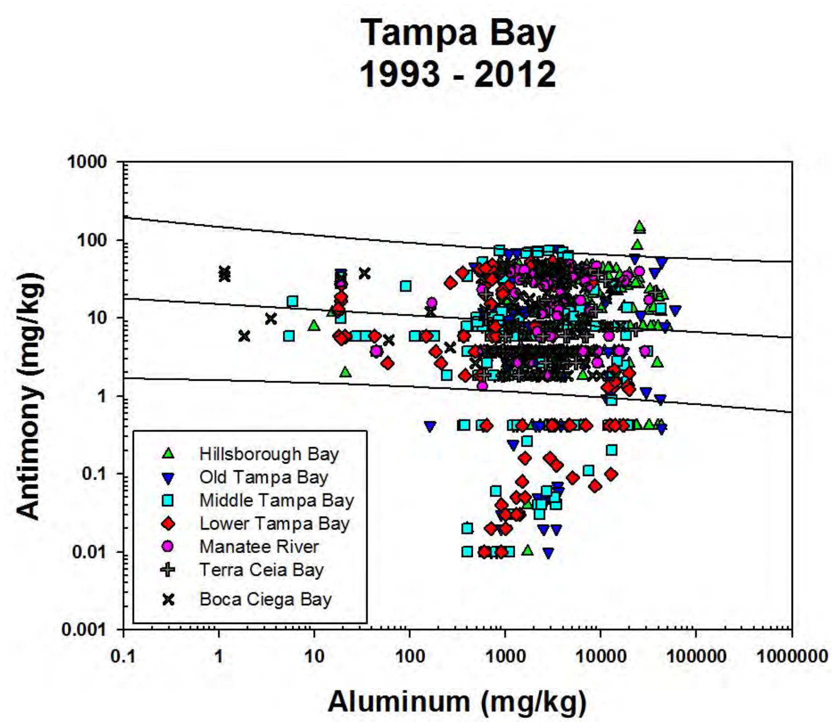


Figure 29. **Tampa Bay Sb:Al ratio with 95% prediction intervals (solid lines).**

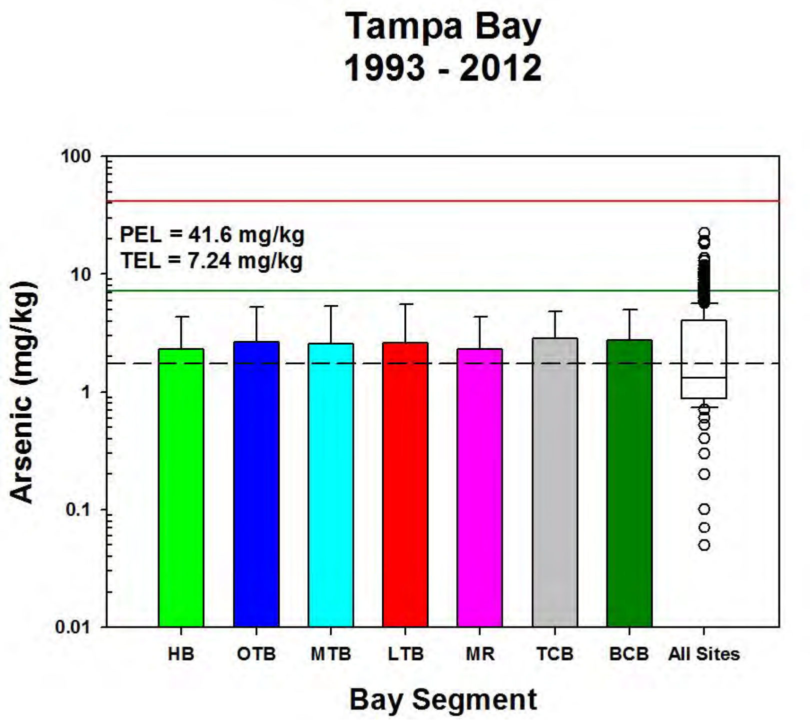


Figure 30. **Mean sediment arsenic concentrations by bay segment. Error bars = 1 standard deviation, Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.**

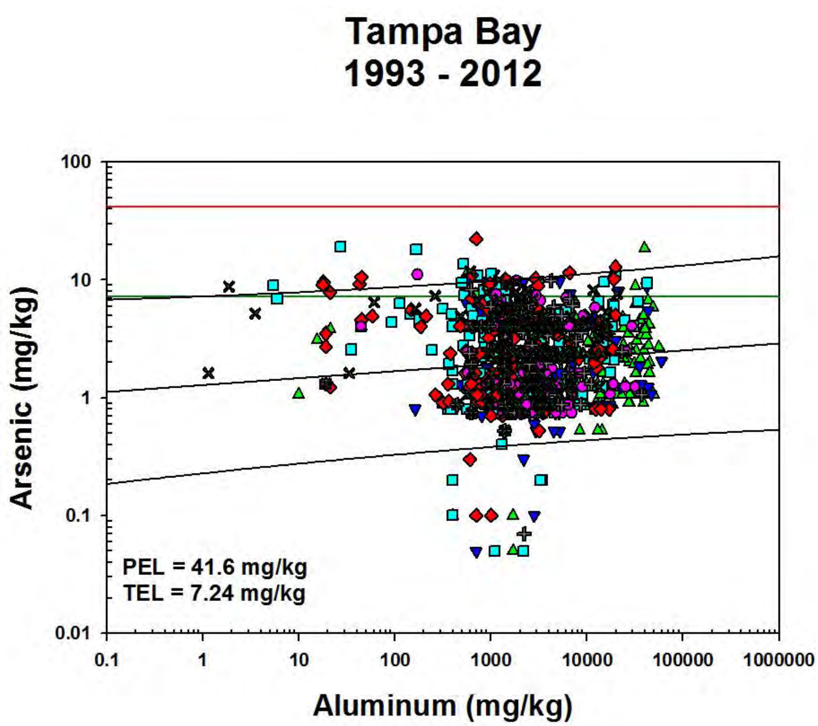


Figure 31. **Tampa Bay As:Al ratio with 95% prediction intervals (solid lines). Solid lines represent PEL (upper; red) and TEL (lower; green) values.**

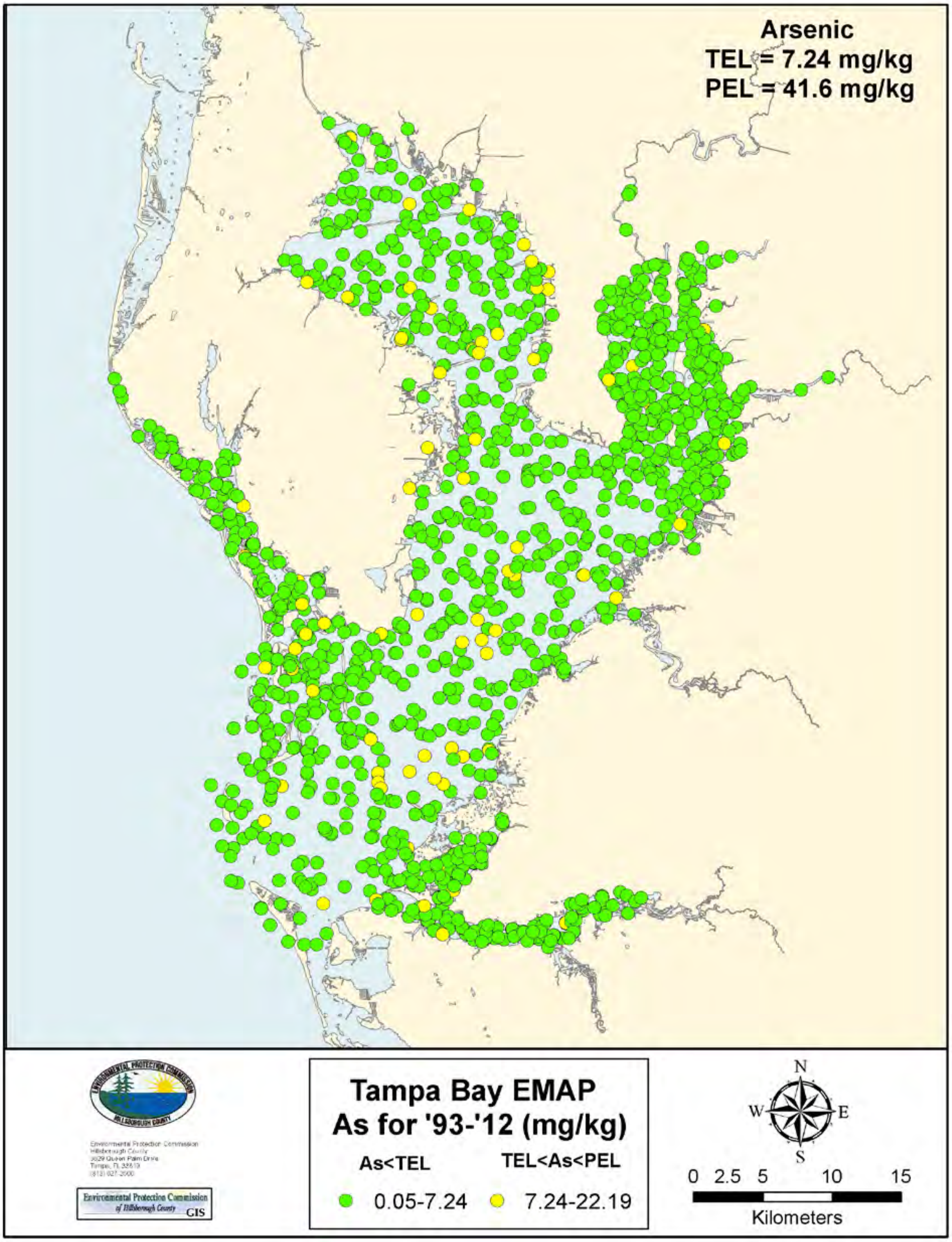


Figure 32. Spatial distribution of arsenic in Tampa Bay 1993-2012.

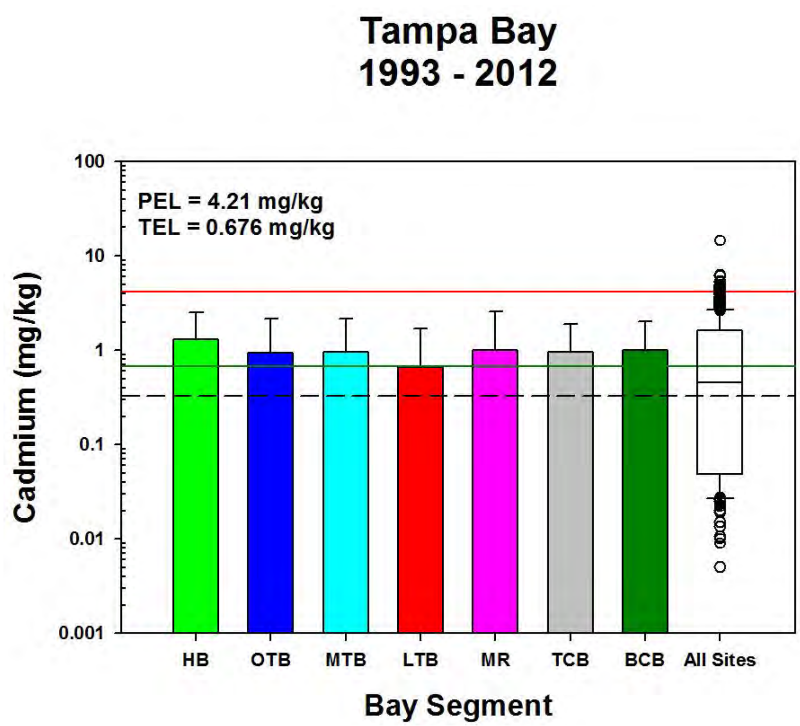


Figure 33. **Mean sediment cadmium concentrations by bay segment. Error bars = 1 standard deviation, Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.**

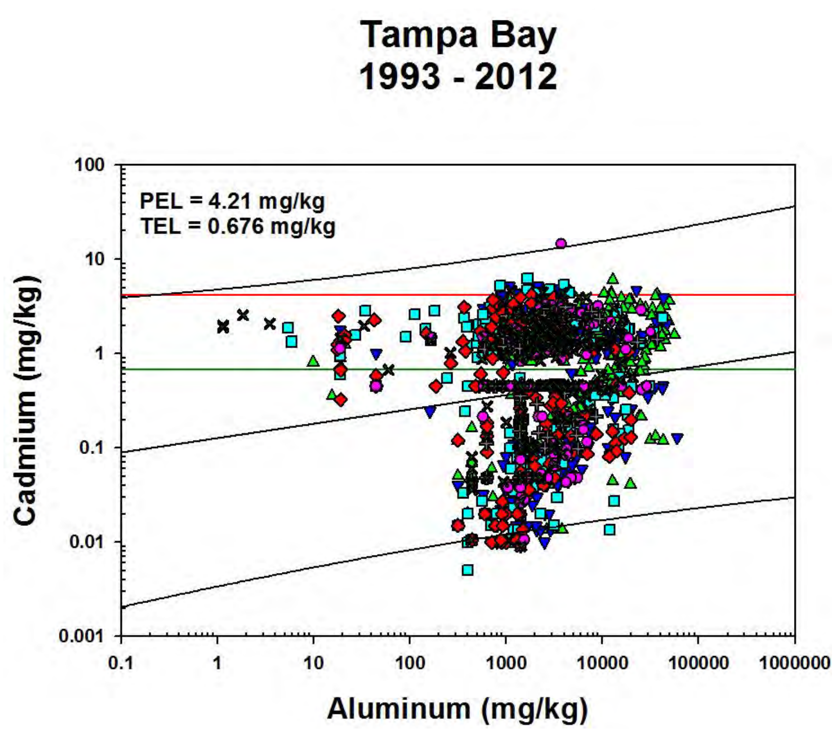


Figure 34. **Tampa Bay Cd:Al ratio with 95% prediction intervals (solid lines). Dashed lines represent PEL (upper) and TEL (lower) values.**

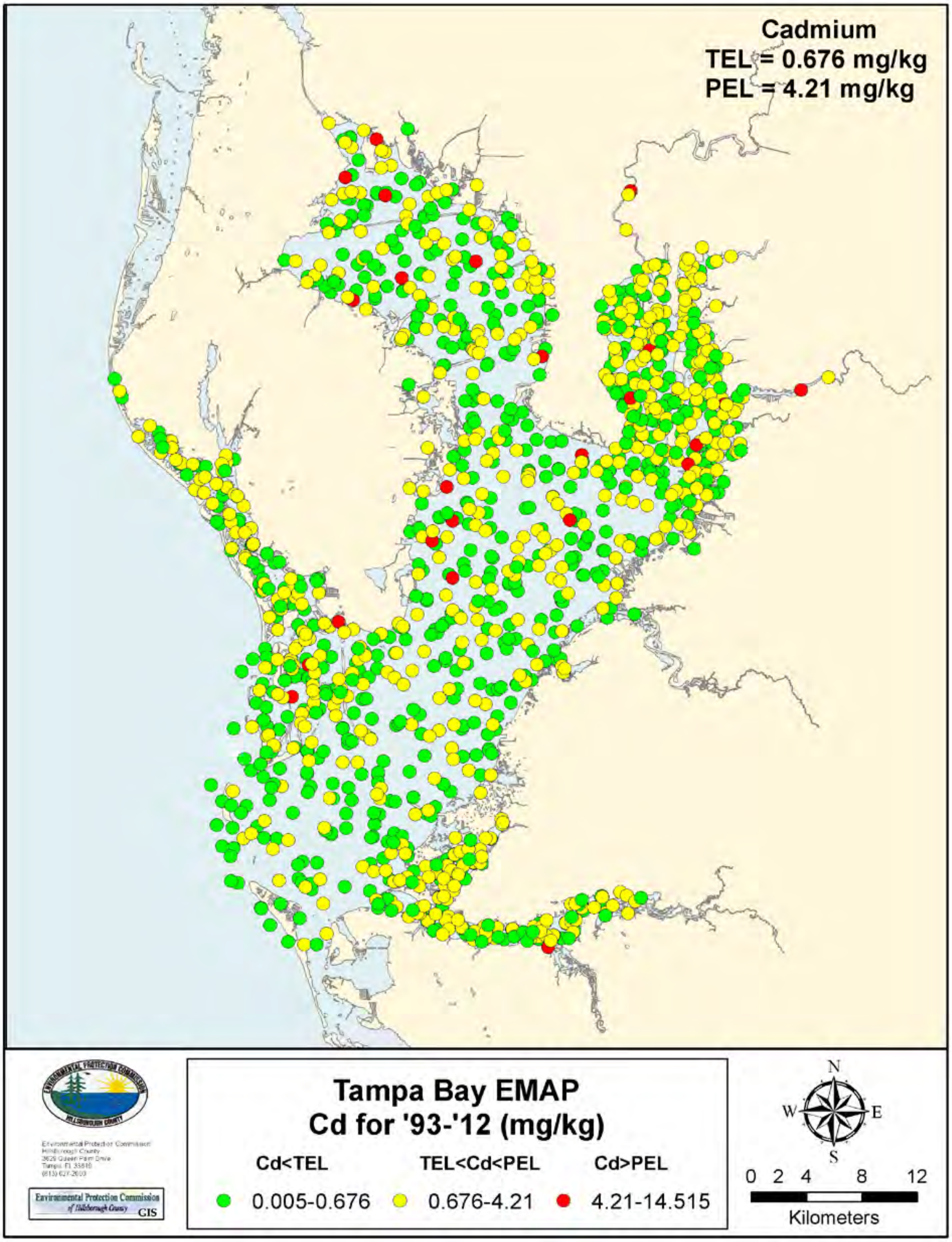


Figure 35. **Distribution of cadmium in Tampa Bay 1993-2012.**

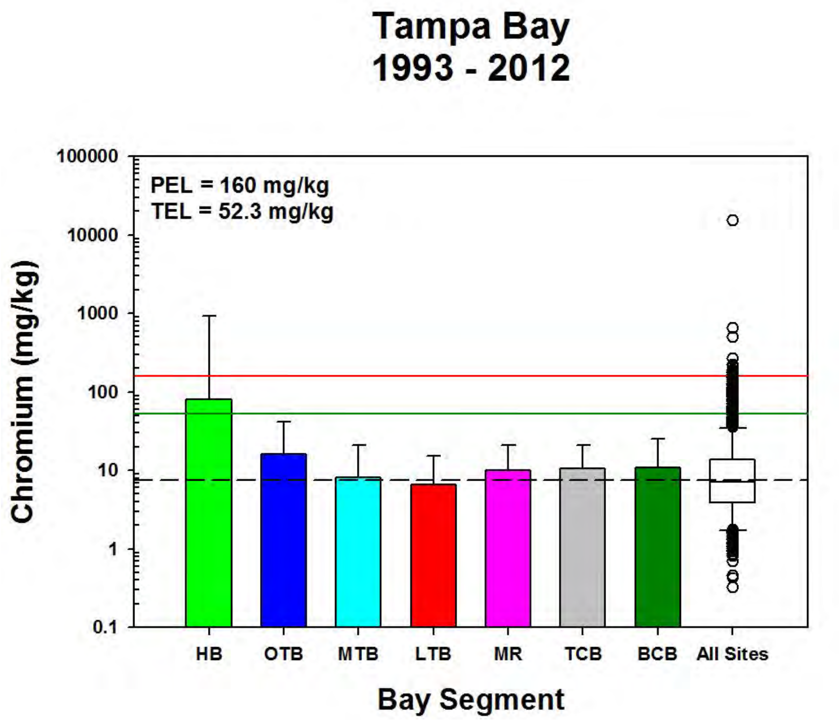


Figure 36. **Mean sediment chromium concentrations by bay segment. Error bars = 1 standard deviation, Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.**

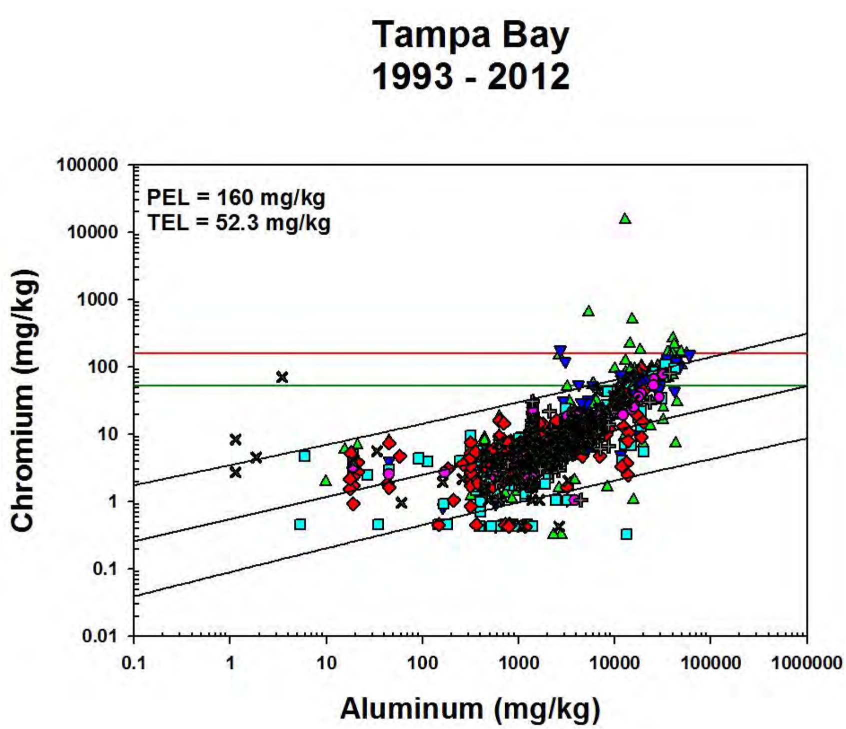


Figure 37. **Tampa Bay Cr:Al ratio with 95% prediction intervals (solid lines). Solid lines represent PEL (upper; red) and TEL (lower; green) values.**

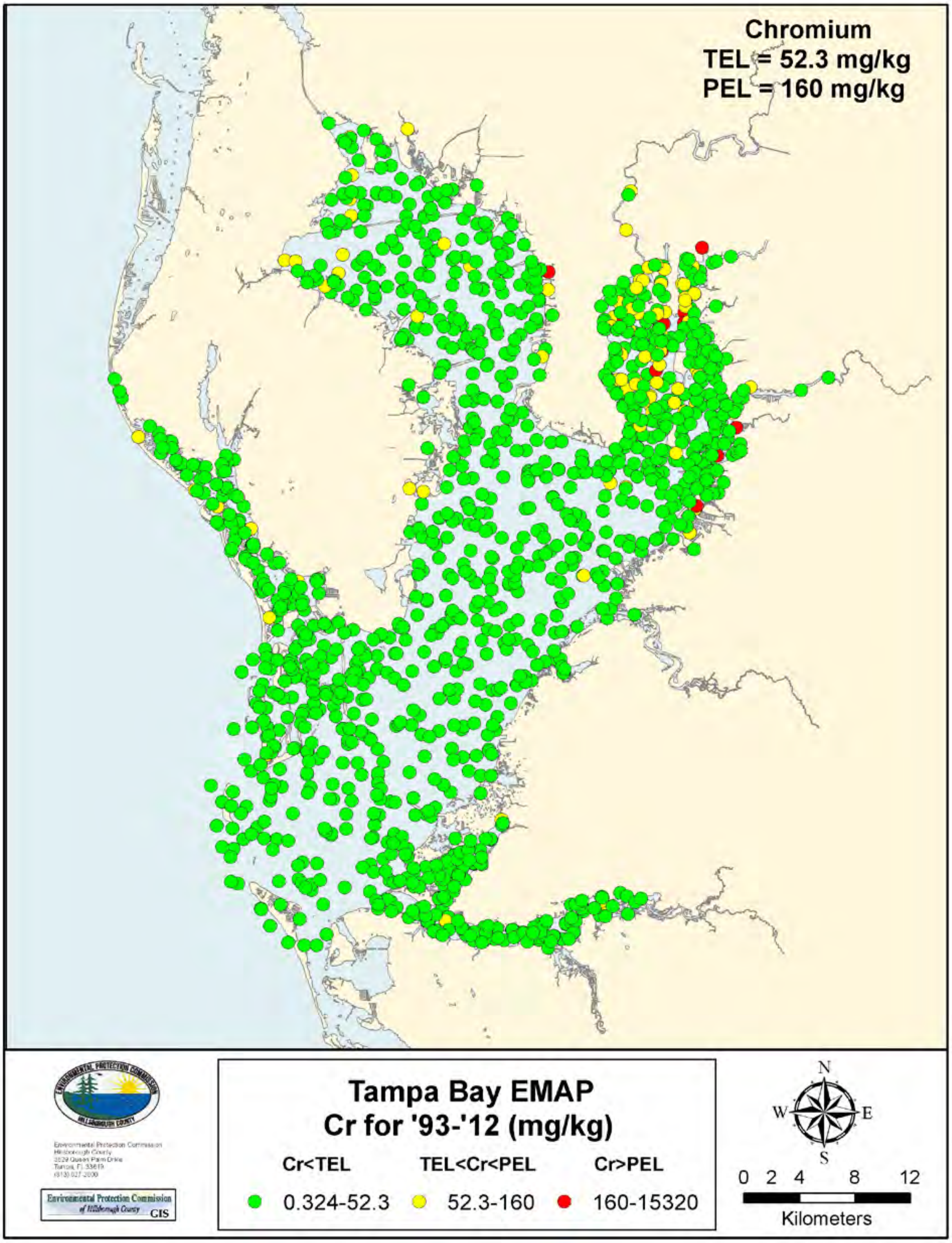


Figure 38. Distribution of chromium in Tampa Bay 1993-2012.

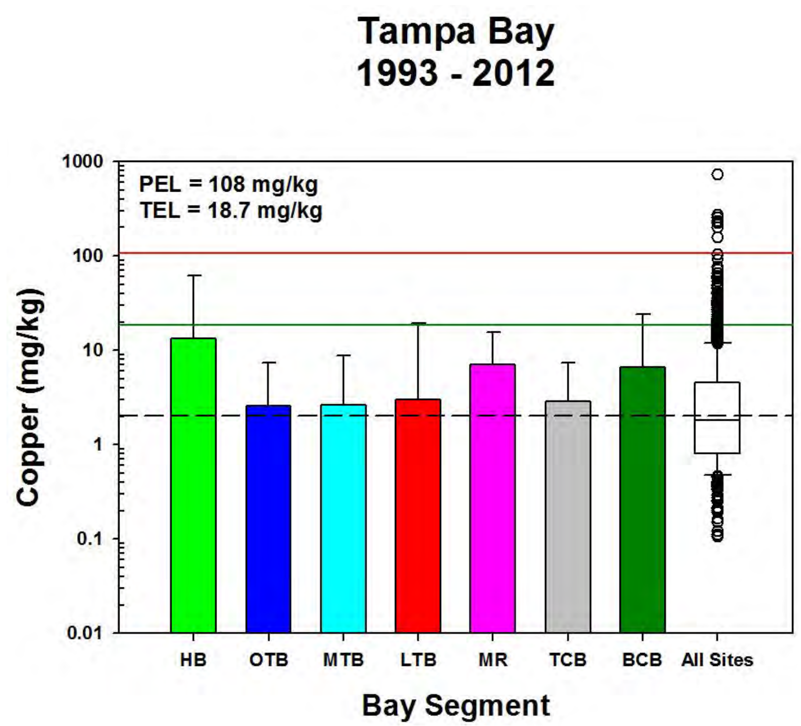


Figure 39. **Mean sediment copper concentrations by bay segment. Error bars = 1 standard deviation, Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.**

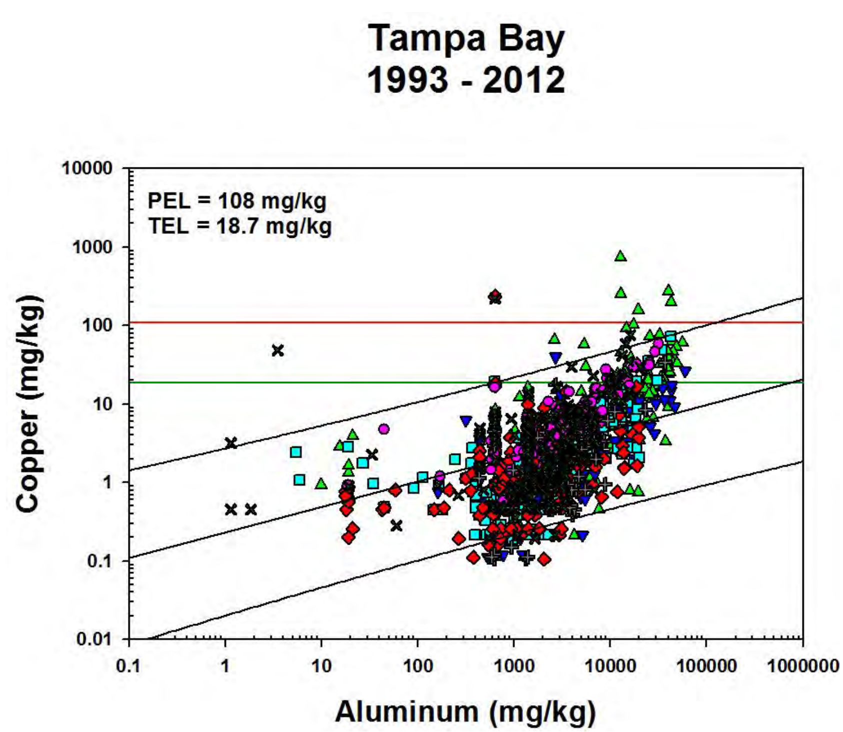


Figure 40. **Tampa Bay Cu:Al ratio with 95% prediction intervals (solid lines). Solid lines represent PEL (upper; red) and TEL (lower; green) values.**

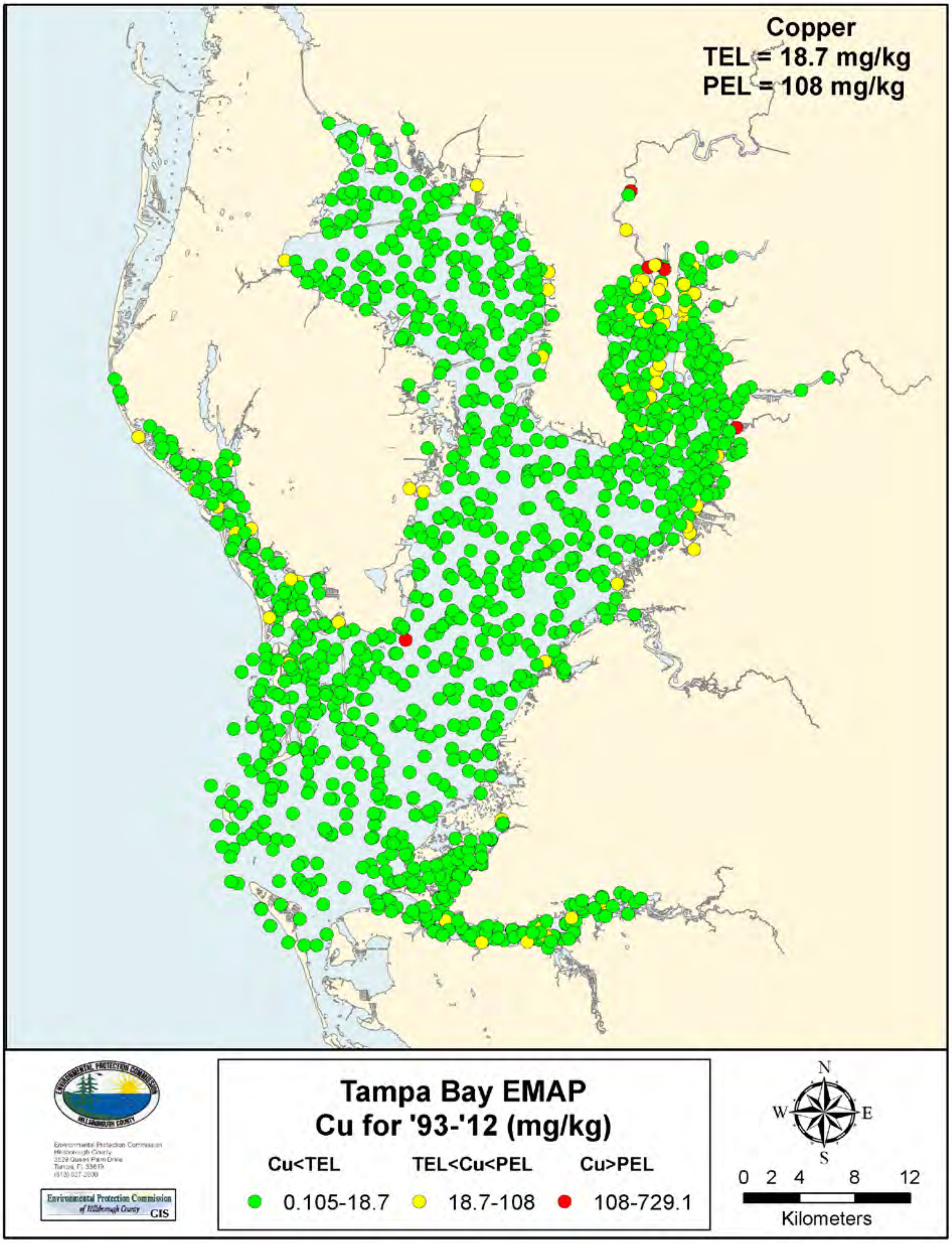


Figure 41. **Distribution of copper in Tampa Bay 1993-2012.**

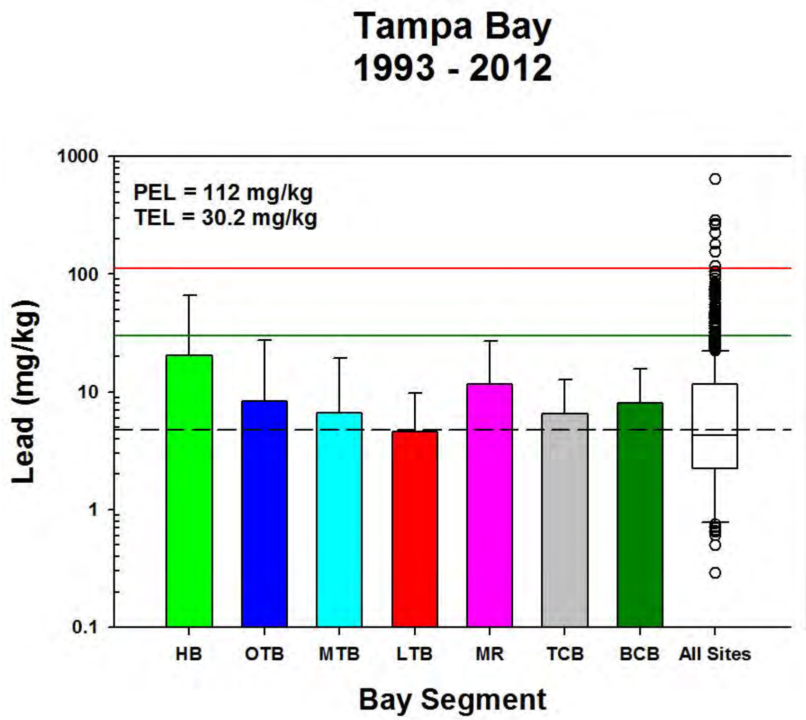


Figure 42. **Mean sediment lead concentrations by bay segment. Error bars = 1 standard deviation, Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.**

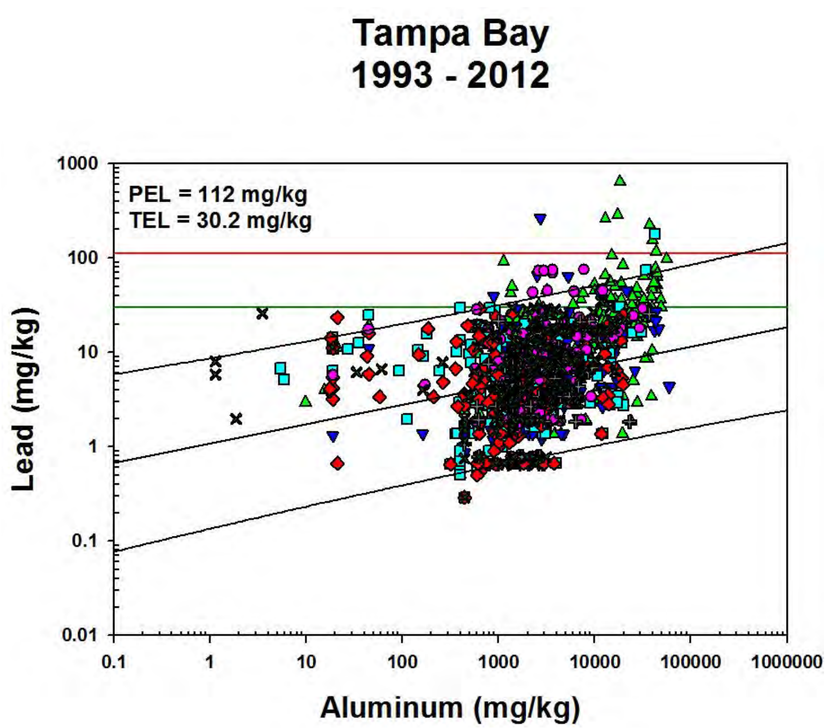


Figure 43. **Tampa Bay Pb:Al ratio with 95% prediction intervals (solid lines). Solid lines represent PEL (upper; red) and TEL (lower; green) values.**

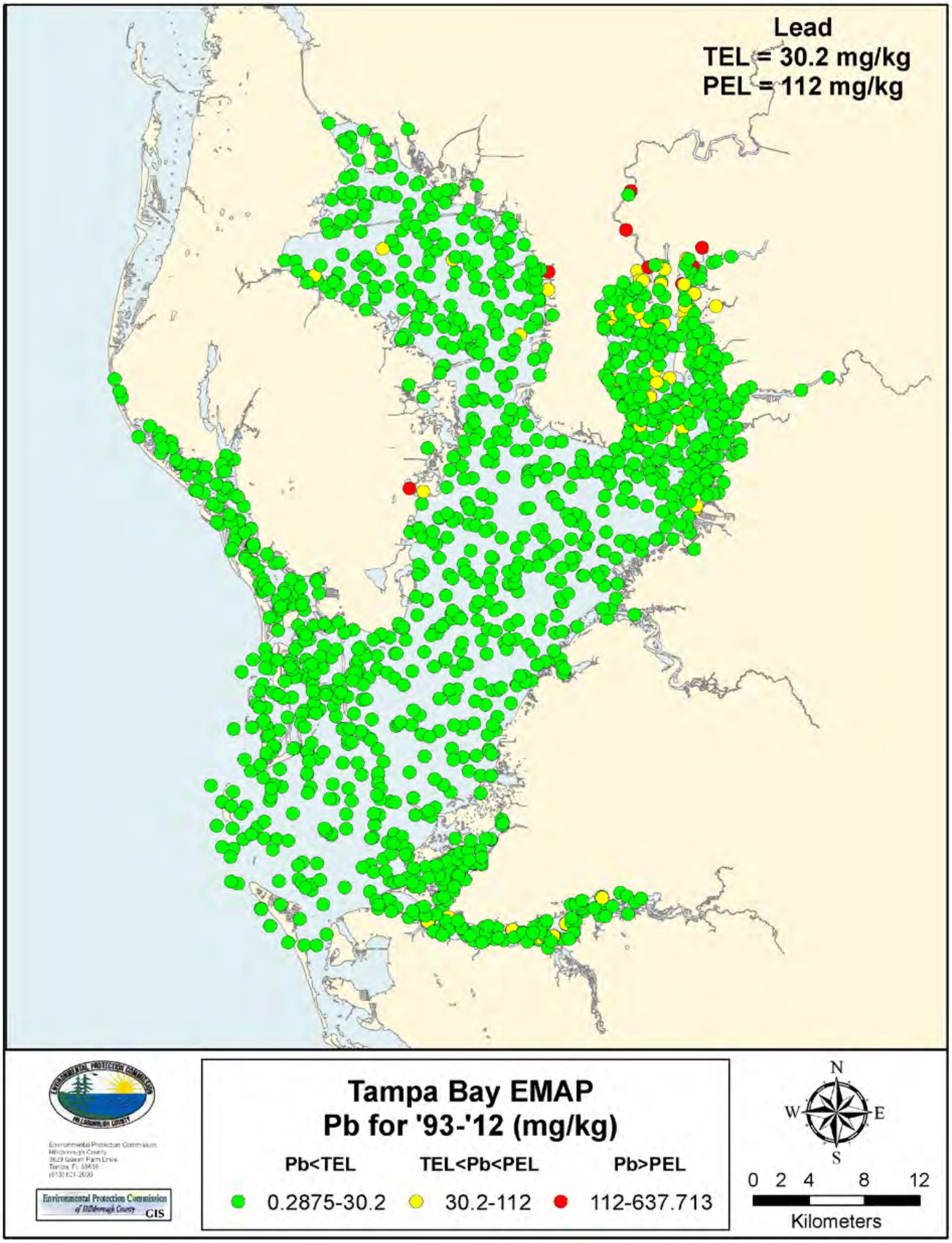


Figure 44. Distribution of lead in Tampa Bay 1993-2012.

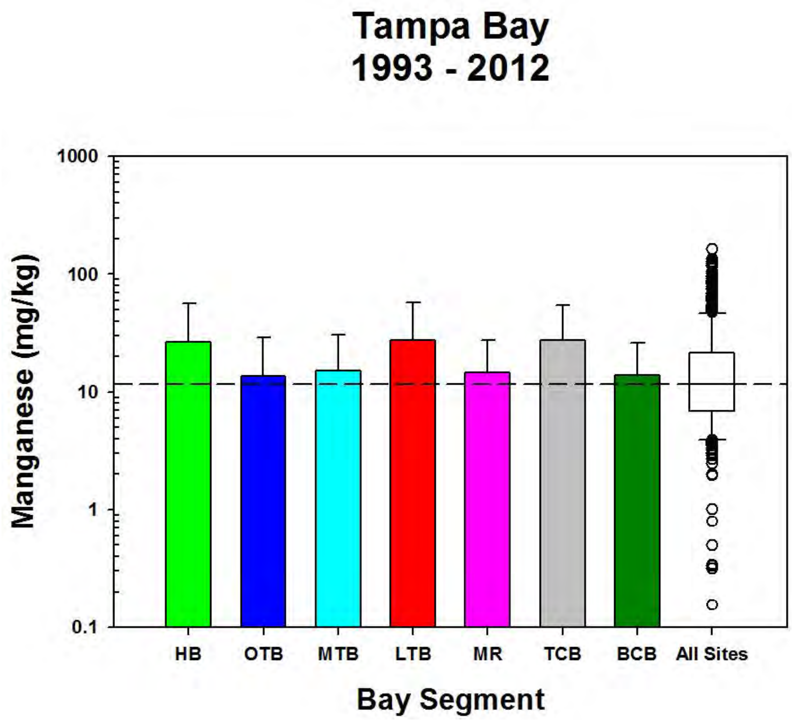


Figure 45. **Mean sediment manganese concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean.**

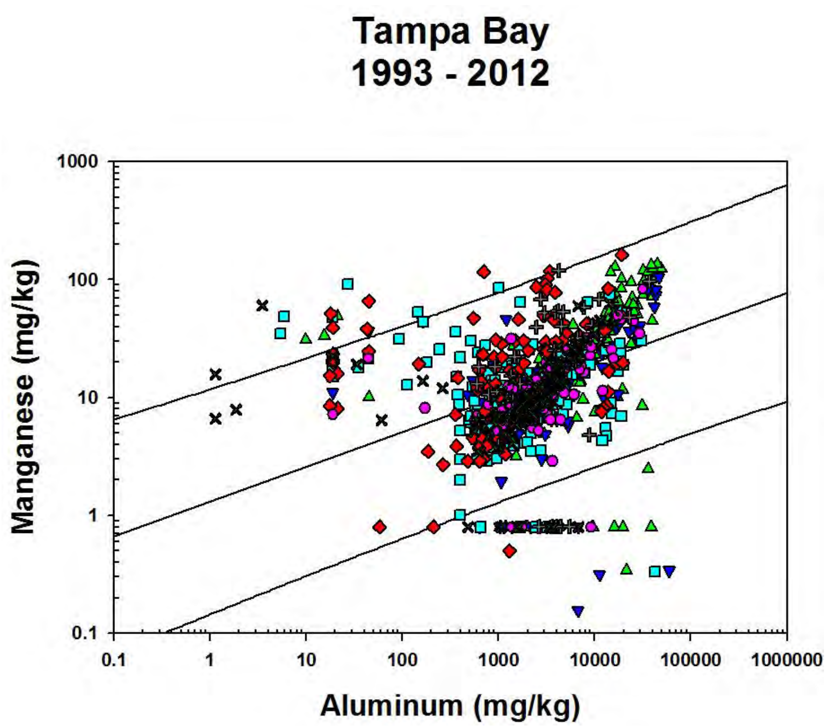


Figure 46. **Tampa Bay Mn:Al ratio with 95% prediction intervals (solid lines).**

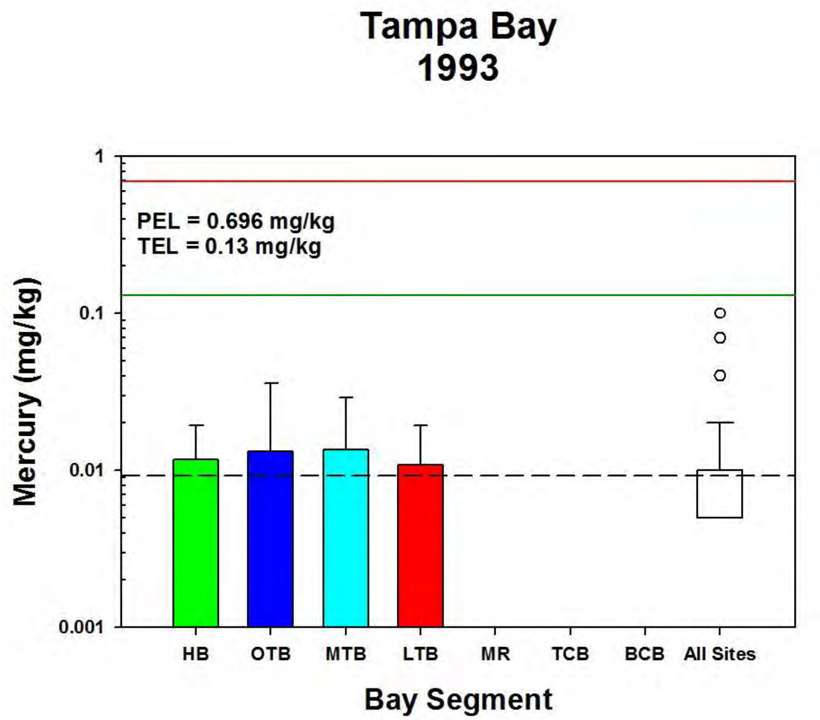


Figure 47. **Mean sediment mercury concentrations by bay segment. Error bars = 1 standard deviation, Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.**

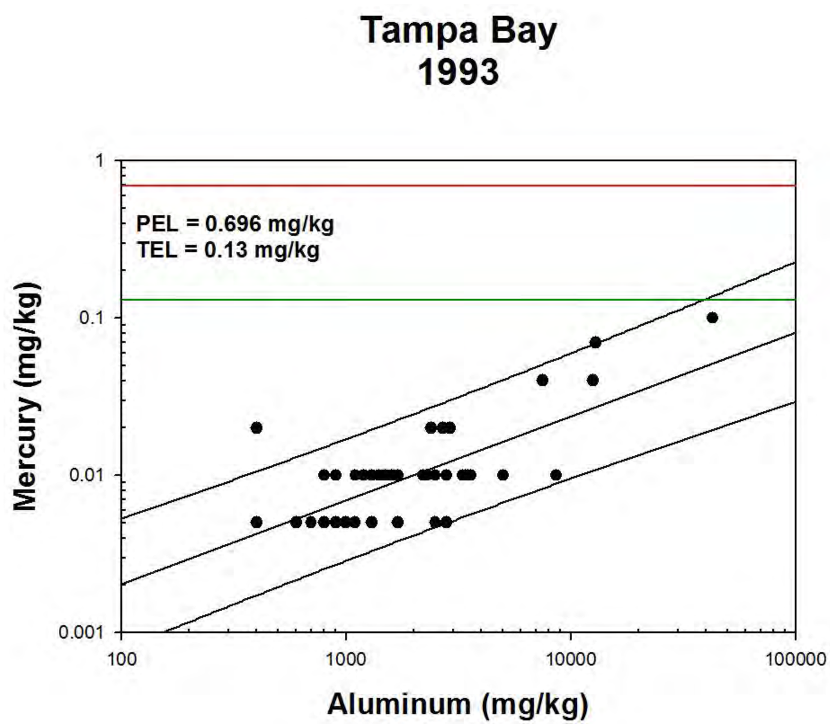


Figure 48. **Tampa Bay Hg:Al ratio with 95% prediction intervals (solid lines). Solid lines represent PEL (upper; red) and TEL (lower; green) values.**

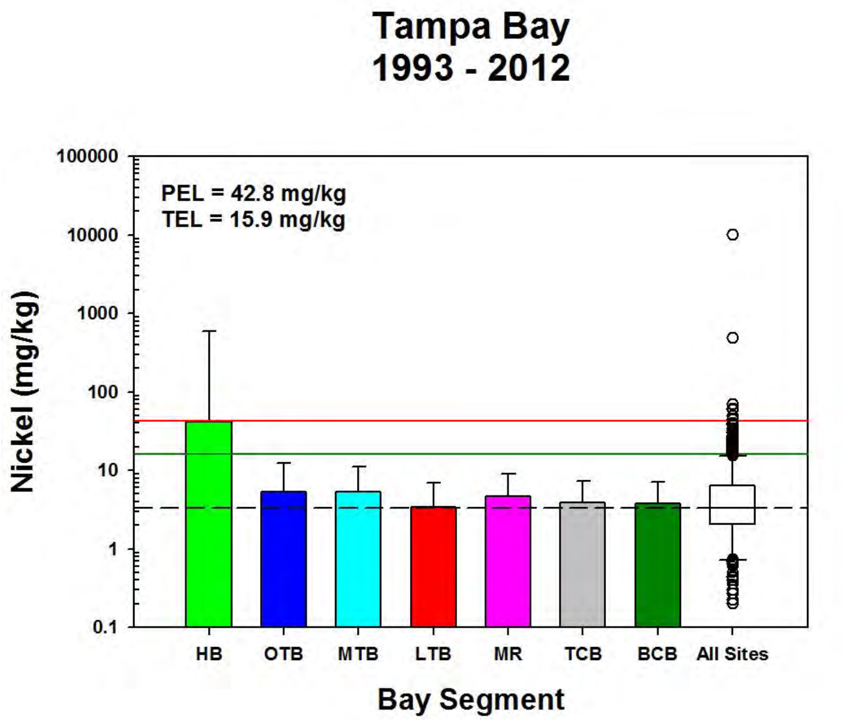


Figure 49. **Mean sediment concentrations of nickel by bay segment. Error bars = 1 standard deviation, Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.**

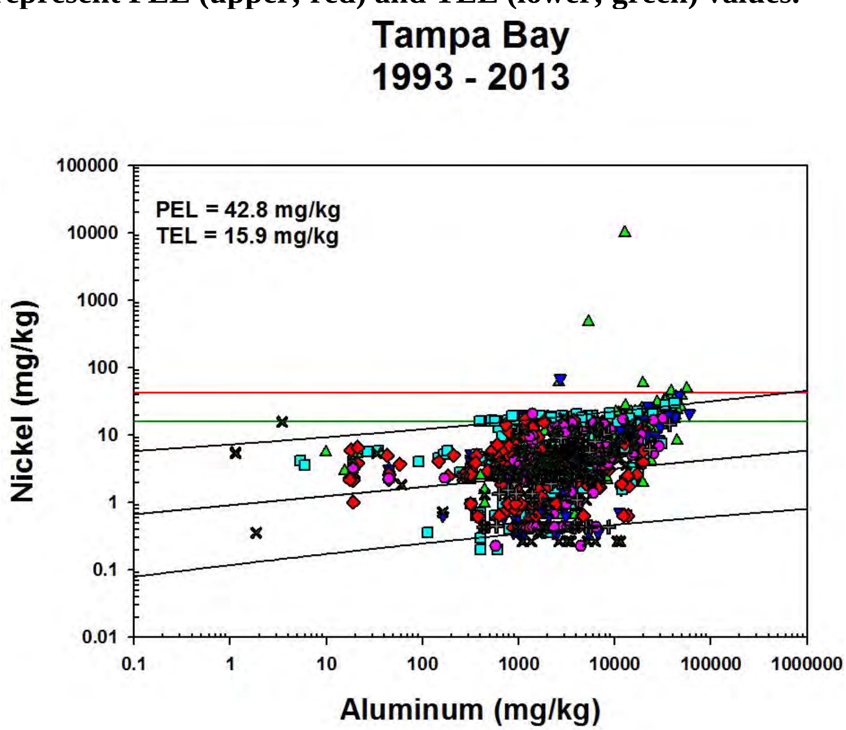


Figure 50. **Tampa Bay Ni:Al ratio with 95% prediction intervals (solid lines). Solid lines represent PEL (upper; red) and TEL (lower; green) values.**

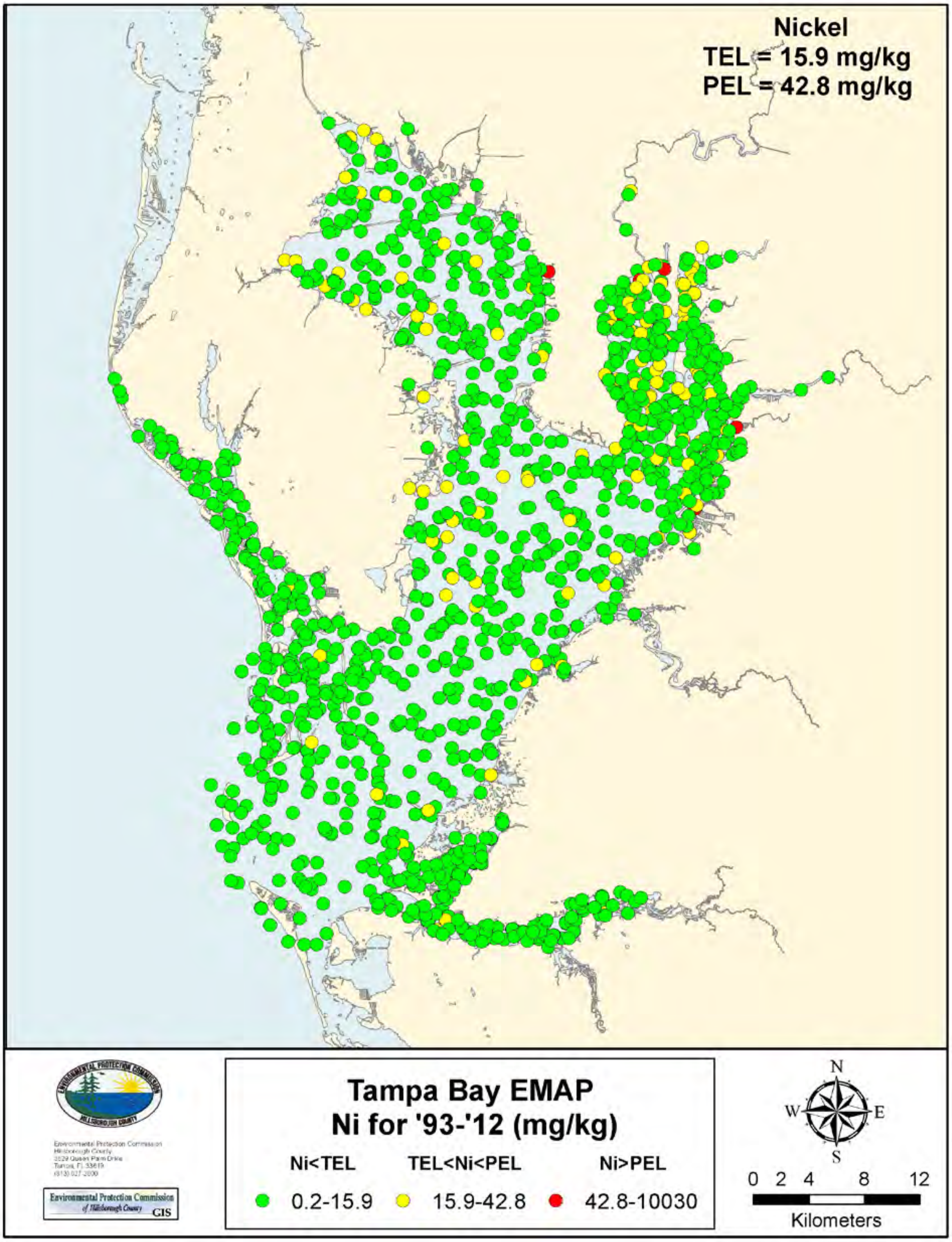


Figure 51. Distribution of nickel in Tampa Bay 1993-2012.

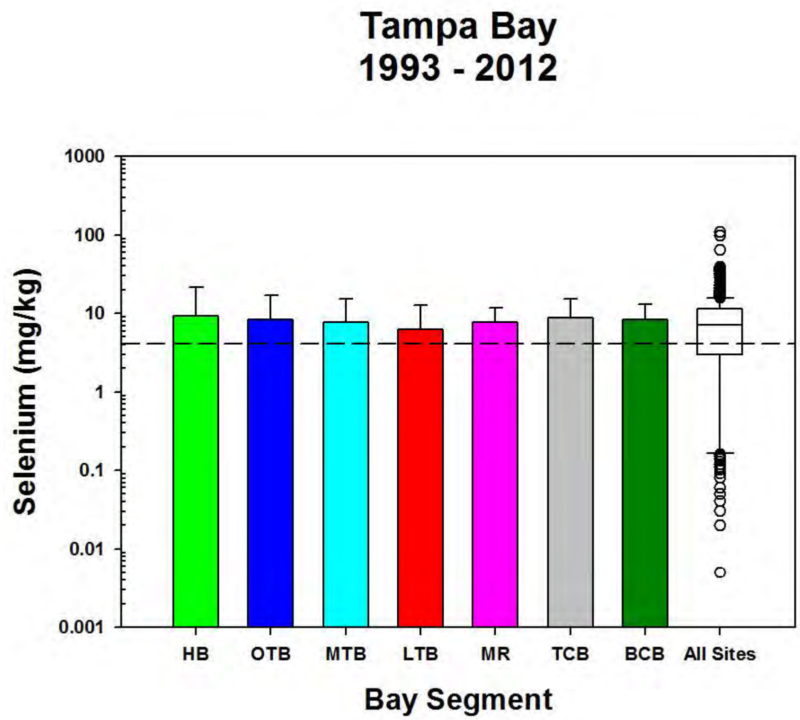


Figure 52. **Mean sediment selenium concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean.**

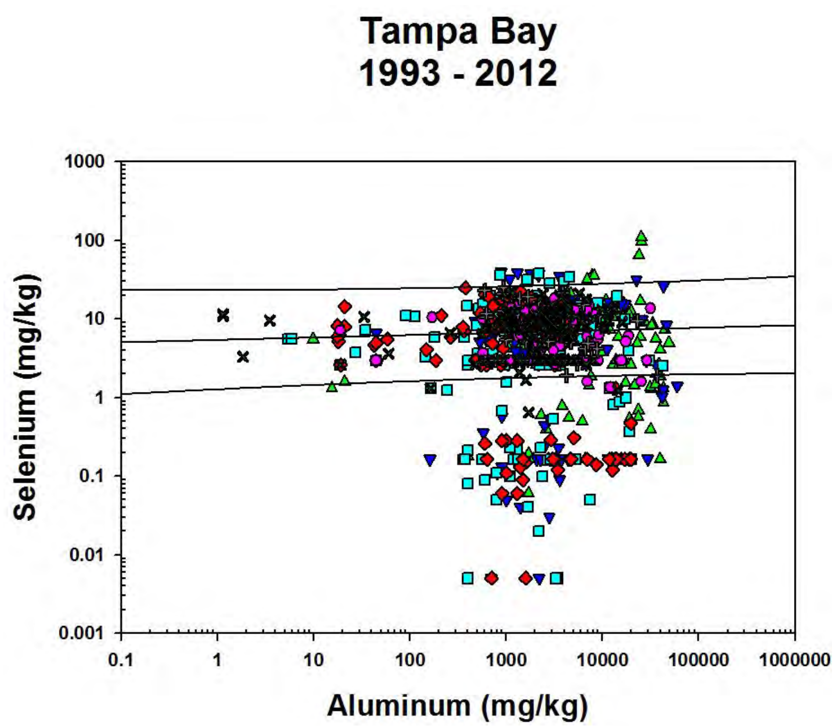


Figure 53. **Tampa Bay Se:Al ratio with 95% prediction intervals (solid lines).**

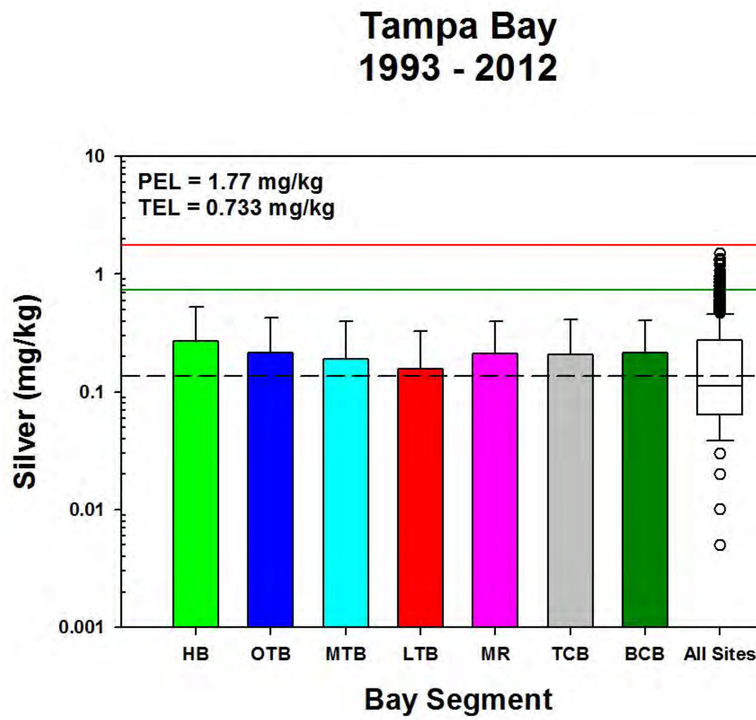


Figure 54. Mean sediment silver concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.

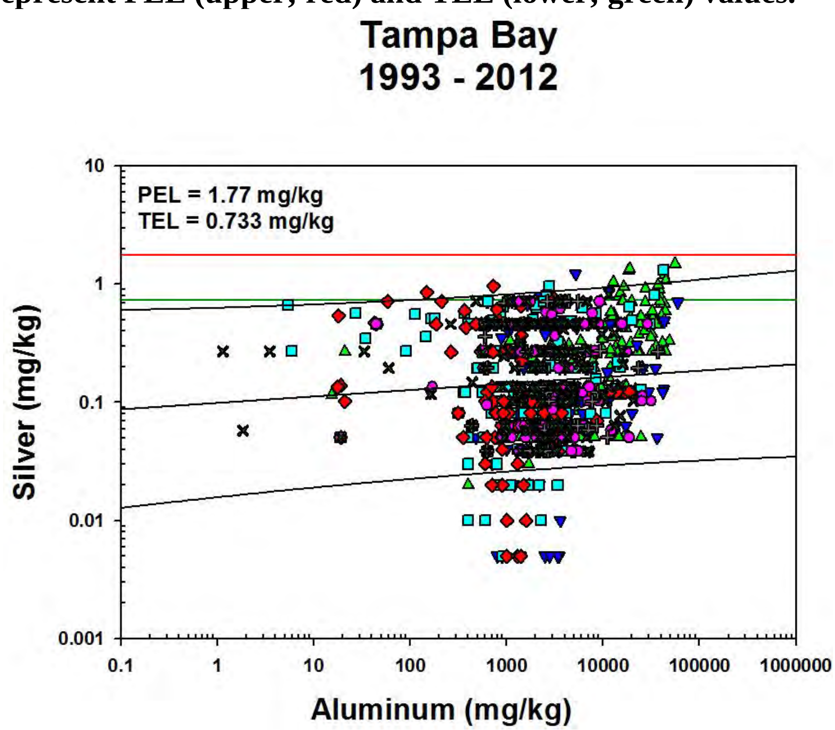


Figure 55. Tampa Bay Ag:Al ratio with 95% prediction intervals (solid lines). Solid lines represent PEL (upper; red) and TEL (lower; green) values.

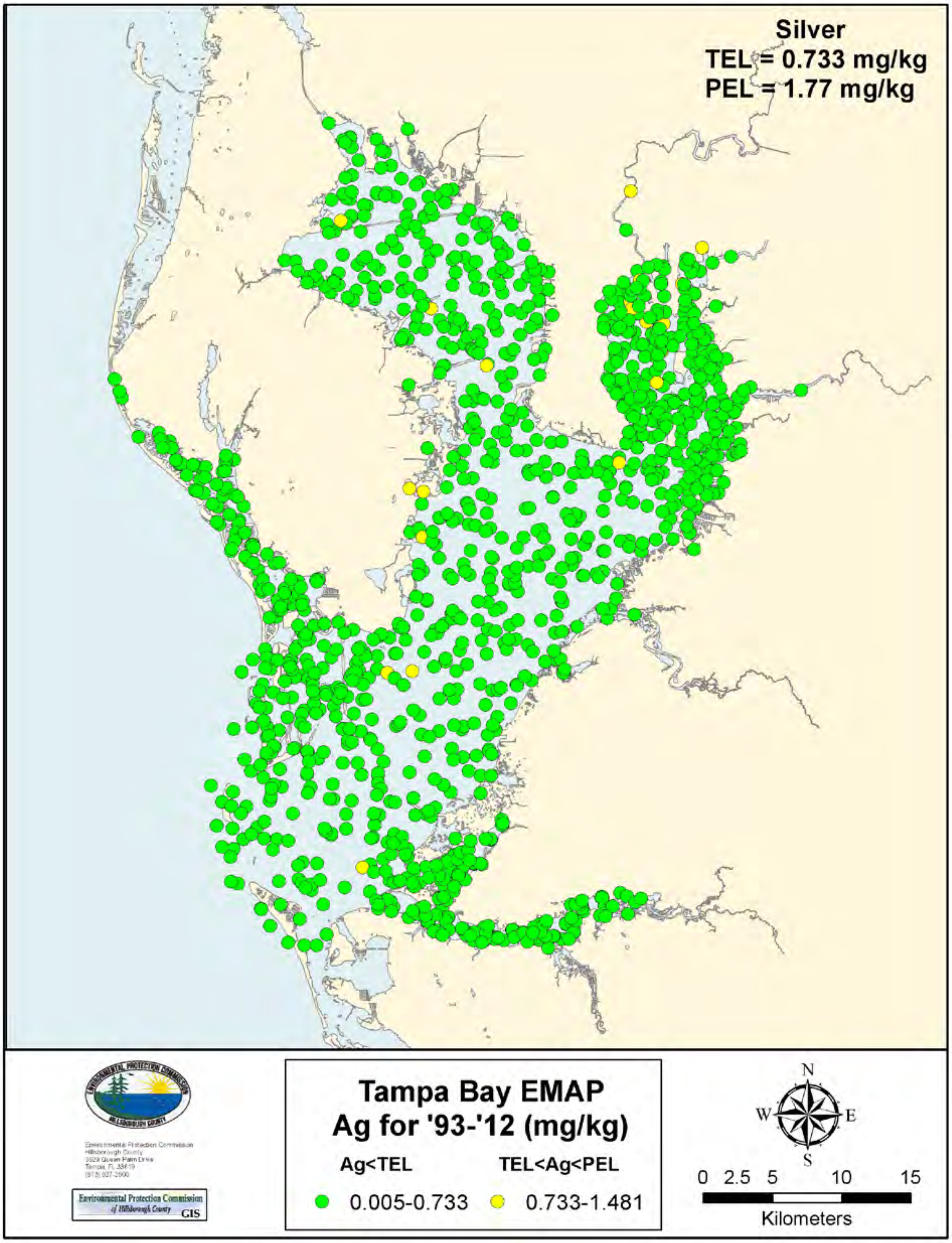


Figure 56. Spatial distribution of silver in Tampa Bay 1993-2012.

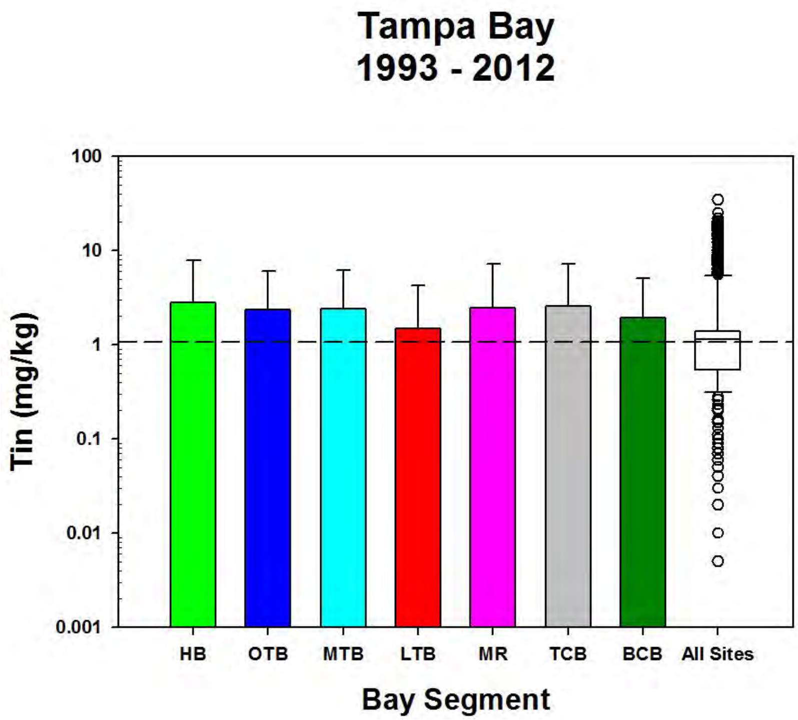


Figure 57. **Mean sediment tin concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents bay-wide mean.**

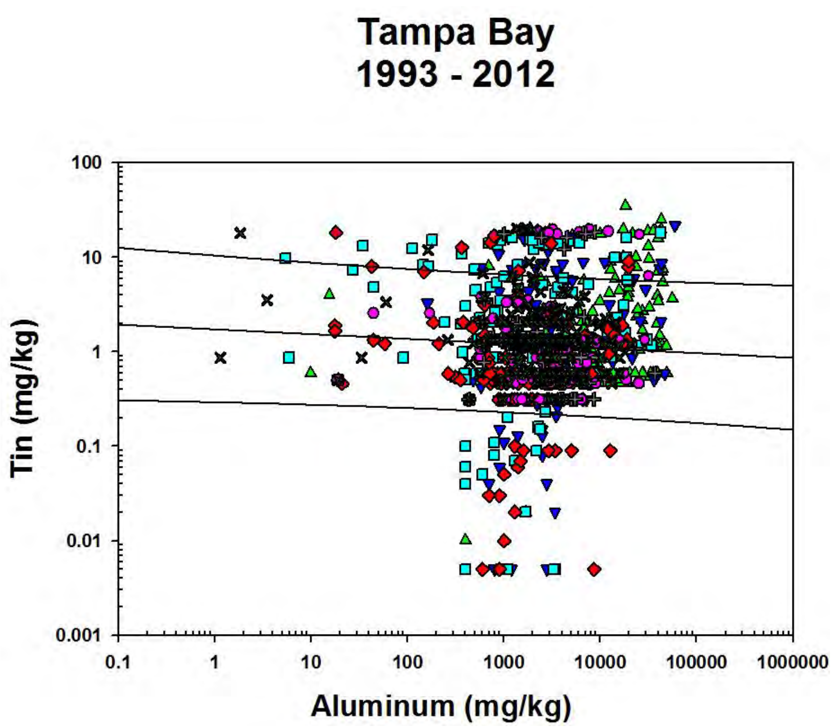


Figure 58. **Tampa Bay Sn:Al ratio with 95% prediction intervals (solid lines).**

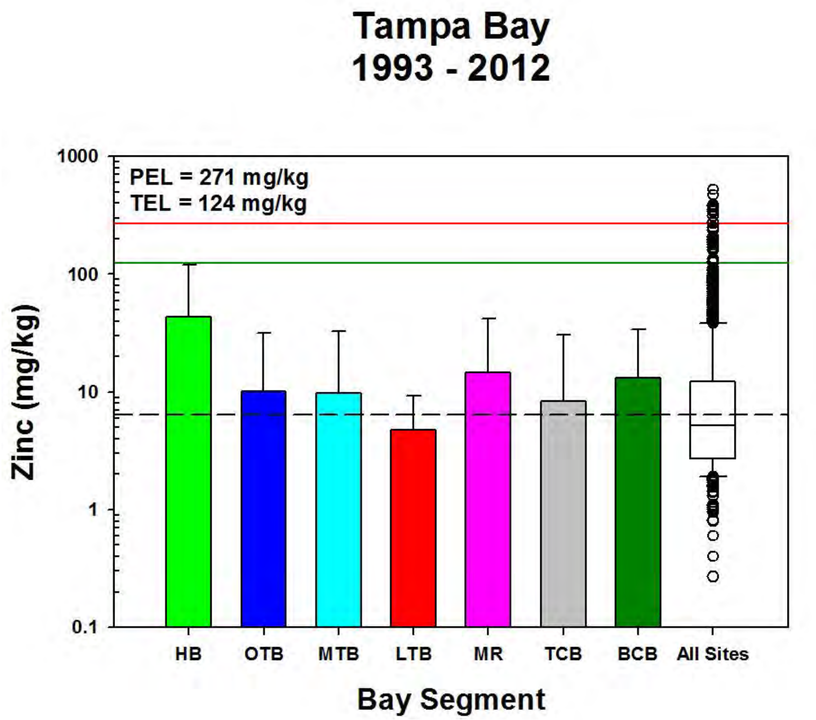


Figure 59. **Mean sediment zinc concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.**

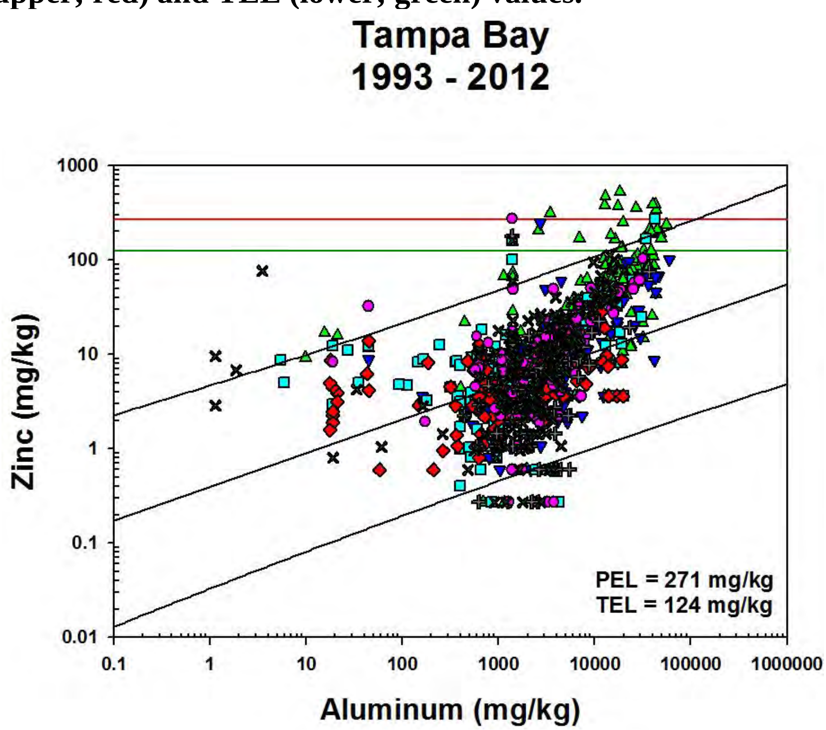


Figure 60. **Tampa Bay Zn:Al ratio with 95% prediction intervals (solid lines). Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.**

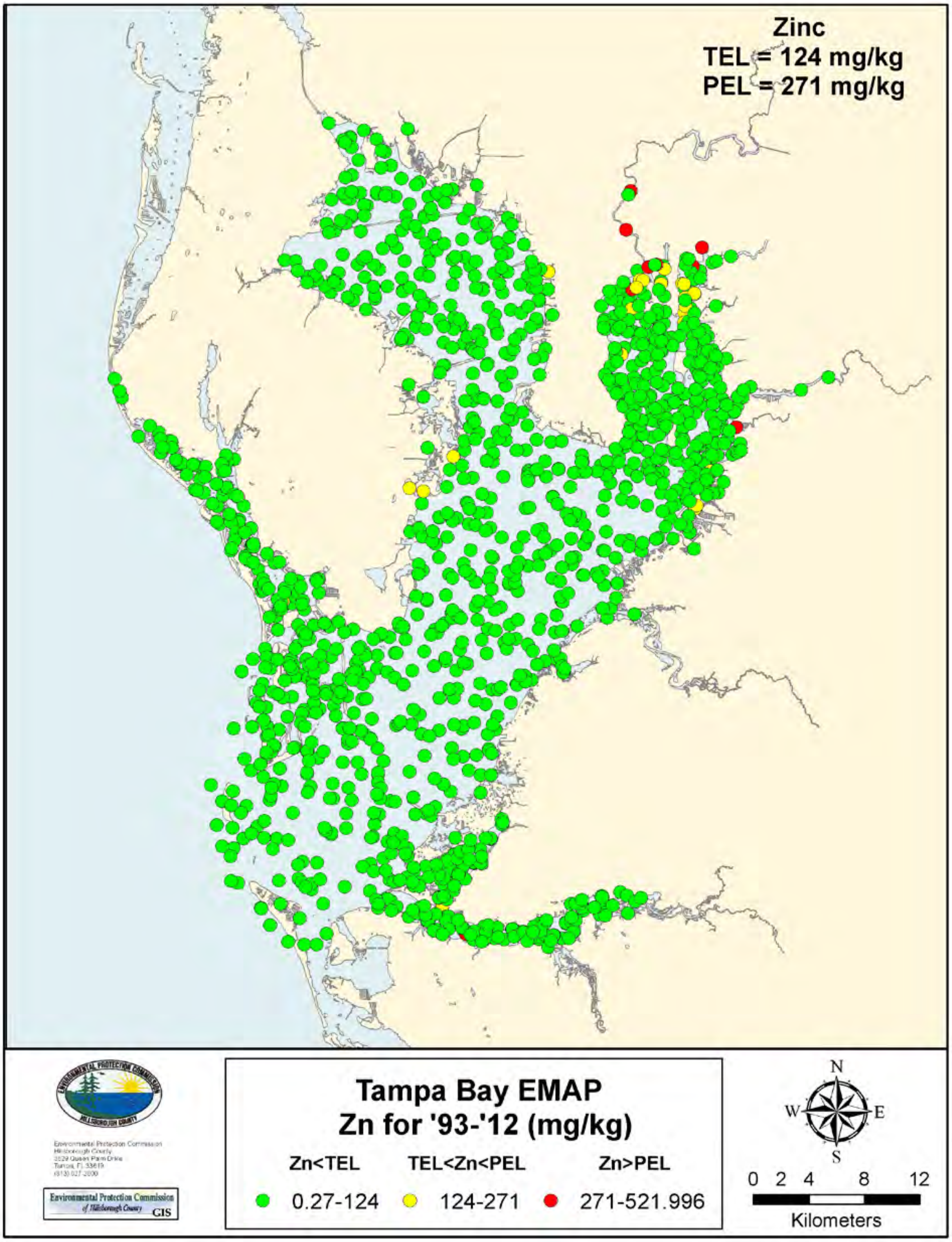


Figure 61. Distribution of Zinc in Tampa Bay 1993-2012.

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) in animals (Long et al. 1994; Kennish 1998).

Natural sources of PAHs include the decomposition or combustion of organic matter and petroleum seeps (Long et al. 1994, Kennish 1998). 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). Coal-tar based seal coats on parking lots and driveways have been found to be a source of PAHs in stormwater runoff (Mahler et al., 2010; Scoggins et al., 2007; Van Metre and Mahler, 2010; Watts et al., 2010; Witter et al., 2014; Yang et al., 2010). Stormwater runoff from roads and urban areas is a major route of introduction for PAHs in estuarine systems with highest PAH concentrations in water and sediments 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 fuel via automobile emissions (Grabe and Barron 2002, 2004) which enters Tampa Bay through stormwater runoff (McConnell and Brink 1997). Sediment chemistry samples from Tampa Bay 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).

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

Low Molecular Weight PAHs

Summary statistics and percentage of samples exceeding toxicity cut-offs for low molecular weight PAHs (LMW-PAHs) are presented in Table 11. Results for individual LMW-PAHs are summarized below.

Acenaphthene ($C_{12}H_{10}$; MW=154.22): Acenaphthene consists of a two-ringed naphthalene molecule bound with an ethylene molecule (Table 11). Acenaphthene is used as an insecticide and fungicide, in the production of dyes, pharmaceuticals and plastics (ATSDR, 1995a). The baywide mean was 4.15 µg/kg with a maximum concentration of 129 µg/kg (Table 11). Acenaphthene exceeded the TEL concentrations at 4.84% of the sites and the PEL at 0.19% of the sites (Table 11) with higher concentrations being found in Hillsborough Bay and Boca Ciega

Bay (Figure 62). The sites with the highest levels of acenaphthene were in McKay Bay and near the Port of Tampa (Figure 64).

Acenaphthylene ($C_{12}H_8$; MW = 152.19): Acenaphthylene is similar in structure to acenaphthene but with a double bond in the ethylene molecule (Table 11). It is a component of petroleum products and coal tar and is released into the environment through the combustion of petroleum and wood (ATSDR, 1995a). Long et al. (1994) found a significant correlation between acenaphthylene concentration and amphipod survival in sediment toxicity tests from Tampa Bay sites. Acenaphthylene sediment concentrations in Tampa Bay ranged from below its MDL to 414 µg/kg with a mean of 4.05 µg/kg (Table 11). Acenaphthylene exceeded the TEL at 4.21% of the sites and the PEL at 0.21% of the sites (Table 11). There was no significant difference between the bay segments (KW; p=0.086). Mean concentrations were highest in Hillsborough Bay (Figure 63) with highest levels of acenaphthylene in McKay Bay and the East Bay portion of the Port of Tampa (Figure 65).

Anthracene ($C_{14}H_{10}$; MW = 178.23): Anthracene is a 3-ring PAH (Table 11). It is used commercially in the production of dyes and synthetic fibers, in wood preservatives and in the synthesis of some chemotherapeutics (ATSDR, 1995a). Anthracene can be taken up by organisms and has been found to accumulate in the gill tissue of freshwater mussels (Cheney et al., 2009). Feeding and growth rate in fish was reduced with anthracene exposure (Palanikumar et al., 2013). Anthracene in Tampa Bay sediments was above its TEL at 1.38% of the sites but there were no recorded PEL exceedences (Table 11). There was a significant difference in mean anthracene concentrations among bay segments (ANOVA; p<0.001) with highest levels occurring in Hillsborough Bay (Figure 66) particularly in McKay Bay and in the vicinity of the Port of Tampa (Figure 68).

Fluorene ($C_{13}H_{10}$; MW = 166.22): Fluorene is a 3-ring PAH (Table 11). It is a component of diesel emissions and coal tar, and an intermediate compound in many chemical processes and in the manufacture of dyes (ATSDR, 1995a). Fluorene exceeded its TEL at 1.62% of the sites, but there were no recorded PEL exceedences (Table 11). There was a significant difference among bay segments (KW; p<0.001) with lower fluorene levels in Middle and Lower Tampa Bay relative to the other segments (Figure 67). Sites with fluorene concentrations above the TEL threshold were primarily in Hillsborough Bay around the Port of Tampa, McKay Bay and Hillsborough River (Figure 69).

Naphthalene ($C_{10}H_8$; MW = 128.17): Naphthalene is a 2-benzene ring PAH (Table 11) and a constituent of petroleum and coal tar (ATSDR, 2005d). It is used in the production of phthalic anhydride which is utilized in phthalic plasticizers, resins, dyes, pharmaceuticals and insect repellents (ATSDR, 2005d). Naphthalene crystals are also used as a moth repellent (moth balls) and as a deodorizer (ATSDR, 2005d). Human exposure to high doses of naphthalene can cause lysis of red blood cells (hemolytic anemia) and cataracts (ATSDR, 2005d). High concentrations are lethal and lower concentrations can reduce feeding rates in marine copepods which affect egg production (Calbet et al., 2007). Naphthalene uptake in freshwater mussels is incorporated into gill tissues which reduces gill cilia activity (Cheney et al., 2009).

Naphthalene concentrations in Tampa Bay sediments were above the TEL at 1.54% of the sites and no sites exceeded the PEL (Table 11). There was a significant difference among bay segments (KW; $p<0.001$) with mean naphthalene levels being highest in Hillsborough Bay and lowest in Middle Tampa Bay (Figure 70). Most sites with TEL exceedences were located in Hillsborough Bay around the Port of Tampa, McKay Bay and the Hillsborough River (Figure 72).

Phenanthrene ($C_{14}H_{10}$; MW = 178.23): Phenanthrene has the same chemical formula and molecular weight as anthracene but differs in the configuration of its 3-ring chain structure (Table 11). Phenanthrene is used commercially in the manufacture of explosives and in dyes (ATSDR, 1995a). Potential sources to the environment include diesel emissions, coal tar pitch and fly ash from waste incinerators (ATSDR, 1995a). Addition of phenanthrene to estuarine waters has been found to enhance primary productivity in phytoplankton possibly by reducing grazing pressure from zooplankton or by stimulating photosynthetic pathways (Kelly et al., 1999). Blue mussels (*Mytilus edulis*) uptake of phenanthrene was greater with higher concentrations of particulate organic carbon in the water due to adsorption of PAH to food particles and with the increase feeding rate of mussels (Bjork and Gilek, 1996). Phenanthrene has been shown to adsorb onto polyethylene microplastic particles which may serve as a transport vector in estuarine systems (Bakir et al., 2014). A high concentration of phenanthene in sediments is toxic to oligochaetes and copepods while lower concentrations can reduce reproduction success in benthic organisms (Lotufo and Fleeger, 1996; Lotufo and Fleeger, 1997).

Phenanthrene concentrations in Tampa Bay sediment were above the TEL at 1.78% of the sites and exceeded the PEL at 0.32% of the sites (Table 11). Concentrations were highest in Hillsborough Bay and higher in the Manatee River and Boca Ciega Bay relative to Middle and Lower Tampa Bay (Figure 71; KW, $p <0.01$). The sites above the PEL were located in Hillsborough Bay in the vicinity of the Port of Tampa, Hillsborough River and McKay Bay (Figure 73).

Total LMW-PAHs: The total Low Molecular Weight PAH parameter is calculated from the sum of the six individual low molecular weight PAHs discussed above. The total LMW PAH concentrations in Tampa Bay sediments were above the TEL at 1.13 % of the sites and exceeded the PEL at 0.08% (Table 11). Hillsborough Bay had a higher mean concentration than the other bay segments (ANOVA; $p< 0.001$) with high concentration levels in the Manatee River and Boca Ciega Bay (Figure 74). The sites with the highest concentrations of LMW PAHs were around the Port of Tampa and the single site exceeding the PEL was in McKay Bay (Figure 75).

High Molecular Weight PAHs

Summary statistics and percentage of samples exceeding toxicity cut-offs for High molecular weight PAHs (HMW-PAHs) are presented in Table 12. Results for individual LMW-PAHs are summarized below.

Benzo (a) anthracene ($C_{18}H_{12}$; MW=228.29): Benzo (a) anthracene is composed of a four benzene ring chain (Table 12). It has no commercial uses but is a component of many hydrocarbon mixtures and is classified as a probable carcinogen (ATSDR, 1995a). Benzo (a) anthracene in estuarine sediments can bioaccumulate in polychaetes (Ferguson and Chandler, 1998).

Benzo (a) anthracene concentrations in Tampa Bay sediments had a mean value of 21.75 µg/kg with a maximum of 1,564 µg/kg (Table 12). The TEL was exceeded at 3.72% of the sites and concentrations were above the PEL at 0.49% of the sites (Table 13). Benzo (a) anthracene levels were highest in Hillsborough Bay and relatively high in the Manatee River and Boca Ciega Bay (Figure 76; KW; $p < 0.001$). The maximum concentration was recorded in McKay Bay (Figure 78). Sites above the PEL were found in the Hillsborough River, around the Port of Tampa, and a single location in Boca Ciega Bay (Figure 78).

Benzo (a) pyrene ($C_{20}H_{12}$; MW=252.31): Beno (a) pyrene has a 5 benzene ring structure (Table 12). It is not produced commercially but is a product of incomplete combustion (ATSDR, 1995a). Its primary source to the environment is through the atmospheric deposition of particles (ATSDR, 1995a). Benzo (a) pyrene is a known carcinogen and has been found to cause birth defects chromosome damage and sterility in mice (ATSDR, 1995a). High concentrations of benzo(a) pyrene in an algae fed to oysters reduced reproductive output and larval survival (Eun Jung et al., 2007). Exposure to sub-lethal doses caused reduced feeding and growth in fish (Palanikumar et al., 2013). Bioaccumulation of benzo(a) pyrene by infaunal invertebrates is higher in deposit feeders which directly ingest contaminated sediments (Kane Driscoll and McElroy, 1996; Leppanen and Kukkonen, 2000). High total organic carbon content and longer contact time in the sediments can bind benzo(a) pyrene which reduces its bioavailability to infaunal invertebrates (Kukkonen and Landrum, 1998; Leppanen and Kukkonen, 2000).

Benzo (a) pyrene concentrations in Tampa Bay sediments had a mean value of 28.82 µg/kg with a maximum value of over 2100 µg/kg (Table 12). Benzo(a) pyrene exceeded its TEL at 4.05% of the sites and was above the PEL at 0.57% of the sites (Table 12). Highest concentrations were in Hillsborough Bay, the Manatee River and Boca Ciega Bay (Figure77), while Middle and Lower Tampa Bay had significantly lower concentrations relative to the other bay segments (KW; $p<0.001$). The highest concentrations of benzo(a) pyrene were in the Hillsborough River, McKay Bay and other locations within Hillsborough Bay (Figure 79). Other sites that exceeded the PEL were found in Boca Ciega Bay, the Manatee River and in a residential canal off of Riviera Bay in Middle Tampa Bay (Figure 79).

Chrysene (C18H12; MW= 228.29): Chrysene has the same molecular weight and formula as benzo (a) anthracene but a different configuration of its 4-benzene ring structure (Table 12). Chrysene is carcinogenic and causes skin tumors in mice (ATSDR, 1995a). Chrysene is not produced for commercial purposes, but it is a product of combustion (particulate emissions from waste incinerators and burning of natural gas) and has environmental sources (ATSDR, 1995a).

Chrysene in Tampa Bay sediments had a mean concentration of 26 µg/kg and exceeded its TEL at 3% of the sampling sites and exceeded its PEL at 0.65% of the sites (Table 12). Concentrations were significantly different among bay segments (KW; $p<0.001$) and were higher in Hillsborough Bay, Boca Ciega Bay and the Manatee River (Figure 80). The highest levels of Chrysene were found in the Hillsborough River, McKay Bay and around the Port of Tampa with several other sites exceeding the PEL in Boca Ciega Bay, Manatee River and in one site in Middle Tampa Bay in a residential canal off of Riviera Bay (Figure 82).

Dibenzo (a,h) anthracene ($C_{22}H_{14}$; MW = 278.35): Dibenzo (a,h) anthracene is composed of a chain of 5 benzene rings (Table 12). It is known to be carcinogenic, causing skin tumors in mice and fetal death (fetolethal effects) in pregnant rats (ATSDR, 1995a).

Dibenzo (a,h) anthracene has a lower TEL and PEL than the other high molecular weight PAHs (Table 12). Dibenzo (a,h) anthracene was above its TEL at nearly 13% of the sampling sites and exceeded the PEL at 1.47% of the sites (Table 12). The median sediment concentration was 2.75 µg/kg, while the mean was 11.43 µg/kg (almost twice the TEL of 6.2 µg/kg). Sediment concentrations were significantly different between bay segments (KW; $p<0.001$) with Hillsborough Bay having the highest mean concentration (Figure 81). Old Tampa Bay, Manatee River and Boca Ciega Bay mean values exceeded the TEL (Figure 81). Sites with the highest recorded concentrations were in McKay Bay, the Hillsborough River and in the vicinity of the Port of Tampa in Hillsborough Bay (Figure 83). Other sites where dibenzo(a,h.) anthracene was above the PEL were in Boca Ciega Bay, the Manatee River, two sites in Old Tampa Bay and one in Riviera Bay in Middle Tampa Bay (Figure 83).

Fluoranthene ($C_{16}H_{10}$; MW = 202.25): Fluoranthene has a 4-ring structure with the same molecular weight and formula as pyrene and has the smallest molecular mass of the HMW-PAHs (Table 12). Fluoranthene is used commercially in lining material to protect the interior of steel and iron water pipes and storage tanks (ATSDR, 1995a). Sources of fluoranthene to the environment include the particulate exhaust from diesel combustion, waste incinerators and natural gas appliances (ATSDR, 1995a). It is not considered to be carcinogenic but has been linked to liver, kidney and hematological effects in mice (ATSDR, 1995a). Fluoranthene toxicity to invertebrates (crustaceans) in water and sediments is enhanced by exposure to UV light (Boese et al., 1997; Wilcoxen et al., 2003).

Fluoranthene in Tampa Bay sediments had a mean concentration of 38 µg/kg with a maximum of over 3,000 µg/kg (Table 12). Sediment concentrations were above the TEL at 4.61% of the sites and exceeded the PEL at 0.40% of the sites (Table 12). Fluoranthene was significantly higher in Hillsborough Bay, the Manatee River and Boca Ciega Bay relative to the other bay segments (Figure 84; KW; $p<0.001$). Sites with the highest concentrations were in the Hillsborough River, McKay Bay, in the vicinity of the Port of Tampa, and in Boca Ciega Bay (Figure 86).

Pyrene ($C_{16}H_{10}$; MW = 202.25): Pyrene is a 4-ring PAH with the same molecular weight and formula as fluoranthene but differs in its structural arrangement (Table 12). It is not considered to be carcinogenic, but it may enhance the effects of other cancer causing PAHs such as benzo (a) pyrene (ATSDR, 1995a). Pyrene is not produced commercially. Sources of pyrene to the environment include automobile exhaust, particulates from diesel exhaust, emissions from natural gas appliances and as a component of coal tar pitch (ATSDR, 1995a). Exposure to high levels of pyrene has been found to delay molting and reproduction in grass shrimp (*Palaemonetes pugio*) and reduce survivorship of offspring (Oberdorster et al., 2000). Oligochaetes exposed to pyrene spiked sediments had reduced production of offspring (Lotufo and Fleeger, 1996). Pyrene can bioaccumulate in deposit feeding oligochaetes which ingest contaminated sediments (Leppanen and Kukkonen, 2000). Metabolism of ingested contaminated sediments by polychaete worms (*Nereis diversicolor*) and bioturbation of sediments by burrowing polychaetes (such as *Arenicola marina*) can transfer pyrene from sediments to the overlying water column (Christensen et al., 2002).

Pyrene concentrations in Tampa Bay sediments had a mean concentration of 41 µg/kg with a maximum of 4,890 µg/kg (Table 12). Pyrene exceeded its TEL in 3.16% of the sites and was above its PEL in 0.57% of the sites. Pyrene concentrations were significantly higher in Hillsborough Bay, the Manatee River and Boca Ciega Bay (Figure 85). Sites with sediment pyrene concentrations above the PEL were found in the Hillsborough River, McKay Bay, in the vicinity of the Port of Tampa and one location in Boca Ciega Bay (Figure 87).

Total HMW PAHs: The total high molecular weight PAH parameter (HMW-PAHs) is the summation of the six individual HMW-PAHs discussed above. Total HMW-PAHs were above the TEL at 3.4% of the sites and exceeded the PEL at 0.4% of the sites (Table 12). There was a significant difference in HMW-PAH concentrations between bay segments (KW; $p<0.001$) with highest concentrations occurring in Hillsborough Bay, the Manatee River and Boca Ciega Bay (Figure 88). Five sites exceeded the PEL with four sites in Hillsborough Bay (Hillsborough River, McKay Bay in around the Port of Tampa) and one site in Boca Ciega Bay (Figure 90).

Total PAHs: Total PAHs is the summation of the six LMW-PAHs and six HMW-PAHs. Total PAHs were above the TEL at 1.78% of the sites and there were no PEL exceedences (Table 12). Total PAH concentrations between bay segments were significantly different (KW; $p<0.001$) with highest mean values recorded in Hillsborough Bay, the Manatee River, and Boca Ciega Bay (Figure 89). Sites exceeding the TEL were primarily located in Hillsborough Bay (Hillsborough River, McKay Bay and around the Port of Tampa), Manatee River, Boca Ciega Bay and Old Tampa Bay (Figure 91).

Other Polycyclic Aromatic Hydrocarbons

Several PAHs 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 and are summarized below.

Benzo (b) fluoranthene ($C_{20}H_{12}$; MW = 252.31): Benzo (b) fluoranthene is a high molecular weight PAH with a 5-ring structure and has the same formula and molecular weight as benzo (a) pyrene (Table 13). It is known to be carcinogenic and causes skin tumors in mice (ATSDR, 1995a). Benzo (b) fluoranthene has been found to reduce the activity of the enzyme isocitrate dehydrogenase (IDH) which functions in the aerobic energy production in fish muscle tissue (Oliva et al., 2012).

The mean benzo (b) fluoranthene concentration in Tampa Bay sediments was 37.4 µg/kg with a maximum value of 3,382 µg/kg (Table 13). Highest concentrations were in Hillsborough Bay, the Manatee River and Boca Ciega Bay (Figure 92).

Benzo (k) fluoranthene ($C_{20}H_{12}$; MW = 252.31): Benzo (k) fluoranthene has the same formula and molecular weight as benzo (b) fluoranthene but a different configuration of its 5-ring structure (Table 13). It is classified as being carcinogenic but is less potent then benzo (a) fluoranthene in causing skin tumors in mice (ATSDR, 1995a). High dose exposure benzo (k) fluoranthene has also been found to increase antioxidant enzyme activity in scallops (Pan et al., 2005).

The mean benzo (k) fluoranthene concentration in Tampa Bay sediments was 23µg/kg with a maximum value of 1,808 µg/kg (Table 13). The highest concentrations were in Hillsborough Bay, the Manatee River and Boca Ciega Bay (Figure 93) which were significantly higher than Middle and Lower Tampa Bay (KW; $p<0.001$).

Indeno (1,2,3-c,d) pyrene ($C_{22}H_{12}$; MW = 276.33): Indeno (1,2,3-c,d) pyrene is a six-ring PAH (Table 13). Sources include waste incineration and automobile exhaust (ATSDR, 1995a). It is known to be mutagenic and carcinogenic in mice (ATSDR, 1995a).

The mean concentration of indeno (1,2,3-c,d) pyrene in Tampa Bay sediments was 24.25 µg/kg with a maximum value of 2,161 µg/kg (Table 13). Sediment concentrations were significantly higher in Hillsborough Bay, the Manatee River and Boca Ciega Bay relative to Middle and Lower Tampa Bay (Figure 94).

Benzo (g,h,i) perylene ($C_{22}H_{12}$; MW = 276.33): Benzo (g,h,i) perylene is composed of six benzene rings and has the same chemical formula and molecular weight as indeno (1,2,3-c,d) pyrene (Table 13). It is known to be mutagenic and a co-carcinogen in combination with other PAHs (ASTDR, 1995). Sources to the environment include automobile exhaust and fly-ash from waste incinerators (ATSDR, 1995a).

The mean concentration of benzo (g,h,i) perylene in Tampa bay sediments was 32 µg/kg with a maximum value of 2,500 µg/kg (Table 13). Sediment concentrations were significantly higher in Hillsborough Bay, the Manatee River and Boca Ciega Bay relative to Middle and Lower Tampa Bay (Figure 95).

Retene ($C_{18}H_{18}$; MW = 234.34): Retene is composed of a 3-ring phenanthene with attached mehyl and isopropyl groups and is also known as 1-methyl-7-isopropylphenanthene (Table 13). Sources to the environment include the combustion of resin in pine wood (Ramdahl, 1983) and effluent from paper and pulp mills (Oikari et al., 2002). Retene exposure can cause defects in fish embryos (Billiard et al., 1999), and high levels of retene in sediments from paper mill discharges have been found to be bioavailable to fish (rainbow trout) in freshwater systems (Oikari et al., 2002).

Retene analysis started in 2001 for the Tampa Bay samples. The mean concentration of retene in Tampa Bay sediments was 11.16 µg/kg with a maximum of 191.42 µg/kg (Table 13). The highest retene concentrations were in Hillsborough Bay and lowest were in Lower Tampa Bay (Figure 96). The only signifiant difference between bay segments was between the Manatee River and Lower Tampa Bay (KW; $p<0.004$).

Coronene ($C_{24}H_{12}$; MW = 300.35): Coronene is a large PAH composed of a six benzene rings in a larger ring structure (Table 13). It is a component of coal tars (Wise et al. 2010) and is not considered to be carcinogenic (ATSDR, 1995a).

Tampa Bay samples were analysed for coronene only from 2001-2008. The mean concentraion was 16.88 µg/kg with a maximum value of 1,262.48 µg/kg (Table 13) with the highest concentration found at a site in the Hillsborough River sampled in 2003 (03HB09). Hillsborough Bay had the highest mean concentration of coronene, while Middle Tampa Bay had the lowest (Figure 97).

Table 11. Tampa Bay sediment low molecular weight polycyclic aromatic hydrocarbon summary statistics and percentage of sites exceeding TEL and PEL values (1993-2012).

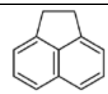
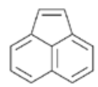
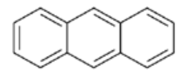
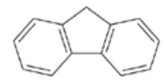
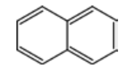
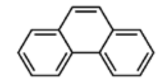
µg/kg	Acenaphthene	Acenaphthylene	Anthracene	Fluorene	Naphthalene	Phenanthrene	Total LMW PAHs
MW	154.22	152.19	178.23	166.22	128.17	178.23	
Formula	$C_{12}H_{10}$	$C_{12}H_8$	$C_{14}H_{10}$	$C_{13}H_{10}$	$C_{10}H_8$	$C_{14}H_{10}$	
Structure							
TEL	6.7	5.9	46.9	21.2	34.6	86.7	312
PEL	88.9	128	245	144	391	544	1440
n	1074	950	1236	1236	1236	1236	1236
Minimum	1.08	0.66	0.83	0.80	1.42	0.77	5.83
Maximum	129.00	414.00	169.00	123.00	358.00	862.93	1928.00
Median	2.92	2.75	2.50	3.26	3.50	5.00	21.00
Mean	4.15	4.05	5.92	4.96	5.94	14.57	38.12
SD	6.68	15.29	12.67	6.58	15.32	55.41	94.54
% >TEL;<PEL	**4.84%**	**4.21%**	**1.38%**	**1.62%**	**1.54%**	**1.78%**	**1.13%**
% >PEL	**0.19%**	**0.21%**	**0.00%**	**0.00%**	**0.00%**	**0.32%**	**0.08%**

Table 12. **Tampa Bay sediment high molecular weight and total polycyclic aromatic hydrocarbon summary statistics and percentage of sites exceeding TEL and PEL values (1993-2012).**

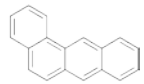
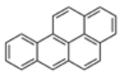
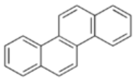
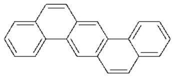
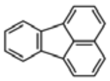
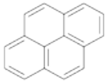
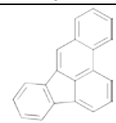
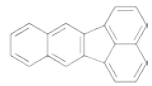
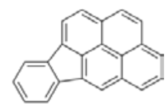
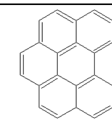
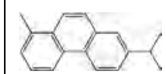
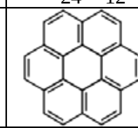
µg/kg	Benzo (a) anthracene	Benzo (a) pyrene	Chrysene	Dibenzo(a,h) anthracene	Fluoranthene	Pyrene	Total HMW PAHs	TOTAL PAHs
MW	228.29	252.31	228.29	278.35	202.25	202.25		
Formula	$C_{18}H_{12}$	$C_{20}H_{12}$	$C_{18}H_{12}$	$C_{22}H_{14}$	$C_{16}H_{10}$	$C_{16}H_{10}$		
Structure								
TEL	74.8	88.8	108	6.2	113	153	655	1680
PEL	693	763	846	135	1490	1400	6680	16800
n	1236	1236	1236	1020	1236	1236	1236	1236
Min.	0.68	1.60	1.49	0.48	0.99	1.40	10.70	16.53
Max.	1564.00	2103.88	2326.89	830.00	3014.98	4889.99	14455.03	15562.48
Median	3.50	3.70	3.40	2.75	4.50	4.50	24.00	45.00
Mean	21.75	28.82	26.09	11.43	38.02	41.04	165.15	203.26
SD	86.80	123.43	115.92	49.78	176.78	222.03	755.87	839.99
% >TEL;<PEL	**3.72%**	**4.05%**	**3.07%**	**12.84%**	**4.61%**	**3.16%**	**3.40%**	**1.78%**
% >PEL	**0.49%**	**0.57%**	**0.65%**	**1.47%**	**0.40%**	**0.57%**	**0.40%**	**0.00%**

Table 13. Other measured hydrocarbons without established TEL/PELs (1993-2012).

µg/kg	Benzo(b) fluoranthene	Benzo(k) fluoranthene	Indeno(1,2,3, c,d) pyrene	Benzo(g,h,i) perylene	Retene	Coronene
MW	252.31	252.31	276.33	276.33	234.34	300.35
Formula	$C_{20}H_{12}$	$C_{20}H_{12}$	$C_{22}H_{12}$	$C_{22}H_{12}$	$C_{18}H_{18}$	$C_{24}H_{12}$
Structure						
n	1236	1236	1236	1236	600	453
Min.	0.61	1.95	1.00	1.80	0.98	1.02
Max.	3382.50	1808.00	2161.00	2500.01	191.42	1262.48
Median	3.75	4.48	2.45	3.35	5.60	3.48
Mean	37.40	23.07	24.25	32.01	11.16	16.88
SD	177.96	96.77	110.31	120.86	15.25	72.12

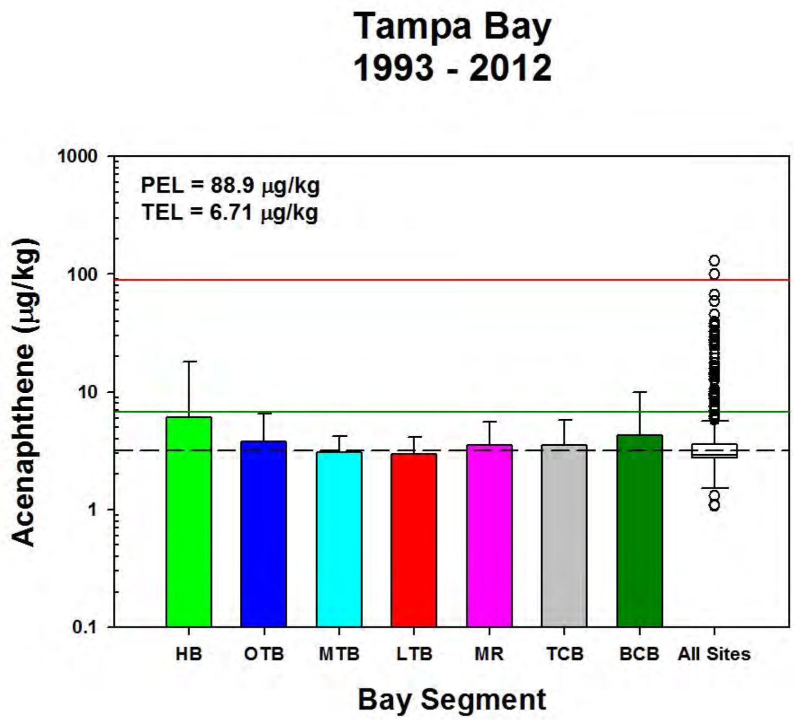


Figure 62. Mean sediment acenaphthene concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.

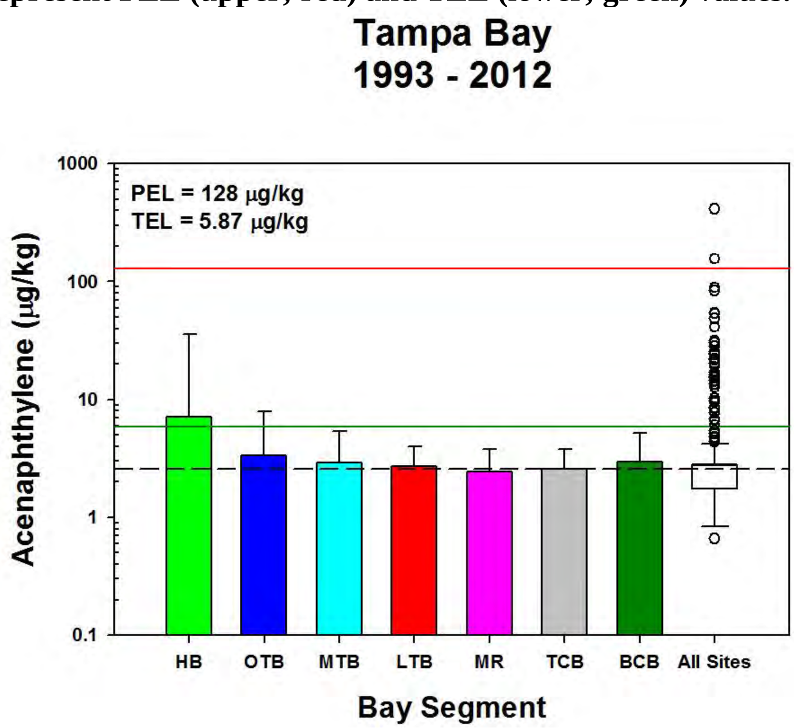


Figure 63. Mean sediment acenaphthylene concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.

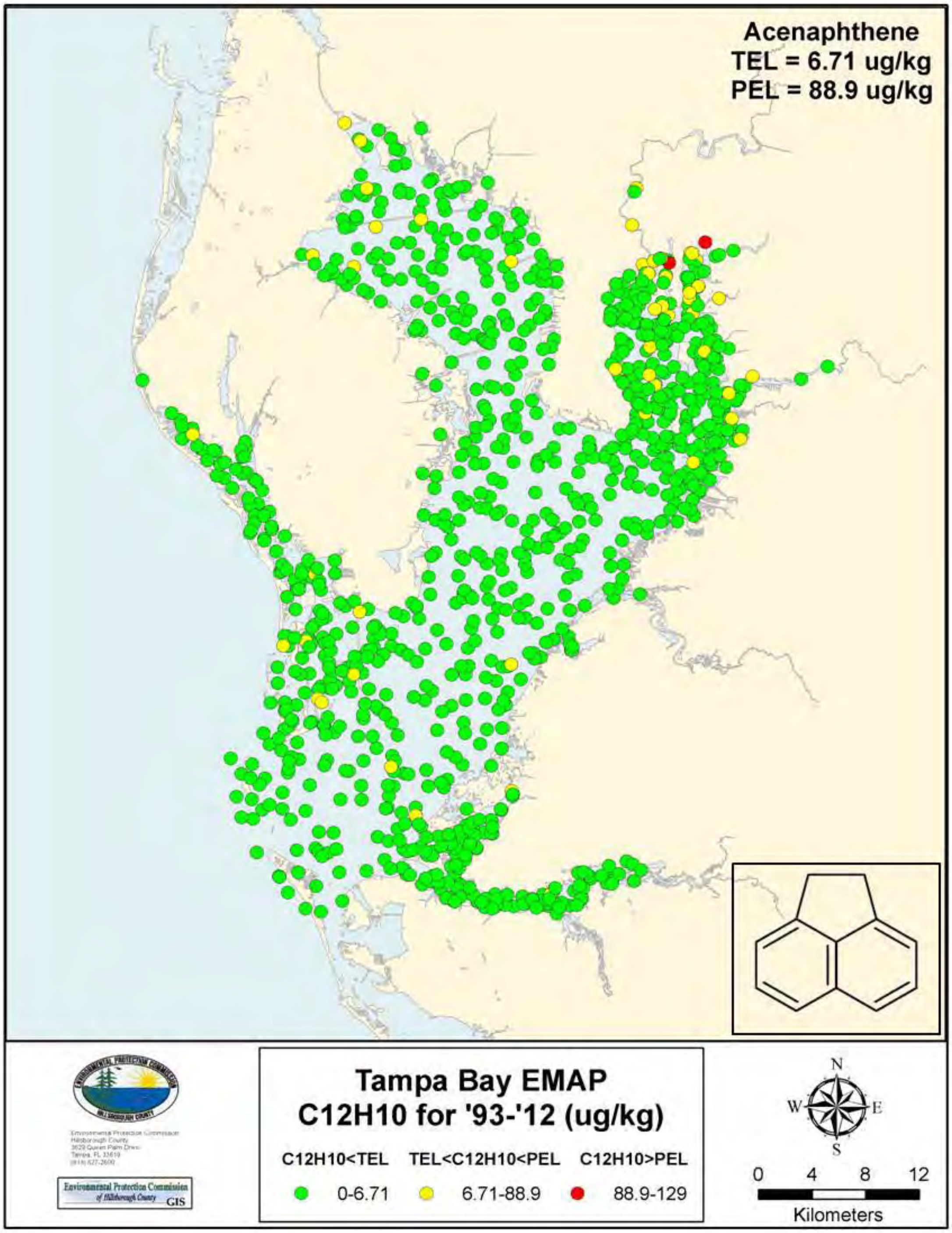


Figure 64. **Distribution of acenaphthene in Tampa Bay, 1993-2012.**

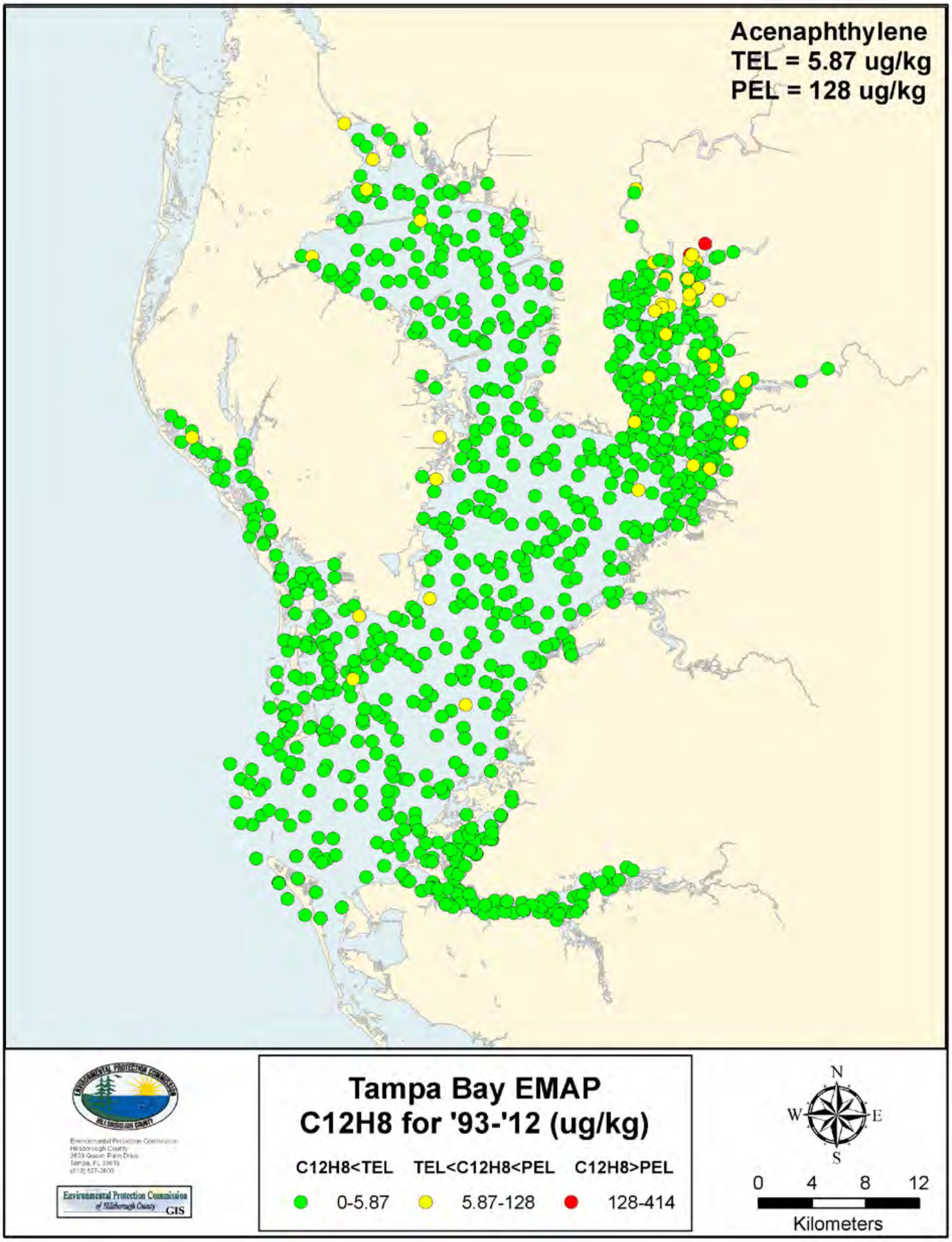


Figure 65. Distribution of acenaphthylene in Tampa Bay, 1993-2012.

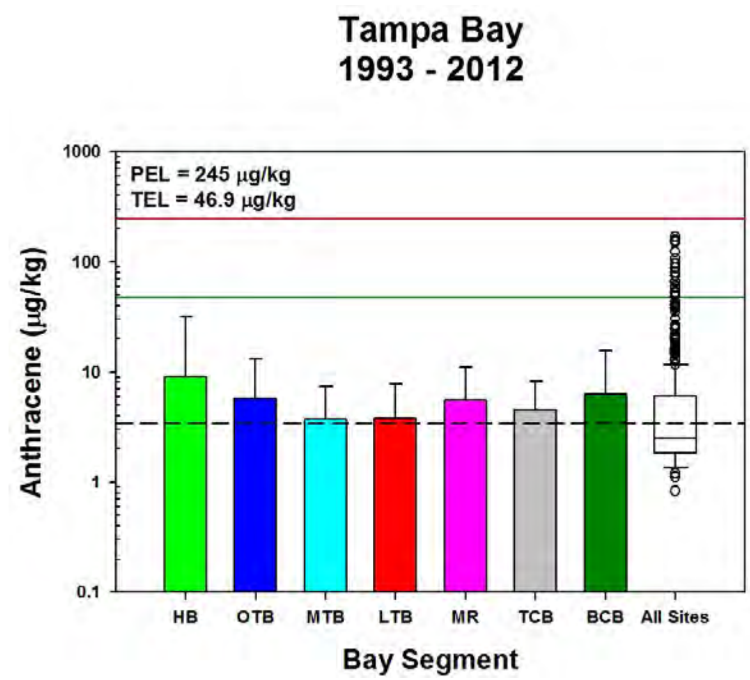


Figure 66. **Mean sediment anthracene concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.**

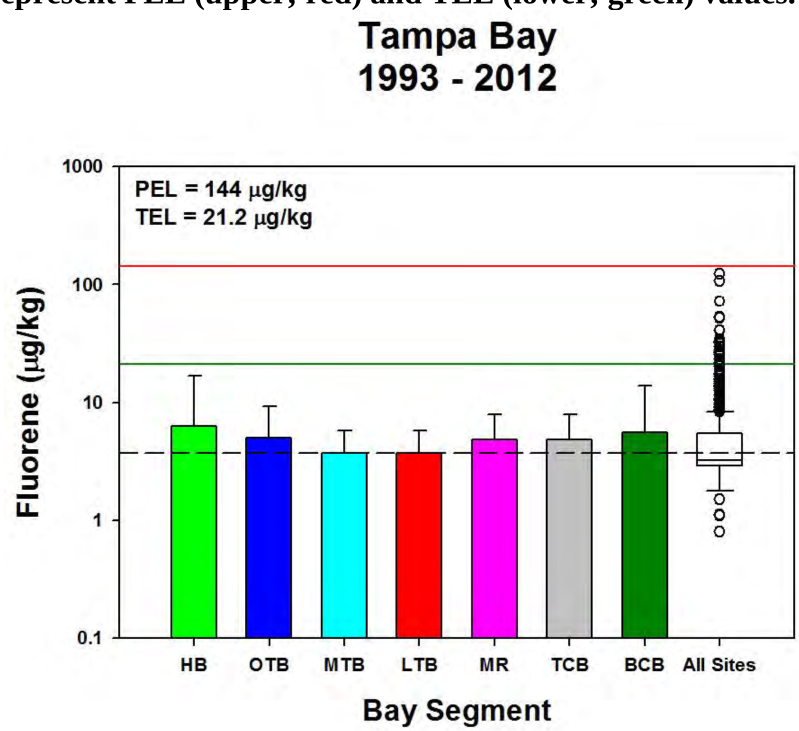


Figure 67. **Mean sediment fluorene concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.**

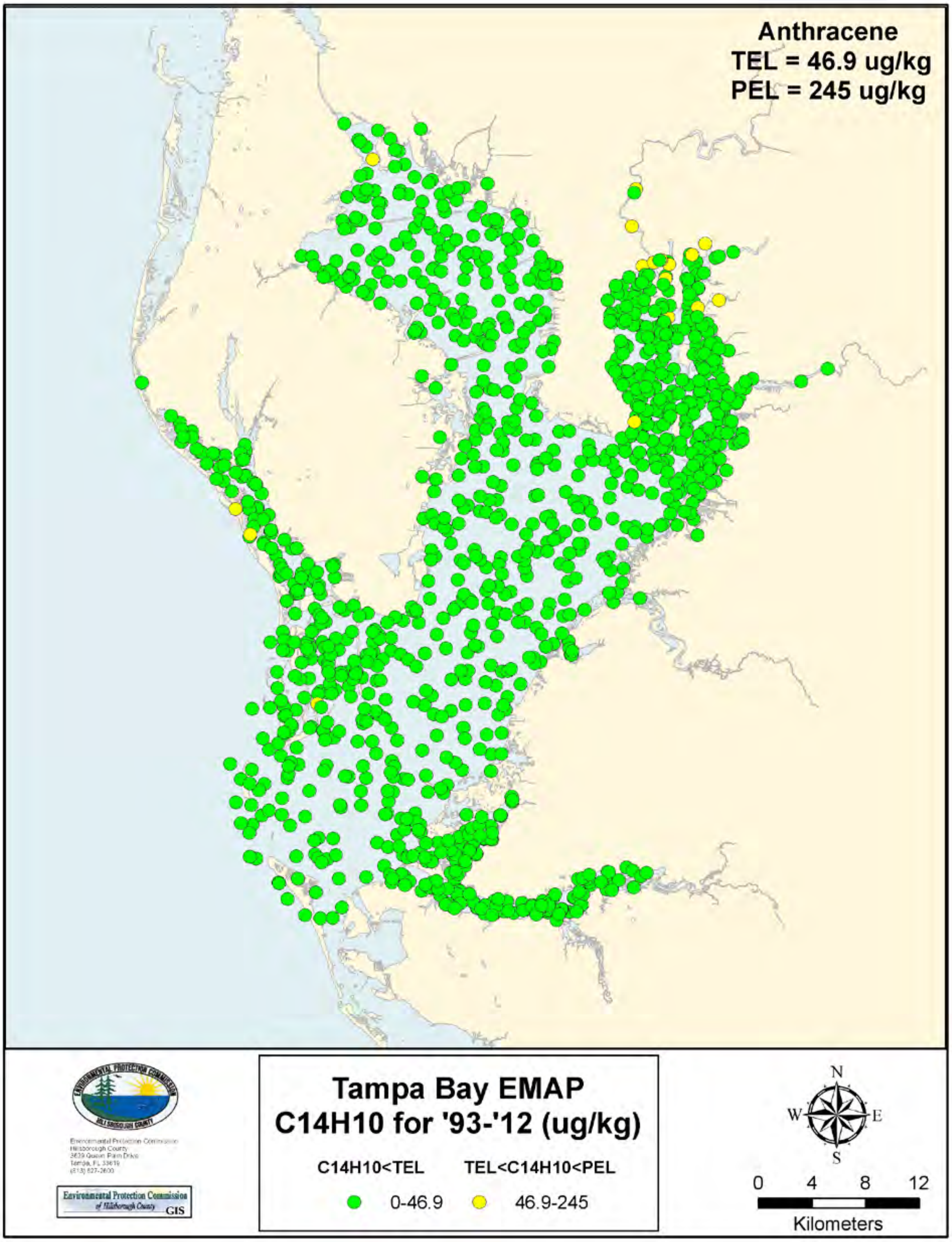


Figure 68. Distribution of anthracene in Tampa Bay, 1993-2012.

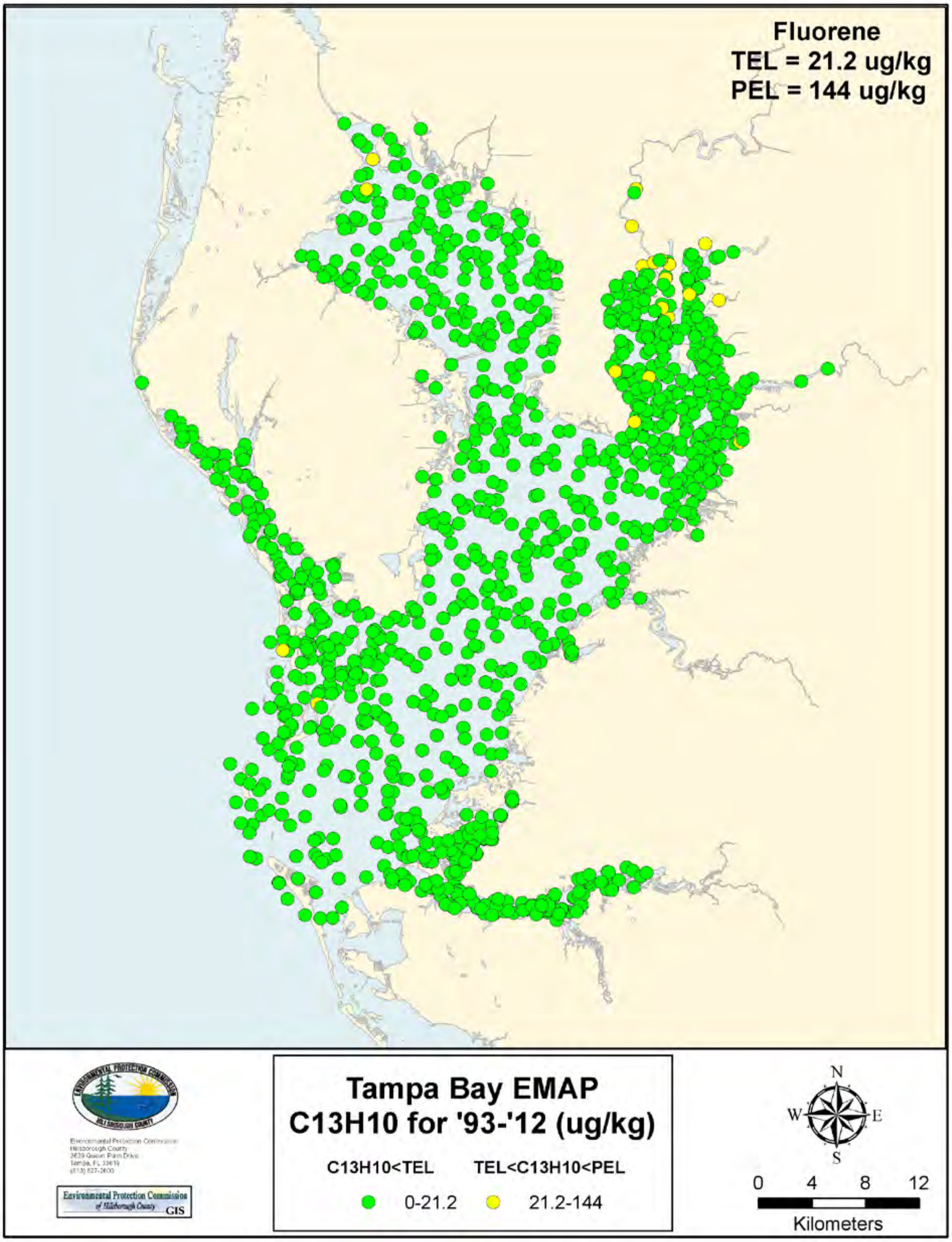


Figure 69. Distribution of fluorene in Tampa Bay, 1993-2012.

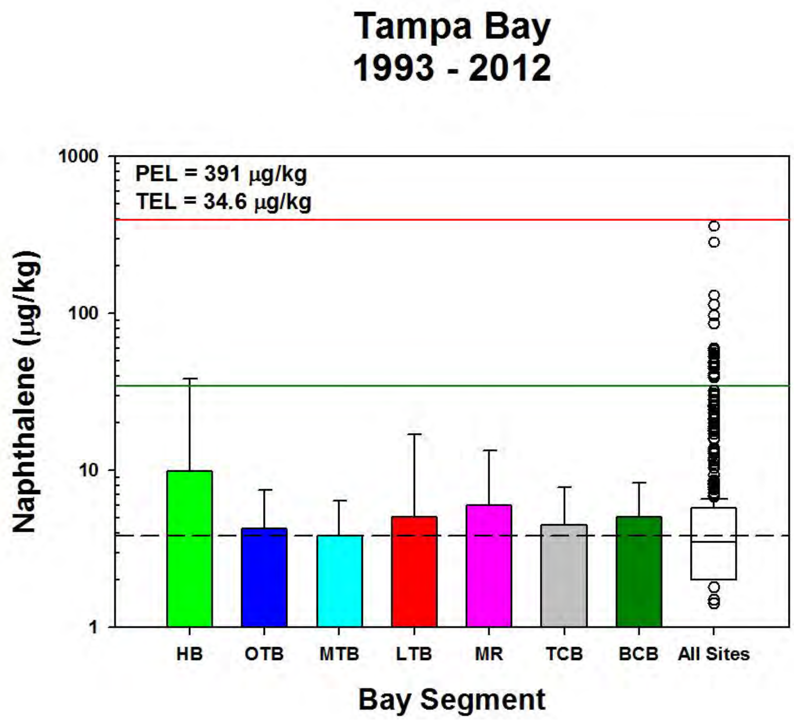


Figure 70. Mean sediment naphthalene concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.

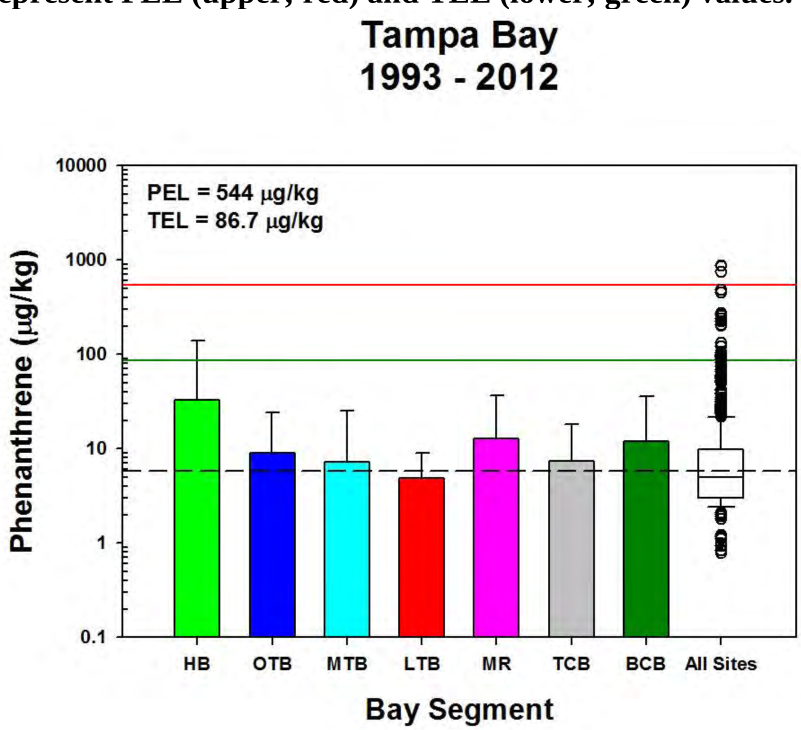


Figure 71. Mean sediment phenanthrene concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.

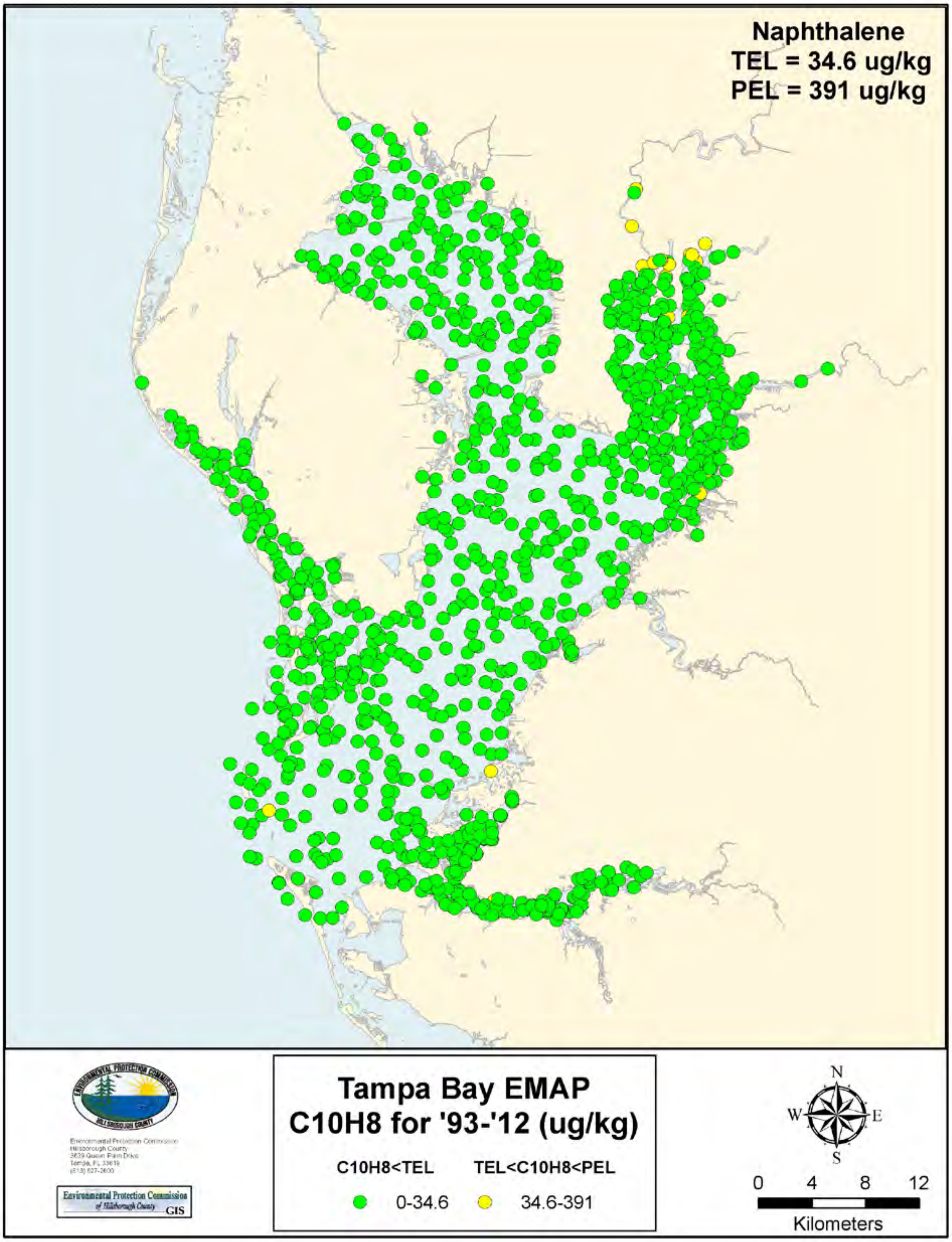


Figure 72. Distribution of naphthalene in Tampa Bay, 1993-2012.

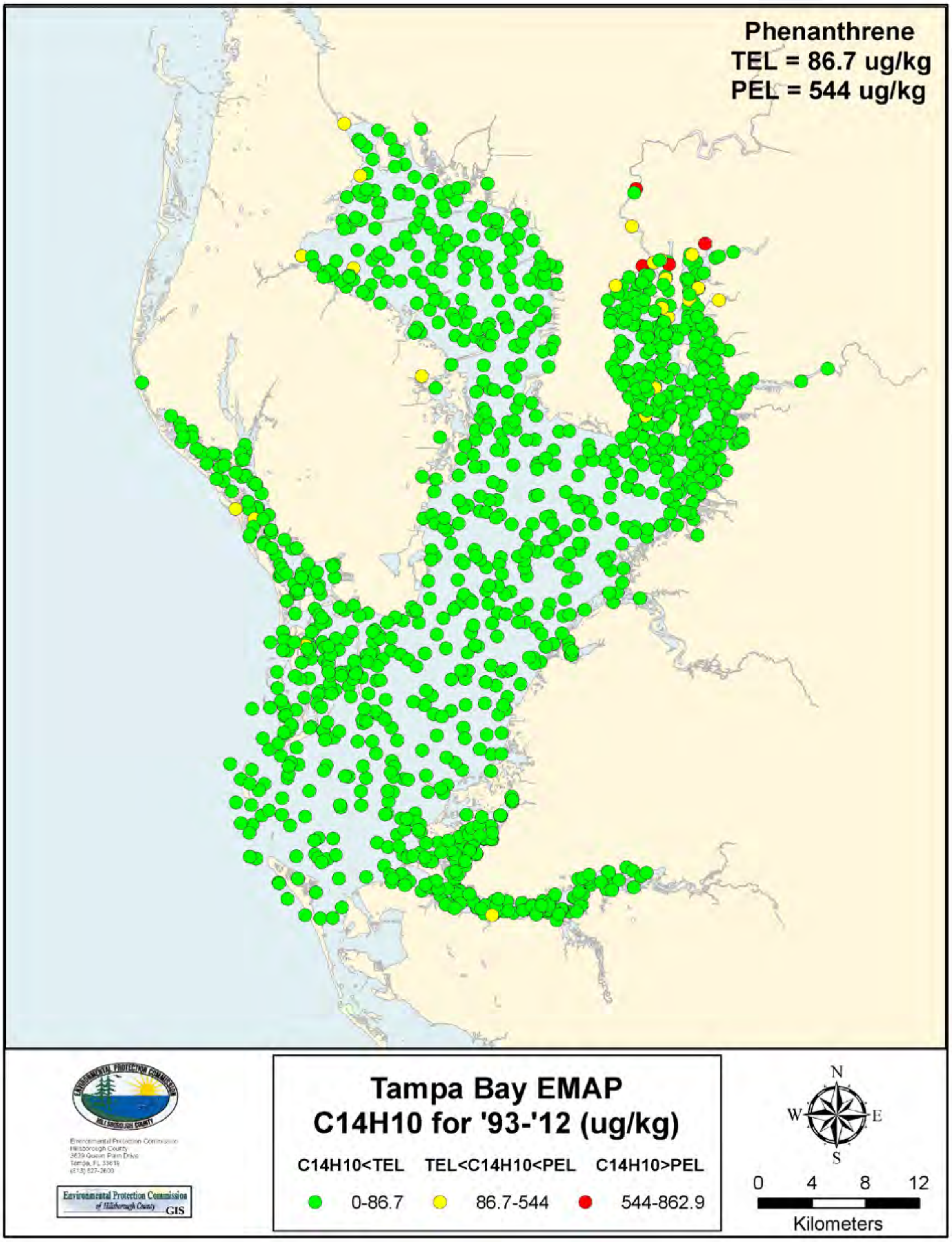


Figure 73. **Distribution of phenanthrene in Tampa Bay, 1993-2012.**

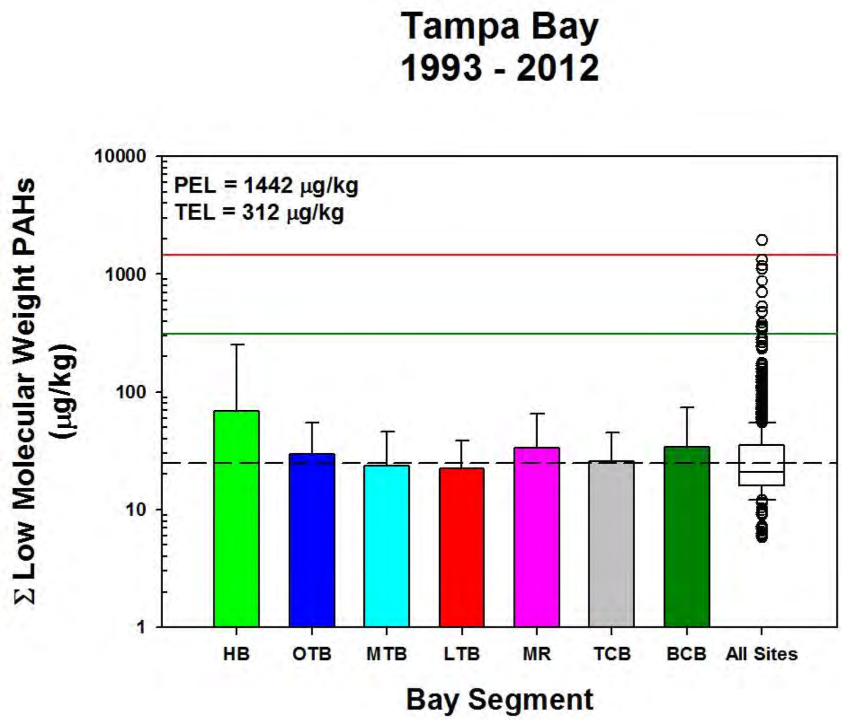


Figure 74. **Mean sediment low molecular weight PAH concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.**

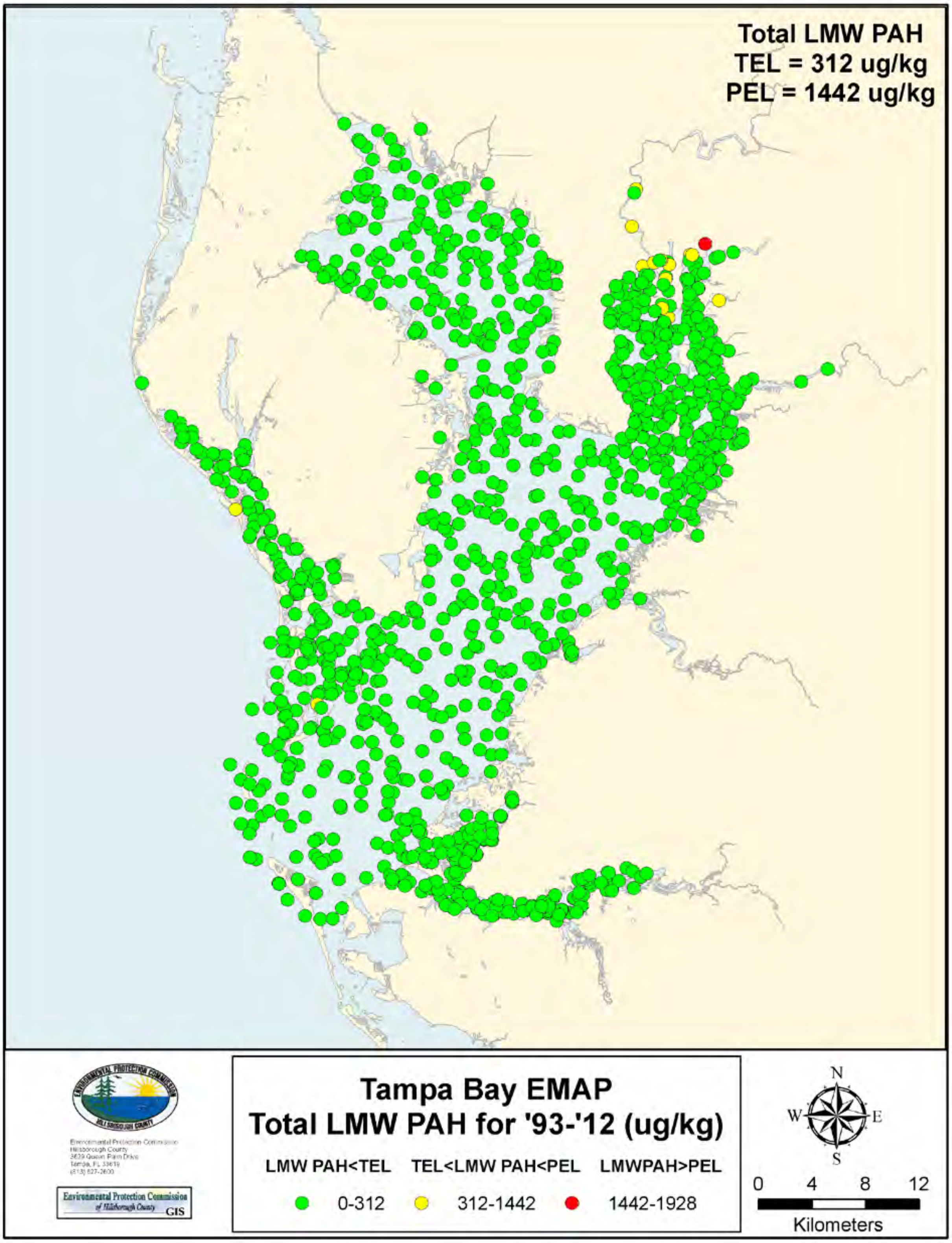


Figure 75. Distribution of total low molecular weight PAHs in Tampa Bay, 1993-2012.

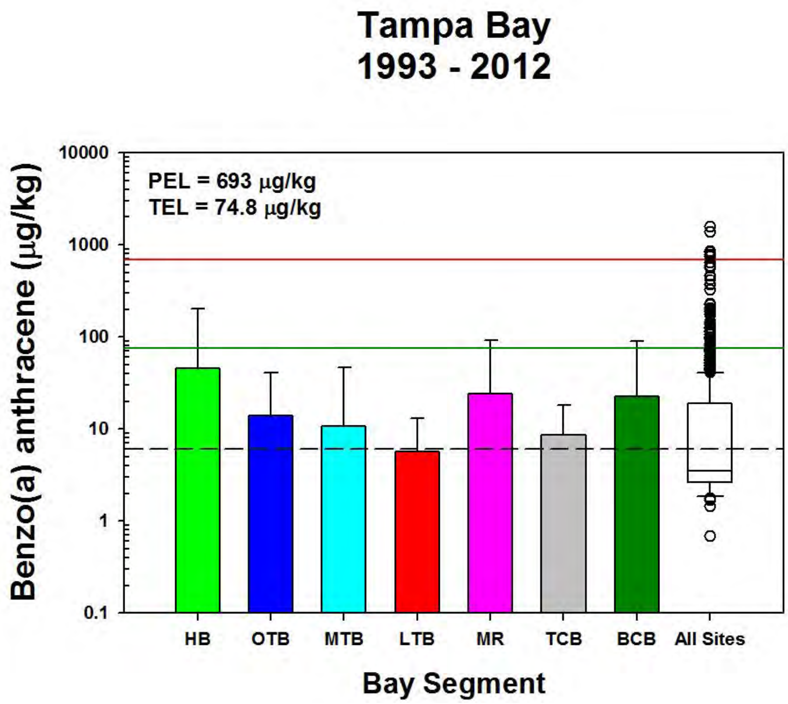


Figure 76. **Mean sediment benzo (a) anthracene concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.**

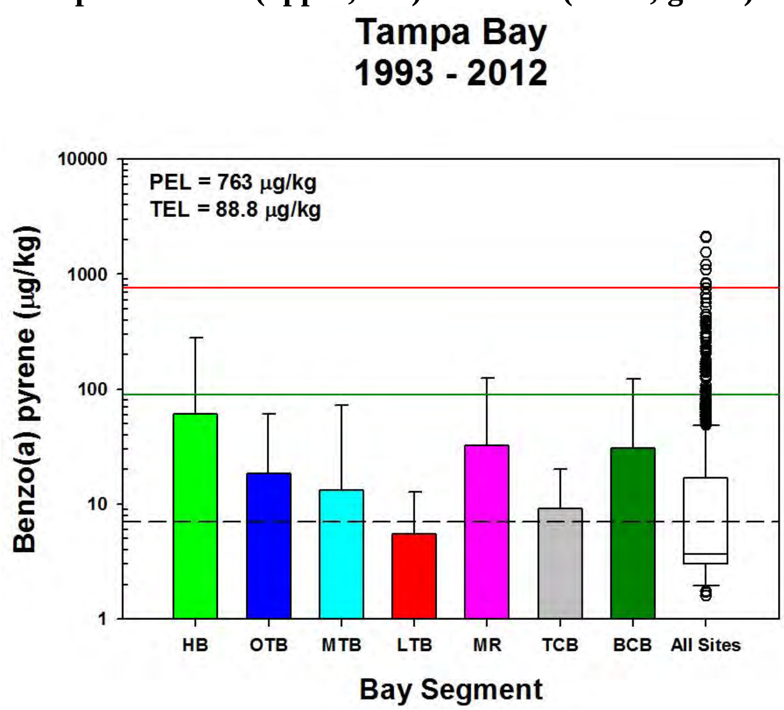


Figure 77. **Mean sediment benzo (a) pyrene concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.**

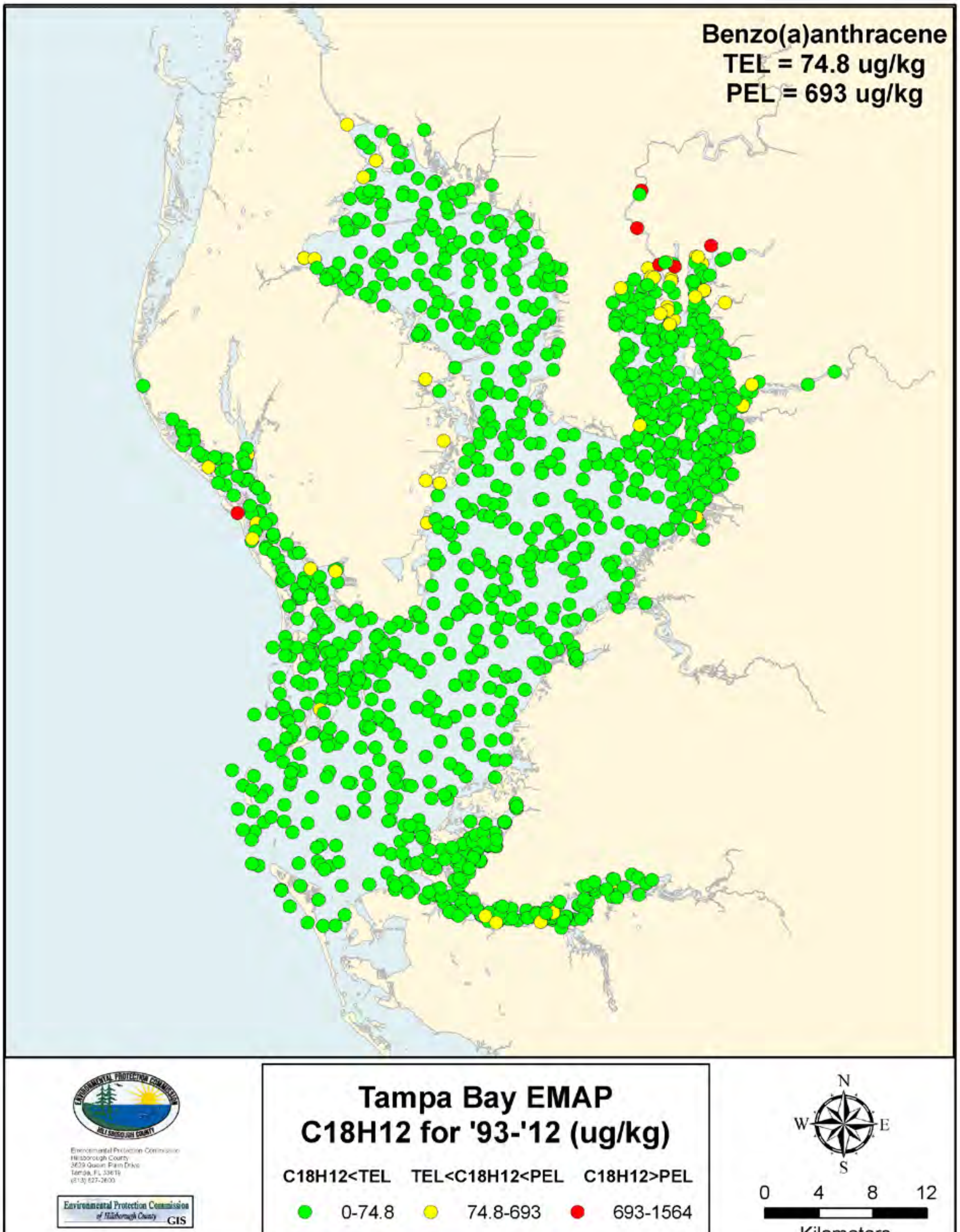


Figure 78. **Distribution of benzo(a) anthracene in Tampa Bay, 1993-2012.**

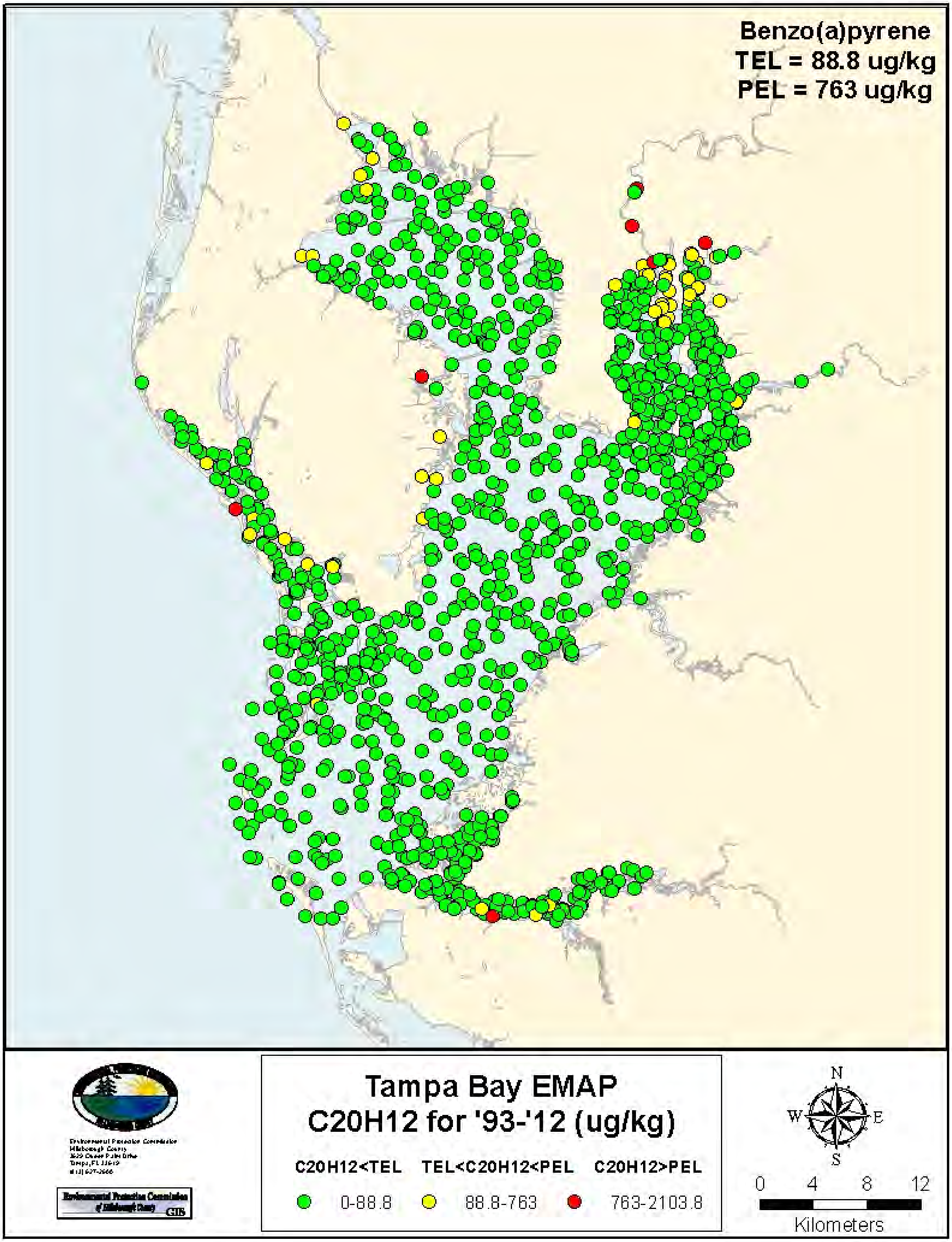


Figure 79. Distribution of benzo(a) pyrene in Tampa Bay, 1993-2012.

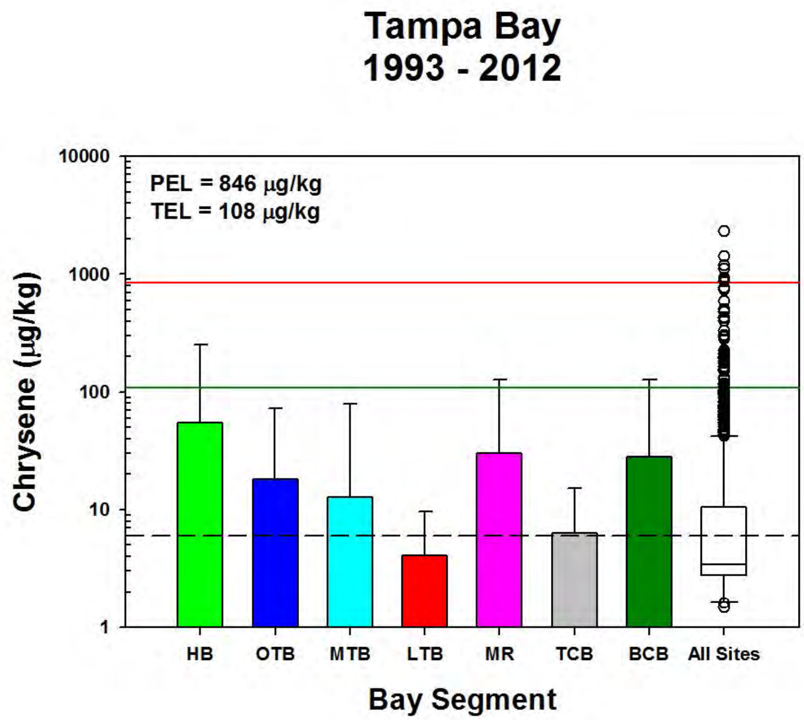


Figure 80. Mean sediment chrysene concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.

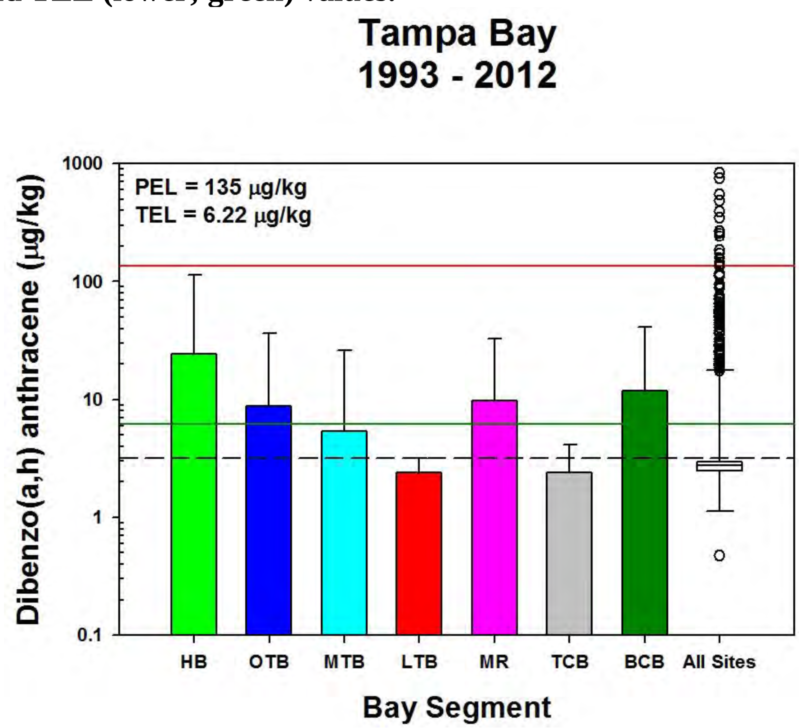


Figure 81. Mean sediment dibenzo (a,h) anthracene concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.

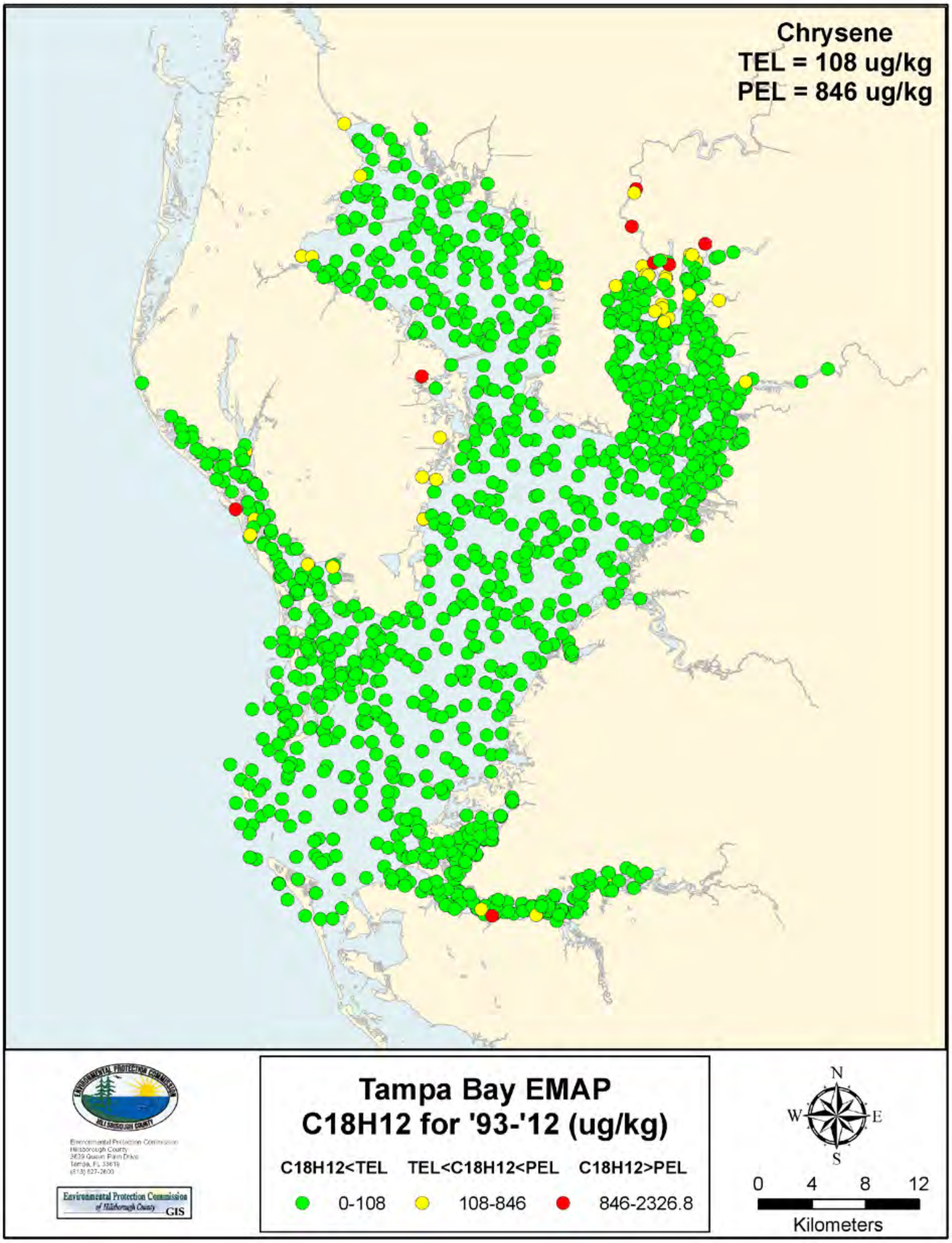


Figure 82. **Distribution of chrysene in Tampa Bay, 1993-2012.**

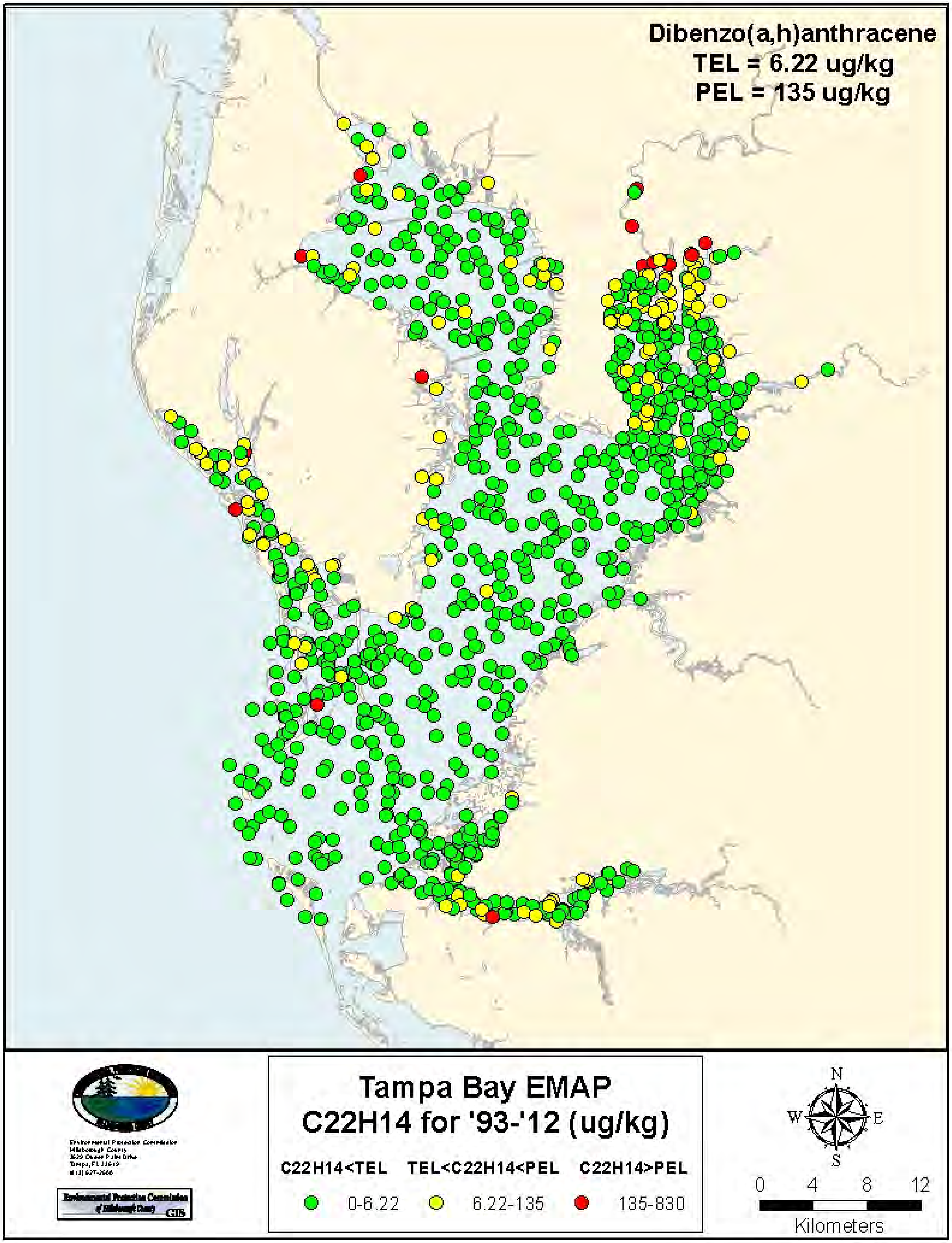


Figure 83. Distribution of dibenzo (a,h) anthracene in Tampa Bay, 1993-2012.

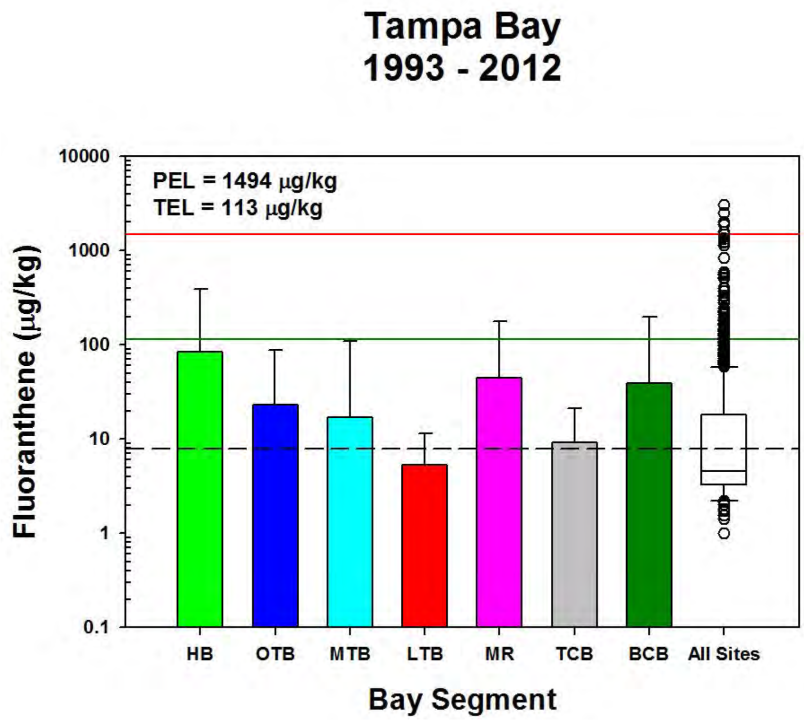


Figure 84. **Mean sediment fluoranthene concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.**

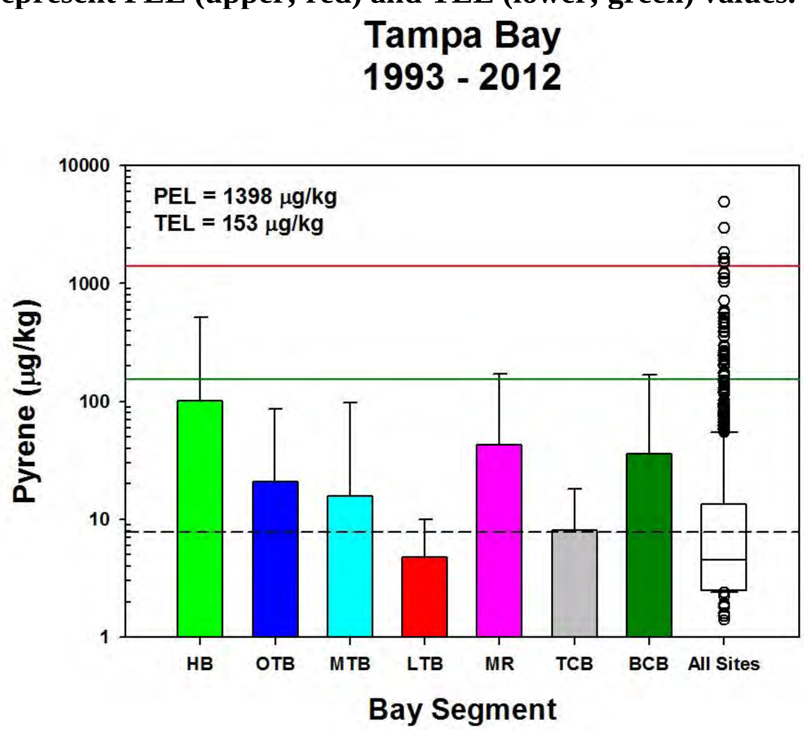


Figure 85. **Mean sediment pyrene concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.**

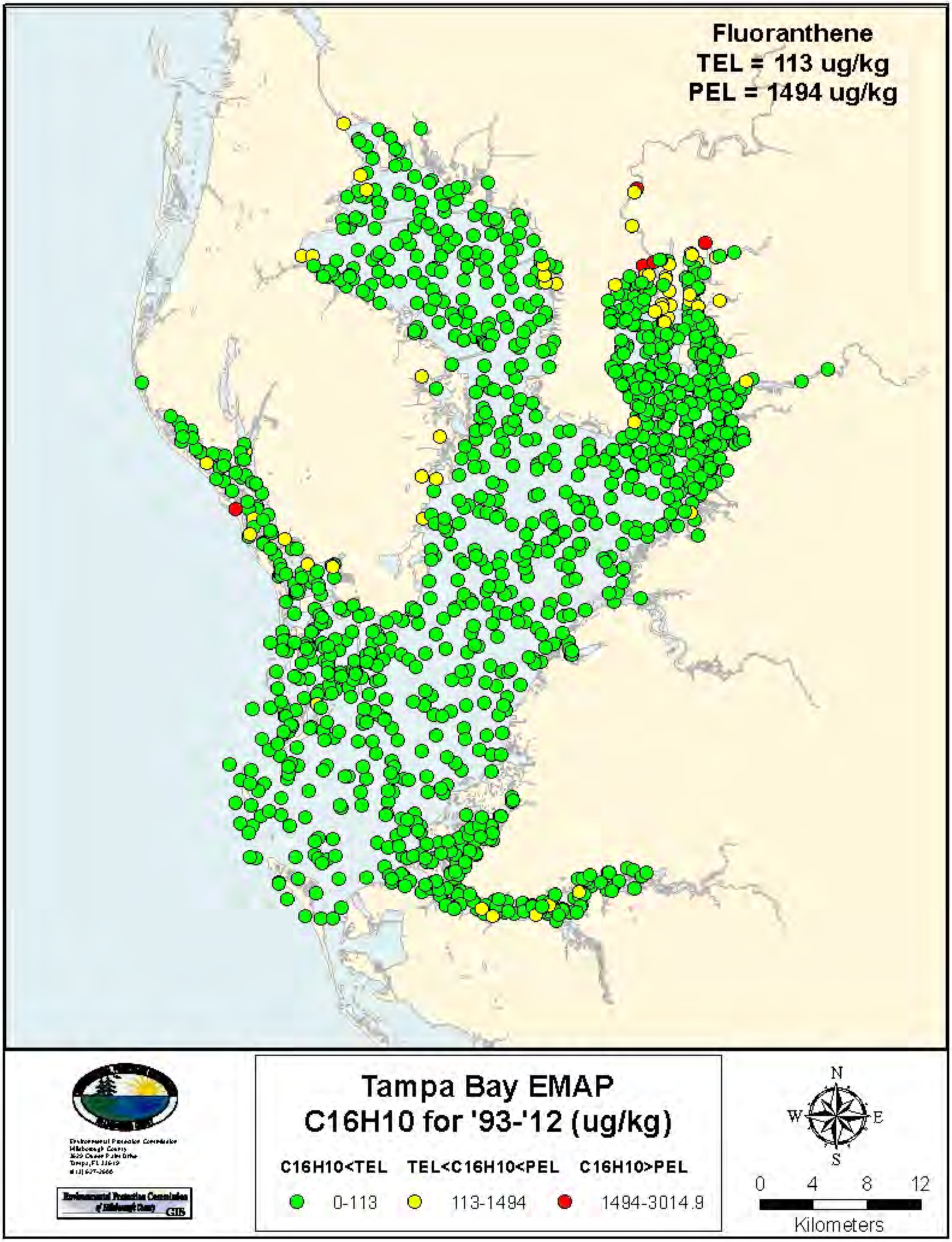


Figure 86. Distribution of fluoranthene in Tampa Bay, 1993-2012.

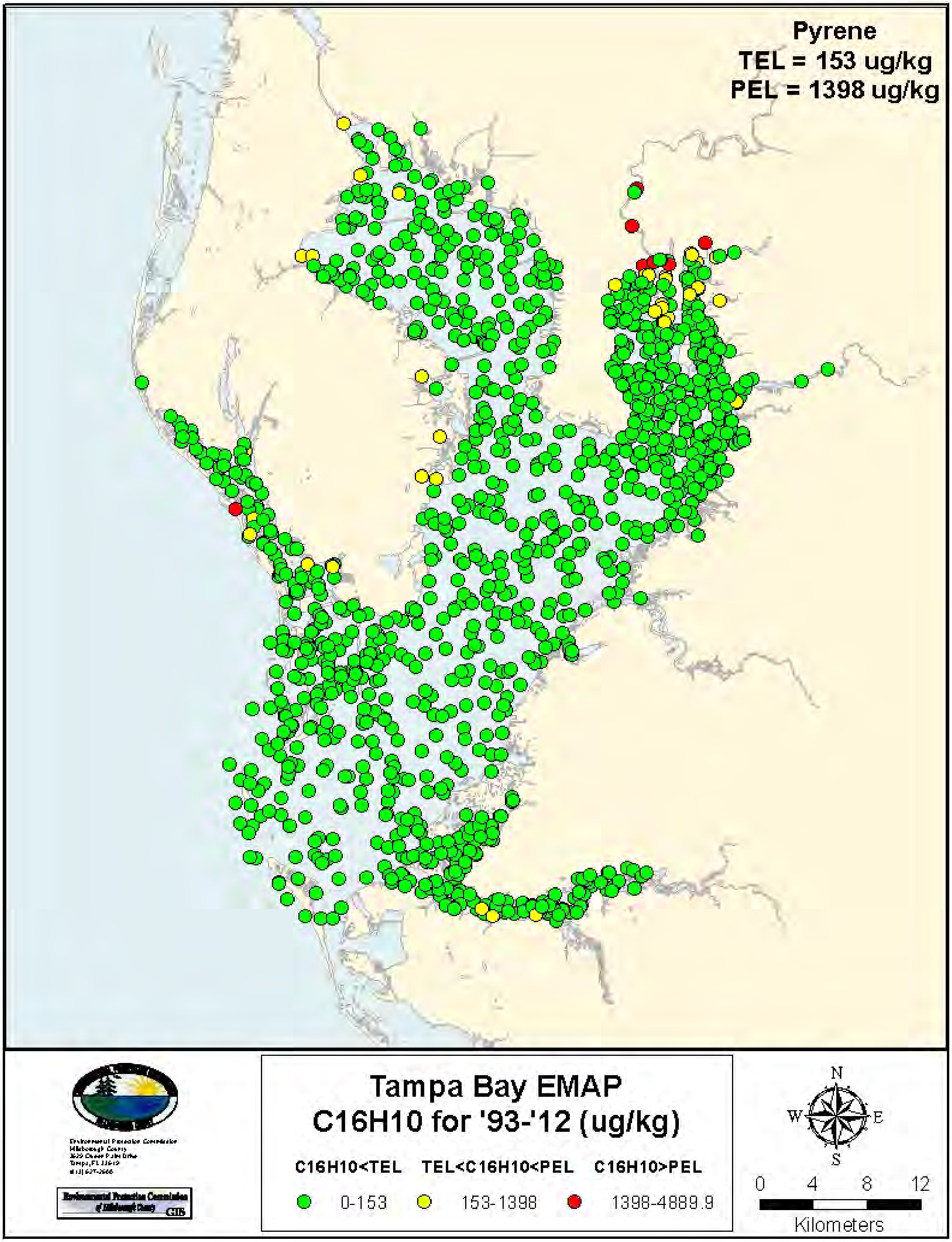


Figure 87. Distribution of pyrene in Tampa Bay, 1993-2012.

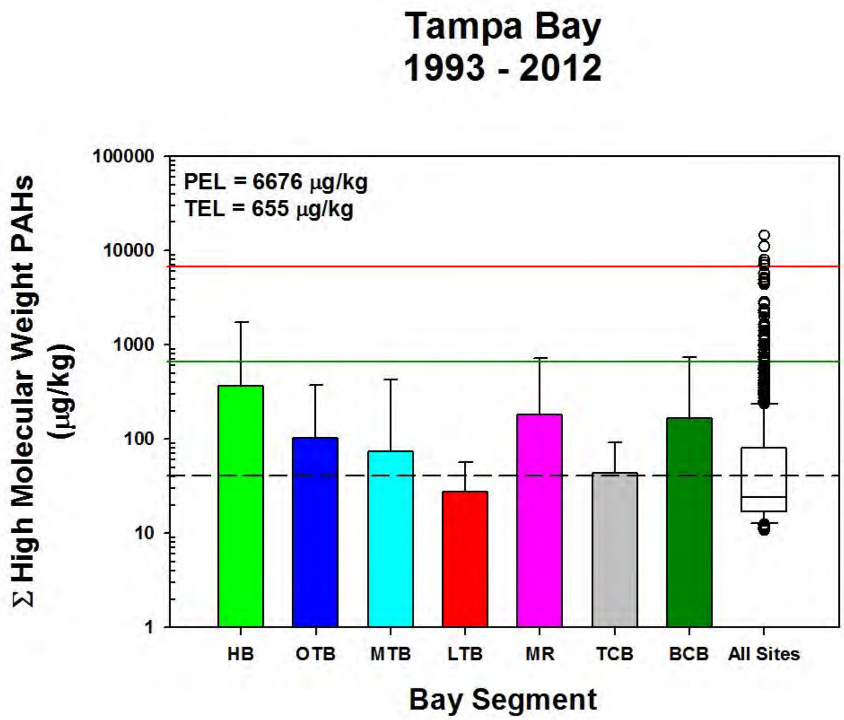


Figure 88. Mean sediment high molecular weight PAH concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.

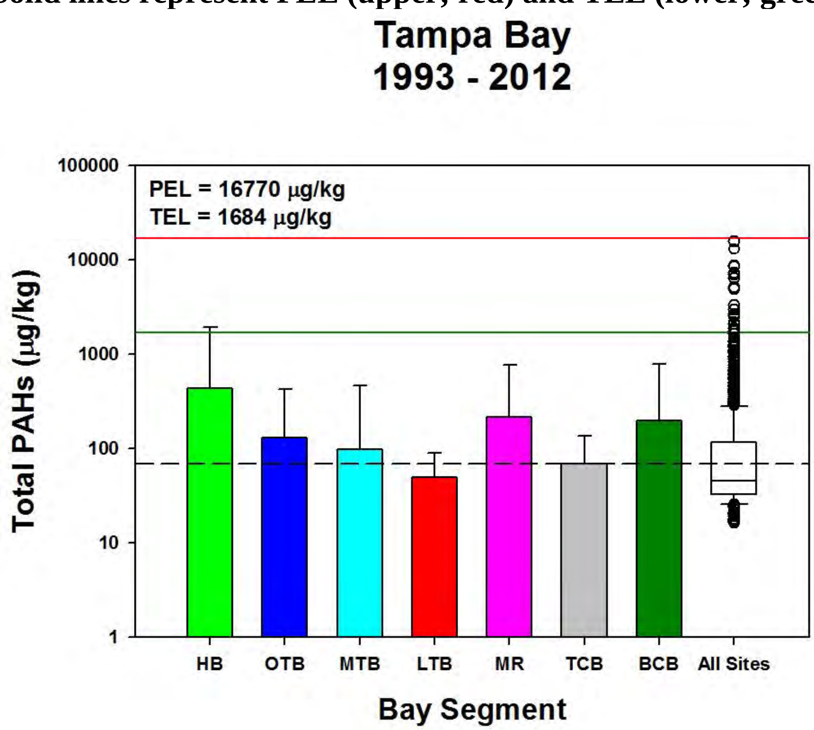


Figure 89. Mean sediment total PAH concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.

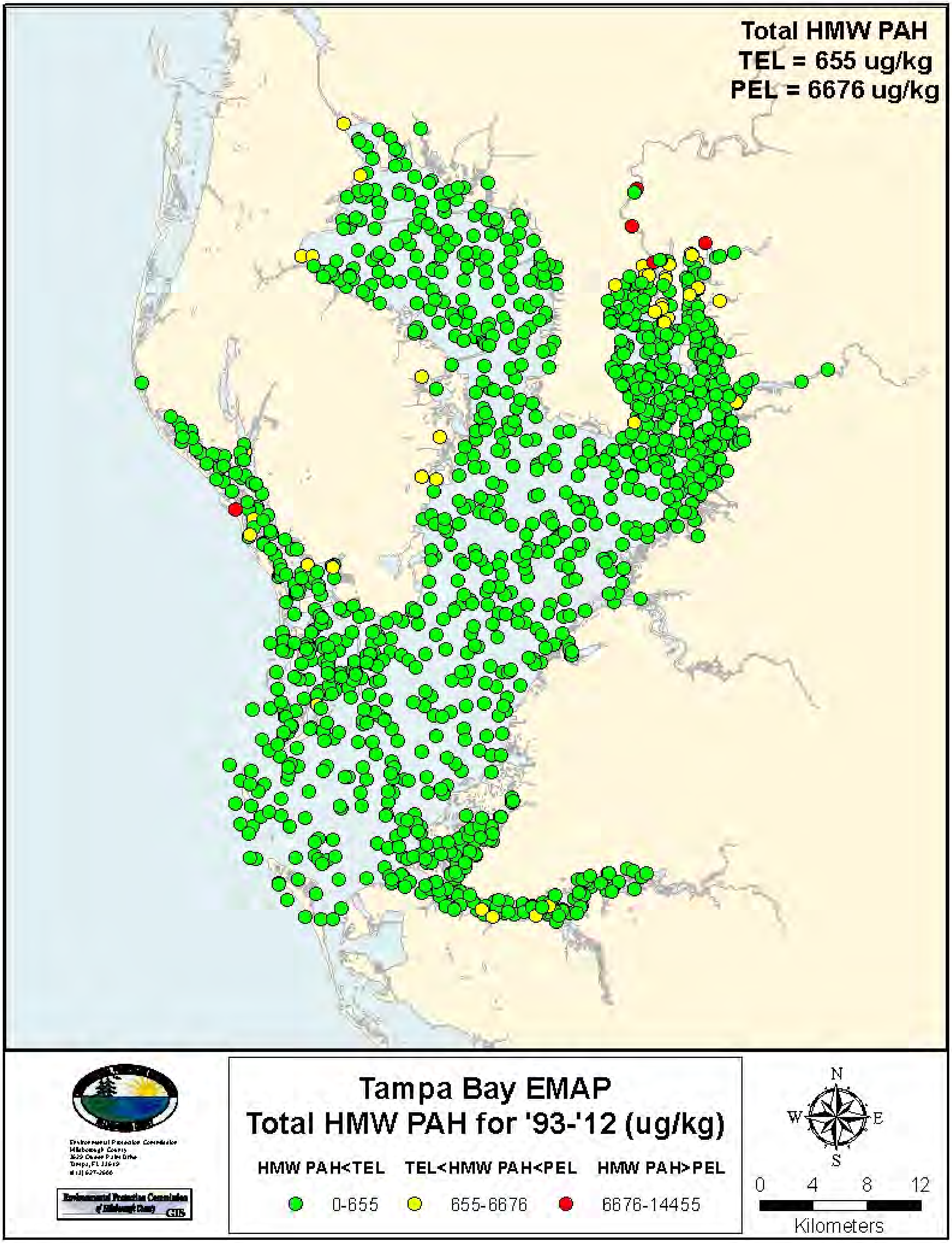


Figure 90. **Distribution of high molecular weight PAHs in Tampa Bay, 1993-2012.**

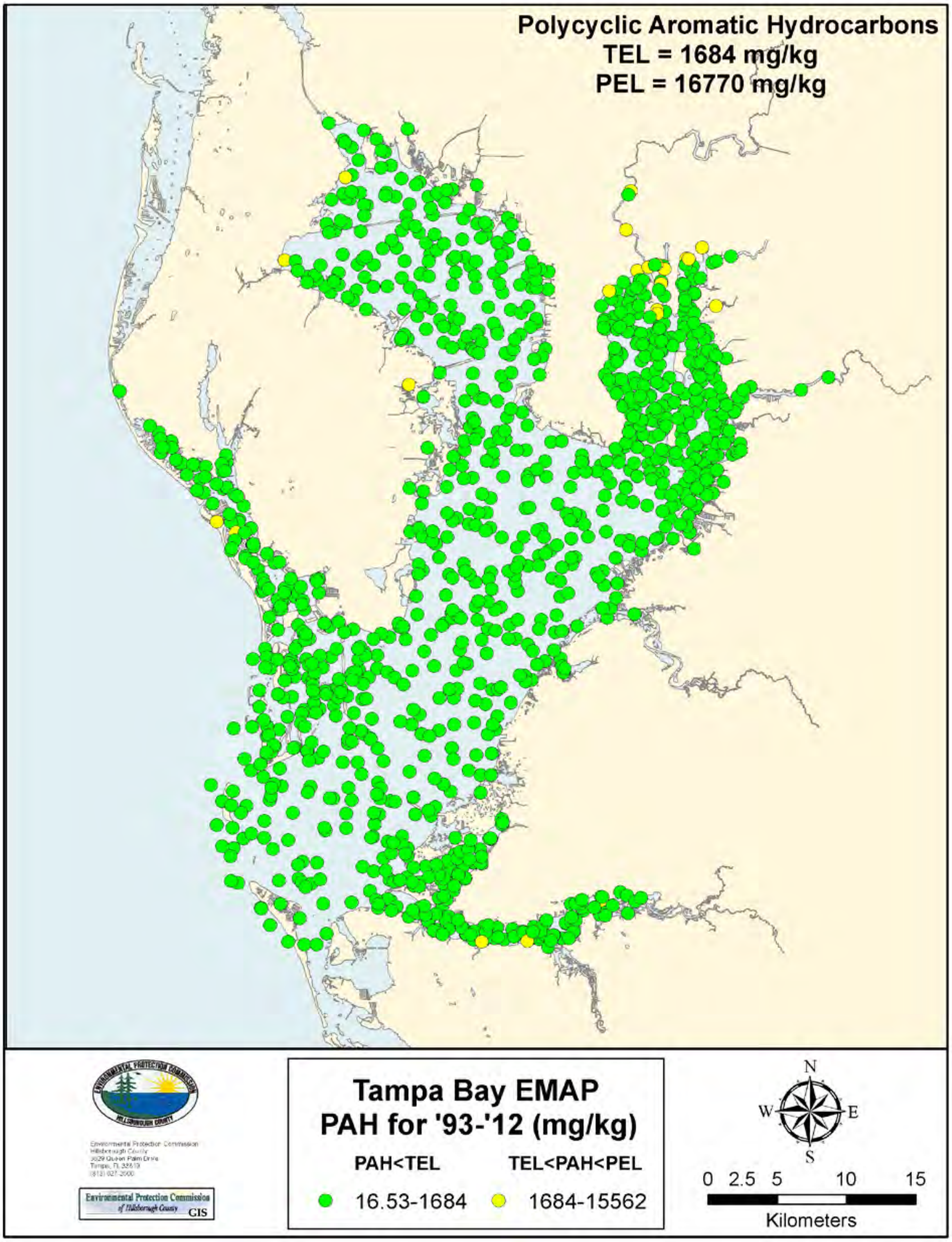


Figure 91. **Distribution of total PAHs in Tampa Bay, 1993-2012.**

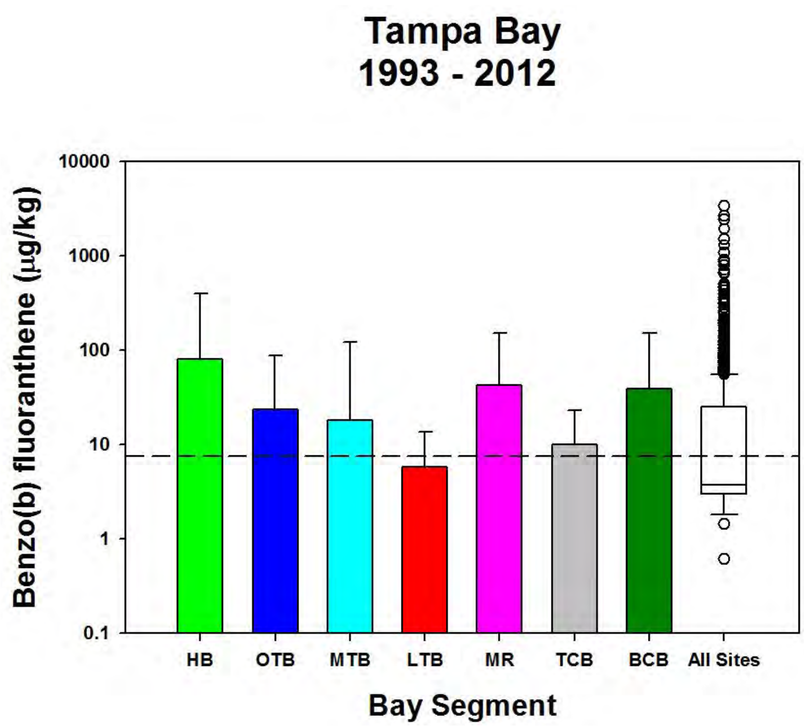


Figure 92. **Mean sediment benzo (b) fluoranthene concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean.**

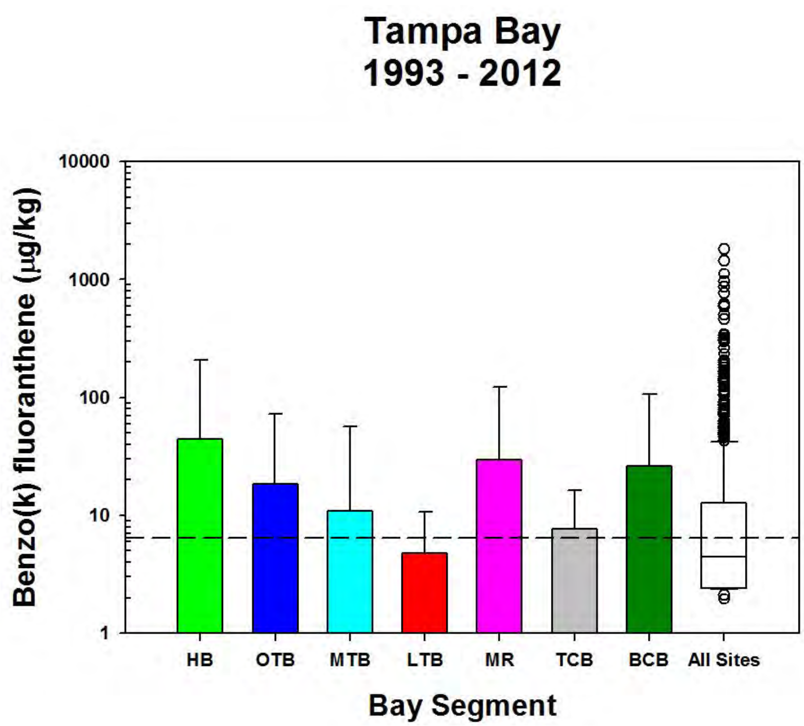


Figure 93. **Mean sediment benzo (k) fluoranthene concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean.**

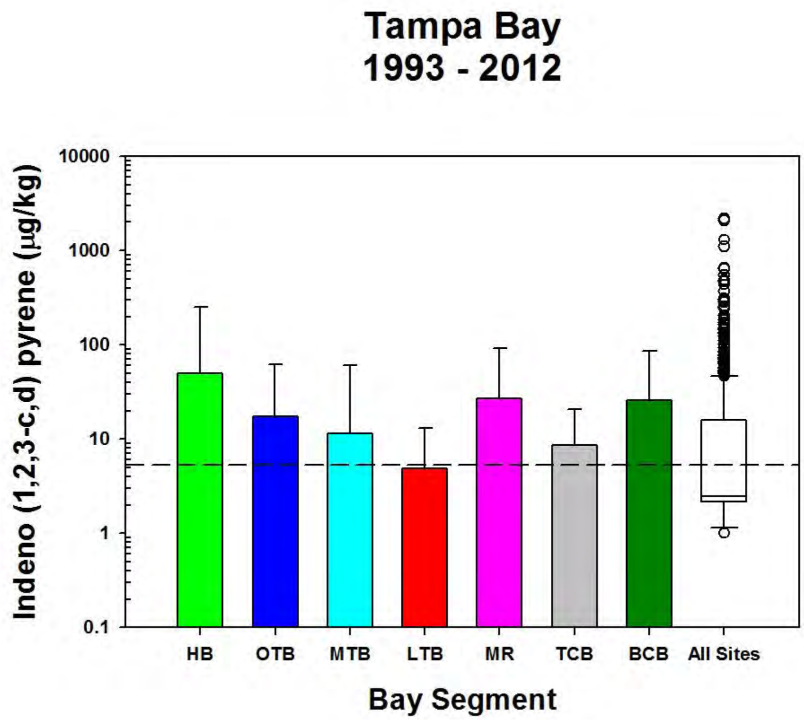


Figure 94. **Mean sediment indeno (1,2,3-c,d) pyrene concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean.**

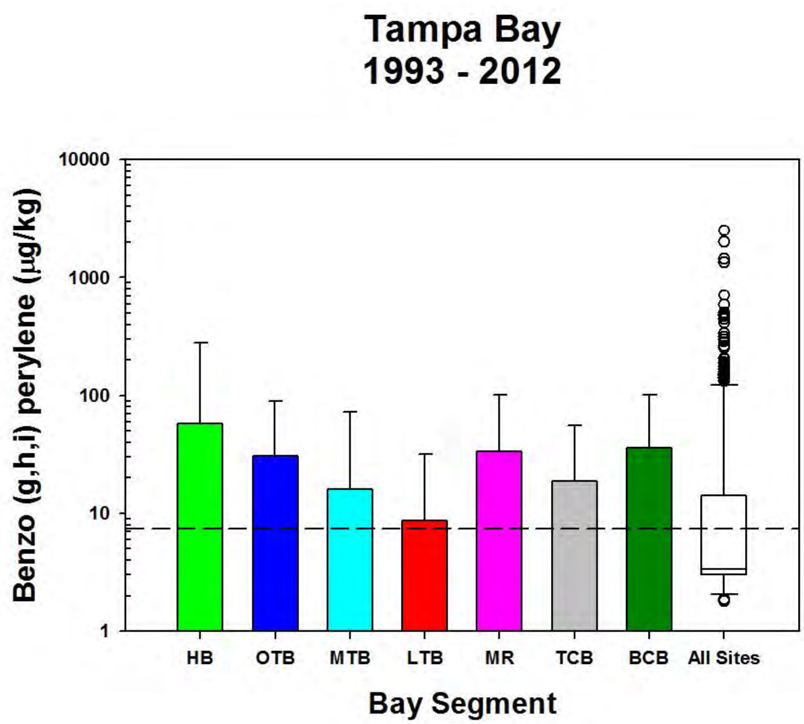


Figure 95. **Mean sediment benzo (g,h,i) perylene concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean.**

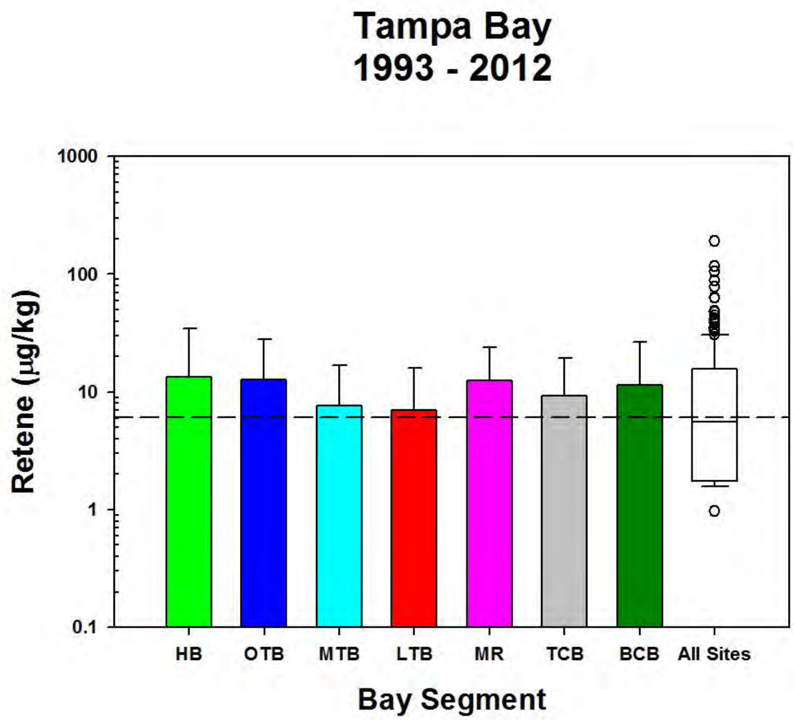


Figure 96. **Mean sediment retene concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean.**

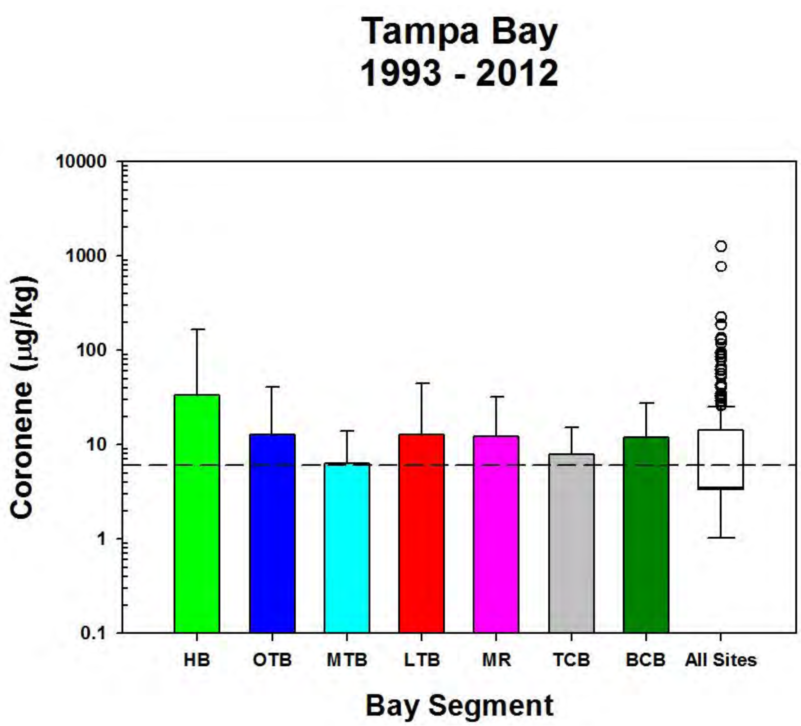


Figure 97. **Mean sediment coronene concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean.**

Polychlorinated biphenyls (PCBs) and Chlorinated Pesticides

Baywide summary statistics for Total PCBs and pesticides are presented in Table 14. The mean values are presented for between bay-segment comparisons, due to the large number of low readings for these contaminants.

Polychlorinated biphenyls (PCBs) ($C_{12}H_xCl_x$; MW = 188.65 – 498.66): Polychlorinated biphenyls (PCBs) are organic compounds composed of a biphenyl polycyclic aromatic hydrocarbon ($C_{12}H_{10}$) with one (monochlorobiphenyl; $C_{12}H_9Cl$) to ten (decachlorobiphenyl; $C_{12}Cl_{10}$) 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 (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). PCBs are known to be carcinogenic and can cause numerous developmental, endocrine and immunological defects (ATSDR, 2000, 2011). 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).

PCBs are stable compounds and insoluble in water and tend to accumulate in fine grained sediments with high organic content (ATSDR, 2000). PCBs bioaccumulate in organisms and biomagnify at higher trophic levels in the food web (Kennish 1998; Fair et al., 2010). 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). PCB levels in marine and freshwater organisms are related to sediment concentrations and proximity of known areas of contamination (Kuzyk et al. 2005; Straub et al. 2007).

The mean total PCBs concentration in Tampa Bay sediments was 4.61 µg/kg with a maximum value of < 200 µg/kg (Table 14). PCBs exceeded the TEL in 1.84% of the sites and was above the PEL at 0.08% of the sites (Table 14). Total PCBs was significantly different between bay segments (KW; $p<0.001$) with the highest values in Hillsborough Bay (Figure 98). The only PEL exceedence was at a site in the Hillsborough River (Figure 99).

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, particularly in the Palm River.

Organochlorine Pesticides

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 (Kamrin 1997; Kennish 1998).Most uses were reduced or eliminated in the United States since the 1970's due to their adverse affects on nontarget organisms, but they are still used in other parts of the world (Kamrin 1997; Kennish 1998). Chlorinated pesticides work by attacking the central nervous system and affecting the sodium/potassium balance along nerves causing continuous transmission of impulses along the nerve fiber (Kamrin 1997; Kennish 1998). This 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 and adsorb to organic sediments. These compounds bioaccumulate and the highest tissue concentrations are found in predatory species at the top of the food chain (Kamrin 1997; Kennish 1998).

Aldrin ($C_{12}H_8Cl_6$; MW = 364.91) and Dieldrin ($C_{12}H_8Cl_6O$; MW = 380.91): Aldrin and dieldrin were used as pesticides on agricultural crops during the 1950's until the US Department of Agriculture suspended its use in 1970, but they were still used for termite control until 1987 (MacDonald 1994; ATSDR 2002a). Both pesticides can cause neurological damage resulting in convulsions and they can cause liver tumors and kidney damage in animals (ATSDR, 2002). Aldrin converts to dieldrin in the environment due to bacterial action and when exposed to sunlight (ATSDR 2002a). Dieldrin is more stable in the environment and persists in soil and sediments (ATSDR, 2002a). High dieldrin concentrations in the sediments have been found to be toxic to amphipods (Swartz et al., 1994). Dieldrin can bioaccumulate in fish tissue (Muller et al., 2004). Frithsen et al. (1995) estimate annual loading of dieldrin to Tampa Bay at 775 kg and 99% of the input is from agricultural runoff.

There was a significant difference among bay segments for aldrin (KW; $p=0.004$). The site with the highest aldrin concentration was in Boca Ciega Bay (Figure 100). Middle Tampa Bay and Terra Ceia Bay had slightly elevated mean levels (Figure 100). Dieldrin was above the TEL concentration in 1.51% of the sites and exceeded its PEL in only 0.17% of the sites (Table 14). There were significant differences between bay segments for dieldrin (KW, $p<0.001$) with Hillsborough Bay having the highest mean value and several sites above the TEL and PEL concentrations (Figures 101 & 102). Dieldrin concentrations were significantly higher in Hillsborough Bay, Old Tampa Bay and Middle Tampa Bay relative to Terra Ceia Bay and the Manatee River.

Total DDT and metabolites: Dichlorodiphenylethane (DDT) was widely used as an agricultural pesticide and for mosquito control throughout the 1960s (Kamrin 1997). DDT has been banned in the United States for over 30 years. Total DDT and its 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 (Kennish 1998). This has historically led to the reproductive failure and population decline of several bird species (Kennish 1998). DDT can accumulate in aquatic food webs (Wang and Wang 2005). It 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). Exposure to DDT can affect the nervous system and cause liver damage (ATSDR 2002b). All metabolites are classified as possible carcinogens (ATSDR 2002b). Results for the three DDT metabolites and total DDT are highlighted below.

Dichlorodiphenyldichoroethane (p,p'-DDD; $C_{14}H_{10}Cl_4$; MW = 320.04): DDD in Tampa Bay sediments had a mean concentration of 0.20 µg/kg with a maximum value of 29.98 µg/kg (Table 14). It was above its TEL at 1.26% of the sites and exceeded its PEL at 4 of the sites (0.34%) (Table 14). DDD levels were highest in Hillsborough Bay with elevated levels in Boca Cieaga Bay and lowest levels in Lower Tampa Bay (KW; p<0.001; Figure 103). The site with the highest concentration was in the Hillsborough River (03HB09, 4x above the PEL). Sites above the PEL were located in the Hillsborough River, Alafia River and McKay Bay (Figure 107).

Dichlorodiphenyldichloroethylene (p,p'-DDE; $C_{14}H_8Cl_4$; MW = 318.02): The mean concentrations of p,p'-DDE in Tampa Bay sediment was 0.51µg/kg with a maximum value of 1,17.35 µg/kg which is 3x above the PEL (Table 14). The TEL for DDE was exceeded at around 2% of the sites and only one site had concentrations above the PEL (03HB09 in the Hillsborough River) (Table 14; Figure 108). DDE was highest in Hillsborough Bay and the Manatee River with lower levels in Middle Tampa Bay (KW; p< 0.001, Figure 104).

Dichlorodiphenyltrichoroethane (p,p'-DDT; $C_{14}H_9Cl_5$; MW = 354.49): The mean concentration for p,p'-DDT in Tampa Bay sediment was 0.21 µg/kg with a maximum value of 43.06 µg/kg (Table 14). Concentrations were above the TEL at 1.34% of the sites and above the PEL at 0.34% of the sites (Table 14). Hillsborough Bay had the highest mean concentration and elevated levels were present in the Manatee River, Terea Ceia Bay and Boca Ciega Bay (Figure 105). The highest concentration was found in a sample collected in the sea plane basin at Davis Island in Hillborough Bay (07HB21) which was 9x greater than the PEL. The other three sites that exceeded the PEL were in the Hillsborough River including sample 03HB09 which was 4x above the PEL (Figure 109).

Total DDT (ΣDDT): Total DDT was generally highest in Hillsborough Bay (Figure 62). High concentrations 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 sites (Table 14).

Lindane (gamma-BHC) and Benzene hexachloride isomers ($C_6H_6Cl_6$; MW = 290.83): Benzene hexachloride (BHC), also known as hexachlorocyclohexane (HCH) is a six carbon ring structure with six attached chlorine atoms (Table 14). Four isomers of BHC which were commonly found in technical grade mixtures of this chemical (ATSDR, 2005e) are presented in Table 14. These include α-BHC, β-BHC, γ-BHC, and δ-BHC. The pesticide lindane (γ-BHC) has been used as an insecticide on crops, to control insect-borne diseases, and in shampoo and lotions to control lice in humans (ATSDR, 2005e, Kamrin 1997). Production of lindane in the United States ended in 1976 but it can still be imported for insecticide use (ATSDR, 2005e). Lindane is highly toxic to aquatic invertebrates and fish (Kamrin 1997), and it affects phytoplankton and zooplankton abundances (Fliedner and Klein 1996). 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. Frithsen et al. (1995) did not include lindane in their loading estimates for Tampa Bay.

The concentration of α-BHC was higher in Hillsborough Bay than in Lower Tampa Bay (KW, $p=0.013$; Figure 111). There were no significant differences among the other bay segments. The mean concentration of β-BHC (Figure 112) was statistically higher in Old Tampa Bay, Boca Ciega Bay and the Manatee River relative to Middle Tampa Bay (KW; $p<0.001$). Mean concentrations were low in Lower Tampa Bay.

Lindane (γ-BHC) was above the TEL concentration in 2.18% of the sites and exceeded the PEL at 0.34% of the sites (Table 14). There was a significant difference in lindane concentrations among bay segments (KW, $p = 0.048$). No pair-wise differences between bay segments were detected and mean values among the bay segments were similar (Figure 113).
Four sites exceeded the PEL for lindane with the highest concentration found at a site in Hillsborough Bay (08HB21), and the other sites being located in Lower Tampa Bay (2 sites) and Middle Tampa Bay at Cockroach Bay (Figure 115).

The concentration of δ-BHC was higher in Old Tampa Bay than in the Manatee River (KW; $p = 0.017$; Figure 114). The other pair-wise comparisons between bay segments had no significant differences.

Endosulfan ($C_6H_6Cl_6O_3S$; MW = 406.93) and Endosulfan sulfate ($C_6H_6Cl_6O_4S$; MW = 422.92): Endosulfan is found in two isomeric forms; endosulfan 1 (α-endosulfan) and endosulfan 2 (β-endosulfan). Endosulfan sulfate is a breakdown product of endosulfan and is more persistant in the environment (ATSDR, 2013). . Endosulfan in the United States is currently restricted to certain crops and is scheduled to be phased out in 2016 (ATSDR, 2013). Exposure to high doses of endosulfan can cause neurological effects such as seizures, kidney damage and death (ATSDR, 2013). It is not known to be carcinogenic (Kamrin, 1997; ATSDR, 2013).

MacDonald (1994) did not establish SQGLs for endosulfan or endosulfan sulfate. The USEPA recommended a level of 62 µg/L for endosulfan sulfate in freshwater lakes, rivers and streams (ATSDR, 2013). The grass shrimp (*Palaemonetes pugio*) had a LC_{50} of 0.92 µg/L for male and 1.99 µg/L for females while mixed populations had a LC_{50} of 0.62 µg/L (Wirth et al., 2001). Grass shrimp embryos exposed to endosulfan had a significantly longer hatching time than without endosulfan (Wirth et al., 2001). Endosulfan exposure delayed reproduction in female grass shrimp and significantly reduced the number of gravid individuals (Wirth et al., 2002). Endosulfan has been found to cause reduced growth rates in some freshwater snails and delay the release of brooding hatchlings in streams near coffee plantations in Jamaica (Ellis-Tabanor and Hyslop, 2005). Embryos of the Oriental fire-bellied toad (*Bombina orientalis*) exposed to endosulfan had decreased survival rate and develop more abnormalities (Kang et al., 2008). Endosulfan can bioaccumulate and potentially be transferred up the food chain. Freshwater crabs initially accumulated endosulfan in the hepatopancreas tissues (digestive gland) and transferred it to the gonads which served a sink for the pesticide (Negro et al., 2012). Exposure to sublethal concentrations of endosulfan have been found to reduce the levels of total proteins and carbohydrates in muscle tissues of commercially important penaeid shrimp (*Metapenaeus monoceros*) decreasing its nutritional value (Suryavanshi et al., 2009).

Mean and median sediment concentrations for endosulfan 1 were higher than both endosulfan 2 and endosulfan sulfate (Table 14). The maximum value for endosulfan 1 occurred in

Hillsborough Bay (95HB22) in the East Bay area of the Port of Tampa near Gannon Power Plant. Hillsborough Bay, Old Tampa Bay, Middle Tampa Bay and Lower Tampa Bay generally had higher median concentrations of endosulfan 1 (KW; $p<0.001$) than the other bay segments, although mean concentrations were similar (Figure 116). Endosulfan 2 concentrations were highest in Hillsborough Bay with highest concentration at the Davis Island Sea plane basin in 2007 (07HB21) (Figure 117). Lower Tampa Bay was significantly lower relative to the other bay segments (KW; $p<0.001$; Figure 117). Endosulfan sulfate had highest sediment concentrations in Hillsborough Bay and the Manatee River (Figure 118) with the maximum concentration occurring at a site in Hillsborough Bay in 2004 (04HB13).

Endrin, Endrin aldehyde and Endrin ketone ($C_{12}H_8Cl_6O$); MW = 380.91): Endrin is a stereoisomer of dieldrin and was used as a pesticide for insects, rodents and birds (ATSDR, 1996). Endrin aldehyde and endrin ketone are degradation products of endrin formed through exposure to heat and light (ATSDR, 1996). All three compounds have the same formula and molecular weight, but they differ in their oxygen bond. Production of endrin in the United States ended in 1986 although it is still used in other countries (ATSDR, 1996). Human exposure to endrin primarily affects the central nervous system, causing convulsions and possibly death at high exposures (ATSDR, 1996). It is not considered to be carcinogenic, but it has been found to cause liver damage and can accumulate in fat tissues (ATSDR, 1996). MacDonald (1994) did not develop SQGLs for endrin, endrin aldehyde or endrin ketone. Bioassys on freshwater chironomid larvae (*Chironomus tentans*) have reported a 10-day LC_{50} of 4.22 ng/g_{oc} (corrected for organic content) (You et al., 2004). Endrin spiked sediments were also found to affect sediment reworking by the freshwater oligochaetes *Limnodrilus hoffmeisteri* and *Stylodrilus heringianus* because their activity was reduced (Keilty et al., 1988). Freshwater oligochaetes can bioaccumulate endrin in their body tissues (Keilty et al., 1988). Freshwater oligochaetes body mass decreased from the endrin exposure probably due to decreased feeding and increased stress from the endrin exposure (Keilty et al., 1988).

The mean concentration of endrin in Tampa Bay sediments was less than its degradation products endrin aldehyde and endrin ketone (Table 14). Endrin concentrations were highest in Terra Ceia Bay with the highest occurring in 2008 at a location in southern Terra Ceia Bay (08TCB26) (Figure 119). Endrin aldehyde concentrations were highest in Hillsborough Bay, Terra Ceia Bay and Boca Ciega Bay (Figure 120). The maximum concentration was found in the East Bay area of the Port of Tampa (04HB10) in 2004. Endrin ketone concentrations were highest in the Manatee River with the maximum value found near Bradenton in 1998 (98MR20).

Chlordane ($C_{10}H_6Cl_8$; MW = 409.78): Total chlordane (ΣChlordane) is a composite of several isomers primarily consisting of α-chlordane (*cis*-chlorodane) and γ-chlordane (*trans*-chlordane) (ATSDR, 1994; MacDonald 1994). Chlordane was formally used as a home and garden pesticide, a treatment for termites, and for wood preservation (ATSDR, 1994, MacDonald 1994; Frithsen et al. 1995). It was only approved for termite control after 1983 (ATSDR, 1994). Chlordane has been banned in the U.S. since 1988 after it was classified as a probable carcinogen by the EPA, although production and export are still allowed (ATSDR, 1994; Kamrin, 1997). Exposure to chlorodane can cause cancer, neurological symptoms and liver damage (ATSDR, 1994). This pesticide is highly toxic to marine and aquatic organisms, particularly crustaceans and aquatic insects (Kamrin 1997; Moore et al. 1998). Chlordane can also accumulate in the fatty tissues of commercially and recreationally important fish and shellfish (Kennish and Ruppel 1996, 1997). 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).

The summary statistics for both chlordane isomers and total chlordane are shown in Table 14. Sediment concentrations for α-chlordane were highest in Hillsborough Bay with maximum values at sites in the Hillsborough River (03HB09) and Alafia River (03HB06) (Figure 122). Sediment concentrations for γ-chlordane were the highest in Hillsborough Bay and maximum values were recorded in the Hillsborough River (03HB09; 98HB006) and in Seddon Channel near the mouth of the Hillsborough River (Figure 123). Sediment concentrations for Total chlordane were highest in Hillsborough Bay and Old Tampa Bay (Figure 125). Total chlordane concentrations for Tampa Bay sediments were above the TEL at 0.67% of the samples and 0.92% of the sites were above the PEL (Table 14). Locations exceeding the PEL were primarily in Hillsborough Bay including sites within the Hillsborough River, Alafia River and McKay Bay (Figure 125). Old Tampa Bay, the Manatee River and Coffeepot Bayou in St. Petersburg had only a single site that exceeded the PEL (Figure 125). Two sites with exceedingly high total chlordane values were in the Hillsborough River (03HB09) and in Old Tampa Bay (95OTB15) (35x and 28x higher than PEL, respectively). Both sites were near shore to urban residential areas.

Heptachlor ($C_{10}H_5Cl_7$; MW = 373.32) and Heptachlor epoxide ($C_{10}H_5Cl_7O$; MW = 389.32): Heptachlor is a component and breakdown product of chlordane and has a similar chemical structure. Heptachlor epoxide is a metabolite produced from the bacterial breakdown of heptachlor in the environment or from the metabolism of heptachlor in animals [Kamrin, 1997, Syracuse Research Corporation (SRC), 2007]. Heptachlor was used as a pesticide on crops and in homes (to control ants, termites and soil insects) until it was phased out in 1988 (Kamrin, 1997; SRC, 2007). It is still approved by the EPA to control fire ants in power transformers (Kamrin, 1997; SRC, 2007). Exposure to high levels of heptachlor can damage the liver, kidneys, and red blood cells (Kamrin, 1997; SRC, 2007). It also can cause neurotoxic effects such as convulsions and coma (Kamrin, 1997; SRC, 2007). Heptachlor and heptachlor epoxide are toxic to birds, fish and aquatic invertebrates (SCR, 2007). They can bioconcentrate in fatty tissues and biomagnify in the food chain (SCR, 2007). MacDonald (1994) did not establish SQGLs for either heptachlor or heptachore epoxide.

The mean concentration of heptachlor in Tampa Bay sediments was 0.23 µg/kg, with a maximum value of 10.1 µg/kg (Table 14). The highest mean concentrations were in Boca Ciega Bay in Mullet Key Bayou (10BCB46) and near Madelaine Key south of Bunces Pass (07BCB41) (Figure 126). Terra Ceia Bay and the Manatee River had lower levels of heptachlor relative to the other bay segments (KW; $p<0.001$).

The mean concentration heptachlor epoxide in Tampa Bay sediments was 0.14 µg/kg with a maximum value of 2.10 µg/kg (Table 14). The highest concentration was found in the Hillsborough River (98HB006). Mean concentrations were significantly lower in the Manatee River, Terra Ceia Bay and Boca Ciega Bay compared to the other bay segments (KW; $p<0.001$; Figure 127).

Methoxychlor ($C_{16}H_{15}Cl_3O_2$; MW = 345.65): Methoxychlor has a similar structure to DDT, but is considered to be less toxic to humans and other mammals (Kamrin, 1997). It is still manufactured and used in the United States (Kamrin, 1997). It is currently used to control insects on agricultural crops, live stock, ornamental gardens and pets (ATSDR, 2002c). It has not been found to be carcinogenic to humans, but animals exposed to high doses have exhibited neurological symptoms such as convulsions (ATSDR, 2002c). Several methoxychlor metabolites are similar to estrogen and have been found to reduce fertility, alter mating cycles and affect reproductive organs in rats (Kamrin, 1997; ATSDR 2002c). Exposure to methoxychlor was found to inhibit testosterone production in ovarian tissues in freshwater bass (Borgert et al., 2004). Methoxychlor has a low toxicity to birds (Kamrin, 1997). It is highly toxic to aquatic invertebrates and some fish (Kamrin, 1997). MacDonald (1994) did not establish SQGLs for Methoxychlor; however, You et al. (2004) determined a 10-day LC_{50} of 36.7 $\mu g/g_{oc}$ for aquatic insects (*Chironomus tentans*) and 85 $\mu g/g_{oc}$ for the freshwater amphipod *Hyalella azteca* in spiked sediments. Methoxychlor can bioaccumulate in invertebrates (Kamrin, 1997; ATSDR 2002c). Most fish can metabolize and excrete methoxychlor, and it is not believed to accumulate in the food web (Kamrin, 1997; ATSDR 2002c).

The mean concentration of methoxychlor in Tampa Bay sediments was 0.28 µg/kg with a maximum value of 55.94 µg/kg (Table 14). Mean concentrations were highest in Hillsborough Bay with the maximum concentration found in the sea plane basin at Davis Island (07HB21). There was a significant difference among the bay segments (KW; p=0.012), but no pair-wise differences were found between bay segments.

Mirex ($C_{10}Cl_{12}$; MW = 545.54): Mirex was manufactured and used as a pesticide in the United States during the 1960s and 1970s until production was stopped in 1976 (ATSDR, 1995b). It was used primarily for the control of fire ants and as a fire retardant under the trade name Dechlorane®in plastics, rubber, paper and electrical products (ATSDR, 1995b). Mirex is classified as a possible carcinogen (ATSDR, 1995b). Exposure to mirex can cause damage to the digestive system, liver, kidneys and affect the nervous and reproductive systems (ATSDR, 1995b). Mirex reacts when exposed to light to form photomirex which is more toxic than mirex (ATSDR, 1995b). Mirex is toxic to aquatic invertebrates (Naqvi and de la Cruz, 1973) and can bioaccumulate in fish and marine mammals (ATSDR, 1995; Yougui et al., 2003).

The mean concentration of mirex in Tampa Bay sediments was 0.15µg/kg with a maximum recorded value of 41.1 µg/kg (Table 14). The highest mean concentration was in Hillsborough Bay near Ballast Point sampled in 2008 (08HB13). Mean concentrations were highest in Hillsborough Bay and Boca Ciega Bay (Figure 129).

Table 14. Total PCBs and Pesticide summary statistics.

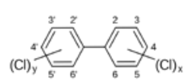
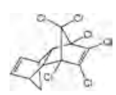
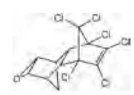
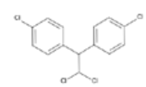
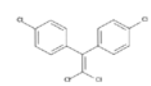
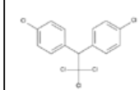
µg/kg	ΣPCBs	Aldrin	Dieldrin	p,p'-DDD	p,p'-DDE	p,p'-DDT	ΣDDT
MW	188.65 – 498.66	364.91	380.91	320.04	318.02	354.49	
Formula	$C_{12}H_xCl_x$	$C_{12}H_8Cl_6$	$C_{12}H_8Cl_6O$	$C_{14}H_{10}Cl_4$	$C_{14}H_8Cl_4$	$C_{14}H_9Cl_5$	
Structure							
TEL	21.6	ND	0.72	1.2	2.1	1.2	3.89
PEL	189	ND	4.3	7.8	37.4	4.8	51.7
n	1194	1194	1194	1194	1194	1194	1194
Minimum	0.43	0.01	0.01	0.02	0.02	0.02	0.08
Maximum	199.90	1.49	7.87	29.98	117.35	43.06	166.36
Median	2.70	0.09	0.07	0.07	0.15	0.09	0.25
Mean	4.61	0.08	0.11	0.20	0.51	0.21	0.93
SD	9.56	0.10	0.34	1.06	3.94	1.40	5.82
% >TEL;<PEL	**1.84%**		**1.51%**	**1.26%**	**2.09%**	**1.34%**	**1.84%**
% >PEL	**0.08%**		**0.17%**	**0.34%**	**0.08%**	**0.34%**	**0.17%**

Table 14. Continued

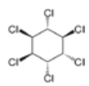
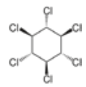
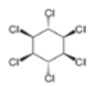
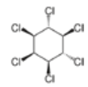
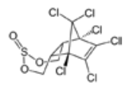
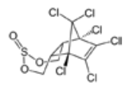
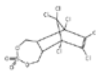
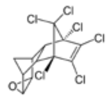
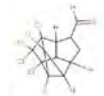
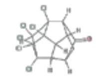
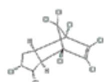
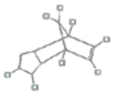
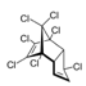
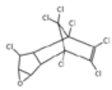
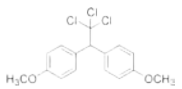
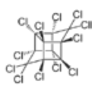
µg/kg	α- BHC	β-BHC	γ-BHC (Lindane)	δ-BHC	Endosulfan 1	Endosulfan 2	Endosulfan sulfate	Endrin	Endrin aldehyde	Endrin ketone
MW	290.83	290.83	290.83	290.83	406.93	406.93	422.92	380.91	380.91	380.91
Formula	$C_6H_6Cl_6$	$C_6H_6Cl_6$	$C_6H_6Cl_6$	$C_6H_6Cl_6$	$C_6H_6Cl_6O_3S$	$C_6H_6Cl_6O_3S$	$C_6H_6Cl_6O_4S$	$C_{12}H_8Cl_6O$	$C_{12}H_8Cl_6O$	$C_{12}H_8Cl_6O$
Structure										
TEL	ND	ND	0.32	ND	ND	ND	ND	ND	ND	ND
PEL	ND	ND	0.99	ND	ND	ND	ND	ND	ND	ND
n	1194	1194	1194	1194	1194	1194	1194	1194	1194	1194
Minimum	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.02
Maximum	4.61	21.20	1.80	2.50	4.90	3.76	5.14	3.32	4.67	5.10
Median	0.05	0.10	0.05	0.09	0.15	0.05	0.05	0.05	0.05	0.13
Mean	0.09	0.25	0.09	0.12	0.16	0.09	0.08	0.08	0.14	0.13
SD	0.18	1.04	0.13	0.15	0.23	0.20	0.20	0.16	0.29	0.20
% >TEL;<PEL			**2.18%**							
% >PEL			**0.34%**							

Table 14. Continued.

µg/kg	α-Chlordane	γ-Chlordane	ΣChlordane	Heptachlor	Heptachlor Epoxide	Methoxychlor	Mirex
MW	409.78	409.78	409.78	373.32	389.32	345.65	545.54
Formula	$C_{10}H_6Cl_8$	$C_{10}H_6Cl_8$	$C_{10}H_6Cl_8$	$C_{10}H_5Cl_7$	$C_{10}H_5Cl_7O$	$C_{16}H_{15}Cl_3O_2$	$C_{10}Cl_{12}$
Structure							
TEL	ND	ND	2.3	ND	ND	ND	ND
PEL	ND	ND	4.8	ND	ND	ND	ND
n	1101	1101	1194	1194	1194	1194	1194
Minimum	0.01	0.01	0.03	0.02	0.03	0.03	0.02
Maximum	76.35	90.40	166.75	10.10	2.10	55.94	41.10
Median	0.05	0.05	0.10	0.10	0.05	0.10	0.05
Mean	0.19	0.23	0.59	0.23	0.14	0.28	0.15
SD	2.38	2.82	6.38	0.43	0.18	1.67	1.24
% >TEL;<PEL			**0.67%**				
% >PEL			**0.92%**				

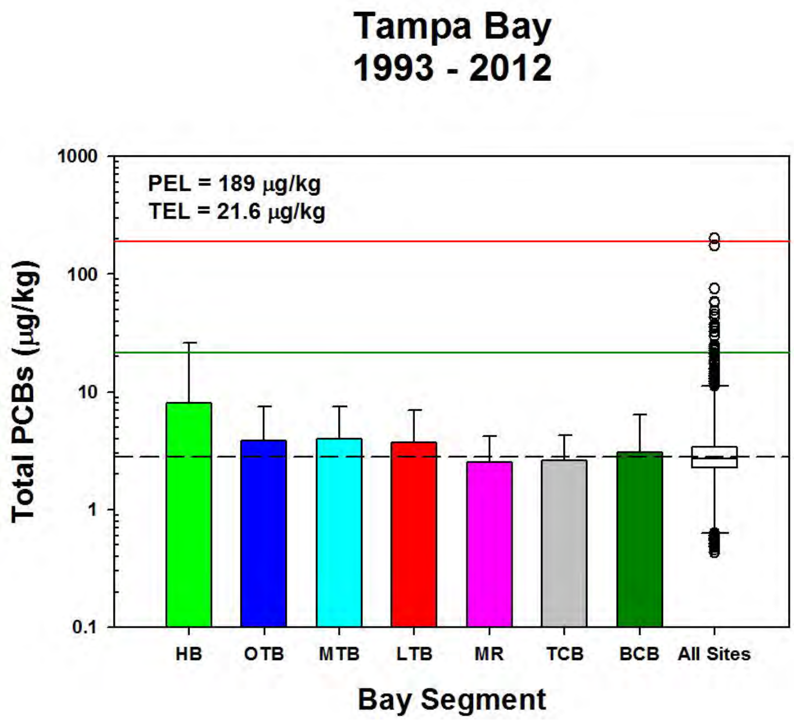


Figure 98. Mean sediment total PCB concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.

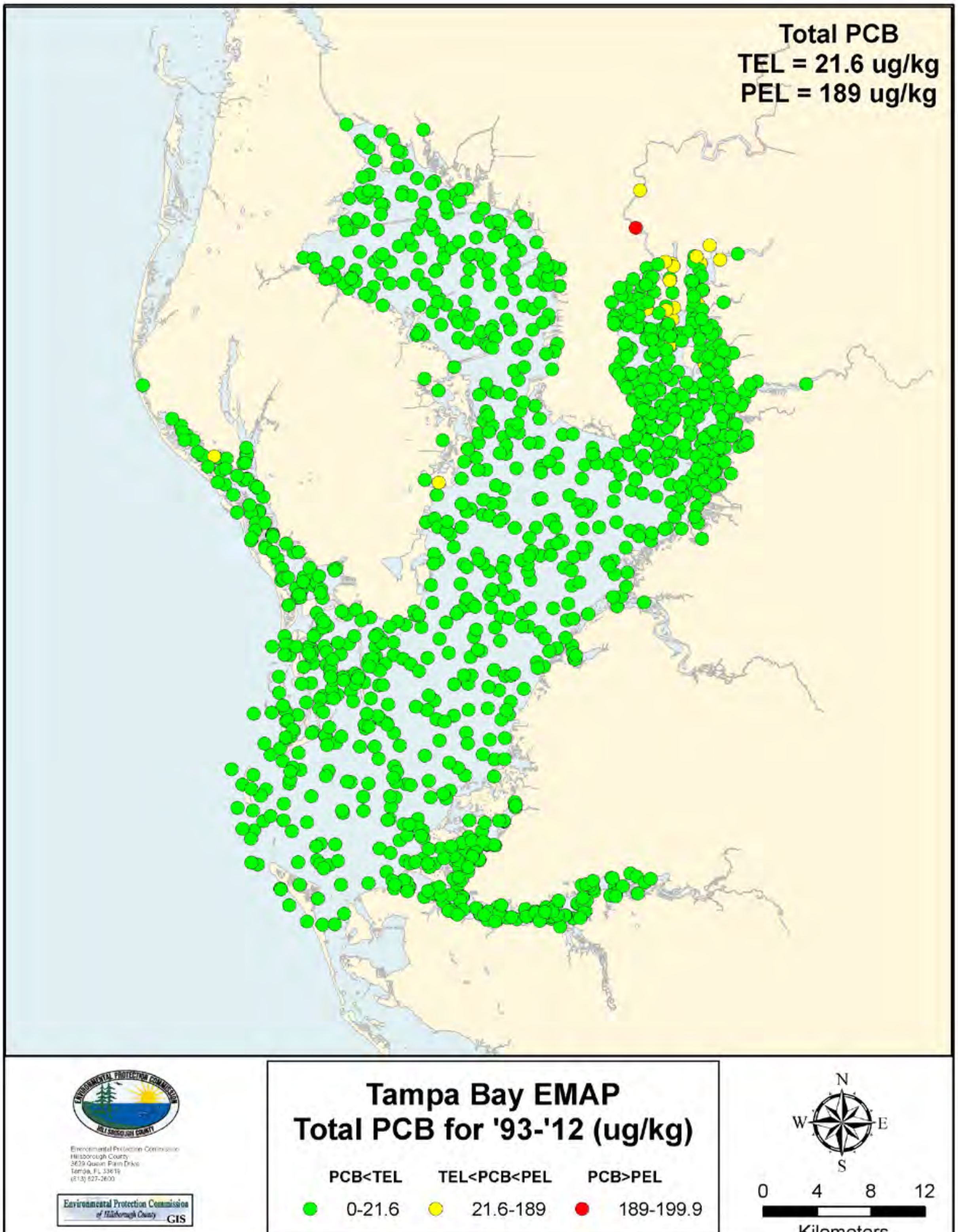


Figure 99. **Distribution of total PCBs in Tampa Bay (1993-2012).**

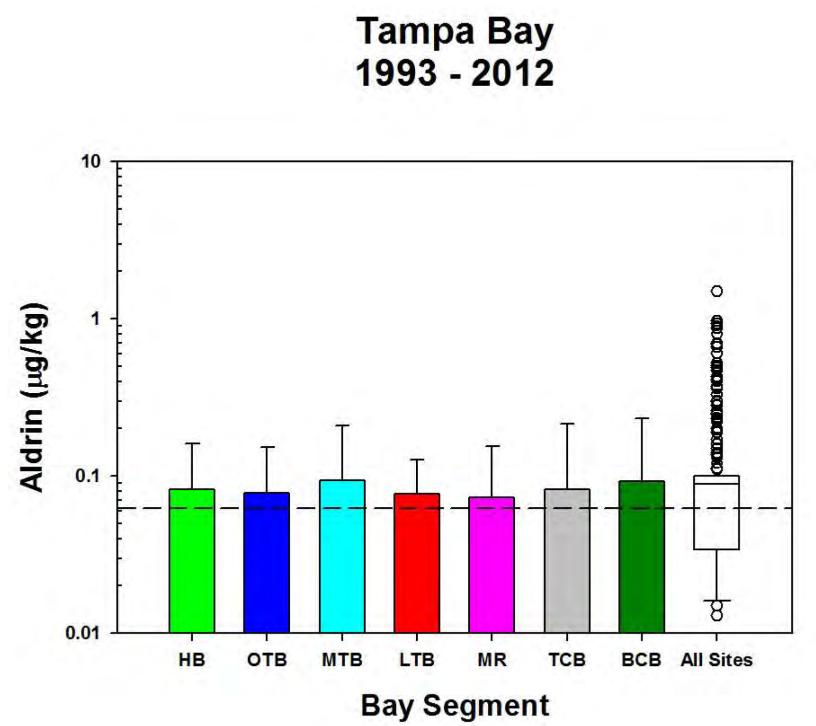


Figure 100. **Mean sediment aldrin concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean.**

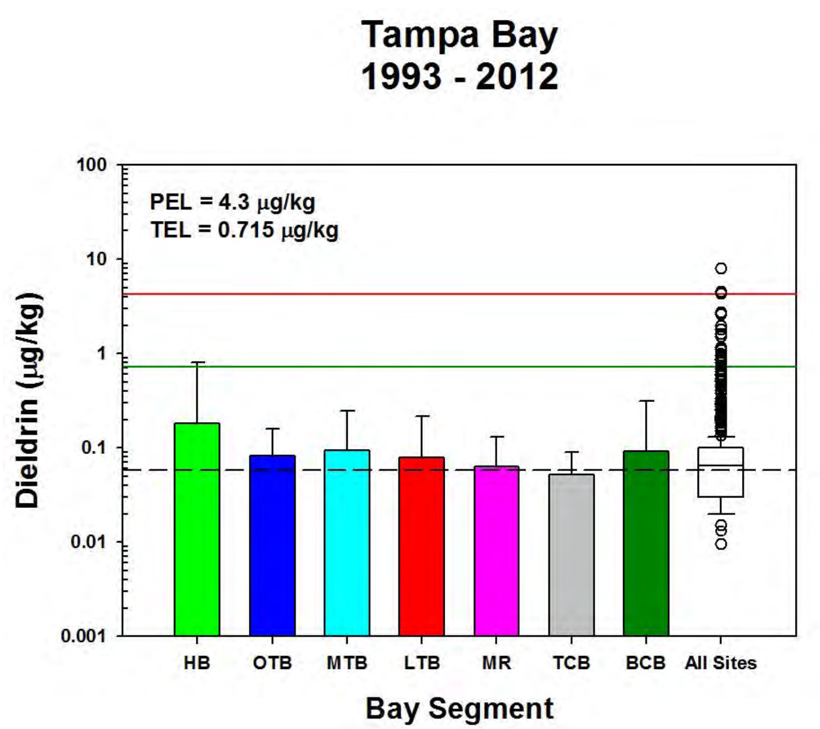


Figure 101. **Mean sediment dieldrin concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.**

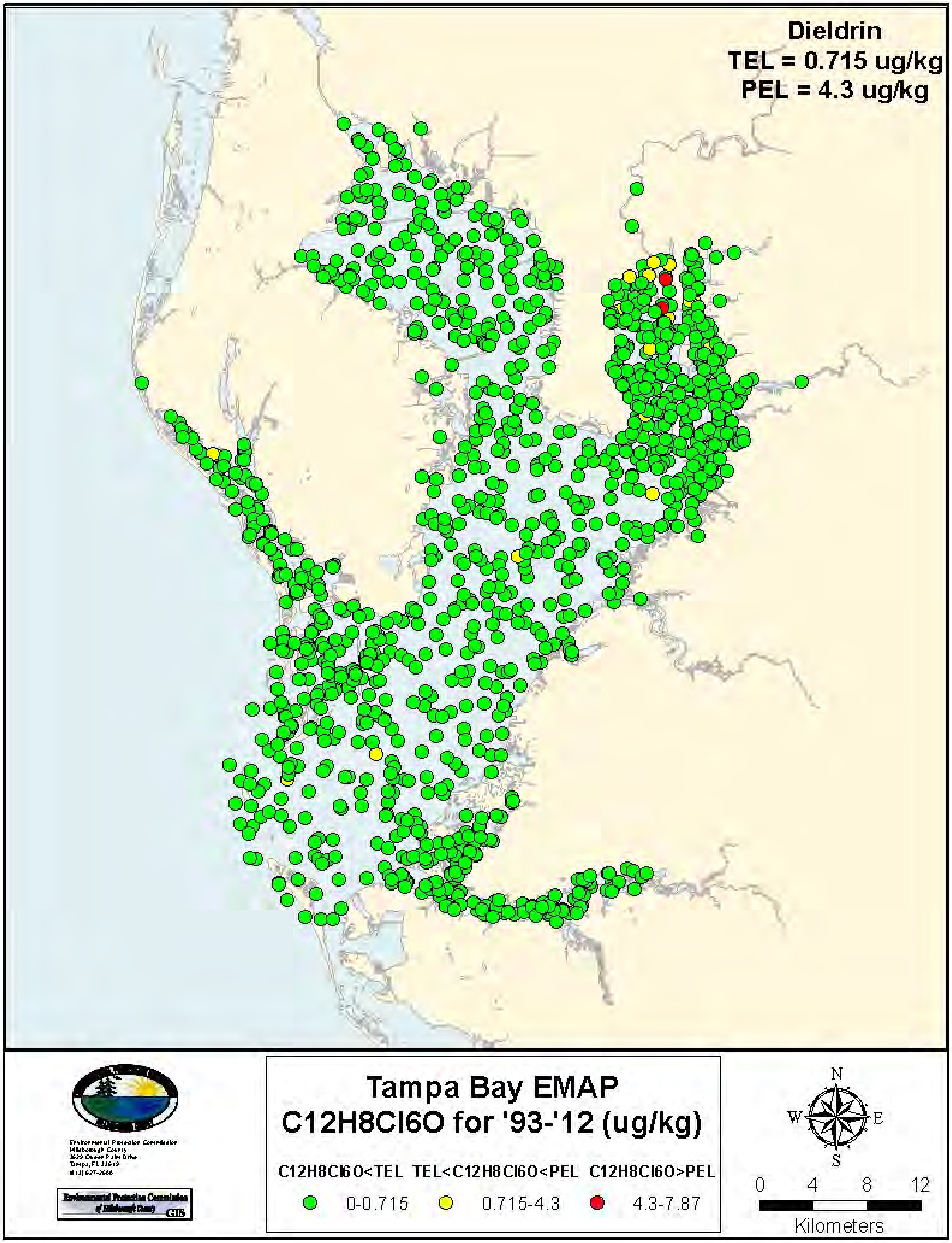


Figure 102. Distribution of dieldrin in Tampa Bay (1993-2012).

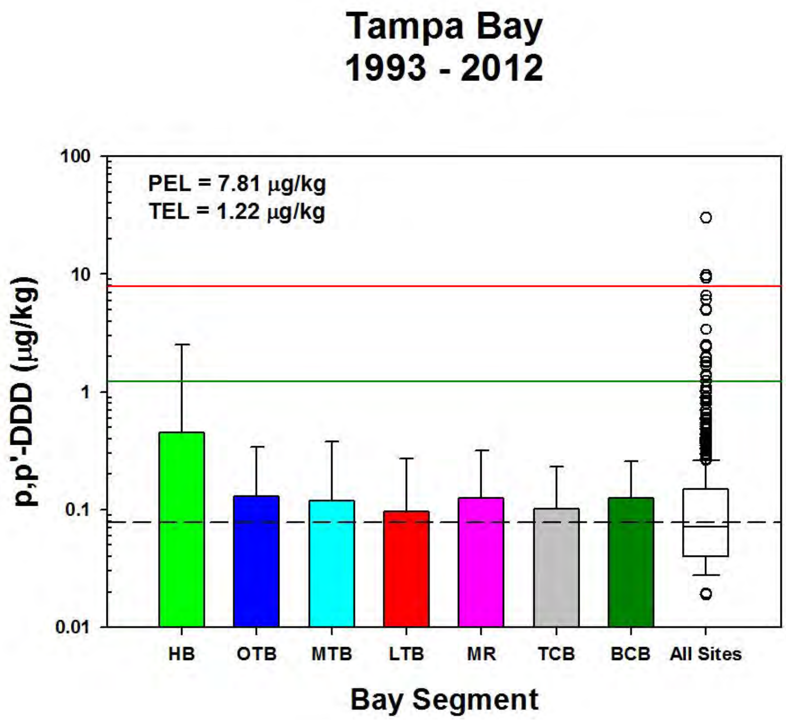


Figure 103. **Mean sediment p,p'-DDD concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.**

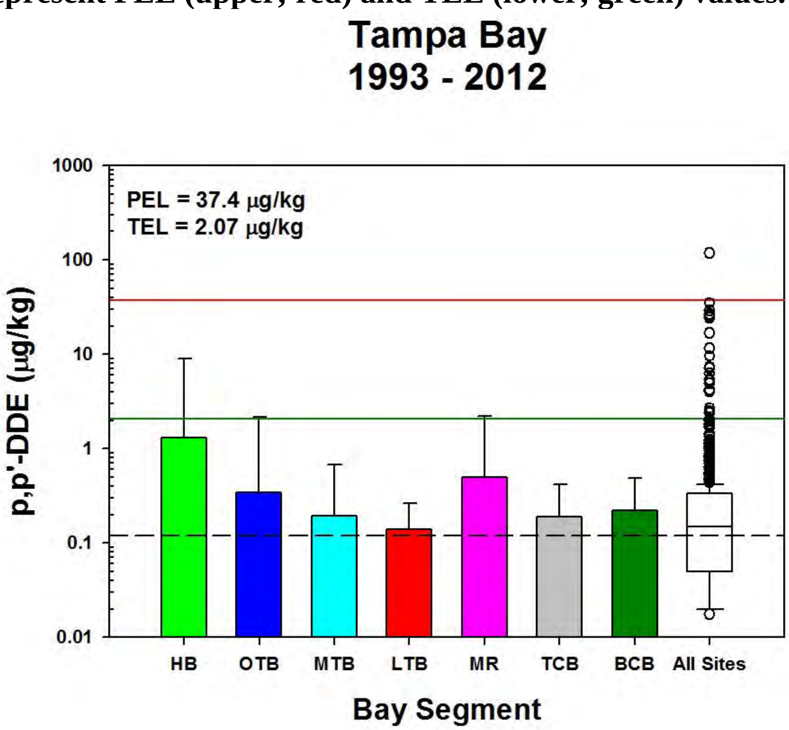


Figure 104. **Mean sediment p,p'-DDE concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.**

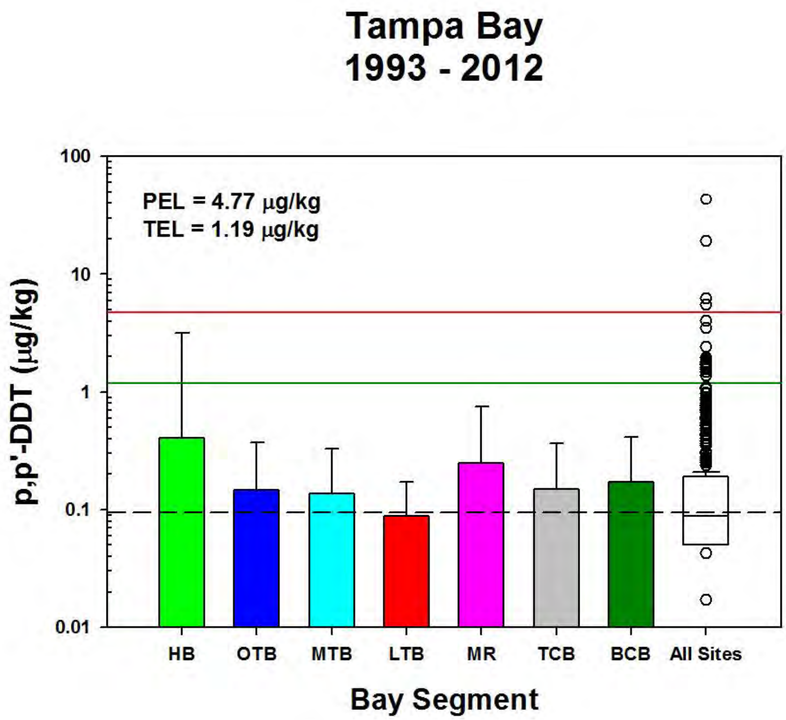


Figure 105. **Mean sediment p,p'-DDT concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.**

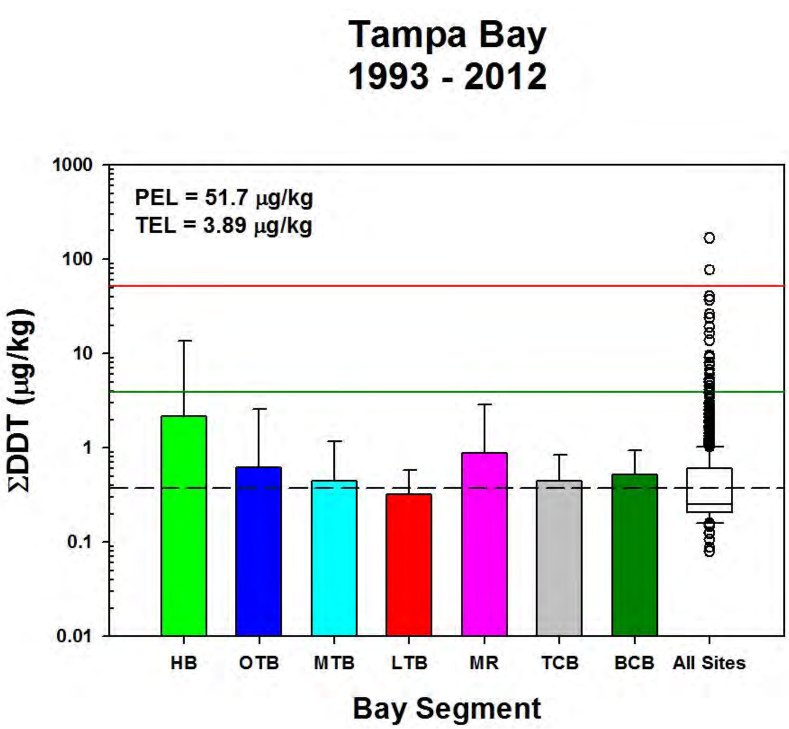


Figure 106. **Mean sediment total DDT concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.**

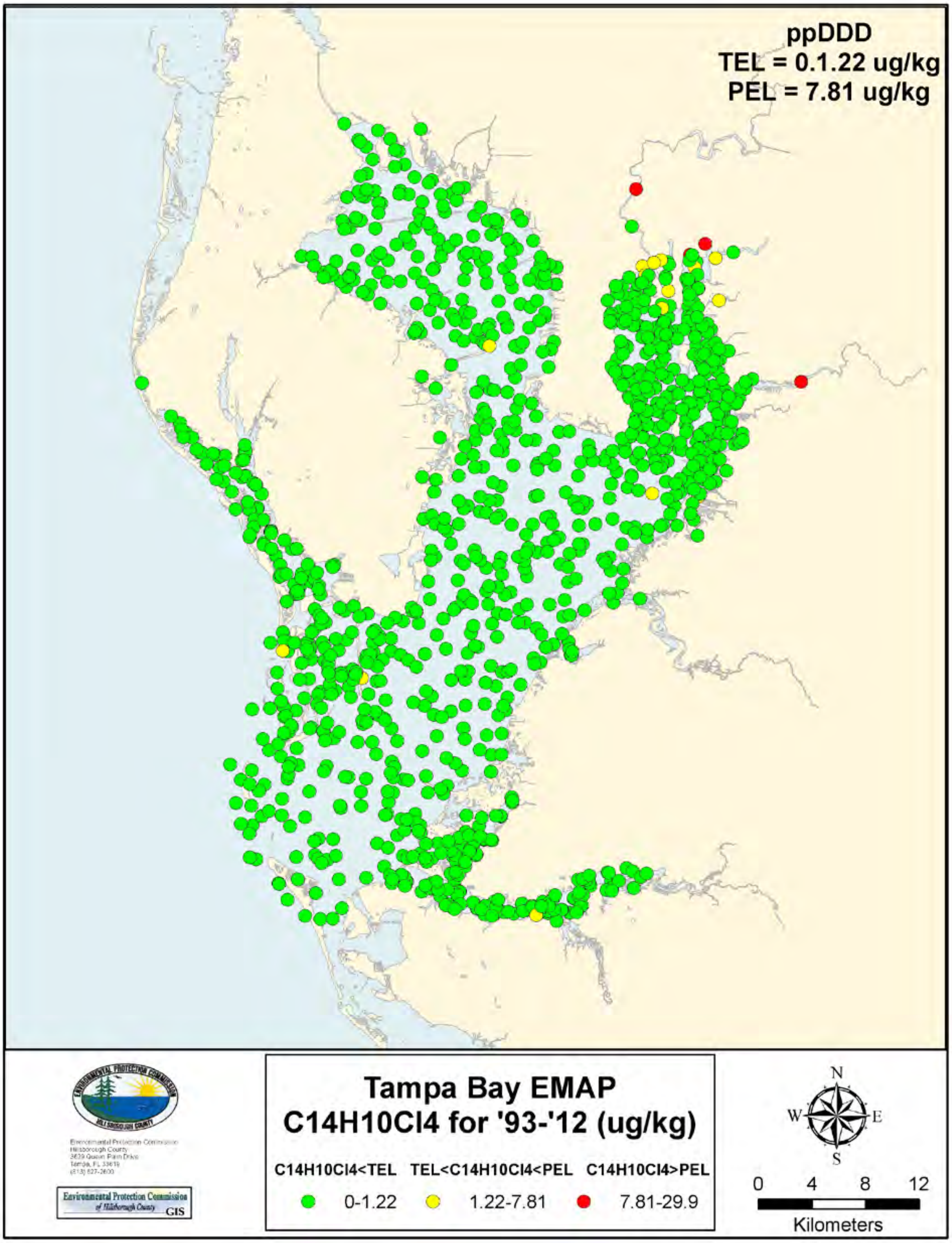


Figure 107. Distribution of p,p'-DDD in Tampa Bay (1993-2012).

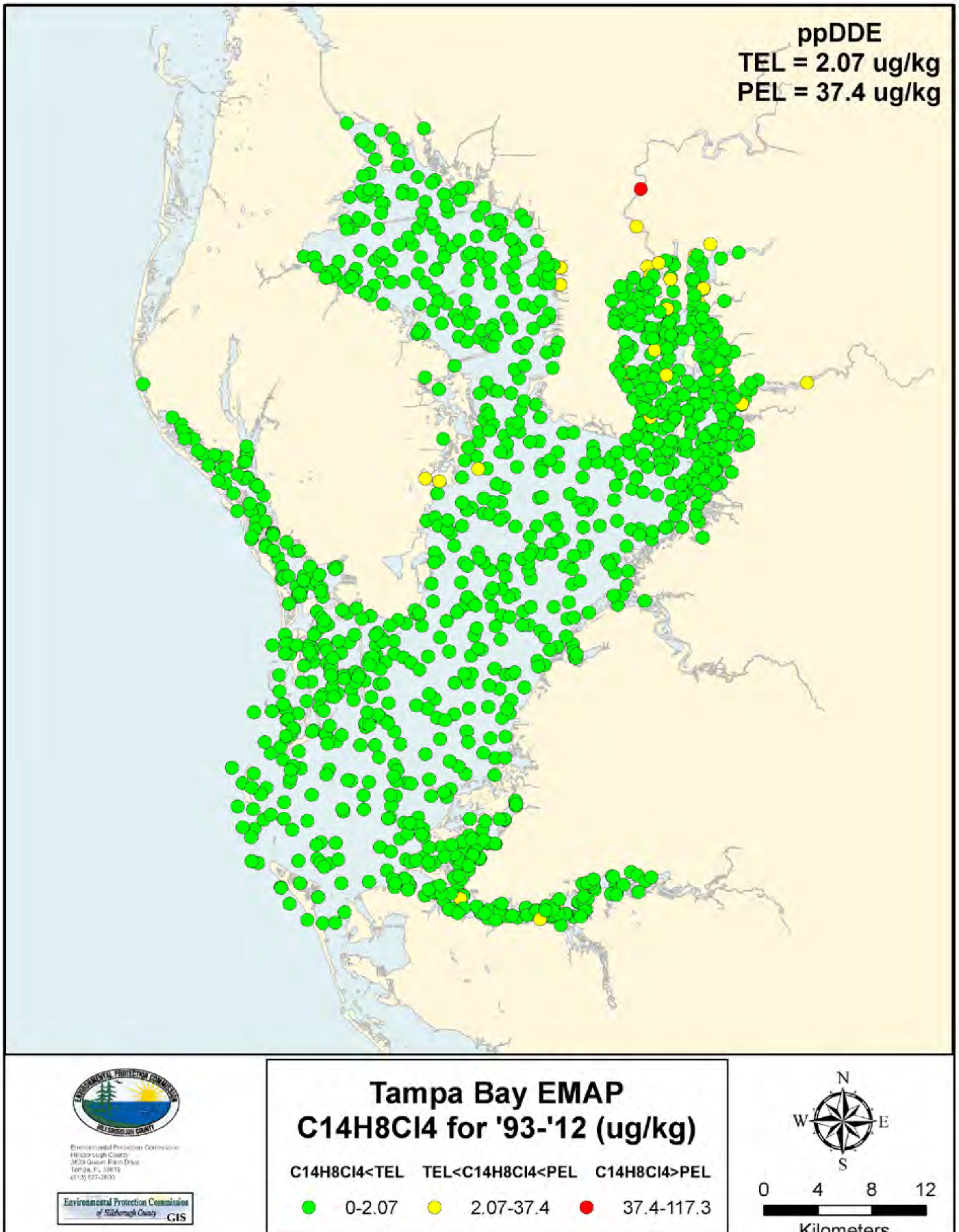


Figure 108. **Distribution of p,p'-DDE in Tampa Bay (1993-2012).**

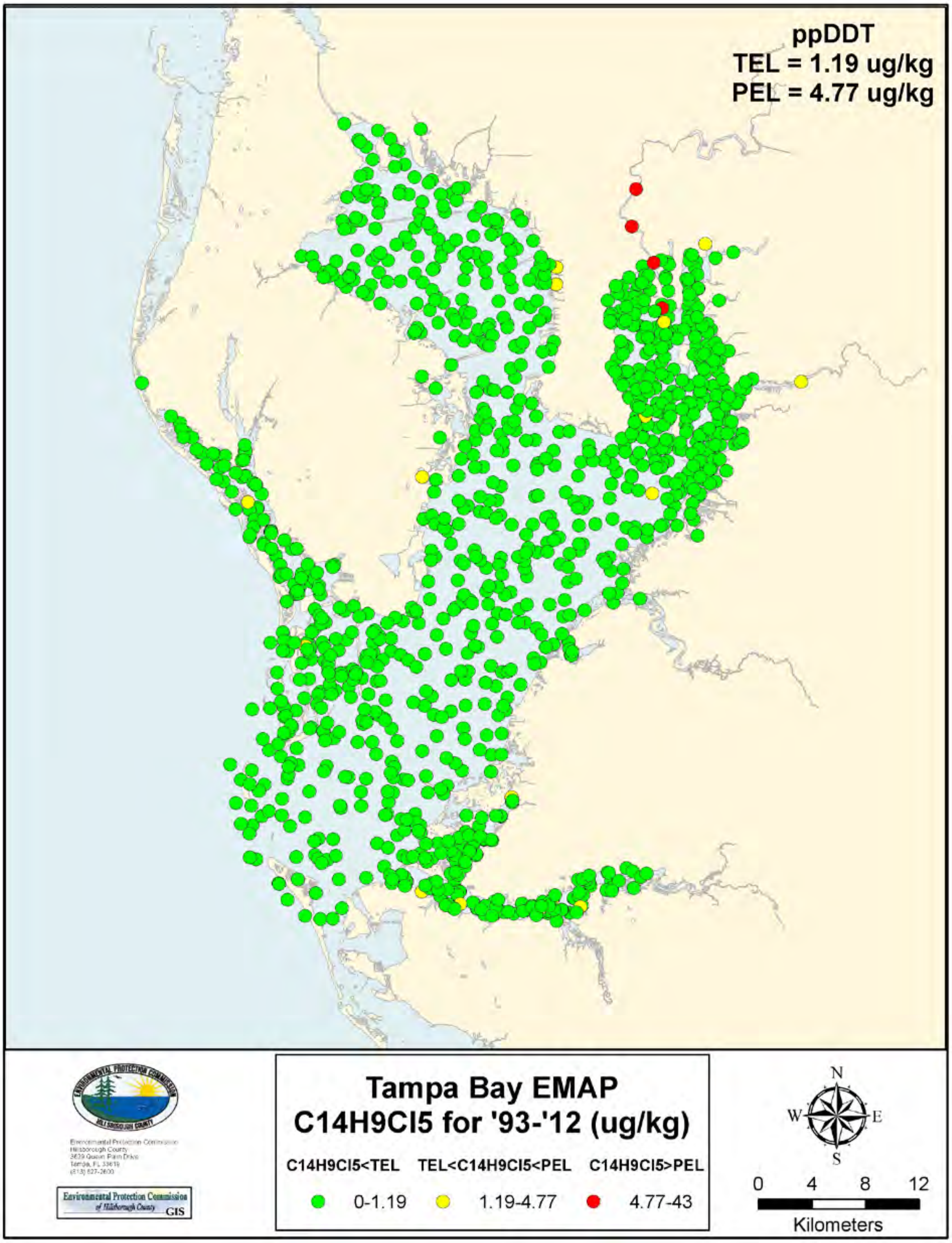


Figure 109. Distribution of p,p'-DDT in Tampa Bay (1993-2012).

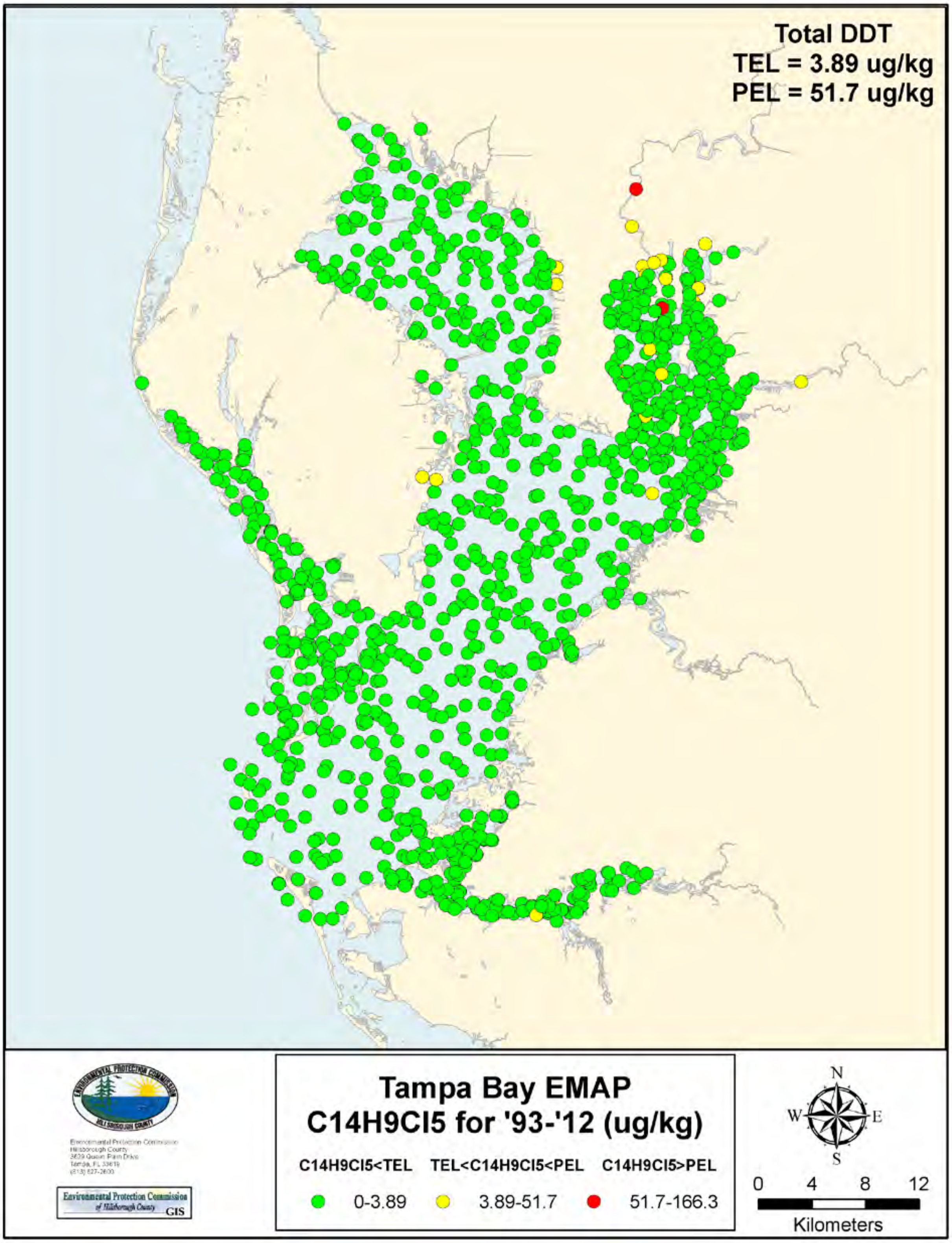


Figure 110. Distribution of total DDT in Tampa Bay (1993-2012).

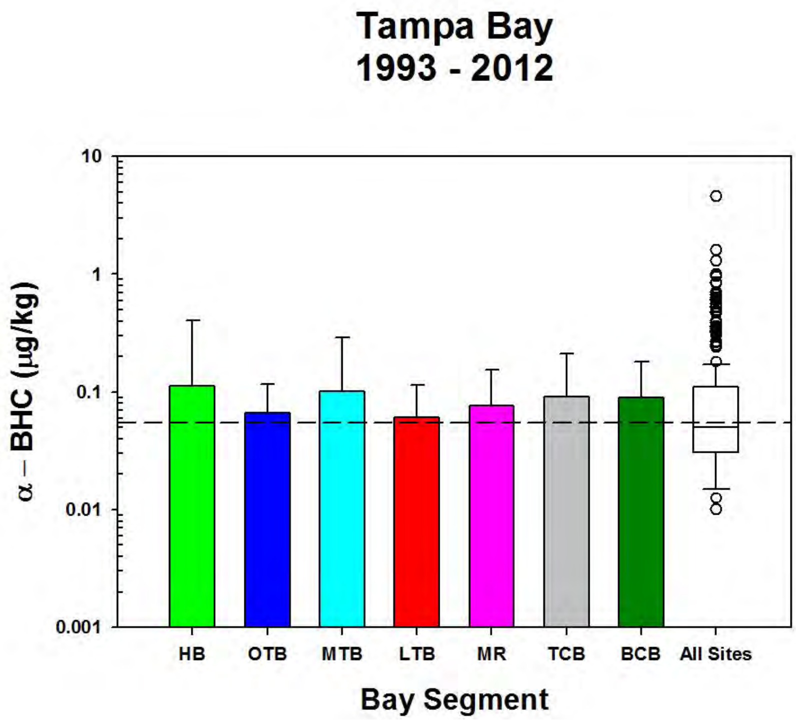


Figure 111. **Mean sediment α-BHC concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean.**

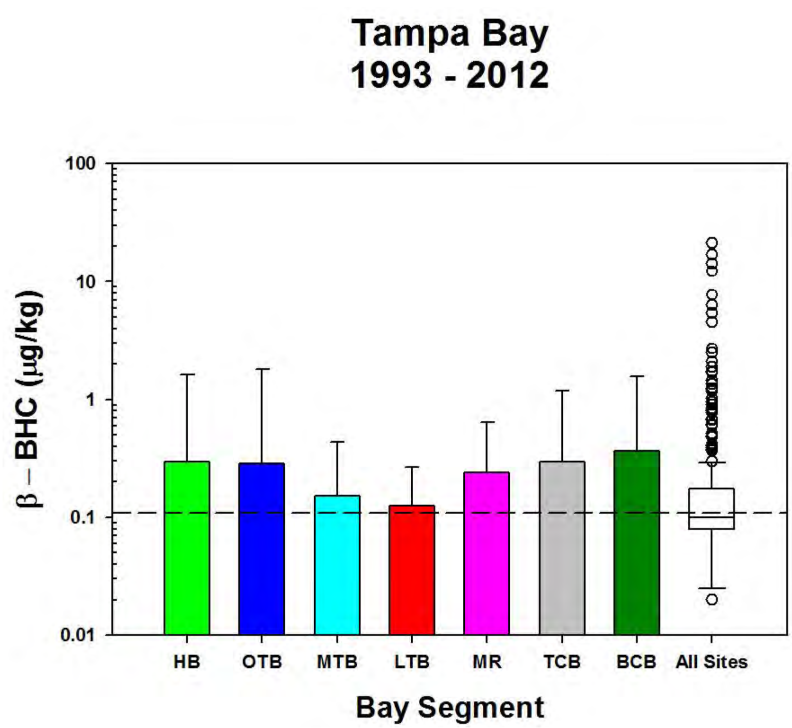


Figure 112. **Mean sediment β-BHC concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean.**

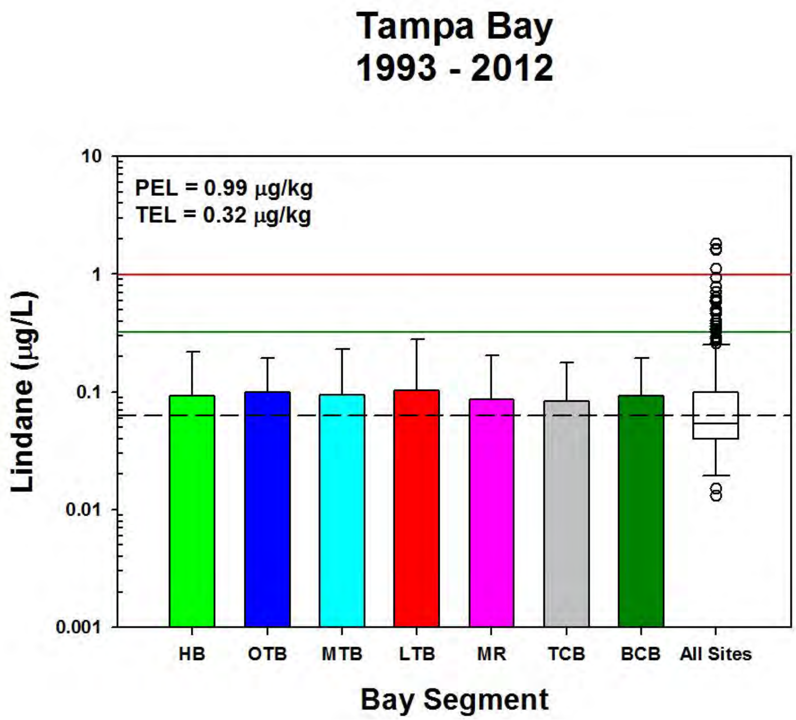


Figure 113. **Mean sediment lindane (γ-BHC) concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.**

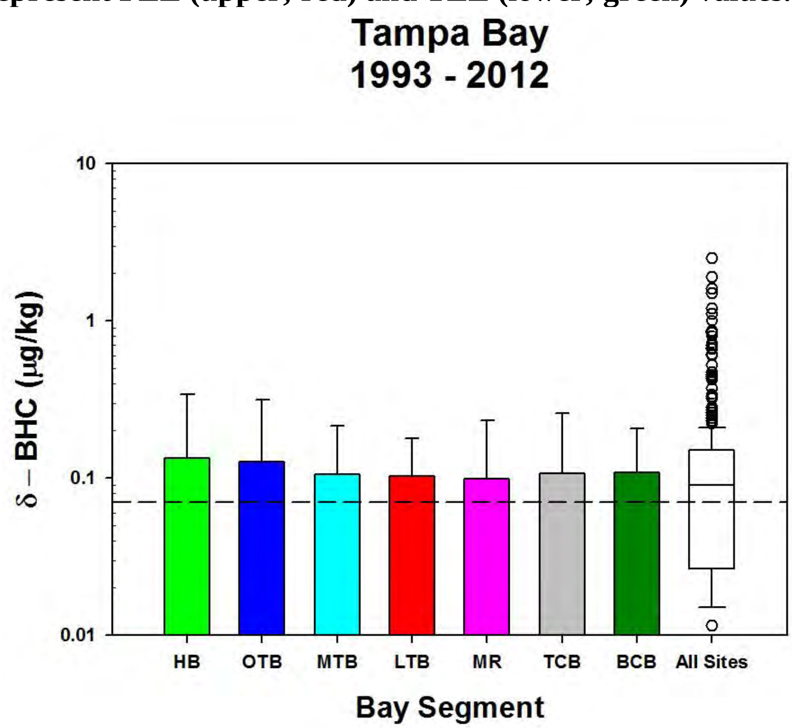


Figure 114. **Mean sediment δ-BHC concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean.**

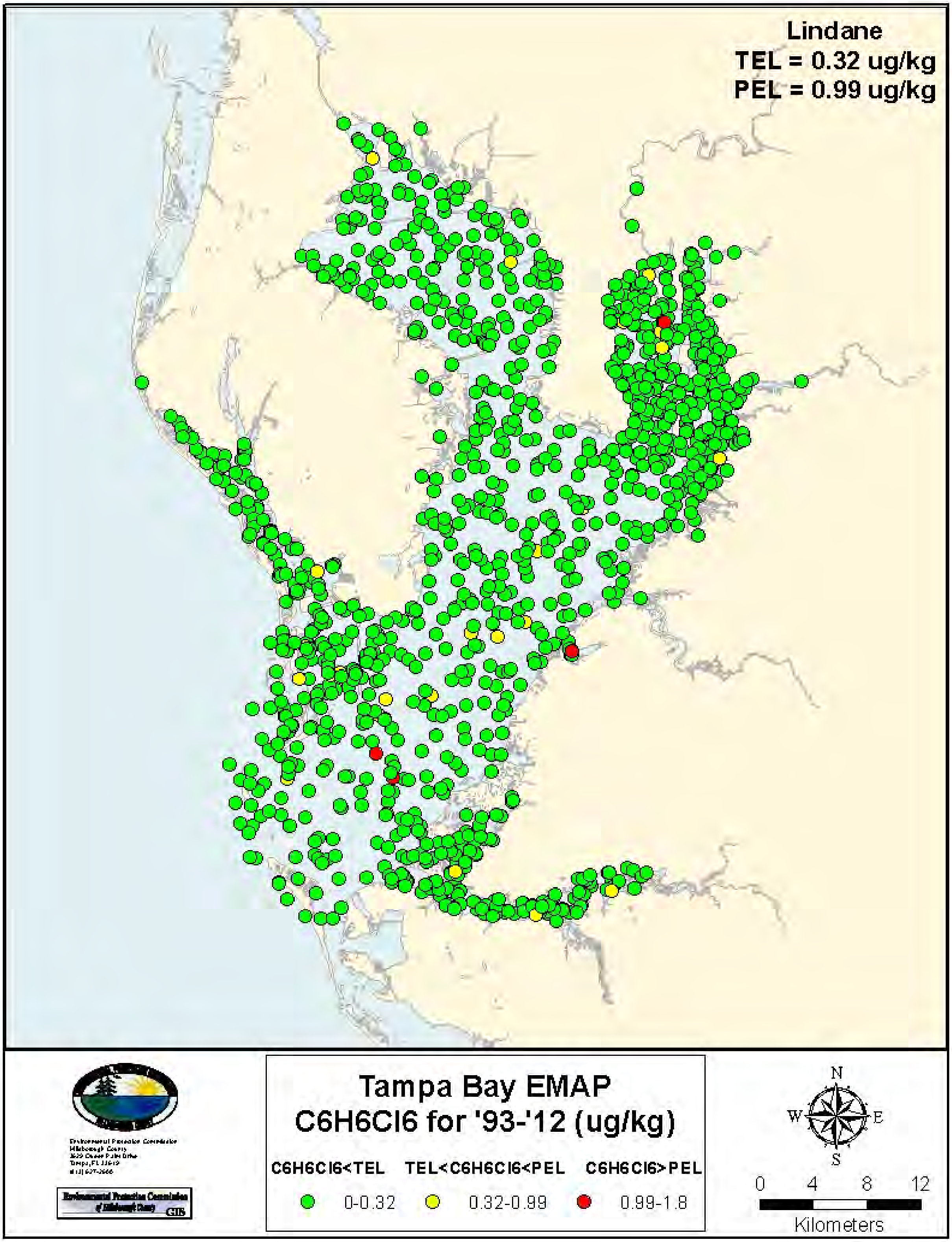


Figure 115. Distribution of lindane in Tampa Bay (1993-2012).

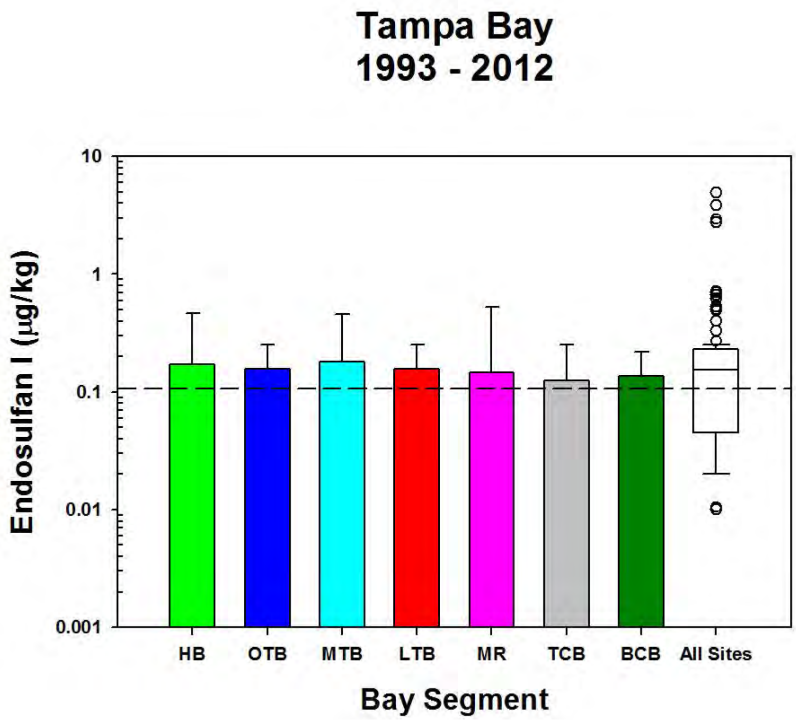


Figure 116. Mean sediment endosulfan l concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean.

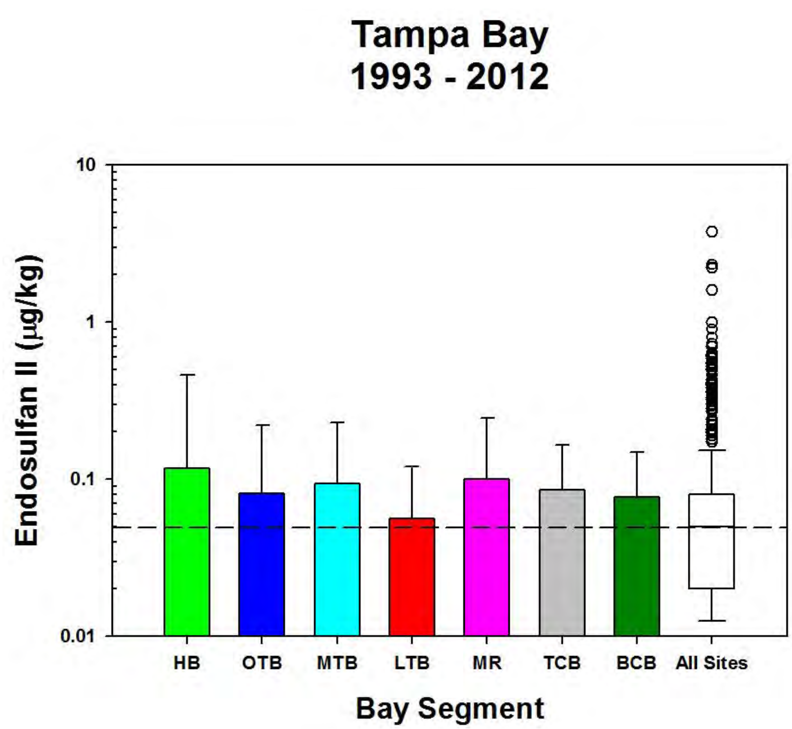


Figure 117. Mean sediment endosulfan ll concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean.

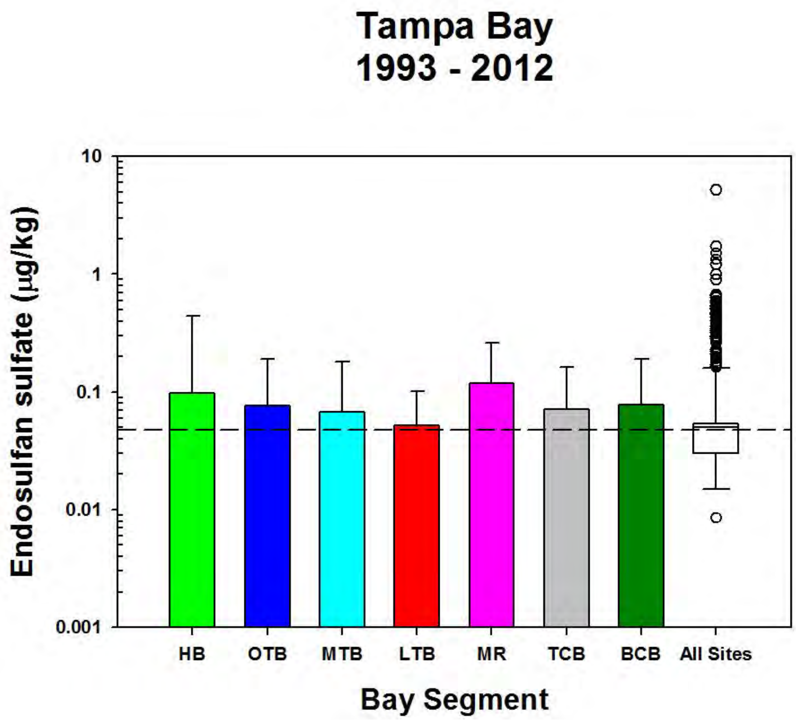


Figure 118. **Mean sediment endosulfan sulfate concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean.**

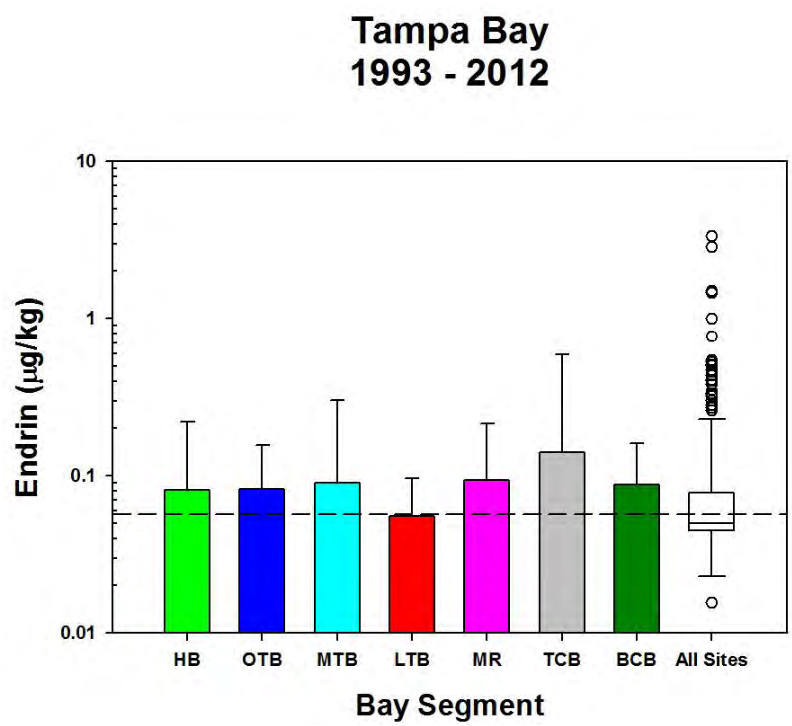


Figure 119. **Mean sediment endrin concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean.**

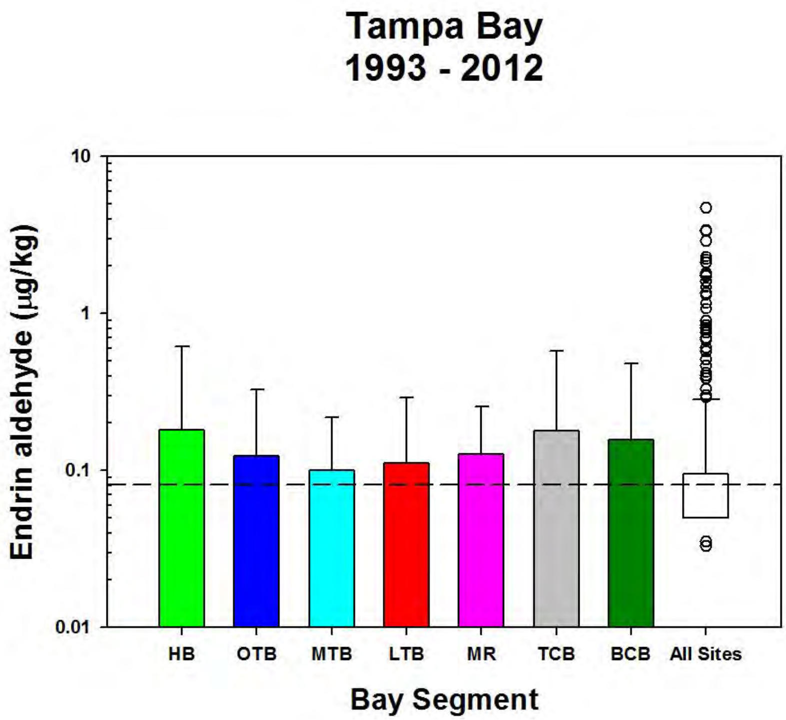


Figure 120. **Mean sediment endrin aldehyde concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean.**

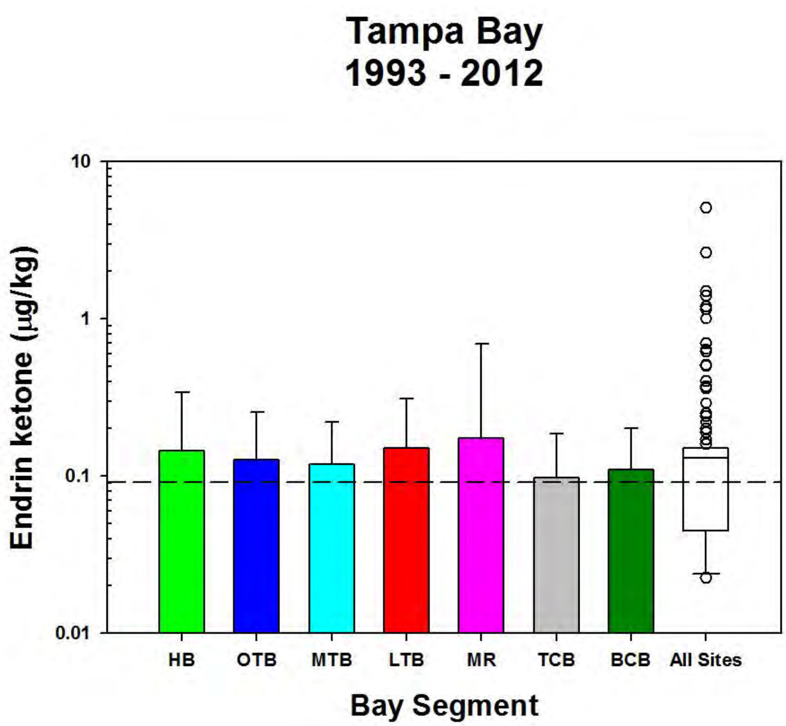


Figure 121. **Mean sediment endrin ketone concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean.**

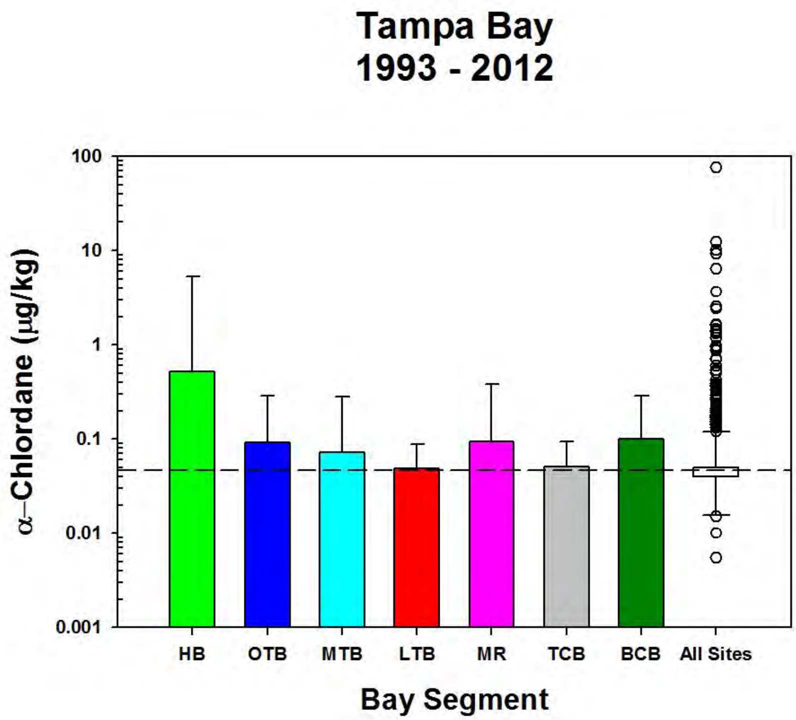


Figure 122. **Mean sediment α-chlordane concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean.**

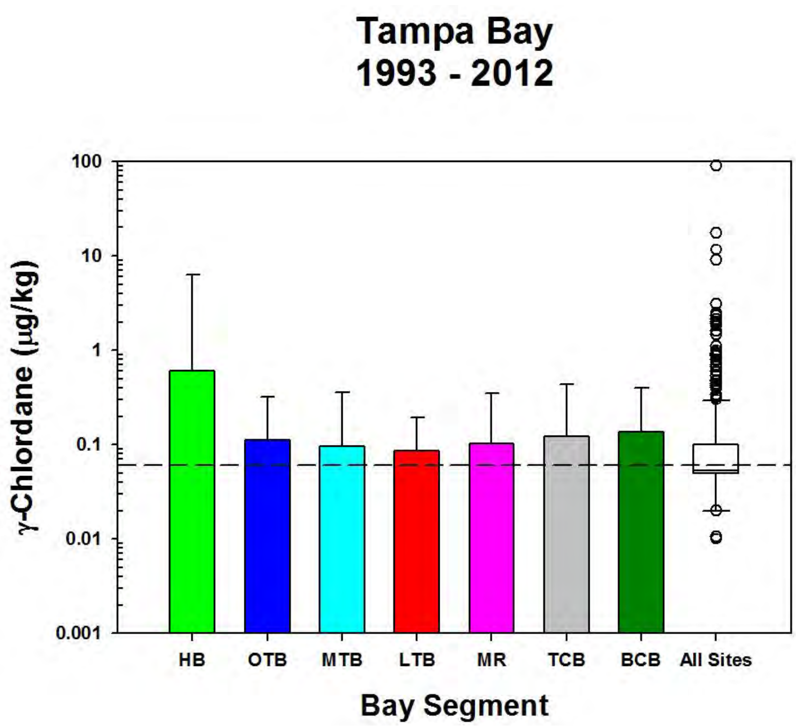


Figure 123. **Mean sediment γ-chlordane concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean.**

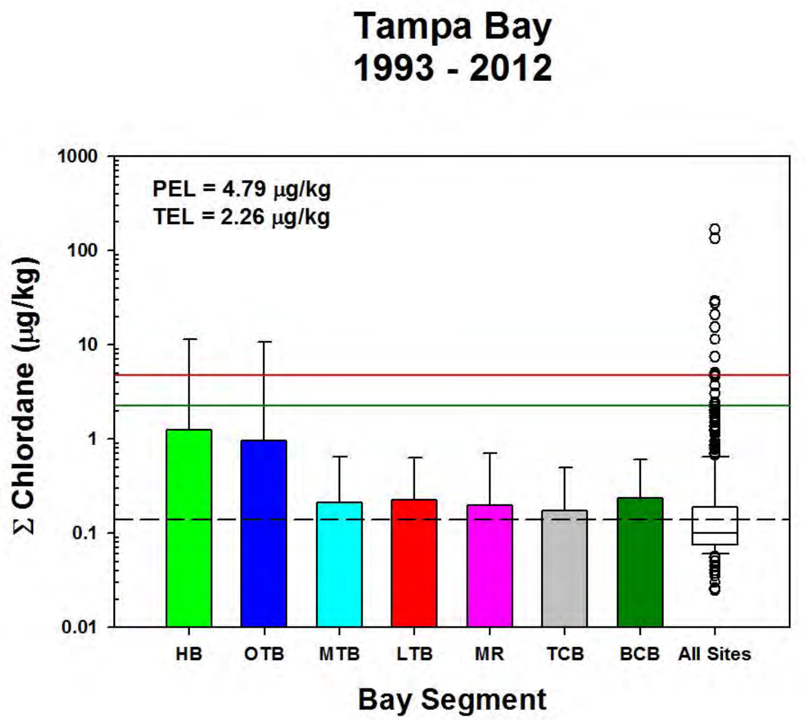


Figure 124. **Mean sediment total chlordane concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean. Solid lines represent PEL (upper; red) and TEL (lower; green) values.**

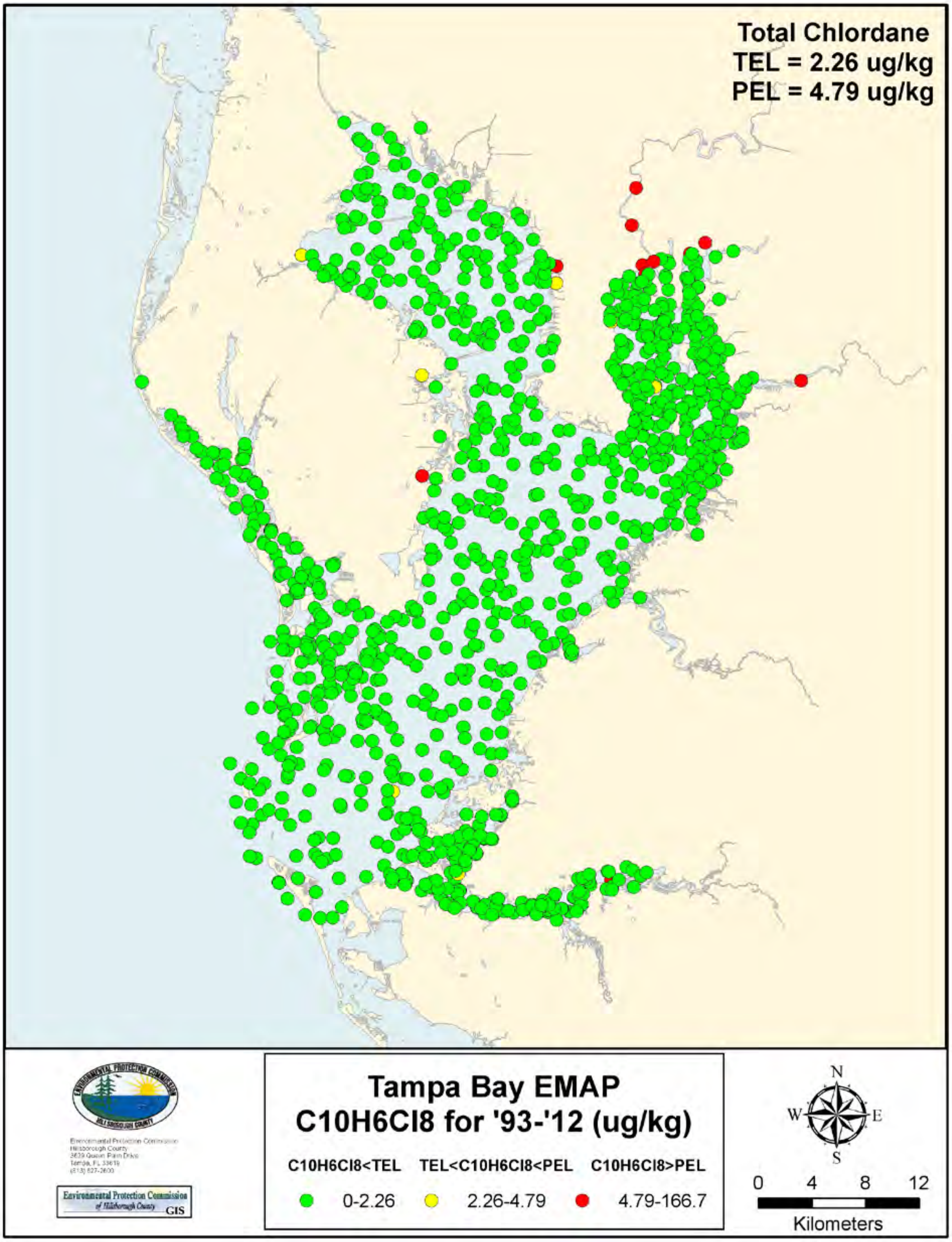


Figure 125. Distribution of total chlordane in Tampa Bay (1993-2012).

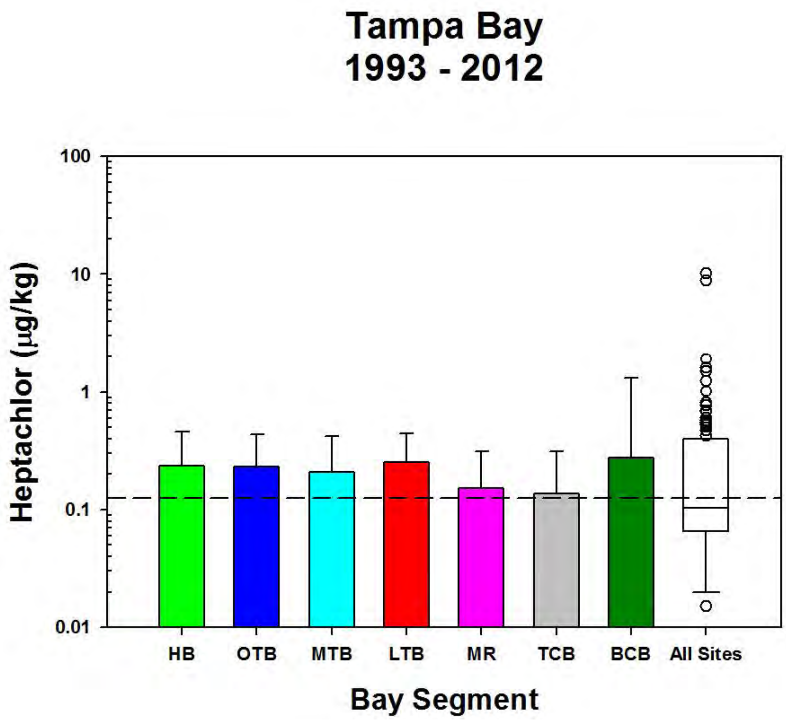


Figure 126. **Mean sediment heptachlor concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean.**

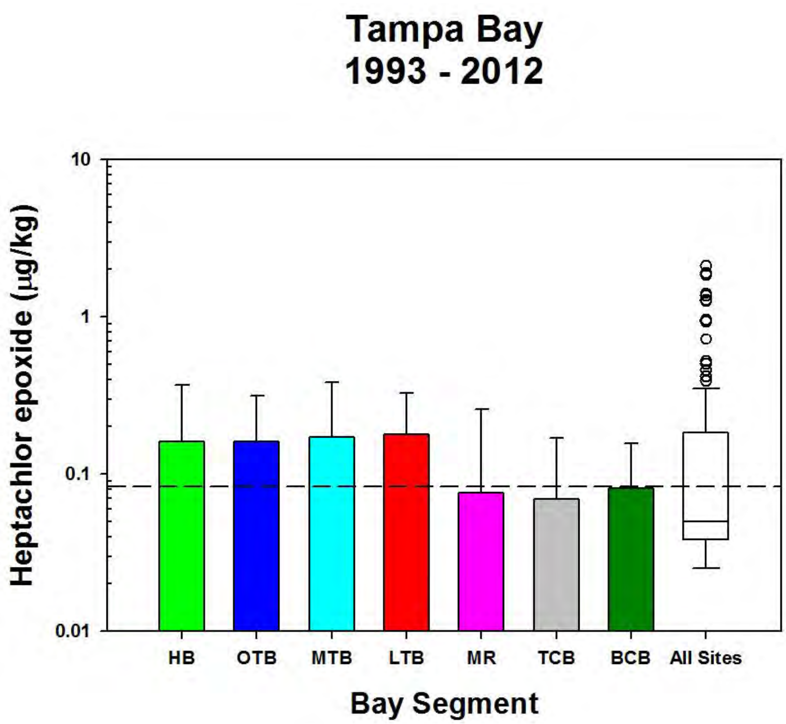


Figure 127. **Mean sediment heptachlor epoxide concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean.**

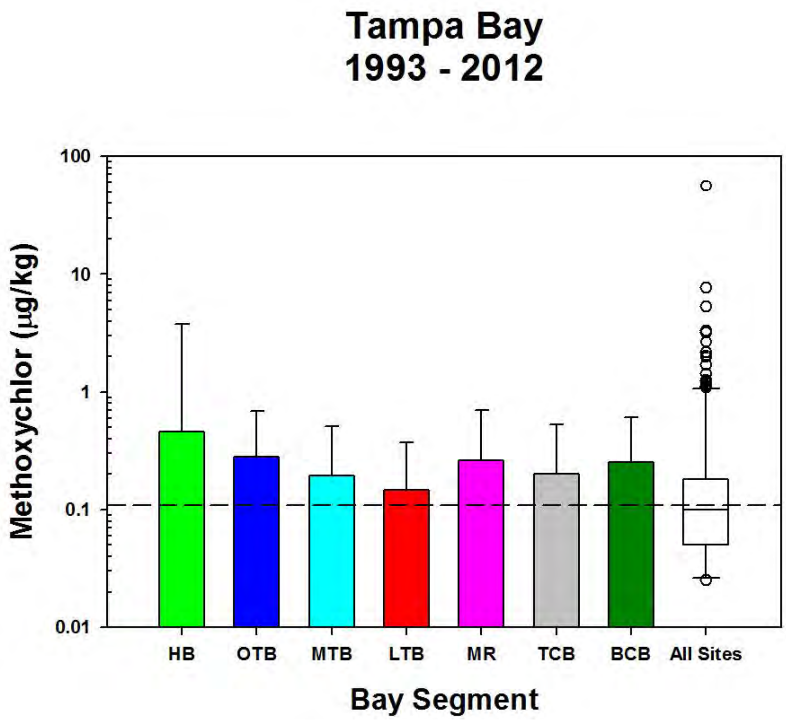


Figure 128. **Mean sediment methoxychlor concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean.**

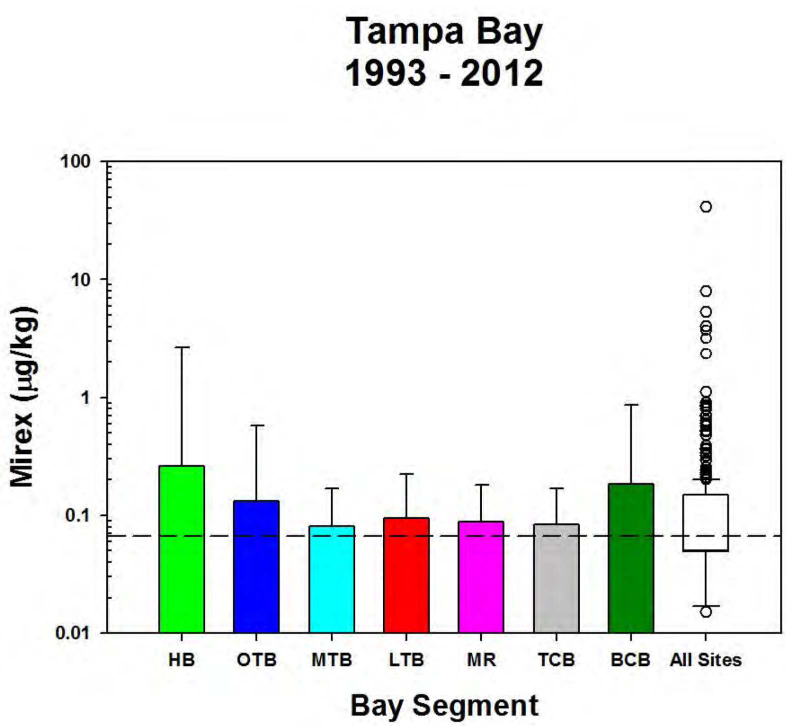


Figure 129. **Mean sediment mirex concentrations by bay segment. Error bars = 1 standard deviation. Dashed line represents baywide mean.**

Benthic Community Structure

Summary Statistics

The overall median number of taxa per site was 35 and ranged from 0 to 136 (Tables 15 &16). The highest median number of taxa were found in 2006 and 2008 (Table 15; Figure 130). The lowest median number of taxa were in 2003 and 2010 (Table 15; Figure 130). There was a significant difference in species richness among years (ANOVA, $p < 0.001$; data log (S+1) transformed). Species richness in 2008 was significantly higher relative to 1998, 2003 and 2010 (Holm-Sidak method; $p < 0.05$). Species richness in 2010 was significantly lower relative to 1993 and 1997 (Holm-Sidak method; $p < 0.05$).

There was a general trend of increasing species richness towards the mouth of Tampa Bay with the highest median number of taxa being recorded in Lower Tampa Bay and Boca Ciega Bay (Table 16; Figure 131). Overall differences in species richness between bay segments were significant (ANOVA; $p < 0.001$; data log (S+1) transformed). 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 Middle Tampa Bay and Boca Ciega Bay but was higher than Hillsborough Bay and the Manatee River. Old Tampa Bay had fewer taxa than Middle Tampa Bay, Lower Tampa Bay and Boca Cieaga Bay but was higher than Hillsborough Bay and the Manatee River. Species richness in Hillsborough Bay was significantly lower than the other bay segments.

The abundance of benthic organisms ranged from 0 to 183,400 organisms (m^{-2}) with a median of 5,813 organisms (m^{-2}) (Table 15 & 16). Abundances were variable between sampling years with significant differences between years (KW; $p < 0.001$; Figure 132). Highest abundances were observed in 1993, 2004 and 2005 (Table 15; Figure 132). Lowest abundances were in 1998, 2010 and 2011 (Table 15; Figure 132). Middle Tampa Bay and Old Tampa Bay had the highest abundances, while the lowest abundance was in Terra Ceia Bay (Table 16; Figure 133). The benthic abundances between bay segments was statistically different (KW; $p <0.001$). Old Tampa Bay and Middle Tampa Bay abundances were higher relative to Hillsborough Bay, the Manatee River, Terra Ceia Bay, and Boca Ciega Bay. There was no difference in abundance between Middle Tampa Bay, Lower Tampa Bay, and Old Tampa Bay. Lower Tampa Bay had a higher abundance than Terra Ceia Bay.

The median Shannon-Diversity Index was 2.53 and ranged from 0 to 3.98 (Tables 15 & 16). Diversity was significantly higher in 2008 than in 2004 (Figure 134: KW; $p = 0.002$). The diversity increased towards the mouth of Tampa Bay (Figure 135). Diversity was the highest in Boca Ciega Bay, Terra Ceia Bay, and Lower Tampa Bay. They were significantly higher than the other bay segments (KW; $p<0.001$). The lowest median diversity values were in Hillsborough Bay and the Manatee River (Table 16; Figure 135).

The Tampa Bay Benthic Index (TBBI) had an overall (all years combined) median value of 84.10 which falls within the “Intermediate” category for benthic habitat health (Tables 15 & 16). Yearly mean values tended to fall in the “Intermediate” range with the exception of 1994 which had a mean TBBI below the “Degraded” threshold (Figure 136). There were significant differences between years (KW; $p < 0.001$). The highest median TBBI scores were in 1996, 2004 and 2005. All three years had median TBBI values slightly above the “Healthy” threshold value of 87 (Table 15). The lowest median TBBI scores were 1993, 1994 and 2011 which all had median values below 80 (Table 15). The TBBI scores were significantly different between bay segments (KW; $p < 0.001$). Highest TBBI values were in Old Tampa Bay, Middle Tampa Bay, and Lower Tampa Bay while lowest values were in Hillsborough Bay, the Manatee River, Terra Ceia Bay, and Boca Ciega Bay (Table 16; Figure 137). The spatial extents of benthic habitat categories based on the TBBI averaged over the 20 year monitoring period are shown in Figure 138. Benthic habitat tended to be “Degraded” in large portions of Hillsborough Bay, in the north and western portions of Old Tampa Bay, and in the upper portions of the Manatee River (Figure 138). Baywide about 20% of the sites were classified as “Empty” or “Degraded” (1.72% and 19.97% respectively) and around 40% of sites were classified as “Healthy” (Table 17). Hillsborough Bay had the highest number of empty sites (4.97%) and one-third (31.9%) of the sites were classified as “Degraded” (Table 17). The Manatee River had a large percentage of “Degraded” sites (32%; Table 17). Lower Tampa Bay and Middle Tampa Bay had over 50% of the sites classified as “Healthy” (Table 17).

The National Estuary Program Coastal Condition Report 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). Baywide benthic community condition was further 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; or “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 rated “Poor”, 20% of the NCA sites rated as “Fair”, and 44% of the NCA sites as “Good” (USEPA 2007).

The benthic community condition of the baywide monitoring sites 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. Year and bay segment results from this analysis are presented in Tables 18-20. The baywide benthic community 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. The baywide benthic community condition for each bay segment is displayed by year in Table 18. The Manatee River and Terra Ceia Bay were merged into a single reporting unit starting in 2000 and Middle Tampa Bay and Lower Tampa Bay were merged into a single reporting unit in 2005 (Table 19). The combined segments and the longer reporting periods were put in place over the course of the past two program redesigns; with a four year reporting period starting in 2000 and continuing through 2004 and a five year reporting period starting in 2005 (Table 20). These are calculated as four-year running averages starting with 2000-2003, and switching to five year running averages staring with 2005-2009. The rational for combining bay segments and multiple years was to compensate for reduced sample sizes in individual years and bay segments.

Baywide results were consistent with the NCA rating of “Poor” for 12 of the 20 years, with the remaining eight years rated as “Fair”. Unweighted sites for the last four years (2009-2012) had “Poor” ratings (Tables 18 & 19). Weighing the sites proportionally by their segment area did increase the baywide rating from “Poor” to “Fair” in 7 of the years. Area-weighted ratings for 2005 went from “Fair” to “Good.” Five of the 20 years rated as “Poor” with 14 years rated as “Fair” and one year rated as “Good” (Tables 18&19). The longer reporting periods and combined reporting units resulted in most years having a baywide weighted rating of “Fair” (Table 20).

Hillsborough Bay, Terra Ceia Bay, the Manatee River and Boca Ciega Bay generally had “Poor” to “Fair” benthic community conditions for most years (Table 18-20). Terra Ceia Bay rated as “Good” in 2004; however, this was based on a single sample that was collected that year (Table 18). Old Tampa Bay, Middle Tampa Bay, and Lower Tampa Bay generally had “Fair” or “Good” benthic community conditions (Table 18-20).

Table 15. Benthic community summary statistics by year (1993-2012) and five-year cumulative periods.. Top values are medians, lower left= minimum, lower right = maximum.

Year	n	Number of taxa		Number per m^2		Diversity (H')		TBBI	
1993	91	39		7975		2.66		79.71	
		5	89	250	45500	0.66	3.53	0.34	95.22
1994	90	33		5863		2.53		75.67	
		0	75	0	27800	0	3.41	0	95.83
1995	134	33		5525		2.49		85.86	
		0	99	0	183400	0	3.93	0	98.19
1996	132	36		7250		2.42		87.42	
		0	73	0	91575	0	3.62	0	97.85
1997	123	41		7175		2.55		85.04	
		0	93	0	49450	0	3.7	0	98.37
1993 - 1997	570	36		6651		2.53		84.47	
		0	99	0	183400	0.00	3.93	0.00	98.36
1998	120	30		3264		2.55		82.28	
		0	89	0	44575	0	3.57	0	98.28
1999	124	36		6450		2.47		84.43	
		0	121	0	54175	0	3.79	0	100.53
2000	86	37		7663		2.64		86.02	
		2	87	50	43925	0.69	3.61	21.12	95.49
2001	80	31		3750		2.53		82.63	
		0	88	0	21675	0	3.61	0	94.98
2002	83	38		5850		2.54		84.85	
		0	125	0	97075	0	3.63	0	97.6
1998 - 2002	493	34		5375		2.54		84.26	
		0	125	0	97075	0.00	3.79	0.00	100.53
2003	78	27		4113		2.4		80.74	
		0	86	0	50376	0	3.58	0	96.62
2004	77	36		8725		2.33		87.34	
		2	101	50	61125	0.51	3.48	46.73	97.27
2005	35	37		10650		2.38		87.41	
		1	113	25	51052	0	3.98	60.54	98.63
2006	41	45		7901		2.68		83.52	
		5	119	200	70251	1.36	3.63	51.42	96.29
2007	43	40		5250		2.67		83.85	
		1	84	25	46101	0	3.56	28.99	94.97
2003 - 2007	274	35		6539		2.43		84.65	
		0	119	0	70251	0.00	3.97	0.00	98.63
2008	44	45		7800		2.87		84.82	
		4	106	175	36725	1.05	3.76	14	99.76
2009	44	37		5188		2.73		85.86	
		0	113	0	45200	0	3.72	0	98.6
2010	59	24		2600		2.55		80.37	
		0	136	0	46606	0	3.59	0	103.79
2011	44	34		2975		2.66		78.27	
		0	80	0	18801	0	3.76	0	91.69
2012	44	34		4050		2.74		86.1	
		0	136	0	46451	0	3.74	0	100.3
2008 - 2012	235	35		4050		2.70		82.87	
		0	136	0	46606	0.00	3.76	0.00	103.79
Cumulative 1993-2012	1572	35		5813		2.53		84.10	
		0	136	0	183400	0	3.98	0	103.79

Table 16. Benthic community summary statistics by bay segment (1993-2012). Top values are medians, lower left= minimum, lower right = maximum.

Segment	n	Number of taxa		Number per m^2		Diversity (H')		TBBI	
Hillsborough Bay	**362**	26		5000		2.18		79.12	
		0	68	0	53825	0.00	3.52	0.00	97.27
Old Tampa Bay	**235**	35		7350		2.47		86.11	
		0	87	0	183400	0.00	3.56	0.00	99.89
Middle Tampa Bay	**278**	38		7750		2.56		87.45	
		0	125	0	97075	0.00	3.79	0.00	100.30
Lower Tampa Bay	**206**	44		6213		2.91		87.78	
		2	113	50	54175	0.68	3.98	36.85	100.56
Manatee River	**163**	25		4600		2.29		79.09	
		1	75	51	91575	0.00	3.50	8.53	95.89
Terra Ceia Bay	**95**	36		4225		2.93		81.39	
		1	100	25	17525	0.00	3.67	27.93	97.85
Boca Ciega Bay	**233**	42		4450		3.00		82.66	
		0	136	0	61125	0.00	3.93	0.00	103.79
Tampa Bay	**1572**	**35**		**5813**		**2.53**		**84.10**	
		0	**136**	**0**	**183400**	**0.00**	**3.98**	**0.00**	**103.79**

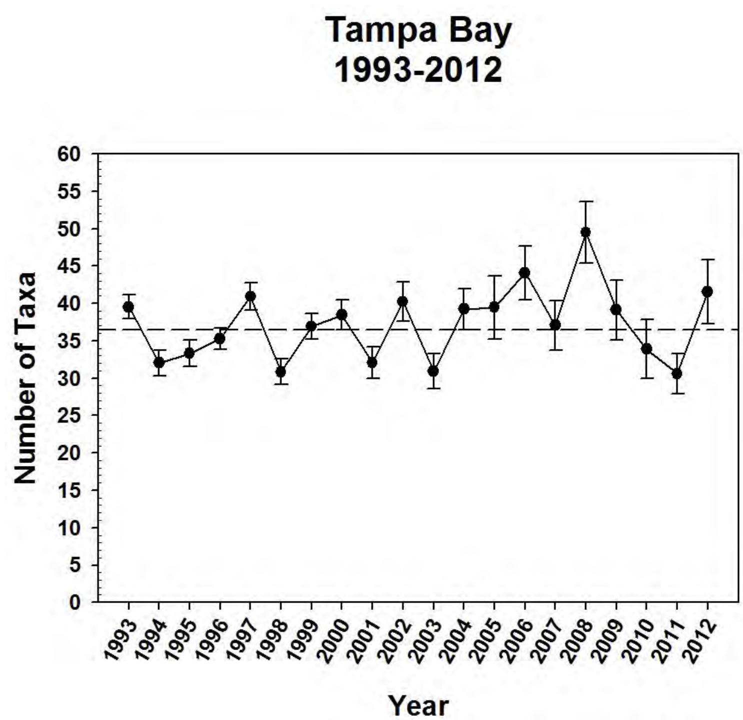


Figure 130. Mean number of benthic taxa by year. Error bars = 1 standard error, dashed line represents baywide mean value.

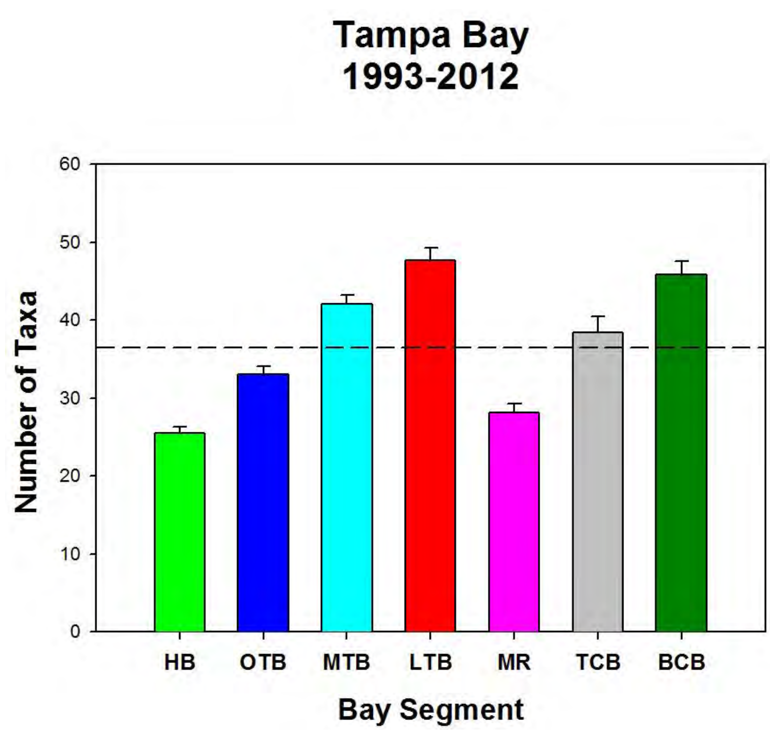


Figure 131. Mean number of benthic taxa by bay segment. Error bars = 1 standard error, dashed line represents baywide mean value.

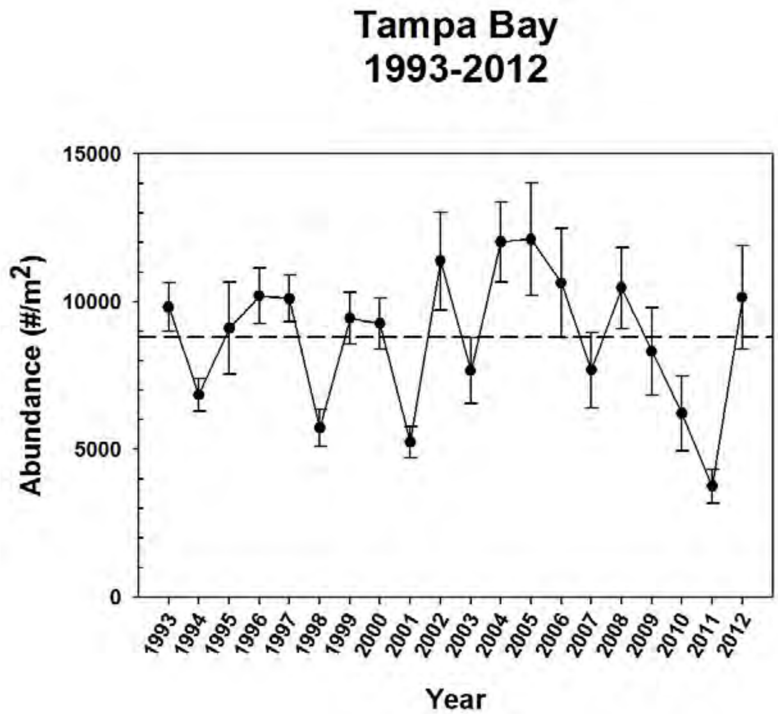


Figure 132. **Median benthic abundance by year. Error bars = 90th percentile, solid line represents baywide median value.**

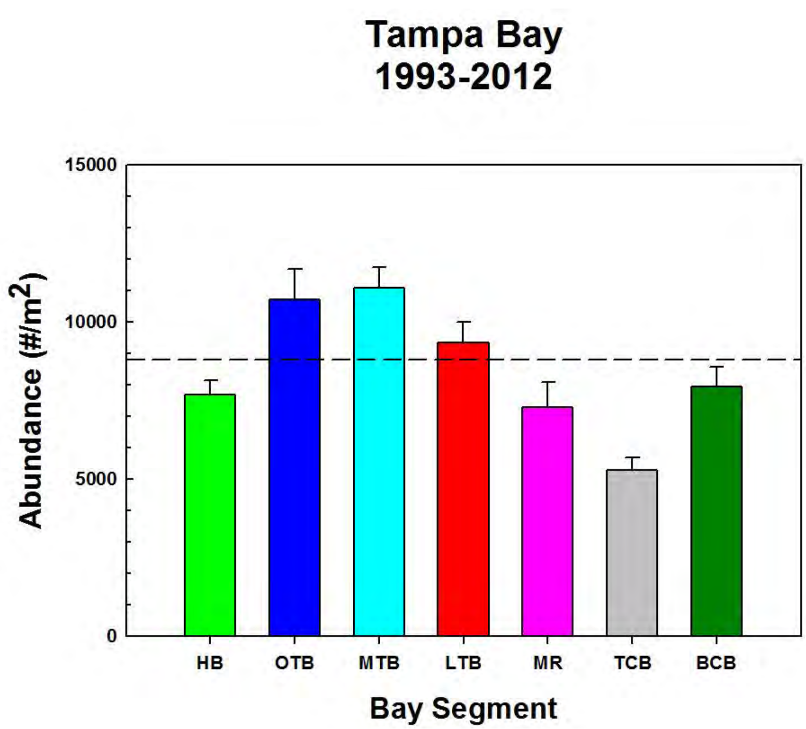


Figure 133. **Mean benthic abundance by bay segment. Error bars = 1 standard error, dashed line represents baywide mean value.**

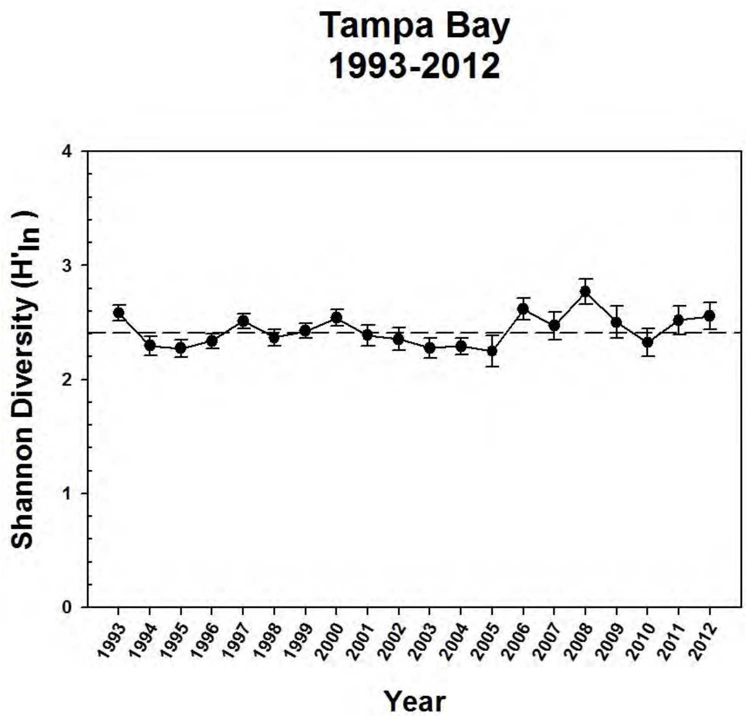


Figure 134. **Mean Shannon-Wiener Diversity Index ($\log_e$) by year. Error bars = 1 standard error, dashed line represents baywide mean value.**

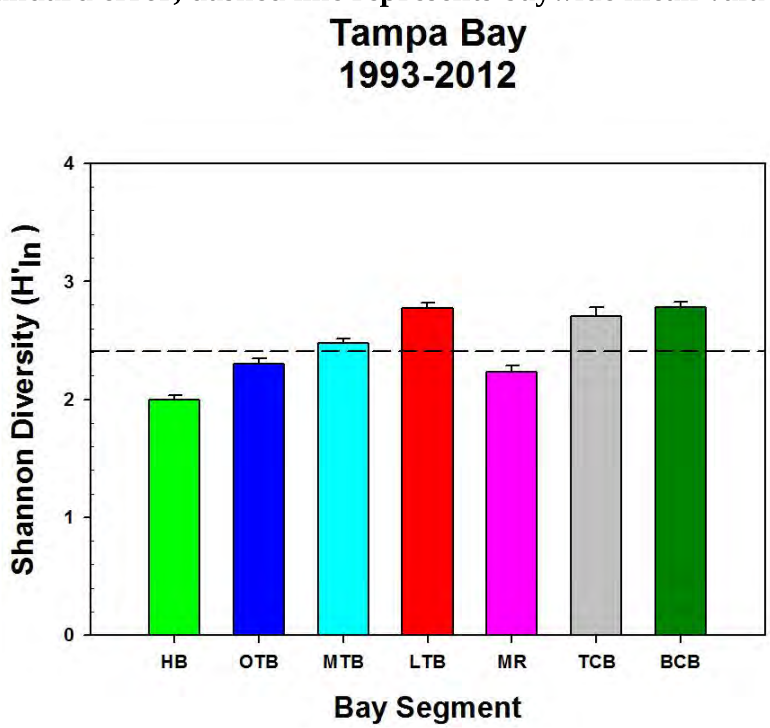


Figure 135. **Mean Shannon-Wiener Diversity Index ($\log_e$) by bay segment. Error bars = 1 standard error, dashed line represents baywide mean value.**

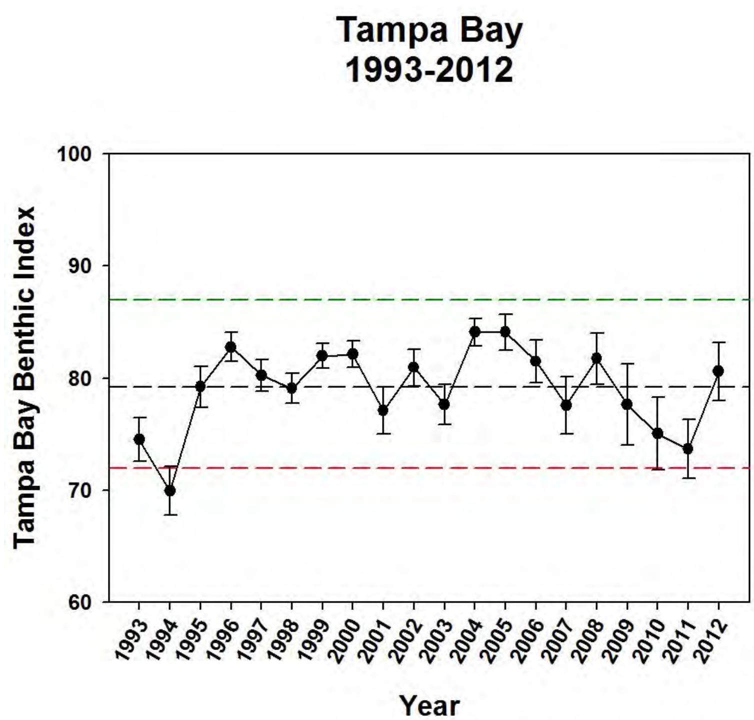


Figure 136. **Mean Tampa Bay Benthic Index by year. Error bars = 1 standard error, solid horizontal line represents baywide mean value, dashed lines indicate cutoffs for "Degraded" (<73) and "Healthy" (>87) benthic habitats.**

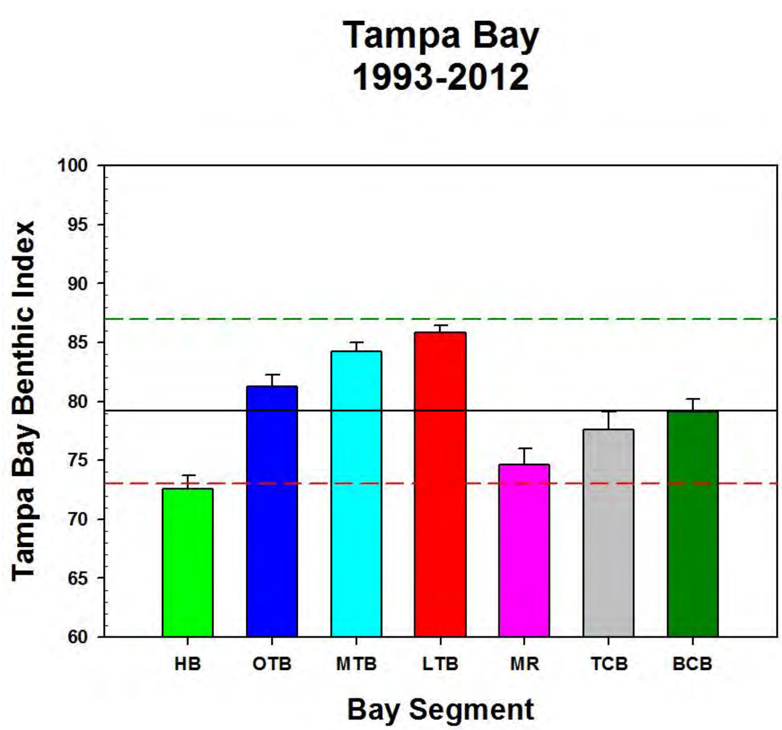


Figure 137. **Mean Tampa Bay Benthic Index by bay segment. Error bars = 1 standard error, solid horizontal line represents baywide mean value, dashed lines indicate cutoffs for "Degraded" (<73) and "Healthy" (>87) benthic habitats.**

Table 17. Percentage of sites within TBBI categories by bay segment and baywide (1993-2012).

	n	ND	Empty	Degraded	Intermediate	Healthy
Hillsborough Bay	362	0.28%	4.97%	31.22%	39.50%	24.03%
Old Tampa Bay	235	0.00%	1.70%	15.74%	37.02%	45.53%
Middle Tampa Bay	278	0.36%	0.36%	9.35%	37.77%	52.16%
Lower Tampa Bay	206	0.00%	0.00%	6.31%	37.86%	55.83%
Manatee River	163	3.68%	0.00%	31.90%	42.33%	22.09%
Terra Ceia Bay	95	1.05%	0.00%	26.32%	45.26%	27.37%
Boca Ciega Bay	233	0.43%	1.72%	20.60%	47.21%	30.04%
Tampa Bay (Total)	**1572**	**0.64%**	**1.72%**	**19.97%**	**40.39%**	**37.28%**

Table 18. Condition of Tampa Bay benthic communities based on the TBBI using the EPA's National Coastal Assessment program criteria by year and segment (1993-2012).

Year	HB	OTB	MTB	LTB	MR	TCB	BCB	Baywide	Weighted Baywide*
1993	Poor (19)	Poor (17)	Fair (20)	Poor (17)	Fair (11)	Fair (7)		Poor (91)	Poor (91)
1994	Poor (19)	Poor (17)	Poor (20)	Poor (17)	Poor (10)	Poor (7)		Poor (90)	Poor (90)
1995	Poor (29)	Good (23)	Good (21)	Good (22)	Fair (11)	Poor (7)	Fair (21)	Fair (134)	Fair (134)
1996	Poor (27)	Good (15)	Fair (24)	Good (24)	Fair (13)	Fair/Good* (8)	Poor (21)	Fair (132)	Fair (132)
1997	Poor (22)	Fair/Good* (16)	Good (22)	Good (21)	Poor (13)	Fair/Good* (8)	Poor (21)	Fair (123)	Fair (123)
1998	Poor (26)	Fair (16)	Fair (20)	Good (17)	Poor (13)	Fair (7)	Poor (21)	Poor (120)	Fair (120)
1999	Fair (23)	Fair (19)	Good (21)	Fair (19)	Fair (13)	Poor (8)	Fair (21)	Fair (124)	Fair (124)
2000	Poor (22)	Good (11)	Fair (23)	Fair (8)	Poor (9)	Fair (7)	Fair (6)	Fair (86)	Fair (86)
2001	Poor (25)	Poor (7)	Fair/Good* (26)	Good (5)	Fair (2)	Poor (1)	Poor (14)	Poor (80)	Fair (80)
2002	Poor (25)	Fair (8)	Good (21)	Fair (9)	Poor (7)	Poor (4)	Poor (9)	Poor (83)	Fair (83)
2003	Poor (28)	Poor (9)	Good (9)	Good (12)	Poor (7)	Poor (3)	Poor (10)	Poor (78)	Poor (78)
2004	Fair (25)	Poor (9)	Good (11)	Good (11)	Poor (10)	Good (1)	Fair (10)	Fair (77)	Fair (77)
2005	Poor (9)	Good (3)	Good (3)	Good (6)	Fair (5)	Fair (3)	Fair/Good* (6)	Fair (35)	Good (35)
2006	Poor (9)	Good (8)	Good (4)	Fair (3)	Poor (4)	Fair (5)	Poor (8)	Poor (41)	Fair (41)
2007	Poor (9)	Good (7)	Good (7)	Fair (1)	Poor (5)	Poor (4)	Fair (10)	Poor (43)	Fair (43)
2008	Poor (9)	Fair (7)	Good (5)	Good (3)	Fair (6)	Poor (3)	Fair (11)	Fair (44)	Fair (44)
2009	Poor (9)	Fair (7)	Good (6)	Fair/Good* (2)	Fair (5)	Poor (4)	Poor (11)	Poor (44)	Fair (44)
2010	Fair (9)	Poor (22)	Poor (5)	Good (3)	Fair (5)	Fair/Good* (4)	Good (11)	Poor (59)	Poor (59)
2011	Poor (9)	Poor (7)	Fair (5)	Poor (3)	Poor (7)	Fair (2)	Fair (11)	Poor (44)	Poor (44)
2012	Poor (9)	Good (7)	Fair (5)	Poor (3)	Poor (7)	Poor (2)	Fair (11)	Poor (44)	Fair (44)

*Weighted by Bay Segment Area

Table 19. Condition of Tampa Bay benthic communities based on the TBBI using the EPA's National Coastal Assessment program criteria by year and combined segments (1993-2012).

Year	HB	OTB	MTB	LTB	MR	TCB	BCB	Baywide	Weighted Baywide*
1993	Poor (19)	Poor (17)	Fair (20)	Poor (17)	Fair (11)	Fair (7)		Poor (91)	Poor (91)
1994	Poor (19)	Poor (17)	Poor (20)	Poor (17)	Poor (10)	Poor (7)		Poor (90)	Poor (90)
1995	Poor (29)	Good (23)	Good (21)	Good (22)	Fair (11)	Poor (7)	Fair (21)	Fair (134)	Fair (134)
1996	Poor (27)	Good (15)	Fair (24)	Good (24)	Fair (13)	Fair/Good* (8)	Poor (21)	Fair (132)	Fair (132)
1997	Poor (22)	Fair/Good* (16)	Good (22)	Good (21)	Poor (13)	Fair/Good* (8)	Poor (21)	Fair (123)	Fair (123)
1993-1997	Poor (116)	Good (88)	Fair (208)		Poor (95)		Poor (63)	Poor (570)	Fair (570)
1998	Poor (26)	Fair (16)	Fair (20)	Good (17)	Poor (13)	Fair (7)	Poor (21)	Poor (120)	Fair (120)
1999	Fair (23)	Fair (19)	Good (21)	Fair (19)	Fair (13)	Poor (8)	Fair (21)	Fair (124)	Fair (124)
2000	Poor (22)	Good (11)	Fair (23)	Fair (8)	Poor (16)		Fair (6)	Fair (86)	Fair (86)
2001	Poor (25)	Poor (7)	Fair/Good* (26)	Good (5)	Poor (3)		Poor (14)	Poor (80)	Fair (80)
2002	Poor (25)	Fair (8)	Good (21)	Fair (9)	Poor (11)		Poor (9)	Poor (83)	Fair (83)
1998-2002	Poor (121)	Fair (61)	Good (169)		Poor (71)		Poor (71)	Fair (493)	Fair (493)
2003	Poor (28)	Poor (9)	Good (9)	Good (12)	Poor (10)		Poor (10)	Poor (78)	Poor (78)
2004	Fair (25)	Poor (9)	Good (11)	Good (11)	Poor (11)		Fair (10)	Fair (77)	Fair (77)
2005	Poor (9)	Good (3)	Good (9)		Fair (8)		Fair/Good* (6)	Fair (35)	Good (35)
2006	Poor (9)	Good (8)	Good (7)		Poor (9)		Poor (8)	Poor (41)	Fair (41)
2007	Poor (9)	Good (7)	Fair/Good* (8)		Poor (9)		Fair (10)	Poor (43)	Fair (43)
2003-2007	Poor (80)	Poor (36)	Good (67)		Poor (47)		Poor (44)	Poor (274)	Fair/Good* (274)
2008	Poor (9)	Fair (7)	Good (8)		Poor (9)		Fair (11)	Fair (44)	Fair (44)
2009	Poor (9)	Fair (7)	Good (8)		Poor (9)		Poor (11)	Poor (44)	Fair (44)
2010	Fair (9)	Poor (22)	Poor (8)		Fair (9)		Good (11)	Poor (59)	Poor (59)
2011	Poor (9)	Poor (7)	Fair (8)		Poor (9)		Fair (11)	Poor (44)	Poor (44)
2012	Poor (9)	Good (7)	Poor (8)		Poor (9)		Fair (11)	Poor (44)	Fair (44)
2008-2012	Poor (45)	Poor (50)	Fair (40)		Poor (45)		Fair (55)	Poor (235)	Fair (235)
Cumulative 1993-2012	Poor (362)	Fair (235)	Good (484)		Poor (258)		Poor (233)	Poor (1572)	Fair (1572)

*Weighted by Bay Segment Area

Table 20. **Condition of Tampa Bay benthic communities based on the TBBI using the EPA's National Coastal Assessment program criteria by year and combined segments and reporting periods (4 or 5-year running average) (1993-2012).**

Year	HB	OTB	MTB	LTB	MR	TCB	BCB	BayWide	Weighted Baywide*
1993	Poor (19)	Poor (17)	Fair (20)	Poor (17)	Fair (11)	Fair (7)		Poor (91)	Poor (91)
1994	Poor (19)	Poor (17)	Poor (20)	Poor (17)	Poor (10)	Poor (7)		Poor (90)	Poor (90)
1995	Poor (29)	Good (23)	Good (21)	Good (22)	Fair (11)	Poor (7)	Fair (21)	Fair (134)	Fair (134)
1996	Poor (27)	Good (15)	Fair (24)	Good (24)	Fair (13)	Fair/Good* (8)	Poor (21)	Fair (132)	Fair (132)
1997	Poor (22)	Fair/Good* (16)	Good (22)	Good (21)	Poor (13)	Fair/Good* (8)	Poor (21)	Fair (123)	Fair (123)
1998	Poor (26)	Fair (16)	Fair (20)	Good (17)	Poor (13)	Fair (7)	Poor (21)	Poor (120)	Fair (120)
1999	Fair (23)	Fair (19)	Good (21)	Fair (19)	Fair (13)	Poor (8)	Fair (21)	Fair (124)	Fair (124)
2000-2003	Poor (100)	Poor (35)	Good (79)	Good (34)	Poor (40)		Poor (39)	Poor (327)	Fair (327)
2001-2004	Poor (103)	Poor (33)	Good (67)	Good (37)	Poor (35)		Poor (43)	Poor (318)	Fair (318)
2002-2005	Poor (87)	Poor (29)	Good (82)		Poor (40)		Poor (35)	Poor (273)	Fair (273)
2003-2006	Poor (71)	Poor (29)	Good (59)		Poor (38)		Poor (34)	Poor (231)	Fair (231)
2004-2007	Poor (52)	Fair (27)	Good (46)		Poor (37)		Poor (34)	Fair (196)	Good (196)
2005-2009	Poor (45)	Good (32)	Good (40)		Poor (44)		Poor (46)	Poor (207)	Fair (207)
2006-2010	Poor (45)	Fair (51)	Good (39)		Poor (45)		Poor (51)	Poor (231)	Fair (231)
2007-2011	Poor (45)	Poor (50)	Good (40)		Poor (45)		Poor (54)	Poor (234)	Fair (234)
2008-2012	Poor (45)	Poor (50)	Fair (40)		Poor (45)		Fair (55)	Poor (235)	Fair (235)

*Weighted by Bay Segment Area

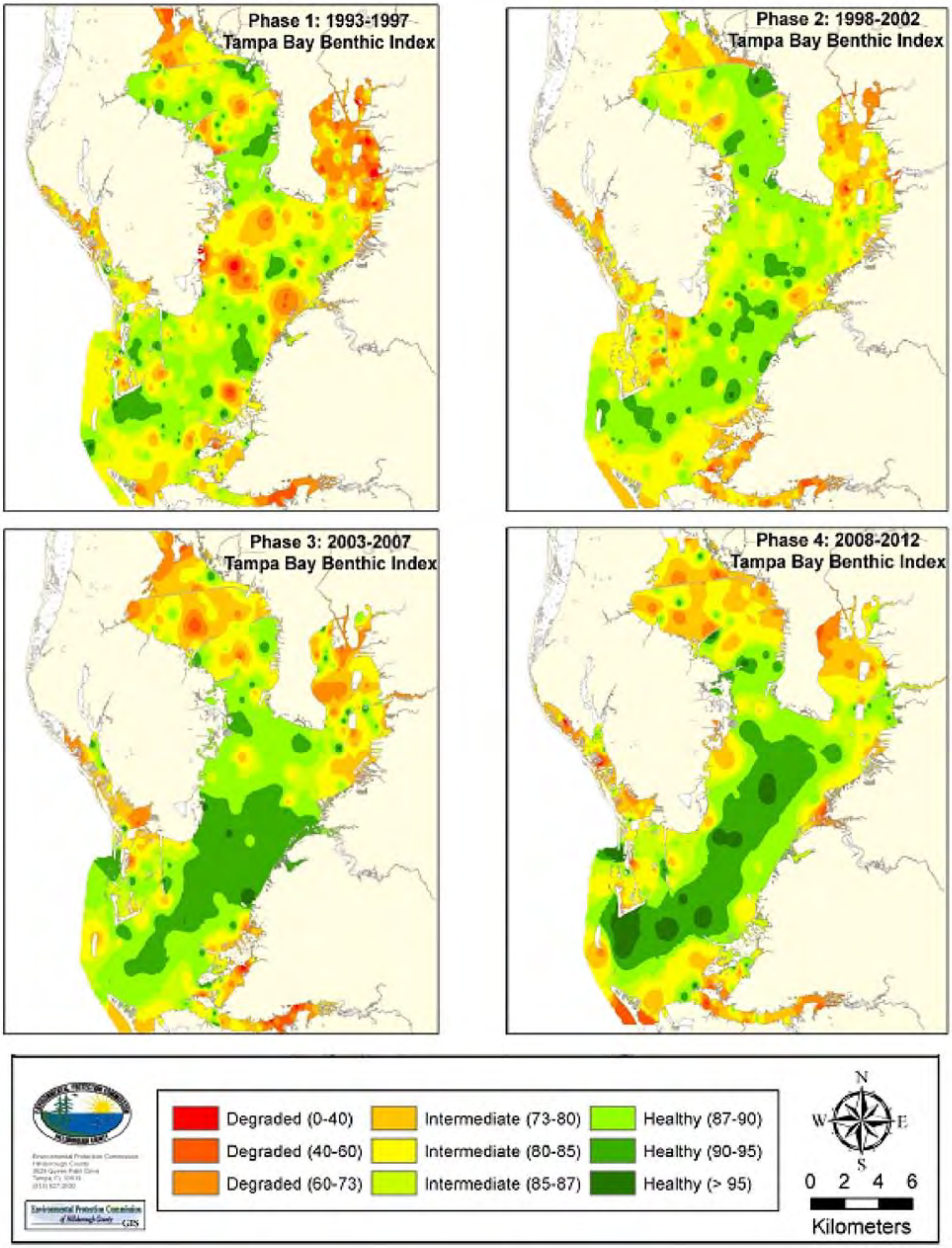


Figure 138. Spatial extent of TBBI scores (1993-2012).

Dominant Taxa

The relative abundance of dominant benthic taxa is presented by sampling year in Table 21 and by bay segment in Table 22. The rank order of all taxa with a relative abundance of 1.5% or higher is also presented in Table 22. The top seven ranked taxa represented over 25% of the total baywide abundance (Table 22).

Glottidia pyramidata (Stimpson, 1860)

The brachiopod *Glottidia pyramidata* was the most abundant infaunal organism baywide (Table 22). It was found at 30.9% of the sites with an average density of 448 m^{-2} and a maximum density of 94,375 m^{-2} (primarily as recently settled post-larvae). Culter (1979) found an average density of 2,275 m^{-2} in Old Tampa Bay near the Courtney Campbell Causeway. The relative abundance of *G. pyramidata* was variable over time. It was not among the top ten dominant taxa during the first four years of the monitoring program or in 1998 and 2000 (Table 21). *Glottidia pyramidata* was the most abundant infaunal organism in 2001, 2002 and 2005. The peak abundance was in 2002 when it accounted for 39.5% of the total benthic abundance (Table 21; Figure 139). *Glottidia pyramidata* was the most abundant animal in Middle Tampa Bay accounting for over 13% of the benthic abundance (Table 22; Figures 140 & 141).It was also among the dominant taxa in Hillsborough Bay and Old Tampa Bay (Table 22; Figures 140 & 141). The SIMPER analysis indicated that *G. pyramidata* was found generally at sites >2 meters depth, with fine to medium grained sediments, polyhaline salinities, and normoxic bottom dissolved oxygen levels. Paine (1963) found *G. pyramidata* populations on the west coast of Florida inhabited salinities ranging from 18 – 35 psu and could tolerate salinities as low as 13 psu. Paine (1963) also noted that *G. pyramidata* was absent from mud or clay bottoms and from calcareous sediments, preferring sandy habitats (Paine, 1963). *Glottidia pyramidata* is unable to burrow in coarse sediments and muddy substrates (Culter, 1979). *Glottidia pyramidata* spawn and larval recruitment occurs over the summer months with highest densities occurring in August (Paine, 1963; Culter 1979). Culter and Simon (1987) found that a small percentage of *G. pyramidata* in Tampa Bay (< 1%) were hermaphroditic, particularly in areas with low population densites.

Branchiostoma floridae Hubbs, 1922

The second most abundant species in Tampa Bay was the cephalochordate *Branchiostoma floridae* which accounted for 4.86% of the overall abundance (Table 22). It was present 39.9% of the sites with an average density of 428 $m^{-2}$and a maximum density of 17,775 m^{-2}. The maximum density is higher than reported in previous studies [Stokes, 1996 (1200 m^{-2})]. It was among the dominant taxa in most years with the exception of 2003, 2005, and 2009-2012 (Table 21). It was the most abundant taxa in 1993, 1997, and 1998 (Table 21). There has been a general trend of decreasing abundance over the twenty year monitoring period,especially since 2004 (Figure 142). *Branchiostoma floridae* was the most abundant species in Lower Tampa Bay (Table 22; Figure 143). It is among the most dominant taxa in Old Tampa Bay and Middle Tampa Bay (Table 22; Figure 143). Highest densities were seen in Middle Tampa Bay and Lower Tampa Bay (Figures 143 & 144). SIMPER analysis indicated that *B. floridae* is found primarily in polyhaline to euhaline salinities, normoxic conditions and in medium to coarse sediments. The preference for higher salinities has been shown in an earlier study, where a sudden drop in salinity due to heavy rainfall resulted in a mass die off (Dawson 1965). *Branchiostoma floridae* reproduces from May to September with larval settlement from late-May to mid-October in Tampa Bay (Stokes, 1996). Several previous studies in Tampa Bay and along the west coast of Florida had reported *Branchiostoma floridae* as *Branchiostoma caribaeum* (Dawson 1965; Pierce 1965; Nelson 1969, Bloom et al. 1972, Hall and Saloman 1975).

Monticellina cf. dorsobranchialis **(Kirkegaard, 1959)**

The third most abundant species in Tampa Bay was the cirratulid polychaete *Monticellina cf. dorsobranchialis* which represented 4.13% of the overall abundance (Table 22). It was the second most frequently occurring taxon (present in 46.2% of the sites). The average density of *M. cf. dorsobranchialis* was 364 m^{-2} with a maximum of 43,250 m^{-2}. It was among the most abundant taxa during all years (except 1995) with highest relative abundances occurring in 1994, 1999 and 2011 (Table 21). *Monticellina* cf. *dorsobranchialis* abundances had a cyclical pattern throughout the 20 year monitoring period (Figure 145). It was the most abundant taxon in Terra Ceia Bay (Table 22). It ranked second most abundant taxon in Hillsborough Bay and the Manatee River (Table 22). Highest abundances of *M. cf. dorsobranchialis* were found in Hillsborough Bay and the Manatee River with high abundances also recorded in Middle Tampa Bay, Terra Ceia Bay and Boca Ciega Bay, and the lowest abundance was in Lower Tampa Bay (Figures 146 & 147). The SIMPER analysis indicated that *M. cf. dorsobranchialis* was found at sites with very fine to medium grained sediments, high mesohaline to euhaline salinities, and a wide range of dissolved oxygen concentrations from anoxic to normoxic. *Monticellina cf. dorsobranchialis* has some tolerance to sediment contaminants including sites that exceeded the PEL for lindane and cadmium. It was also present at sites above the TEL for several other pesticides (DDTs, dieldrin and lindane), most PAHs, and metals (As, Cd, Cr, Cu, Pb, Ni and Ag).

This polychaete was initially identified as *Tharyx annulosus* during the first year of the program based on the taxonomic key in Wolf (1984), and it 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, 1991). Blake (1996) further revised this genus, describing several new species from California and mentioned that future revisions were needed. Several taxa Blake (1991) initially synonymized as *Monticellina dorsobranchialis* (including *M. annulosus*) were to be reinstated as separate species (Blake, 1996). The identity of the *Monticellina* cf. *dorsobranchialis* specimens from Tampa Bay is still uncertain due to the current revisions of this genus. The name *Monticellina cf. dorsobranchialis* is maintained for the Tampa Bay specimens with the understanding that this designation may change in the future.

Mysella planulata **(Stimpson, 1851)**

The small bivalve *Mysella planulata* was ranked fourth in abundance baywide (Tables 19 & 20). It was the most abundant species in 1996, 2008 and 2009 and the second ranked taxa in 1997 and 1998 (Tables 19 & 20). Population trends showed a cyclic pattern over the 20 year monitoring period with peaks in 1996, 2005 and 2008 and the lowest abundance in 2011 (Figure 148). *Mysella planulata* was mainly found in Hillsborough Bay and Old Tampa Bay (ranking first and third in abundance respectively (Table 22; Figures 149 & 150). SIMPER indicated that *M. planulata* has a wide depth range (intertidal to deep subtidal) and was found at sites with fine to medium sediments, high mesohaline to polyhaline salinities and intermediate to normoxic dissolved oxygen conditions. It was found at sites that exceeded the PEL for copper and the TEL for cadmium. *Mysella planulata* is known to be a simultaneous hermaphrodite that can self-fertilize (Franz 1973). It has a larviparous development where the larvae are brooded within the adult shell during the early larval stages then released into the plankton (Franz 1973).

Tubificinae and ***Tubificoides brownae*** **Binkhurst and Baker, 1979**
Tubificid oligochaetes (Tubificinae) were ranked fifth in overall abundance which represented 3.36% of the total abundance with a mean abundance of 296 m^{-2} and a maximum of 13,325 m^{-2} (Table 22). Tubificid oligochaetes were common across all years and bay segments (Tables 19 & 20). They were the most frequently occurring taxa, being found at 60.1% of the sites. This group was composed of immature and/or damaged specimens of multiple species which could not be identified below the subfamily level. Many of the speciments identified as Tubificinae may be immature individuals of *Tubificoides brownae*, one of the more common species in this subfamily. The annual mean abundance trends and mean abundance by bay segment for both unidentified Tubificinae and *Tubificoides brownae* are presented in Figures 151 and 152. Unidentified Tubificinae were abundant and wide spread across all bay segment, but they had lower abundances in the Manatee River (Figures 152 & 153). *Tubificoides brownae* was present in all segments and highest abundances were in Hillsborough Bay (Figures 152 & 154). *Tubificoides brownae* was generally absent in the central portions of Tampa Bay (Figures 152 & 154). SIMPER results indicated that Tubificinae were among the dominant taxa across all depth and salinity categories, in hypoxic-normoxic dissolved oxygen conditions, very fine to medium sediments and were widely tolerant of sediment contaminants.

Ampelisca holmesi **Pearse, 1908** and ***Ampelisca abdita*** **Mills, 1964**
The amphipod *Ampelisca holmesi* was ranked sixth in overall abundance which represented 2.96% of the total abundance (Table 22). It was found at 39.2% of the sites and was the most abundant species in 2004 and 2012 (Table 21). Annual abundances exhibited a cyclical trend (Figure 155). It was among the dominant taxa in Hillsborough Bay, the Manatee River, Terra Ceia Bay and Old Tampa Bay (Table 22; Figure 156). The SIMPER analyses indicated that *A. holmesi* had a wide depth distribution (intertidal to deep subtidal), and it was found in fine to coarse sediments, high mesohaline to polyhaline salinities and low 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. SIMPER analsysis indicated *Ampelisca holmesi* was also present at sites that were above the TEL for arsenic and nickel and at sites that exceeded the PEL for cadmium and zinc.

The congeneric species *Ampelisca abdita* ranked 15th in overall abundance which represented 1.47% of the total abundance. It was found at 19% of the sites. It was among the top ranked taxa in 1993 and second ranked species in 1996 and 2012 (Table 21). It was the most abundant species in the Manatee River (Table 22 Figure 158). *Ampelisca abdita* has a lower salinity preference than *A. holmesi,* and it was typically found at low mesohaline sites (Figure 158). Grabe et. al. (2006) calculated an optimal depth of 1.5 meters, salinity of 14.4 psu, relatively high %silt+clay content (15.6%) and low dissolved oxygen (2.9 mg/l) for this species. SIMPER analysis indicated that *Ampelisca abdita* has a higher tolerance for sediment contaminants than

Ampelisca holmesi, and it was associated with sites that were above the TEL for PCBs, several PAHs and zinc, and with sites that were above the PEL for DDD and lead.

Thoemke (1979) studied the life history and population dynamics of *Ampelisca abdita* in Hillsborough Bay over a two year period (July 1975 – July 1977) and found that reproduction occurred year round, but the life span of individuals varied seasonally and was influenced 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 recruiting between September – February were longer lived (10-13 weeks) and produced two generations of offspring (Thoemke 1979). Highest population densities were in June/July followed by a decline in late summer, possibly in response to low dissolved oxygen concentrations (Thoemke 1979).

Caecum strigosum de Folin, 1868

The gastropod *Caecum strigosum* was ranked seventh in overall abundance which represented 2.93% of the total abundance and was found at 16.9% of the sites (Table 22). *Caecum strigosum* was among the most abundant taxa during all years from 1993-2002 with a peak in 1996, but abundances decreased from 2003 -2012 with the exception of 2007 (Table 21; Figure 159). *Caecum strigosum* was particularly abundant in Middle Tampa Bay and among the top taxa in Old Tampa Bay and Lower Tampa Bay (Table 22; Figures 160 & 161). The decline observed since 2003 may be due to the program sampling redesign which reduced the number of samples collected in Middle Tampa Bay and Lower Tampa Bay. The SIMPER analysis indicated that *C. strigosum* was found at deeper sites (>4 meters) with coarse sediments and was found at sites that were above the TEL for lindane and arsenic.

Caecum strigosum was recorded in Tampa Bay during the Bureau of Commercial Fisheries survey in the 1960's (Hall and Saloman, 1975). It was initially identified as *Caecum cf. johnsoni* during the early years of the current monitoring program (Mote Marine Laboratory, 1995) and in other earlier works (Culter, 1986).

Rudilemboides naglei Bousfield 1973

The amphipod *Rudilemboides naglei* was ranked eighth in overall abundance which represented 2.21% of the total abundance and was found at 18.5% of the sites (Table 22). It had a mean abundance of 125 m^{-2} and a maximum of 29,775 m^{-2} located at an Old Tampa Bay site in 2007 (07OTB25). *Rudilemboides naglei* was most abundant species in 2000 and 2007 (Table 21) and the dominant species in Old Tampa Bay (Table 22). Annual mean abundances showed a cyclical trend with peak abundances in 2000 and 2007 with population crashes in 1998, 2001, 2003 and from 2010-2012 (Figure 162). Highest mean abundance of *R. naglei* was in Old Tampa Bay and relatively high abundances were also observed in lower Hillsborough Bay and in the upper portion and eastern areas of Middle Tampa Bay (Figures 163 & 164).

Grabe et al. (2006) calculated an optimum salinity of 24.4 psu, %silt+clay of 2.1%, and depth of 3.1 meters. They had a preference for normoxic conditions with an optimum dissolved oxygen concentration of 8.3 mg/L in Tampa Bay (Grabe et al., 2006). *Rudilemboides naglei* had highest densities in the fall and winter months which is attributed to lower water temperatures (Thomke, 1979).

Myers (1981) reclassified this species as *Acuminodeutopus naglei* and it may appear under this name in some studies. *Rudilemboides naglei* (original described name) is currently accepted as the valid name according to the World Register of Marine Species (WoRMS; www.marinespecies.org; Lowry, 2014).

Cirripedia

Cirripedia were ranked as the ninth most abundant taxon which was comprised of unidentified juvenile and damaged barnacles. These were most likely a composite of several species (*Amphibalanus* spp. and *Balanus sp.*) and were also identified as Balanidae (Figures 165 & 166). These were typically epiphytic on seagrass blades or larger shell fragments. Cirripedia represented 1.91% of the total abundance (Table 22) and were found at 6.9% of the sites They were recorded in all bay segments (Figure 166). Barnacles were particularly abundant in 1995 where they comprised over 16% of the total abundance (Table 21; Figure 165). They were the second most abundant taxa in Old Tampa Bay (Table 22). The high abundance (172,800 $m^{-2)}$ of cirripedia is largely due to a single site collected in Old Tampa Bay in 1995 (95OTB20). This site accounted for over 65% of the total abundance for this taxon over the 20 year monitoring period.

***Fabricinuda trilobata* (Fitzhugh, 1983)**

The sabellid polychaete *Fabricinuda trilobata* was originally described as *Fabriciola trilobata* by Fitzhugh (1983) and reclassified by Fitzhugh (1990) in a new genus *Fabricinuda.* Some studies may report this species by its original name (i.e. Ubelacker, 1984) or as another related genus (possibly *Fabricia sabella* in Taylor, 1971).

Fabricinuda trilobata was ranked the tenth most abundant species which represented 1.86% of the total abundance and was found at 18.1% of the sites. *Fabricinuda trilobata* mean abundance was 164 m^{-2} with a maximum of 39,825 m^{-2} recorded at a Lower Tampa Bay site in 1999 (99LTB2041). *Fabricinuda trilobata* was among the top ten dominant taxa in 1999 and from 2005-2010 and in 2012 (Table 21). It was the most abundant taxon in 2010 and second most abundant in 2005 (Table 21). It was the second most abundant species in Lower Tampa Bay and among the dominant taxa in the Manatee River and Boca Ciega Bay (Table 22). Annual mean abundances had an increasing trend over the 20 year monitoring period with the highest abundances in 1999 and 2005, while the lowest abundances were in 1998 and 2011 (Figure 167). *Fabricinuda trilobata* abundances increased towards the lower portions of Tampa Bay with Lower Tampa Bay having the highest abundance followed by Boca Ciega Bay and the Manatee River (Figures 168 & 169). SIMPER analysis indicated that *Fabricinuda trilobata* was associated with euhaline sites and with sites exceeding the TEL for arsenic.

Uebelacker (1984) documented *Fabricinuda trilobata* in the Gulf of Mexico (as *Fabriciola trilobata*) reporting it from depths of 10 -189 meters and across a wide spectrum of sediment types. Taylor (1971) reported a small sabellid polychaete he identified as *Fabricia sabella* in his survey of polychaetes in Tampa Bay. His description of this species closely matches the morphology of *Fabricinuda trilobata* and may quite possibly be the same. Taylor (1971) stated that *Fabricia sabella* was the most widely distributed sabellid species, predominantly occurring in Lower Tampa Bay but ranging up to Old Tampa Bay. This species was found at a salinity range of 23.0 – 35.1 psu (mean = 31.5 psu), a depth range of <1 – 4.0 meters (mean = 1.5 meters) and in sand to shell-sand sediments (Taylor, 1971).

***Prionospio perkinsi* Maciolek, 1985**

The spionid polychaete *Prionospio perkinsi* was reported as *Prionospio cirrobranchiata* by Taylor (1971) and as *Prionospio* (or *Minuspio*) *cirrifera* in Tampa Bay prior to its description as a new species in 1985 (Dix et al., 2005).

Prionospio perkinsi was ranked eleventh in overall abundance which represented 1.75% of the total abundance and was found at 44.1% of the sites (Table 22). It had a mean abundance of 154 m^{-2} and a maximum abundance of 7525 m^{-2} located at a Hillsborough Bay site in 1998 (98HB014). It was among the top ten dominant species in 1993-1994, 1998-1999, 2002, 2007 and 2009 (Table 21). It was one of the dominant taxa in Hillsborough Bay and Middle Tampa Bay (Table 22). The annual mean abundance of *P. perkinsi* exhibited a cyclical pattern over the 20 year monitoring period (Figure 170). Highest abundances were in Hillsborough Bay, Old Tampa Bay and Middle Tampa Bay (Figures 171 & 172). SIMPER analysis indicated that *P. perkinsi* was associated with deep subtidal to deeper-depth sites, polyhaline salinities, normoxic to hypoxic dissolved oxygen and with sediments ranging from muds to medium grained sands. SIMPER analysis indicated that it was also associated with sites that exceeded the PEL for chromium and with sites that were above the TEL for several pesticides (lindane, dieldrin, DDD), PCBs, several PAHs, and metals including cadmium, chromium, copper, lead, nickel, silver and zinc. Taylor (1971) reported this species (as *P. cirrobranchiata*) was found in all areas of Tampa Bay except Lower Tampa Bay in poorly sorted very fine to silty sands with a mean %silt+clay content over 18%, salinities ranging from 21.0 – 34.3 psu (mean = 26 psu) and a depth range of <1 to 4 meters (Taylor, 1971).

***Mediomastus spp*.; *Mediomastus ambiseta* (Hartman, 1947); *Mediomastus californiensis* Hartman, 1944**

The capitellid polychaete *Mediomastus* spp. is comprised of damaged specimens of two distinct species found in Tampa Bay: *Mediomastus ambiseta* and *Mediomastus californiensis*. *Mediomastus ambiseta* was originally described as *Capitita ambiseta* (Hartman, 1947). Both species are small worms (<25mm length, 0.5 mm width) (Ewing, 1984). They easily fragment during sample collection and processing making species level identification difficult. These polychaetes are considered to be opportunistic species and are often associated with disturbed habitats (Grassle and Grassle, 1974; Daur and Simon, 1980 a&b; Santos and Simon 1980 a&b). Neither species were reported by Taylor (1971). Santos and Simon (1980 a&b) found *Mediomastus californiensis* recolonized sediments following defaunation due to hypoxia in Hillsborough Bay. *Mediomastus ambiseta* (identified as *Capitita ambiseta* in 1976) were among the dominant polychaetes in the second year following a defaunation event in Old Tampa Bay due to red tide. (Dauer and Simon, 1976 a&b)

Mediomastus spp. was ranked 12th overall in abundance which represented 1.52% of the total abundance and was found at 43% of the samples. It had a mean abundance of 134 m^{-2} with a maximum of 5,975 m^{-2}. It was among the top 10 dominant taxa in 2000 and 2008 and in the Manatee River and Terra Ceia Bay (Table 21 & 22). The mean annual abundance of *Mediomastus* spp. had a cyclical trend over the 20 year monitoring period with a peak in 1993

(Figure 173). Highest abundances were found in the Manatee River and lowest in Old Tampa Bay (Figure 174). It was widespread throughout Tampa Bay with high densities observed in Hillsborough Bay, Middle Tampa Bay, Boca Cieaga Bay and the Manatee River (Figure 175). SIMPER analysis indicated that *Mediomastus* spp. was associated with depths ranging from 1 to >4 meters, fine to medium sediments and salinities ranging from low mesohalne to euhaline. SIMPER analysis indicated *Mediomastus* spp. was associated with sites that were above the TELs for lindane, p,p'-DDT, arsenic and cadmium.

Mediomastus ambiseta was ranked 62nd overall in abundance which represented 0.34% of the total abundance, and it occurred in at 12.8% of the sites. It had a mean abundance of 30 m^{-2} with a maximum of 4,550 m^{-2}. It was among the dominant taxa in 1993 and 1994 with a decreasing trend over the 20 year monitoring period (Table 21; Figure 173). The highest abundances were in Hillsborough Bay and the Manatee River (Figure 174). Its overall distribution was more confined to the periphery of the bay (Figure176). Hartman (1947) recorded this species from intertidal mud flats. The worms build vertical tubes of mucus and debris in the sediments, and the animals are oriented head down (Hartman, 1947; Warren et al. 1994).

Mediomastus californiensis was ranked 52nd in overall abundance which represented 0.42% of the total abundance, and it occurred at 16.4% of the sites. It had a mean abundance of 37 m^{-2} with a maximum of 9,050 m^{-2}. *Mediomastus californiensis* was among the dominant taxa in 1994 with a decreasing trend over the 20 year monitoring period (Table 21; Figure 173). Highest abundances were in the Manatee River (Figure 174). It had a wide distribution throughout the bay (Figure 177). *Mediomastus californiensis* has been previously reported from intertidal, muddy sands (Hartman, 1947), and it has been found throughout the northern Gulf of Mexico and off the coast of Florida at depths of 18-53 meters in sediments ranging from silt/clay, muddy sands to very fine and medium sands (Ewing, 1984).

***Mulinia lateralis* (Say, 1822)**

The bivalve *Mulinia lateralis* was ranked thirteenth overall in abundance which represented 1.50% of the total abundance and occurred at 20.4% of the sites (Table 22). It was among the dominant taxa in 1998-2000 and 2008, and in Hillsborough Bay, the Manatee River and Terra Ceia Bay (Tables 21 & 22). It had a mean abundance of 132 m^{-2} with a maximum of 24,150 m^{-2} located at a Manatee River site in 2000 (00MR19). Wassaw Sound, GA had densities that were as high as 63,000 m^{-2} (Walker and Tenore, 1984). Annual mean abundances were variable over the 20 year monitoring period with peaks in 2000 and 2008 and low abundances in 2010. It was completely absent in 2007 (Figure 178). Highest abundance was in the Manatee River (Figures 179 & 180). High abundances were also found in Hillsborough Bay, Old Tampa Bay, and Terra Ceia Bay (Figures 179 & 180). *Mulinia lateralis* densities are variable over time, but when occurring in high densities, they are 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 associated with fine sand sediments and low to high mesohaline salinities. These habitat types agree with Taylor et al. (1970).

Table 21. Baywide dominant benthic taxa (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	*Clymenella 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 21 (Continued). **Baywide 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 21 (Continued). **Baywide 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	*Clymenella 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 (Continued). Baywide dominant benthic taxa (relative abundance) by year.

2005	%	2006	%	2007	%	2008	%
Glottidia pyramidata (Brachiopoda)	12.26	*Exogone dispar* (Annelida:Polychaeta)	14.84	*Rudilemboides naglei* (Crustacea:Amphipoda)	11.99	*Mysella planulata* (Mollusca:Bivalvia)	12.91
Fabricinuda trilobata (Annelida:Polychaeta)	8.55	*Glottidia pyramidata* (Brachiopoda)	7.02	*Monticellina cf. dorsobranchialis* (Annelida:Polychaeta)	4.73	TUBIFICIDAE (Annelida:Oligochaeta)	4.98
Bittiolum varium (Mollusca:Gastropoda)	5.70	TUBIFICIDAE (Annelida:Oligochaeta)	6.27	*Caecum strigosum* (Mollusca:Gastropoda)	4.06	*Kalliapseudes macsweenyi* (Crustacea:Tanaidacea)	3.60
Ampelisca holmesi (Crustacea:Amphipoda)	5.65	*Rudilemboides naglei* (Crustacea:Amphipoda)	3.74	*Fabricinuda trilobata* (Annelida:Polychaeta)	3.72	*Fabricinuda trilobata* (Annelida:Polychaeta)	3.57
Mysella planulata (Mollusca:Bivalvia)	4.16	*Monticellina cf. dorsobranchialis* (Annelida:Polychaeta)	3.61	*Clymenella mucosa* (Annelida:Polychaeta)	3.48	*Mulinia lateralis* (Mollusca:Bivalvia)	3.13
Amygdalum papyrium (Mollusca:Bivalvia)	2.64	*Mysella planulata* (Mollusca:Bivalvia)	3.37	*Branchiostoma floridae* (Cephalochordata)	3.45	*Branchiostoma floridae* (Cephalochordata)	2.51
Grandidierella bonnieroides (Crustacea:Amphipoda)	2.38	*Branchiostoma floridae* (Cephalochordata)	2.52	*Carazziella hobsonae* (Annelida:Polychaeta)	3.29	*Monticellina cf. dorsobranchialis* (Annelida:Polychaeta)	2.29
TUBIFICIDAE (Annelida:Oligochaeta)	2.26	*Fabricinuda trilobata* (Annelida:Polychaeta)	2.36	*Prionospio perkinsi* (Annelida:Polychaeta)	3.29	*Mediomastus spp.* (Annelida:Polychaeta)	2.01
Monticellina cf. dorsobranchialis (Annelida:Polychaeta)	2.25	*Amygdalum papyrium* (Mollusca:Bivalvia)	2.14	*Exogone dispar* (Annelida:Polychaeta) TUBIFICIDAE (Annelida:Oligochaeta)	3.03	*Aricidea philbinae* (Annelida:Polychaeta)	2.00
Paraprionospio pinnata (Annelida:Polychaeta)	1.70	*Tubificoides brownae* (Annelida:Oligochaeta)	2.04	*Ampelisca holmesi* (Crustacea:Amphipoda)	2.93	*Exogone lourei* (Annelida:Polychaeta)	1.97

Table 21 (Continued). Baywide dominant benthic taxa (relative abundance) by year.

2009	%	2010	%	2011	%	2012	%
Mysella planulata (Mollusca:Bivalvia)	7.72	*Fabricinuda trilobata* (Mollusca:Bivalvia)	5.46	*Monticellina cf. dorsobranchialis* (Annelida:Polychaeta)	11.73	*Ampelisca holmesi* (Crustacea:Amphipoda)	6.62
Glottidia pyramidata (Brachiopoda)	4.60	TUBIFICIDAE (Annelida:Oligochaeta)	5.41	TUBIFICIDAE (Annelida:Oligochaeta)	8.34	*Kalliapseudes macsweenyi* (Crustacea:Tanaidacea) *Ampelisca abdita* (Crustacea:Amphipoda)	4.49
Amygdalum papyrium (Mollusca:Bivalvia)	4.54	*Exogone dispar* (Annelida:Polychaeta)	4.16	*Bittiolum varium* (Mollusca:Gastropoda)	4.57	*Amygdalum papyrium* (Mollusca:Bivalvia)	4.45
Kalliapseudes macsweenyi (Crustacea:Tanaidacea)	3.61	*Caecum pulchellum* (Mollusca:Gastropoda)	4.11	*Parastarte triquetra (Mollusca:Bivalvia)*	3.01	*Fabricinuda trilobata* (Annelida:Polychaeta)	3.82
TUBIFICIDAE (Annelida:Oligochaeta)	3.09	*Kalliapseudes macsweenyi* (Crustacea:Tanaidacea)	2.49	*Heteromastus filiformis* Annelida:Polychaeta)	2.84	TUBIFICIDAE (Annelida:Oligochaeta)	3.38
Rudilemboides naglei (Crustacea:Amphipoda)	2.63	*Bittiolum varium* (Mollusca:Gastropoda)	2.45	*Paraprionospio pinnata* (Annelida:Polychaeta)	2.63	*Clymenella mucosa* (Annelida:Polychaeta)	3.13
Fabricinuda trilobata (Annelida:Polychaeta)	2.40	Balanidae Crustacea:Cirripedia) *Glottidia pyramidata* (Brachiopoda)	2.32	*Aricidea philbinae* (Annelida:Polychaeta)	2.45	*Bittiolum varium* (Mollusca:Gastropoda)	2.87
Prionospio perkinsi (Annelida:Polychaeta)	1.85	*Acteocina canaliculata* (Mollusca:Gastropoda)	2.26	*Ampelisca holmesi* (Crustacea:Amphipoda)	2.44	*Paraprionospio pinnata* (Annelida:Polychaeta)	2.86
Monticellina cf. dorsobranchialis (Annelida:Polychaeta) *Boguea enigmatica* (Annelida:Polychaeta)	1.80	*TELLININAE (Mollusca:Bivalvia)*	2.10	*Acteocina canaliculata* (Mollusca:Gastropoda)	1.88	*Tubificoides wasselli* (Annelida:Oligochaeta)	2.67
TELLININAE (Mollusca:Bivalvia)	1.74	*Monticellina cf. dorsobranchialis* (Annelida:Polychaeta)	1.94	*Haminoea succinea* (Mollusca:Gastropoda)	1.77	*Monticellina cf. dorsobranchialis* (Annelida:Polychaeta)	2.58

Table 22. Dominant benthic taxa (Relative Abundance) by bay segment (1993-2012).

Hillsborough Bay	%	Old Tampa Bay	%	Middle Tampa Bay	%	Lower Tampa Bay	%
Mysella planulata (Mollusca:Bivalvia)	9.52	*Rudilemboides naglei* (Crustacea:Amphipoda)	7.89	*Glottidia pyramidata* (Brachiopoda)	13.72	*Branchiostoma floridae* (Cephalochordata)	11.33
Monticellina cf. dorsobranchialis (Annelida:Polychaeta)	7.98	CIRRIPEDIA (Crustacea:Cirripedia)	7.05	*Branchiostoma floridae* (Cephalochordata)	8.79	*Fabricinuda trilobata* (Annelida:Polychaeta)	5.63
Glottidia pyramidata (Brachiopoda)	6.57	*Mysella planulata* (Mollusca:Bivalvia)	5.56	*Caecum strigosum* (Mollusca:Gastropoda)	7.31	*Caecum strigosum* (Mollusca:Gastropoda)	4.16
Ampelisca holmesi (Crustacea:Amphipoda)	5.97	*Ampelisca holmesi* (Crustacea:Amphipoda)	4.48	*Monticellina cf. dorsobranchialis* (Annelida:Polychaeta)	3.34	TUBIFICIDAE (Annelida:Oligochaeta)	2.75
Amygdalum papyrium (Mollusca:Bivalvia)	3.71	*Branchiostoma floridae* (Cephalochordata)	4.45	TUBIFICIDAE (Annelida:Oligochaeta)	2.66	*Kalliapseudes macsweenyi* (Crustacea:Tanaidacea)	2.32
Carazziella hobsonae (Annelida:Polychaeta)	3.56	*Glottidia pyramidata* (Brachiopoda)	3.44	*Prionospio perkinsi* (Annelida:Polychaeta)	2.06	*Clymenella mucosa* (Annelida:Polychaeta)	2.24
Prionospio perkinsi (Annelida:Polychaeta)	3.34	*Caecum strigosum* (Mollusca:Gastropoda)	3.20	*Janua (Dexiospira) steueri* (Annelida:Polychaeta)	1.86	*Leptochelia/Hargeria sp.* (Crustacea:Tanaidacea)	2.12
TUBIFICIDAE (Annelida:Oligochaeta)	3.25	*Exogone dispar* (Annelida:Polychaeta)	3.01	*Bittiolum varium* (Mollusca:Gastropoda)	1.72	*Janua (Dexiospira) steueri* (Annelida:Polychaeta)	2.11
Paraprionospio pinnata (Annelida:Polychaeta)	2.71	*Tubificoides wasselli* (Annelida:Oligochaeta)	2.25	*Rudilemboides naglei* (Crustacea:Amphipoda)	1.71	*Acanthohaustorius uncinus* (Crustacea:Amphipoda)	1.98
Mulinia lateralis (Mollusca:Bivalvia)	2.60	TUBIFICIDAE (Annelida:Oligochaeta)	2.20	*Clymenella mucosa* (Annelida:Polychaeta)	1.65	*Phascolion cf. caupo* (Sipuncula)	1.91

Table 22 (Continued). **Dominant benthic taxa (relative abundance) by bay segment (1993-2012).**

Manatee River	%	Terra Ceia Bay	%	Boca Ciega Bay	%	Tampa Bay	%
Ampelisca abdita (Crustacea:Amphipoda)	12.64	*Monticellina cf. dorsobranchialis* (Annelida:Polychaeta)	6.65	TUBIFICIDAE (Annelida:Oligochaeta)	7.71	*Glottidia pyramidata* (Brachiopoda)	5.08
Monticellina cf. dorsobranchialis (Annelida:Polychaeta)	8.58	TUBIFICIDAE (Annelida:Oligochaeta)	6.63	*Janua (Dexiospira) steueri* (Annelida:Polychaeta)	4.26	*Branchiostoma floridae* (Cephalochordata)	4.86
Mulinia lateralis (Mollusca:Bivalvia)	6.90	*Ampelisca holmesi* (Crustacea:Amphipoda)	6.05	*Monticellina cf. dorsobranchialis* (Annelida:Polychaeta)	3.44	*Monticellina cf. dorsobranchialis* (Annelida:Polychaeta)	4.13
Amygdalum papyrium (Mollusca:Bivalvia)	5.16	*Paraprionospio pinnata* (Annelida:Polychaeta)	4.60	*Fabricinuda trilobata* (Annelida:Polychaeta)	2.66	*Mysella planulata* (Mollusca:Bivalvia)	3.48
Grandidierella bonnieroides (Crustacea:Amphipoda)	4.90	*Acteocina canaliculata* (Mollusca:Gastropoda)	2.75	*Exogone dispar* (Annelida:Polychaeta)	2.24	TUBIFICIDAE (Annelida:Oligochaeta)	3.36
Ampelisca holmesi (Crustacea:Amphipoda)	4.81	*Mulinia lateralis* (Mollusca:Bivalvia)	2.73	*TELLININAE* (Mollusca:Bivalvia)	2.23	*Ampelisca holmesi* (Crustacea:Amphipoda)	2.96
Cyclaspis varians (Crustacea:Cumacea)	4.05	*Mediomastus spp.* (Annelida:Polychaeta)	2.62	*Kalliapseudes macsweenyi* (Crustacea:Tanaidacea)	2.01	*Caecum strigosum* (Mollusca:Gastropoda)	2.93
Mediomastus spp. (Annelida:Polychaeta)	3.21	*Tubificoides wasselli* (Annelida:Oligochaeta)	1.98	*Clymenella mucosa* (Annelida:Polychaeta)	1.99	*Rudilemboides naglei* (Crustacea:Amphipoda)	2.21
Fabricinuda trilobata (Annelida:Polychaeta)	2.66	*Haminoea succinea* (Mollusca:Gastropoda)	1.96	*Pileolaria rosepigmentata* (Annelida:Polychaeta)	1.93	CIRRIPEDIA (Crustacea:Cirripedia)	1.91
Paraprionospio pinnata (Annelida:Polychaeta)	2.14	*Mysella planulata* (Mollusca:Bivalvia)	1.86	*Cymadusa compta* (Crustacea:Amphipoda)	1.76	*Fabricinuda trilobata* (Annelida:Polychaeta)	1.86
						Prionospio perkinsi (Annelida:Polychaeta)	1.75
						Mediomastus spp. (Annelida:Polychaeta)	1.52
						Mulinia lateralis (Mollusca:Bivalvia)	1.50

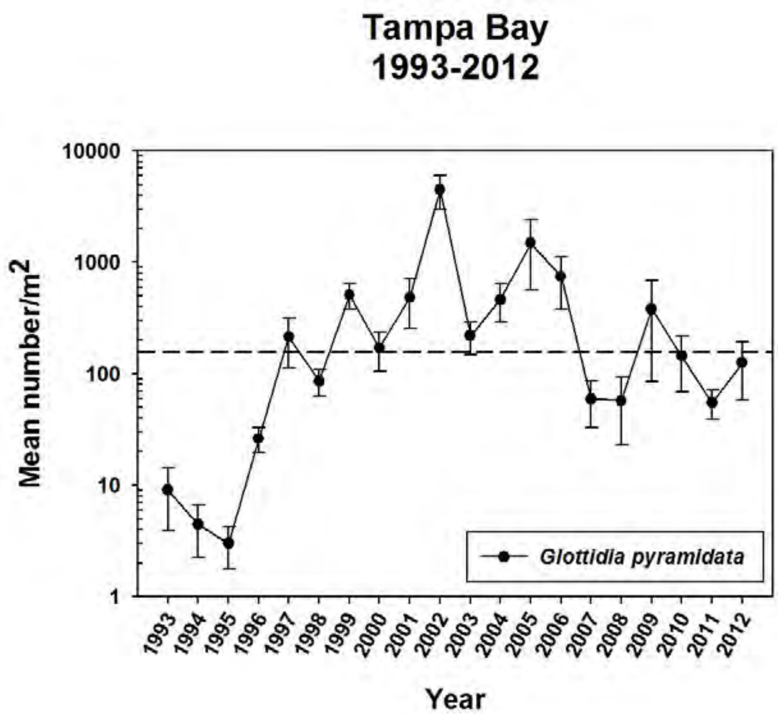


Figure 139. **Mean abundance of *Glottidia pyramidata* by year. Error bars = 1 standard error, dashed line represents baywide mean value.**

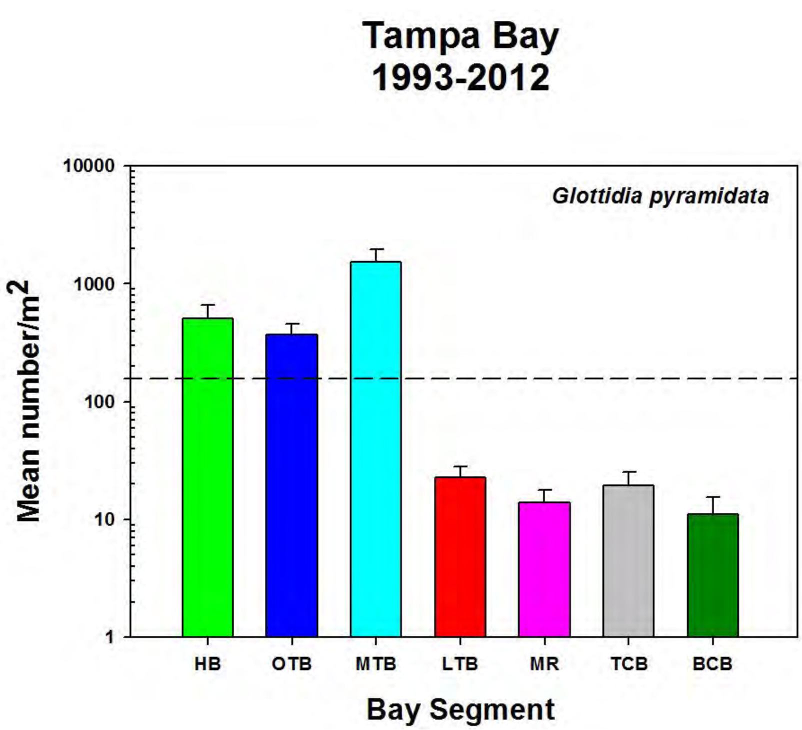


Figure 140. **Mean abundance of *Glottidia pyramidata* by bay segment. Error bars = 1 standard error, dashed line represents baywide mean value.**

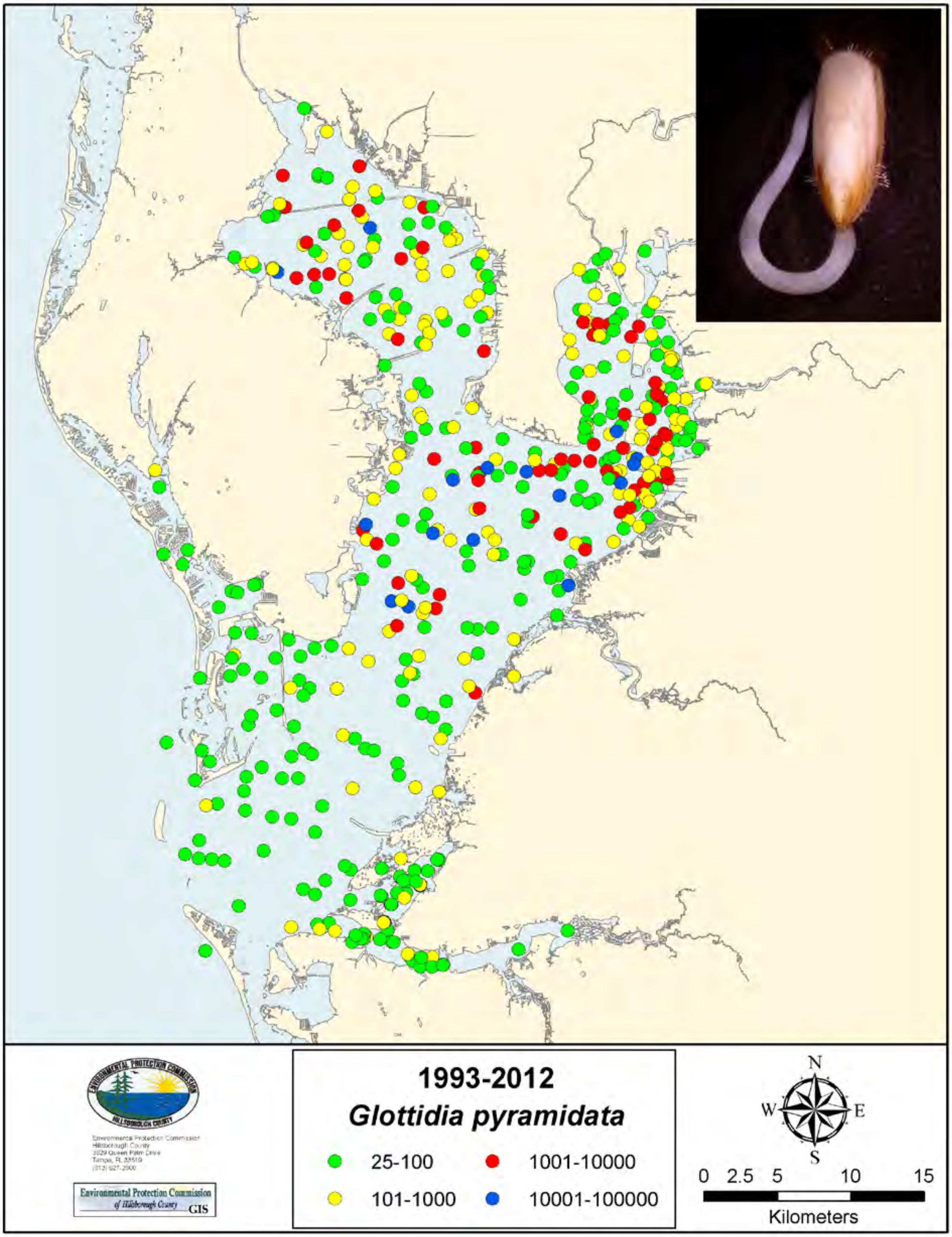


Figure 141. Late-Summer distribution of *Glottidia pyramidata* in Tampa Bay (1993-2012).

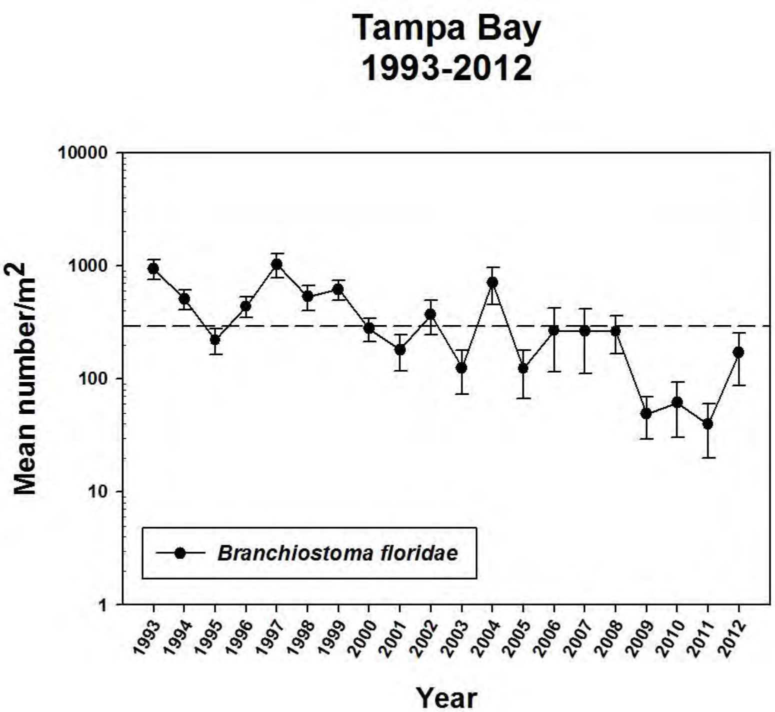


Figure 142. **Mean abundance of *Branchiostoma floridae* by year. Error bars = 1 standard error, dashed line represents baywide mean value.**

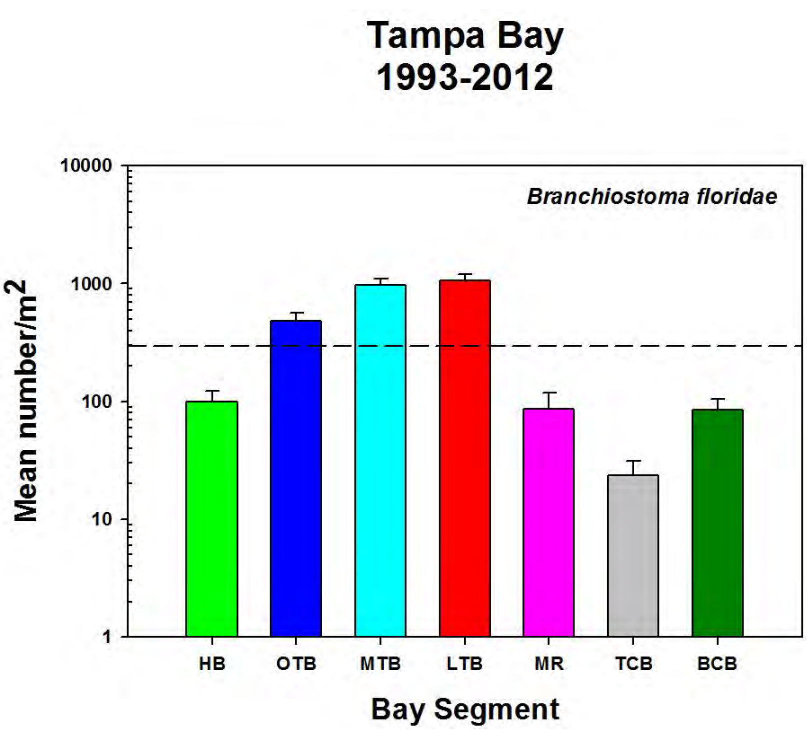


Figure 143. **Mean abundance of *Branchiostoma floridae* by bay segment. Error bars = 1 standard error, dashed line represents baywide mean value.**

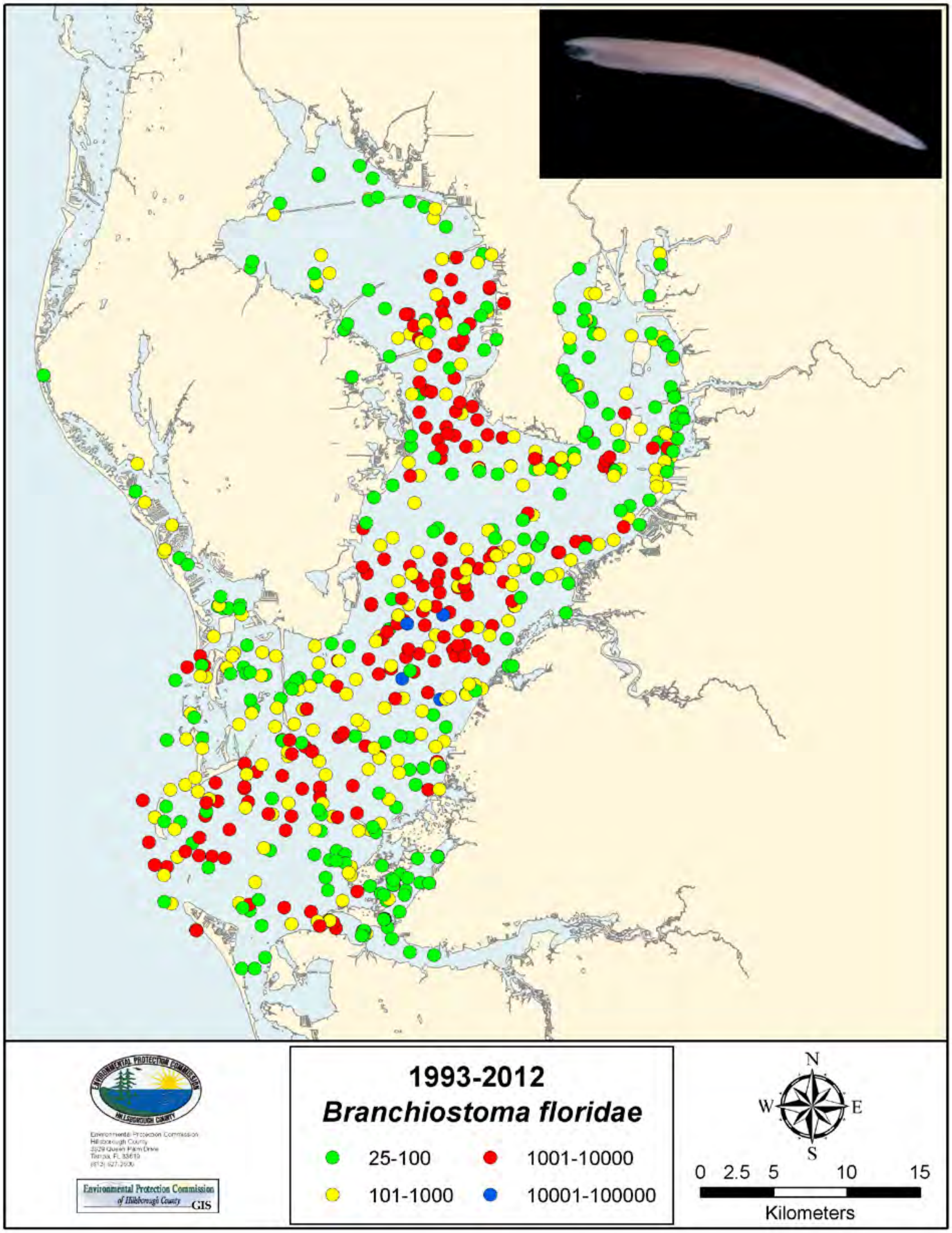


Figure 144. Late-Summer distribution of *Branchiostoma floridae* in Tampa Bay (1993-2012).

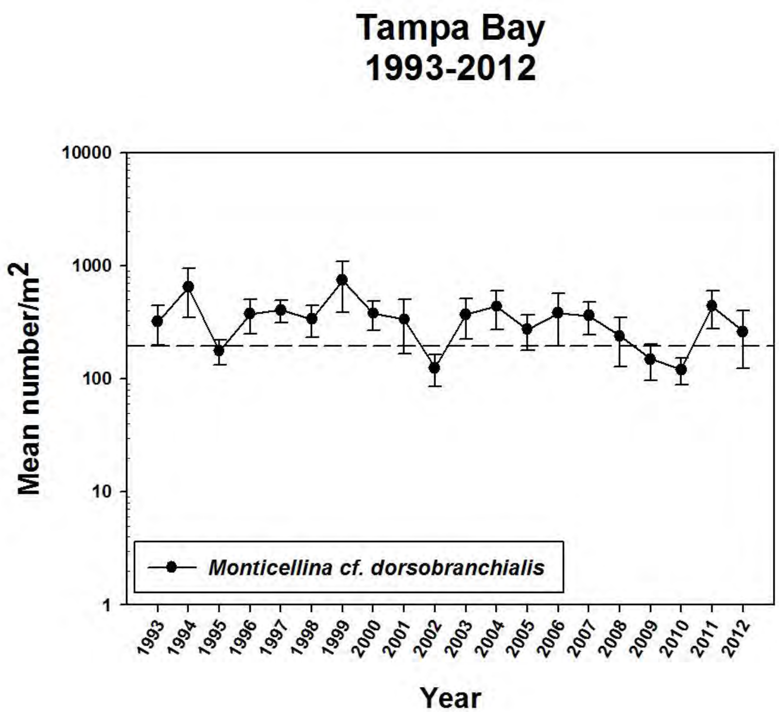


Figure 145. **Mean abundance of *Monticellina cf. dorsobranchialis* by year. Error bars = 1 standard error, dashed line represents baywide mean value.**

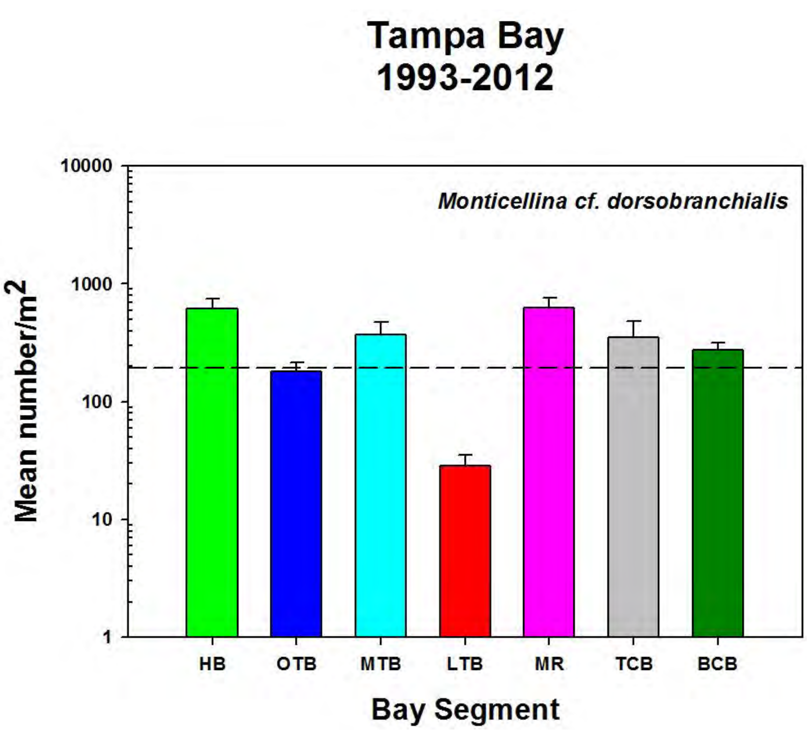


Figure 146. **Mean abundance of *Monticellina cf. dorsobranchialis* by bay segment. Error bars = 1 standard error, dashed line represents baywide mean value.**

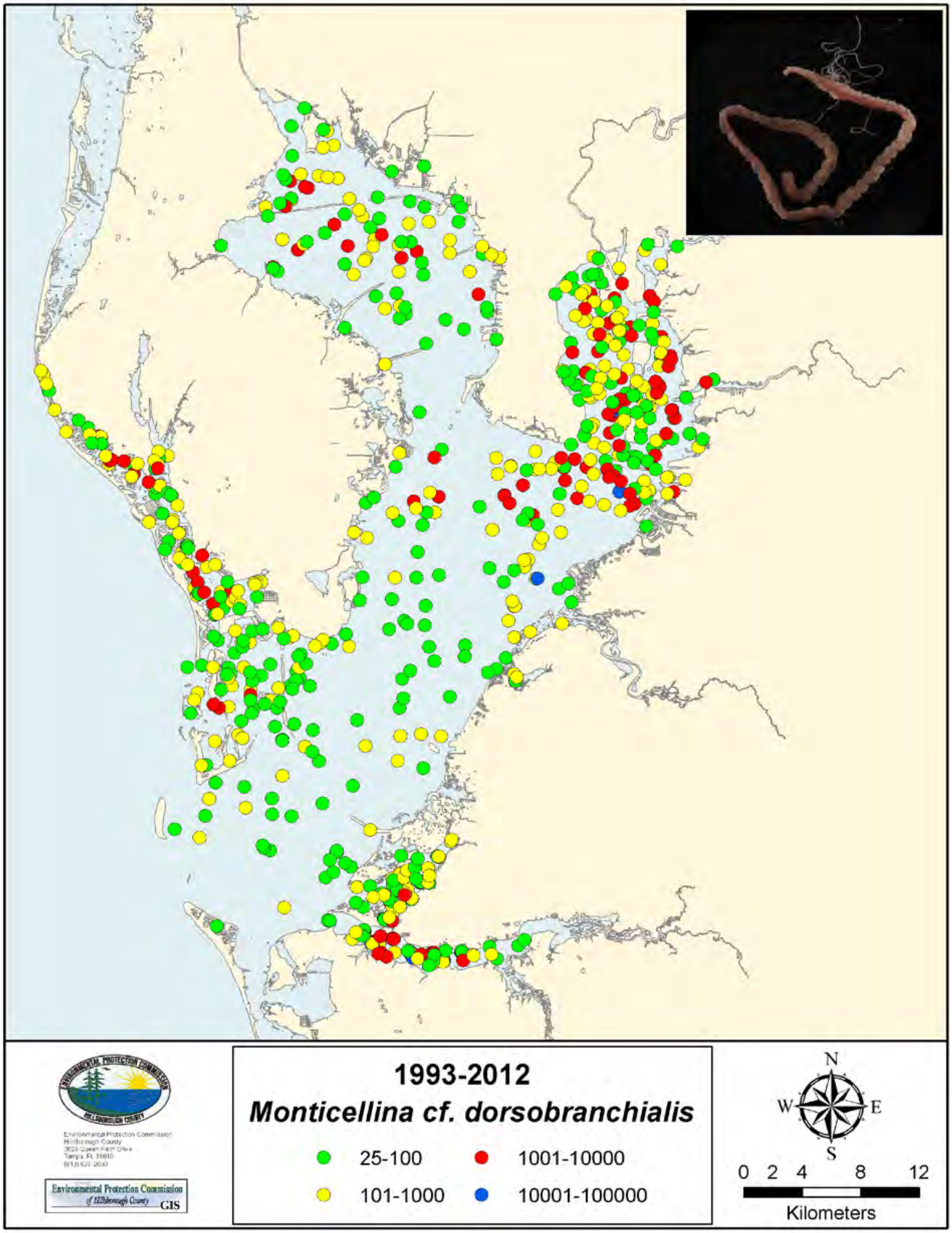


Figure 147. Late-Summer distribution of *Monticellina cf. dorsobranchialis* in Tampa Bay (1993-2012).

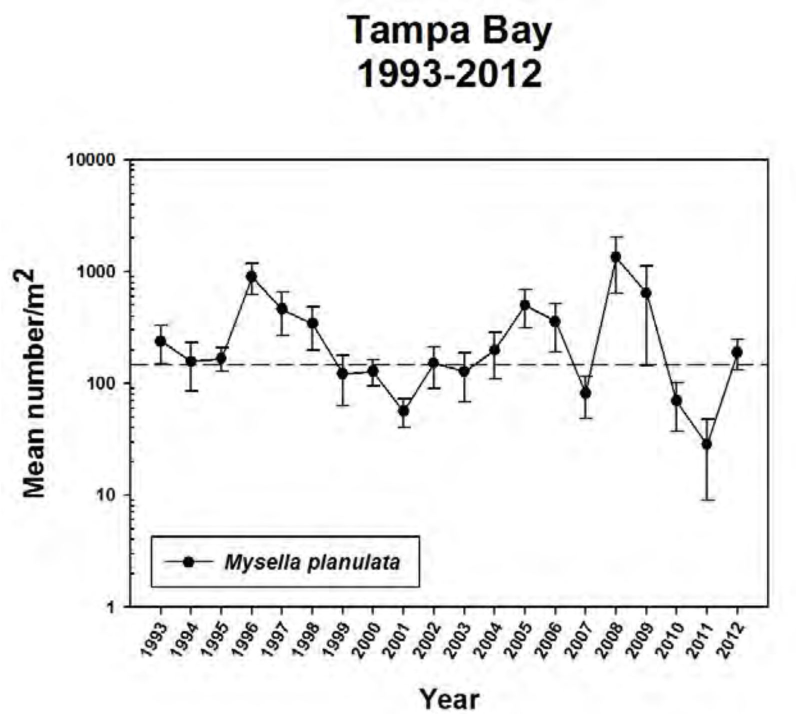


Figure 148. **Mean abundance of *Mysella planulata* by year. Error bars = 1 standard error, dashed line represents baywide mean value.**

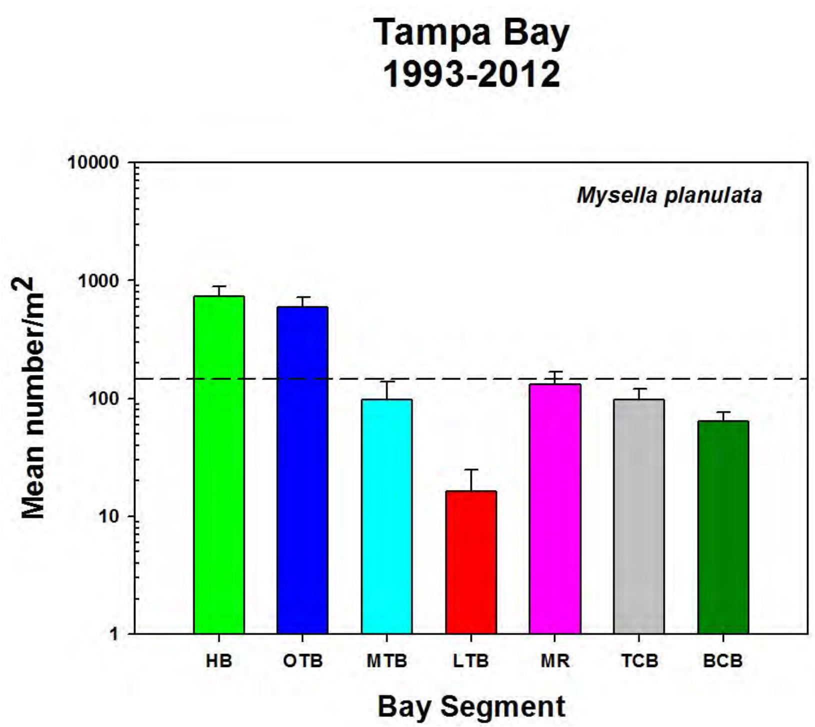


Figure 149. **Mean abundance of *Mysella planulata* by bay segment. Error bars = 1 standard error, dashed line represents baywide mean value.**

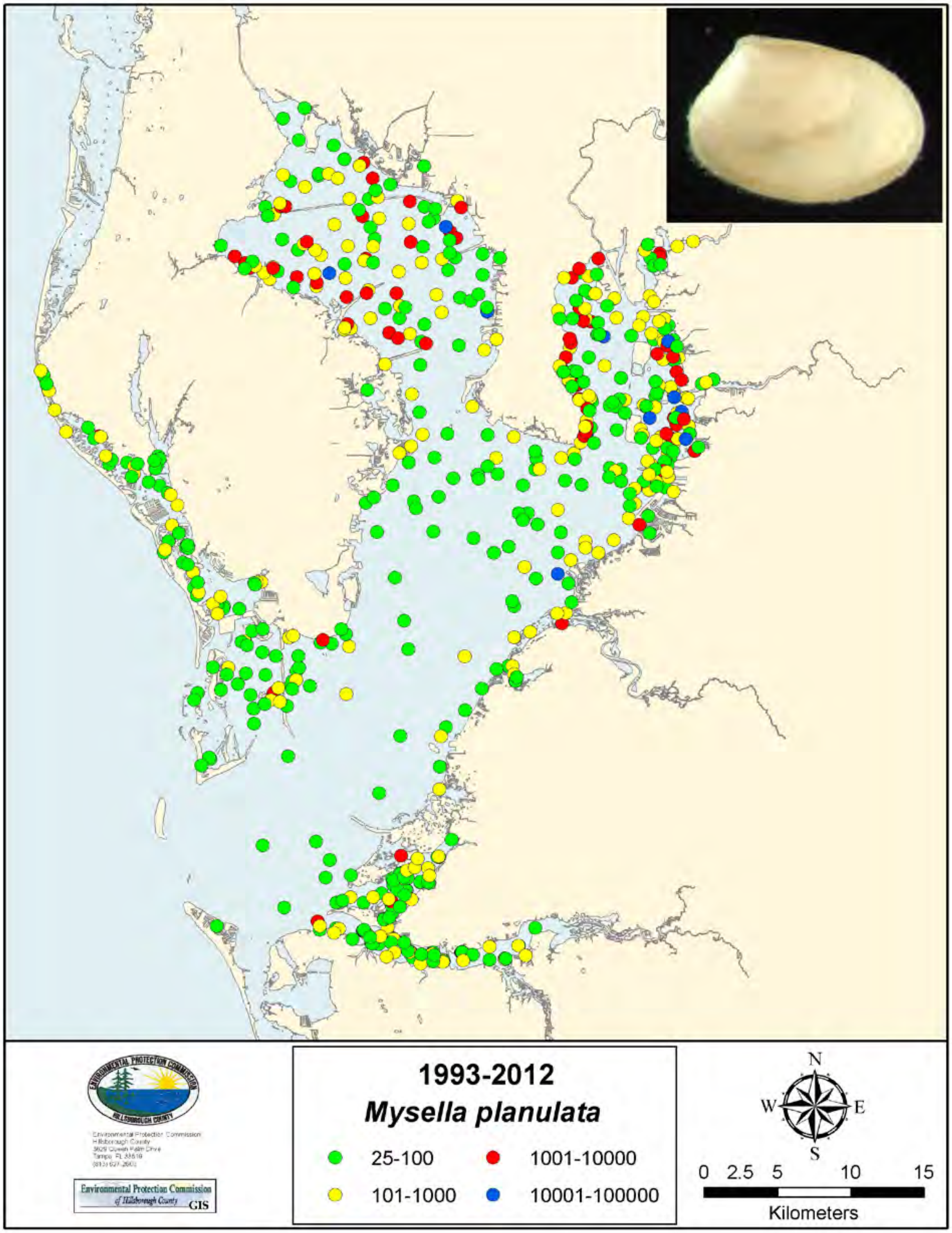


Figure 150. Late-Summer distribution of *Mysella planulata* in Tampa Bay (1993-2012).

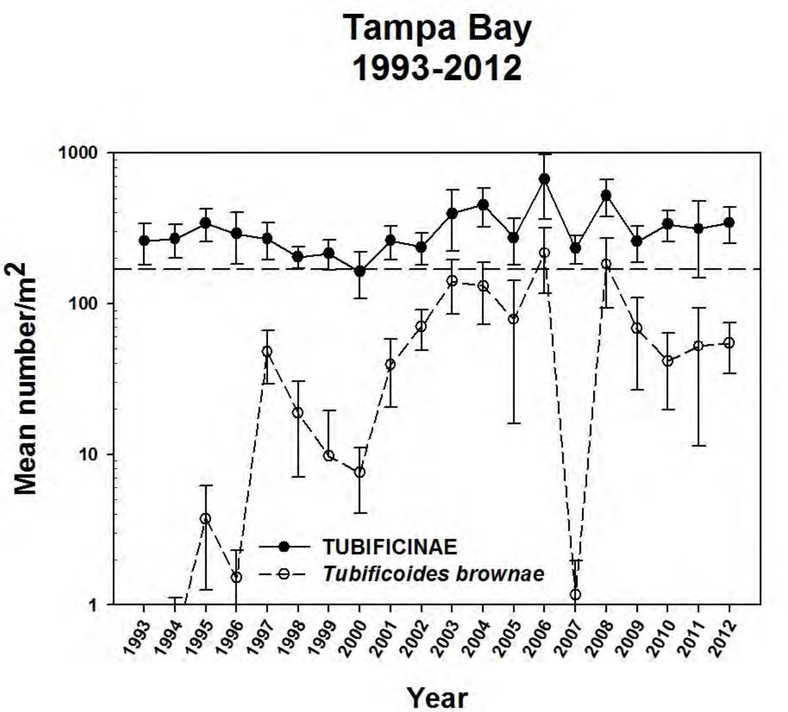


Figure 151. **Mean abundance of unidentified Tubificinae (solid circles) and *Tubificoides brownae* (open circles) by year. Error bars = 1 standard error, dashed line represents baywide mean value.**

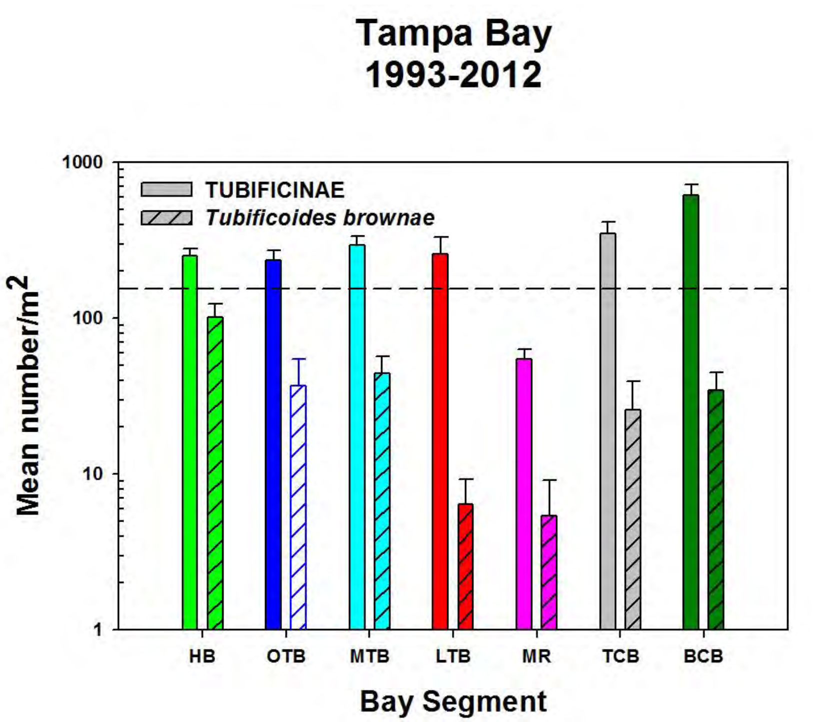


Figure 152. **Mean abundance of unidentified Tubificinae (solid bars) and *Tubificoides brownae* (hashed bars) by bay segment. Error bars = 1 standard error, dashed line represents baywide mean value.**

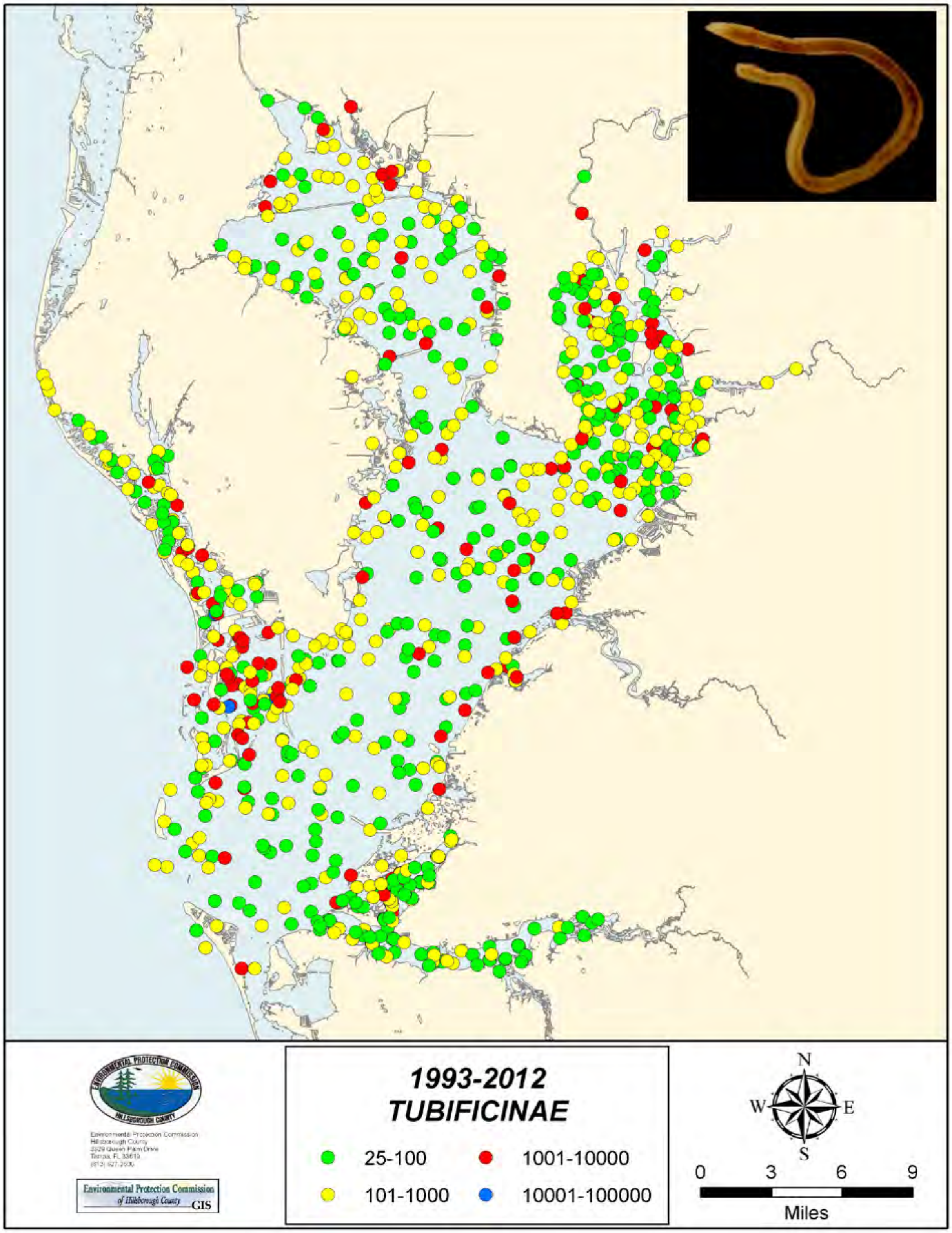


Figure 153. Late-Summer distribution of unidentified Tubificinae in Tampa Bay (1993-2012).

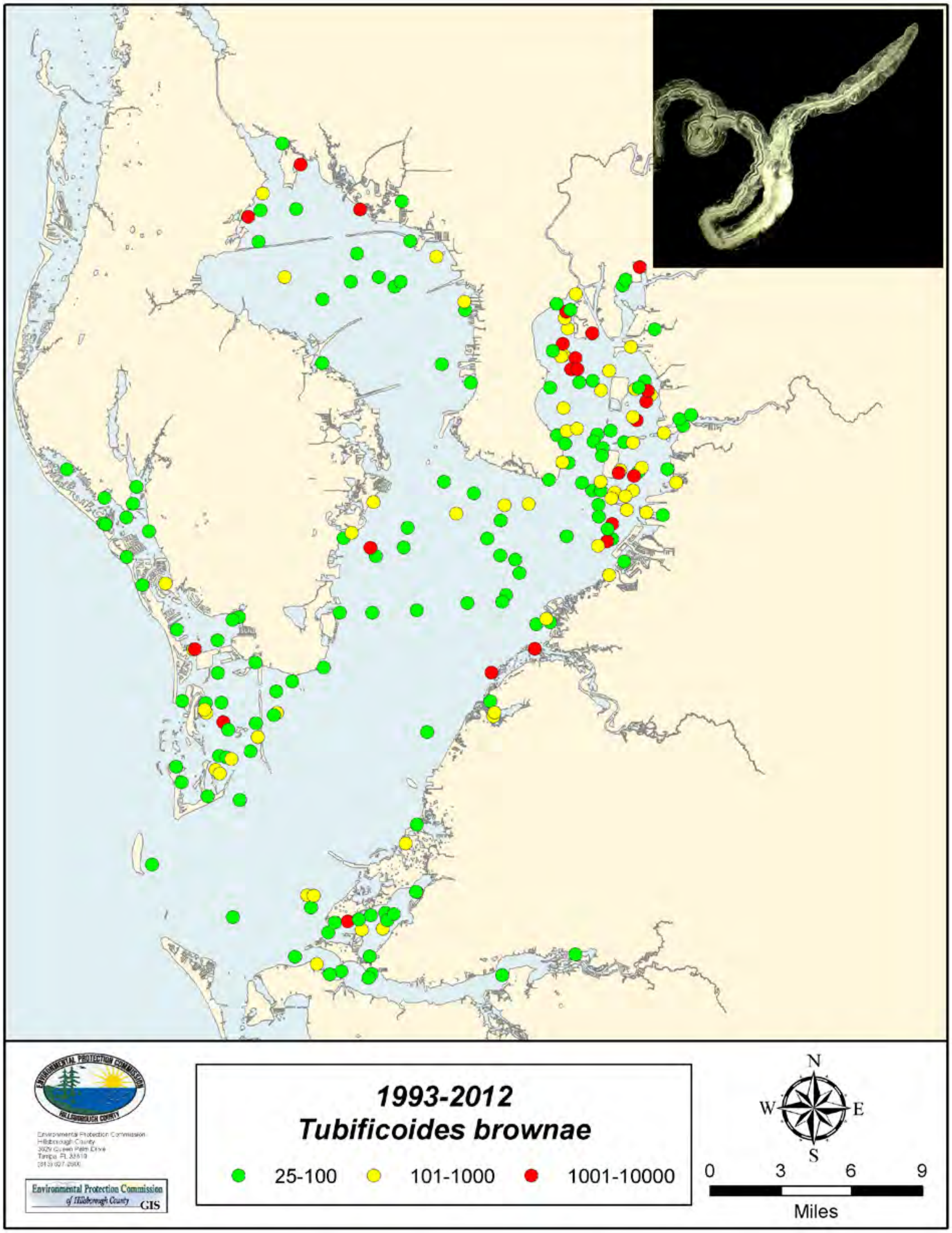


Figure 154. Late-Summer distribution of *Tubificoides brownae* in Tampa Bay (1993-2012).

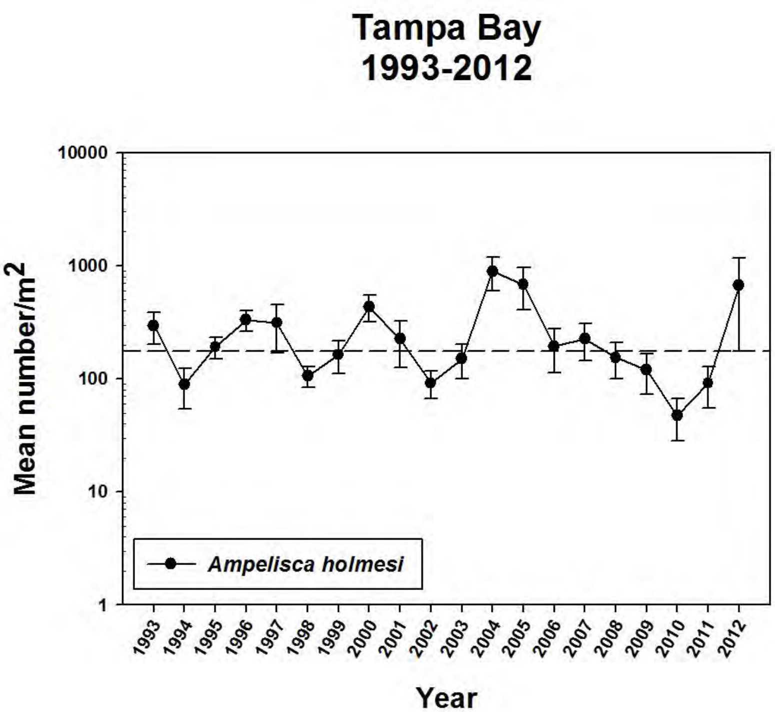


Figure 155. Mean abundance of *Ampelisca holmesi* by year. Error bars = 1 standard error, dashed line represents baywide mean value.

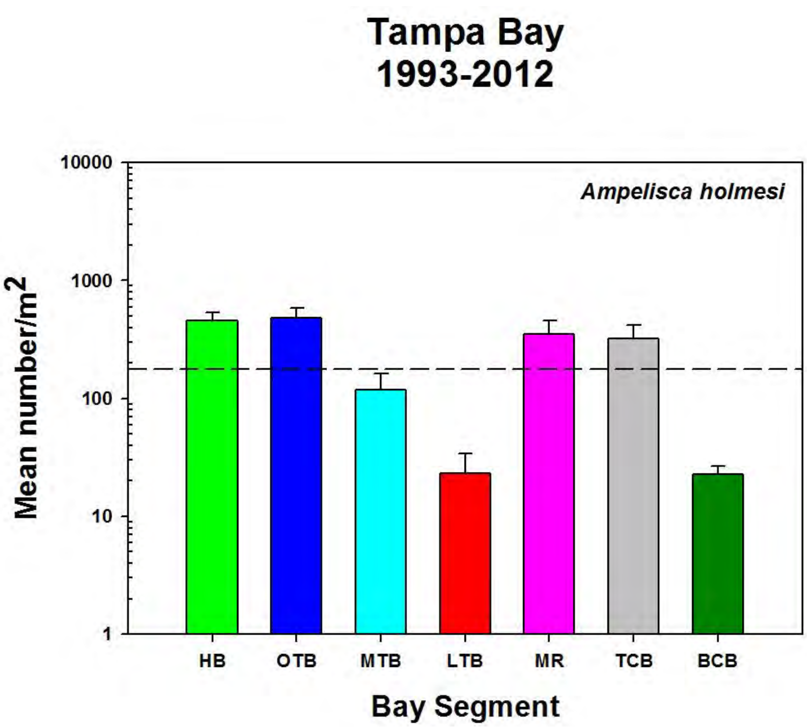


Figure 156. Mean abundance of *Ampelisca holmesi* by bay segment. Error bars = 1 standard error, dashed line represents baywide mean value.

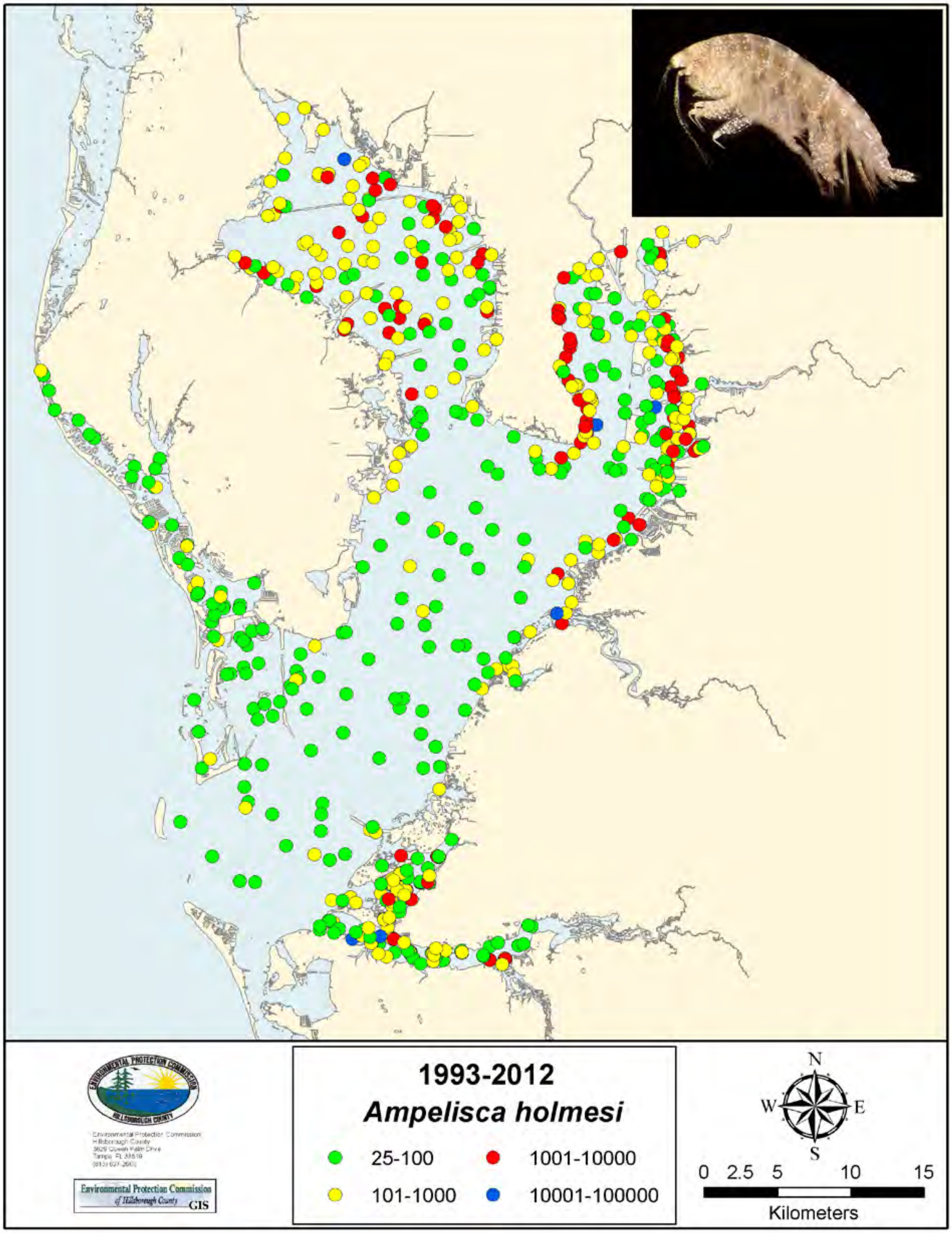


Figure 157. Late-Summer distribution of *Ampelisca holmesi* in Tampa Bay (1993-2012).

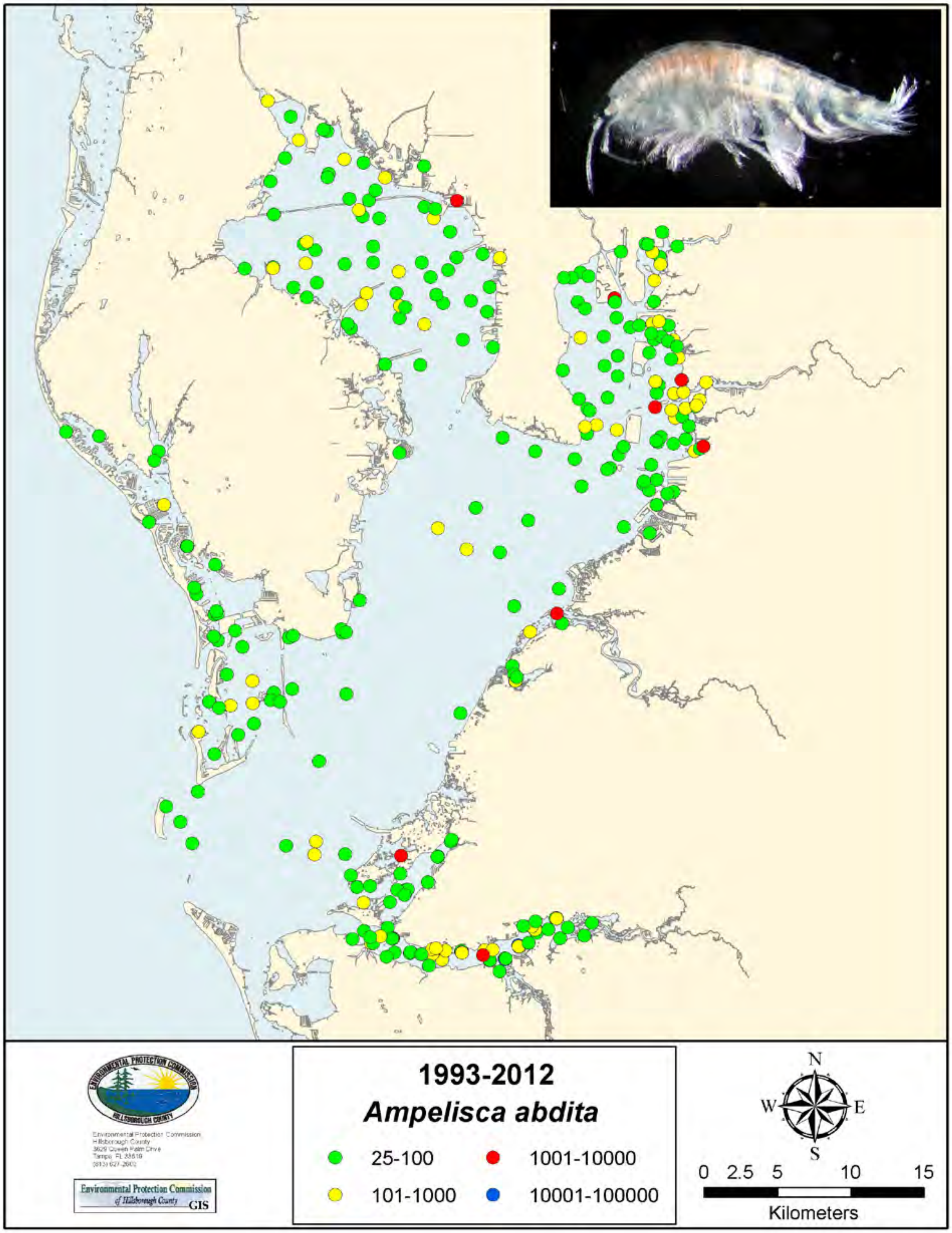


Figure 158. Late-Summer distribution of *Ampelisca abdita* in Tampa Bay (1993-2012).

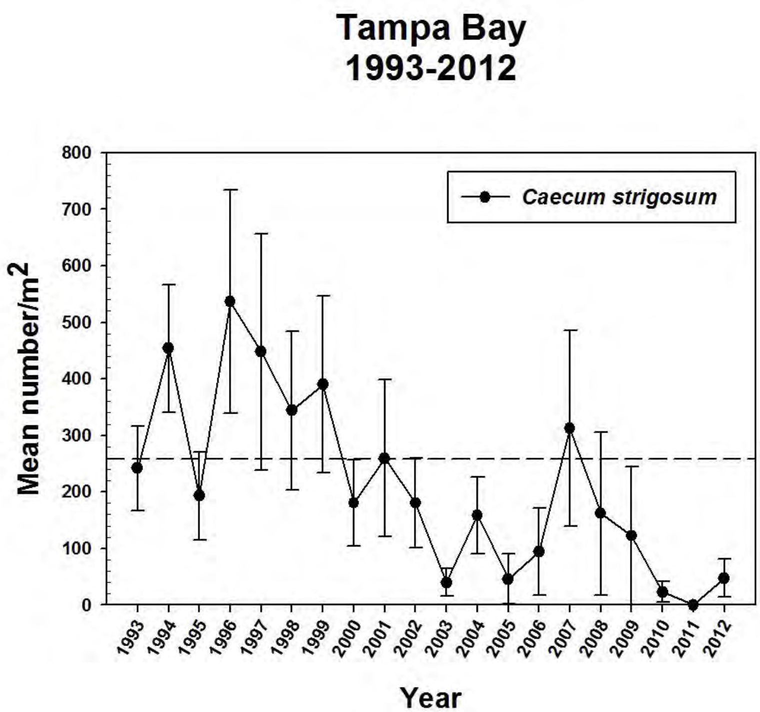


Figure 159. **Mean abundance of *Caecum strigosum* by year. Error bars = 1 standard error, dashed line represents baywide mean value.**

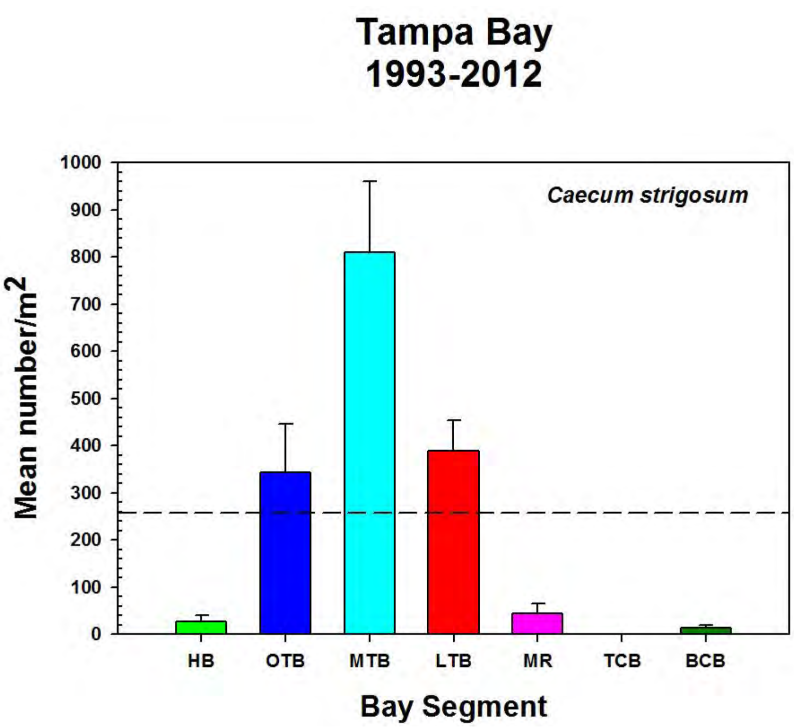


Figure 160. **Mean abundance of *Caecum strigosum* by bay segment. Error bars = 1 standard error, dashed line represents baywide mean value.**

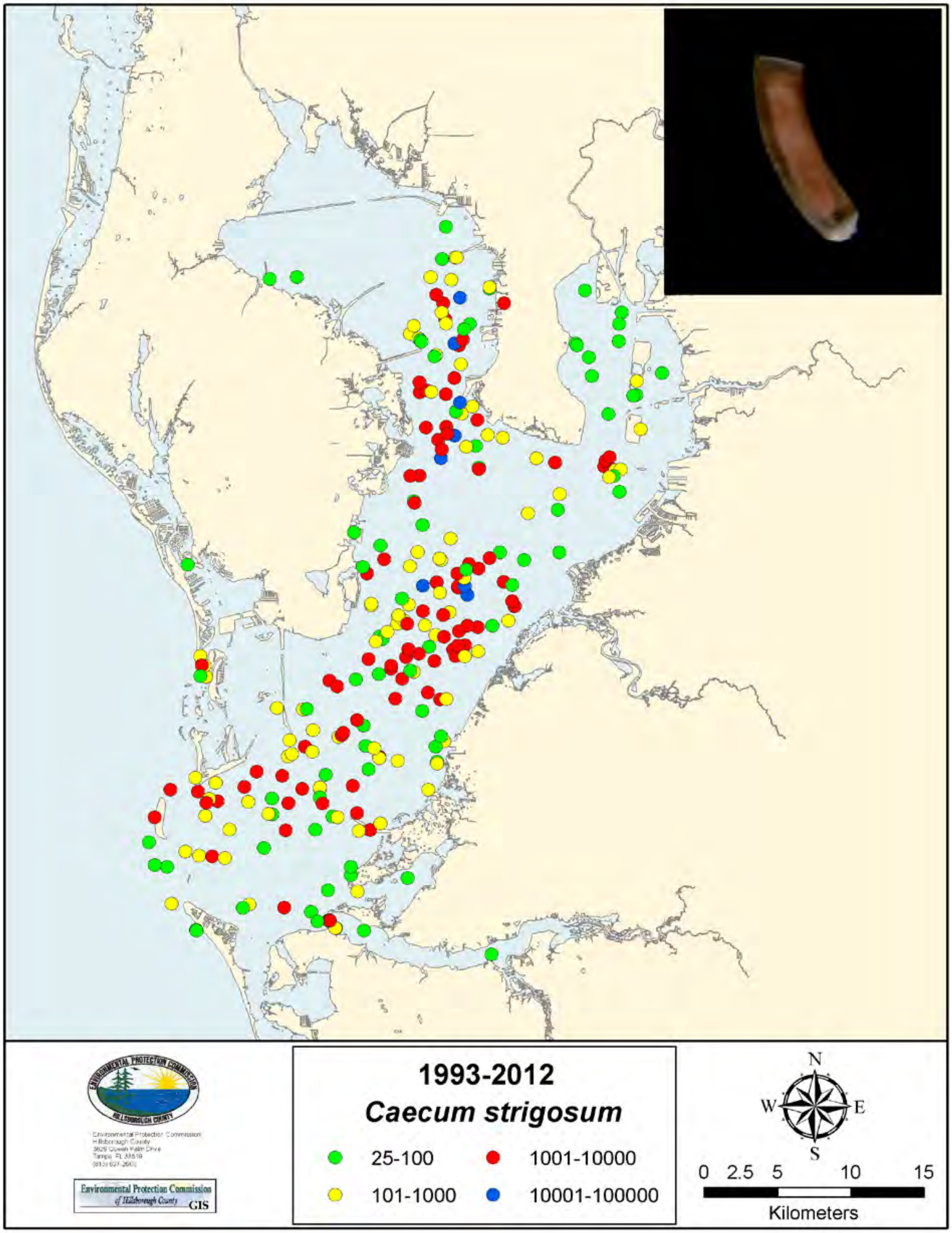


Figure 161. Late-Summer distribution of *Caecum strigosum* in Tampa Bay (1993-2012).

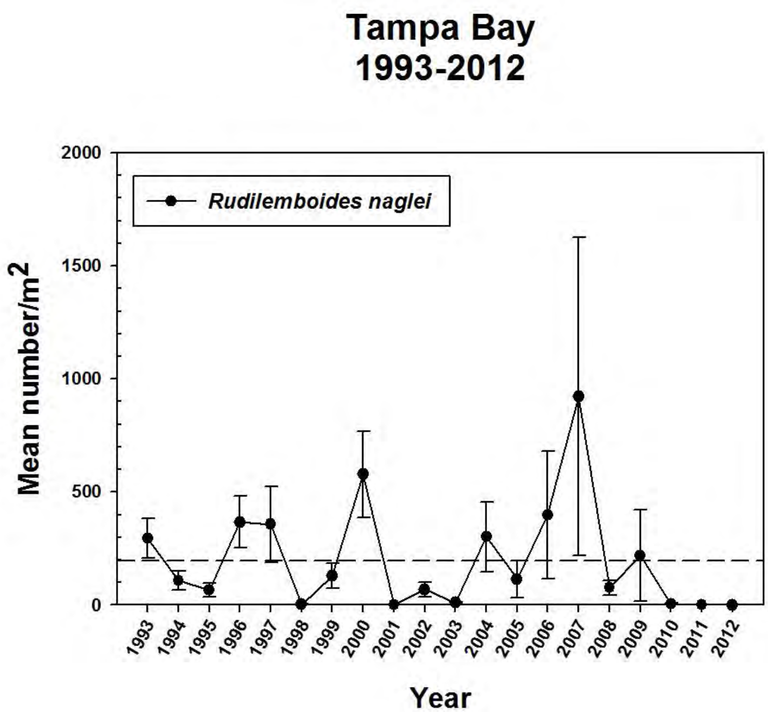


Figure 162. **Mean abundance of *Rudilemboides naglei* by year. Error bars = 1 standard error, dashed line represents baywide mean value.**

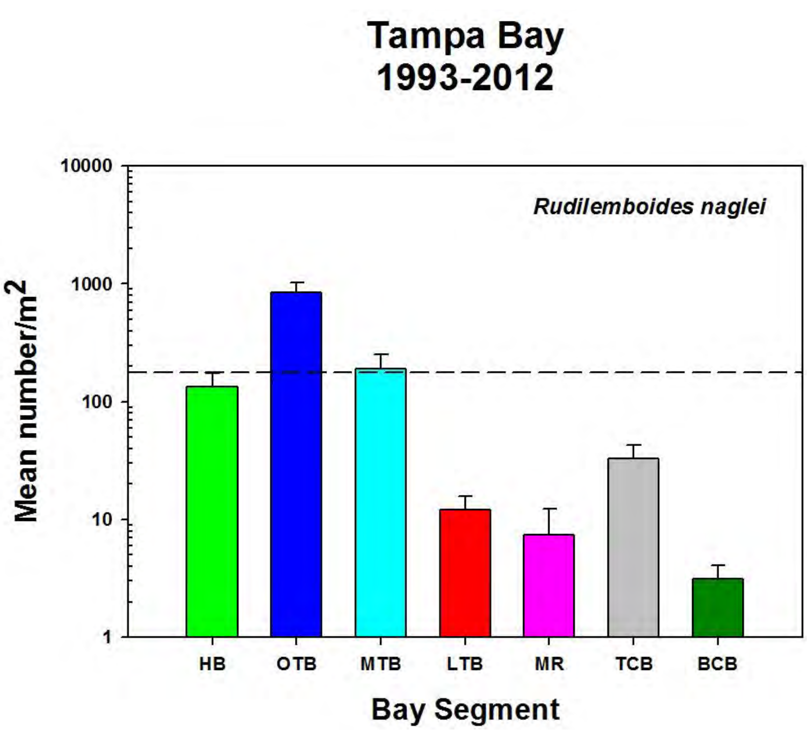


Figure 163. **Mean abundance of *Rudilemboides naglei* by bay segment. Error bars = 1 standard error, dashed line represents baywide mean value.**

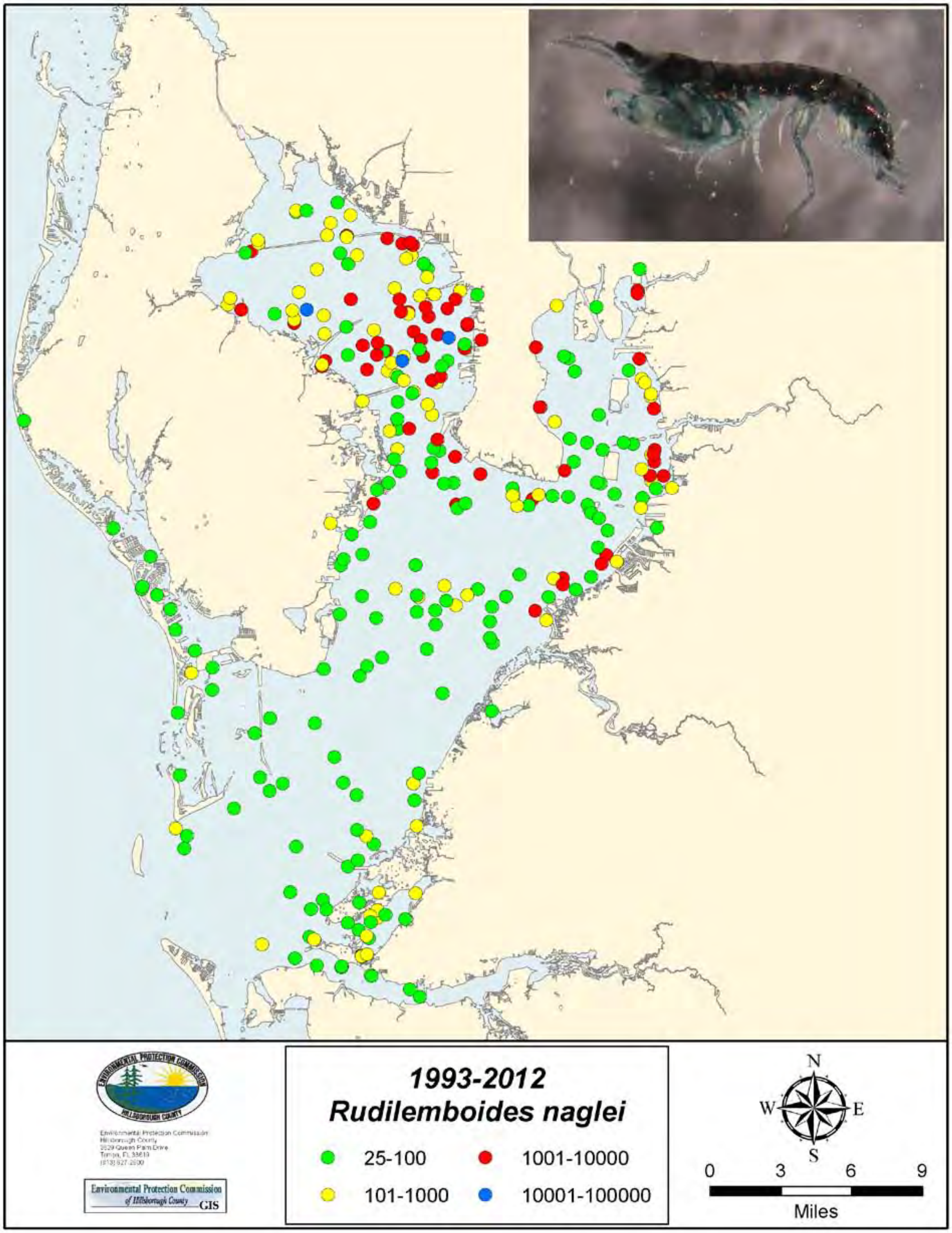


Figure 164. Late-Summer distribution of *Rudilemboides naglei* in Tampa Bay (1993-2012).

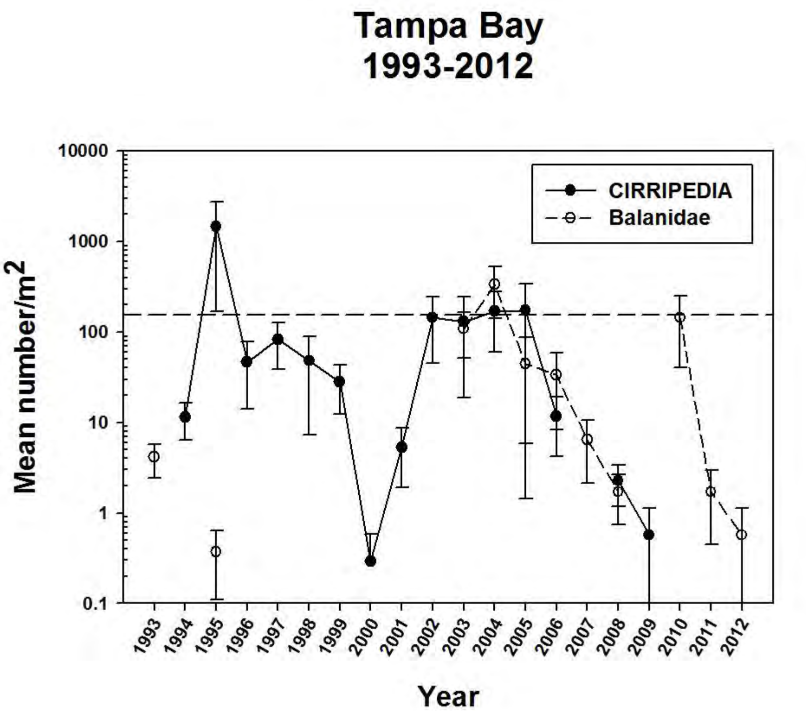


Figure 165. **Mean abundance of unidentified barnacles as Cirripedia (solid circles) and Balanidae (open circles) by year. Error bars = 1 standard error, dashed line represents baywide mean value.**

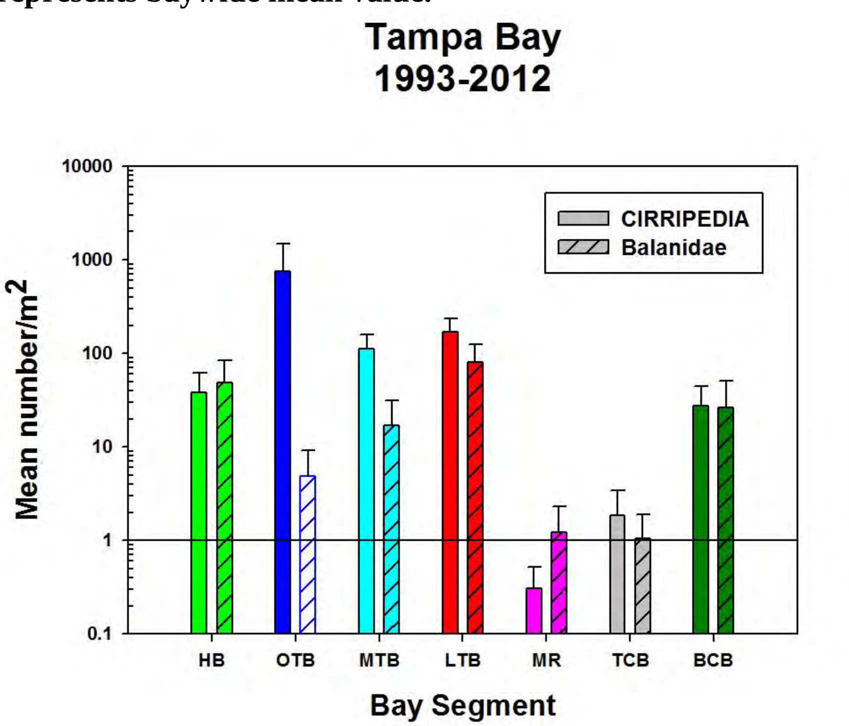


Figure 166. **Mean abundance of unidentified barnacles as Cirripedia (solid bars) and Balanidae (hashed bars) by bay segment. Error bars = 1 standard error, dashed line represents baywide mean value.**

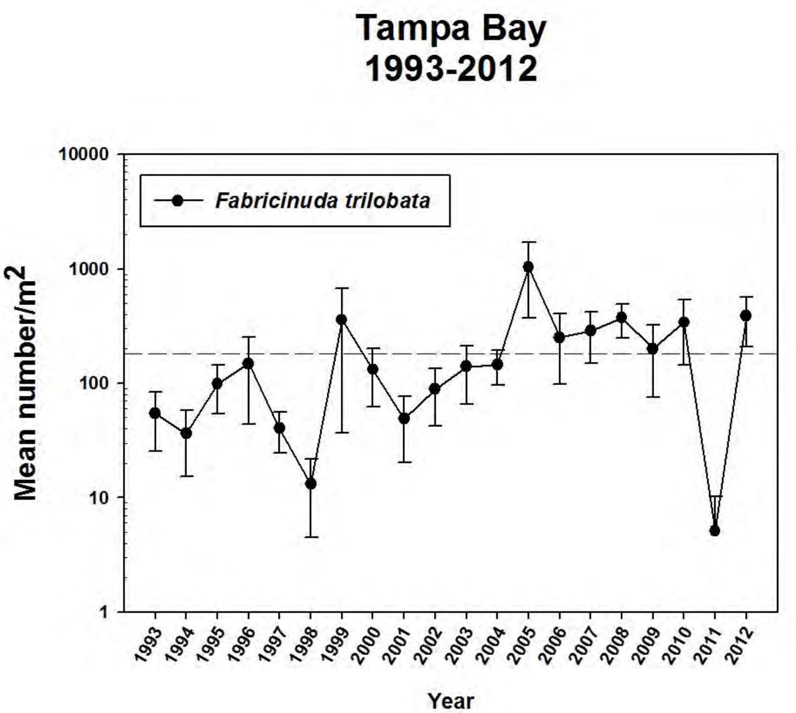


Figure 167. **Mean abundance of *Fabricinuda trilobata* by year. Error bars = 1 standard error, dashed line represents baywide mean value.**

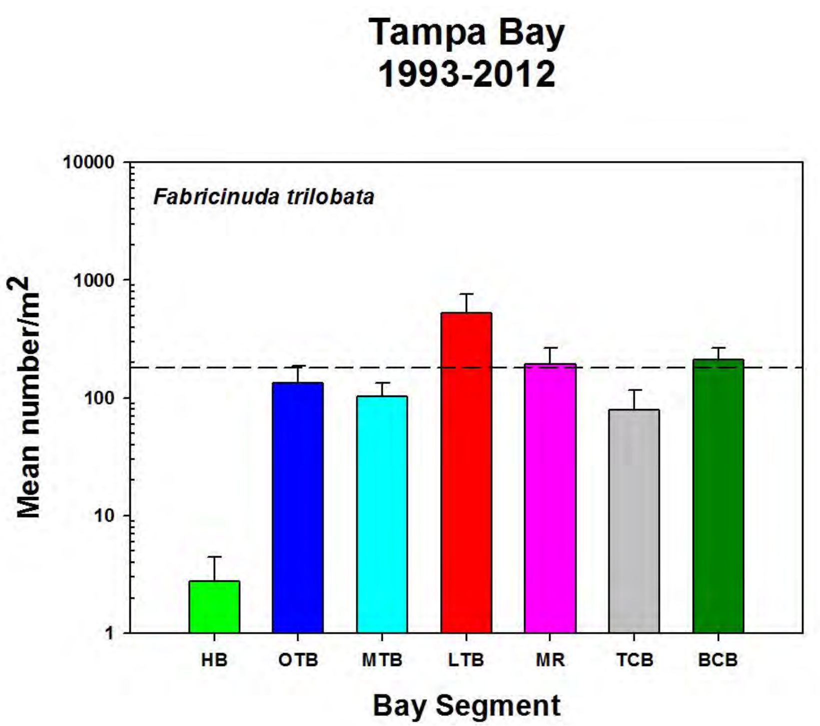


Figure 168. **Mean abundance of *Fabricinuda trilobata* by bay segment. Error bars = 1 standard error, dashed line represents baywide mean value.**

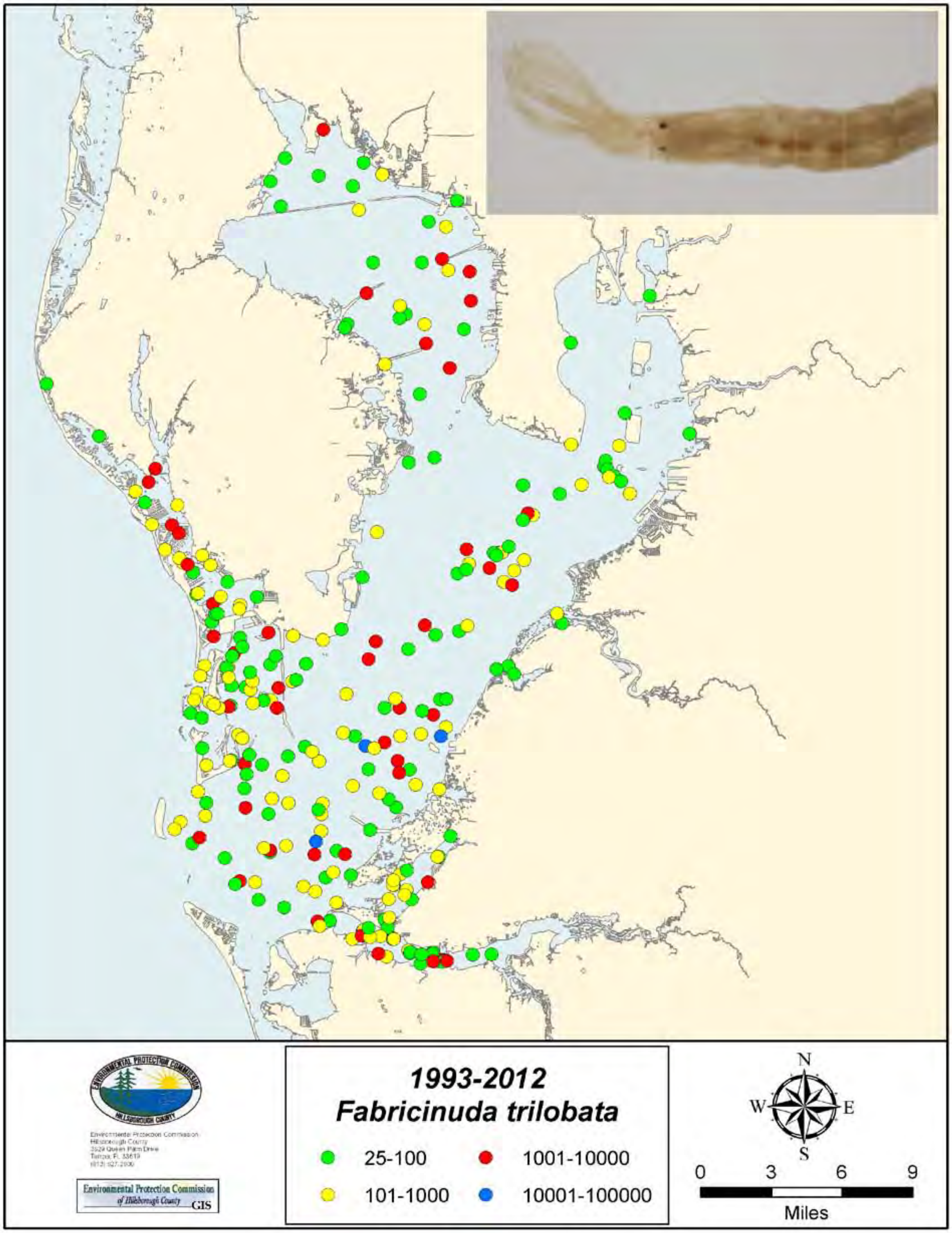


Figure 169. Late-Summer distribution of *Fabricinuda trilobata* in Tampa Bay (1993-2012).

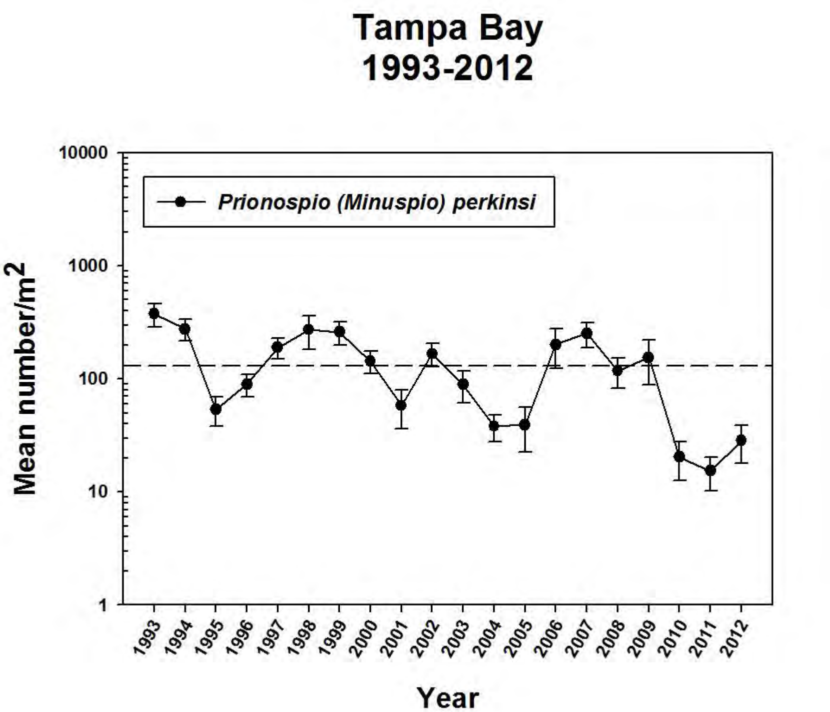


Figure 170. **Mean abundance of *Prionospio perkinsi* by year. Error bars = 1 standard error, dashed line represents baywide mean value.**

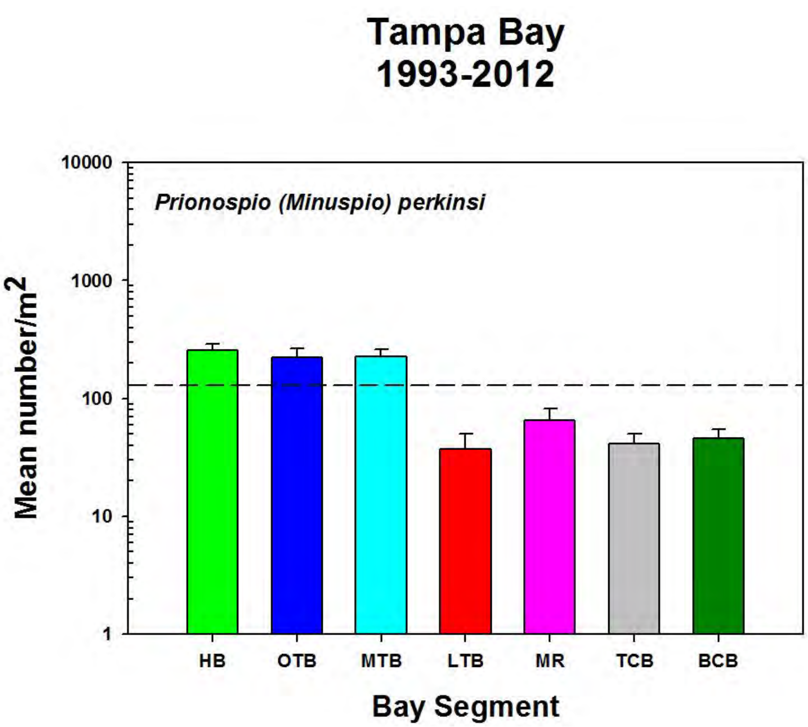


Figure 171. **Mean abundance of *Prionospio perkinsi* by bay segment. Error bars = 1 standard error, dashed line represents baywide mean value.**

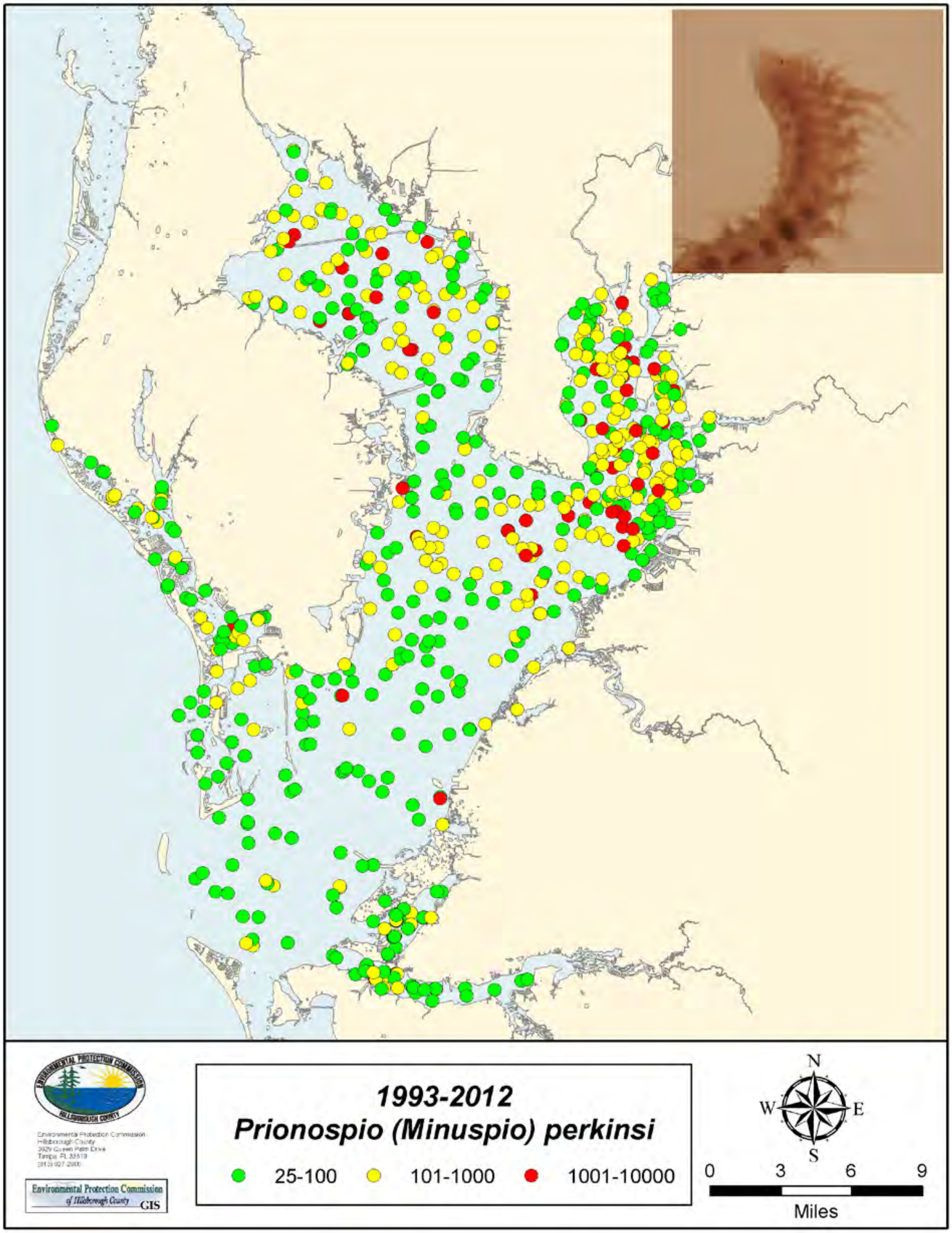


Figure 172. **Late-Summer distribution of *Prionospio perkinsi* in Tampa Bay (1993-2012).**

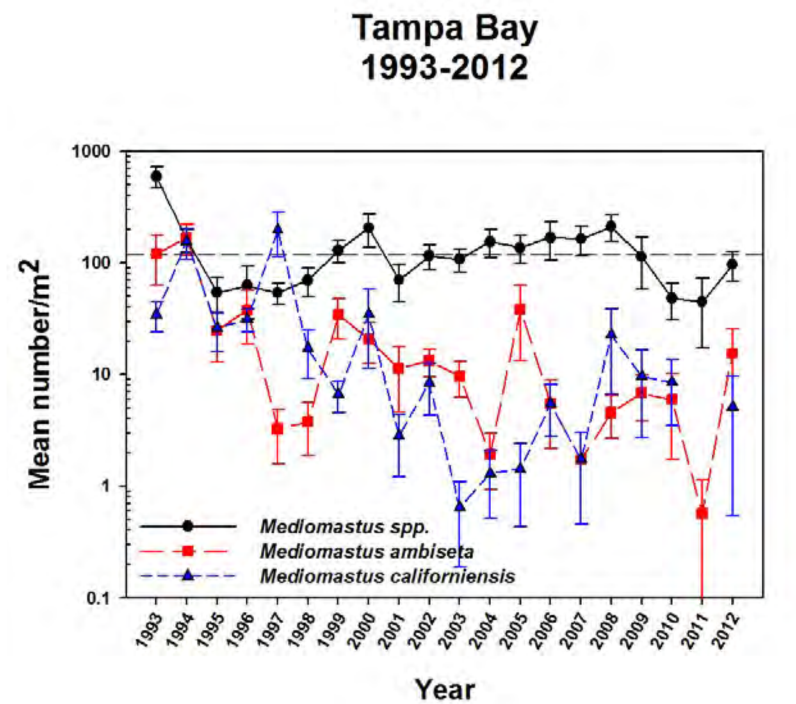


Figure 173. **Mean abundance of unidentified *Mediomastus* spp. (black circles), *Mediomastus ambiseta* (red squares) and *Mediomastus californiensis* (blue triangles) by year. Error bars = 1 standard error, dashed line represents baywide mean value.**

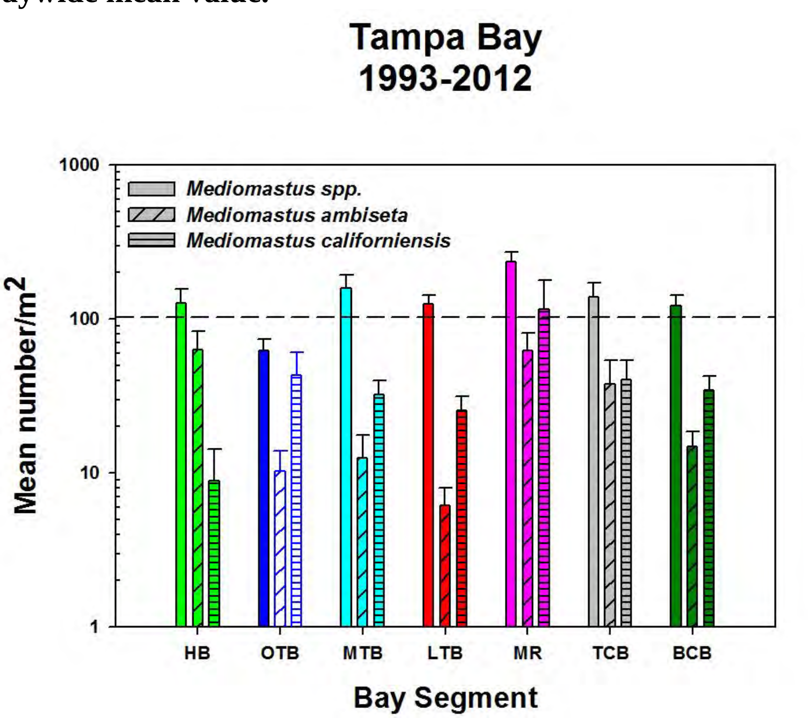


Figure 174. **Mean abundance of unidentified *Mediomastus* spp. (solid bars), *Mediomastus ambiseta* (diagonal hash) and *Mediomastus californiensis* (horizontal hash) by bay segment. Error bars = 1 standard error, dashed line represents baywide mean value (for *Mediomastus* spp.).**

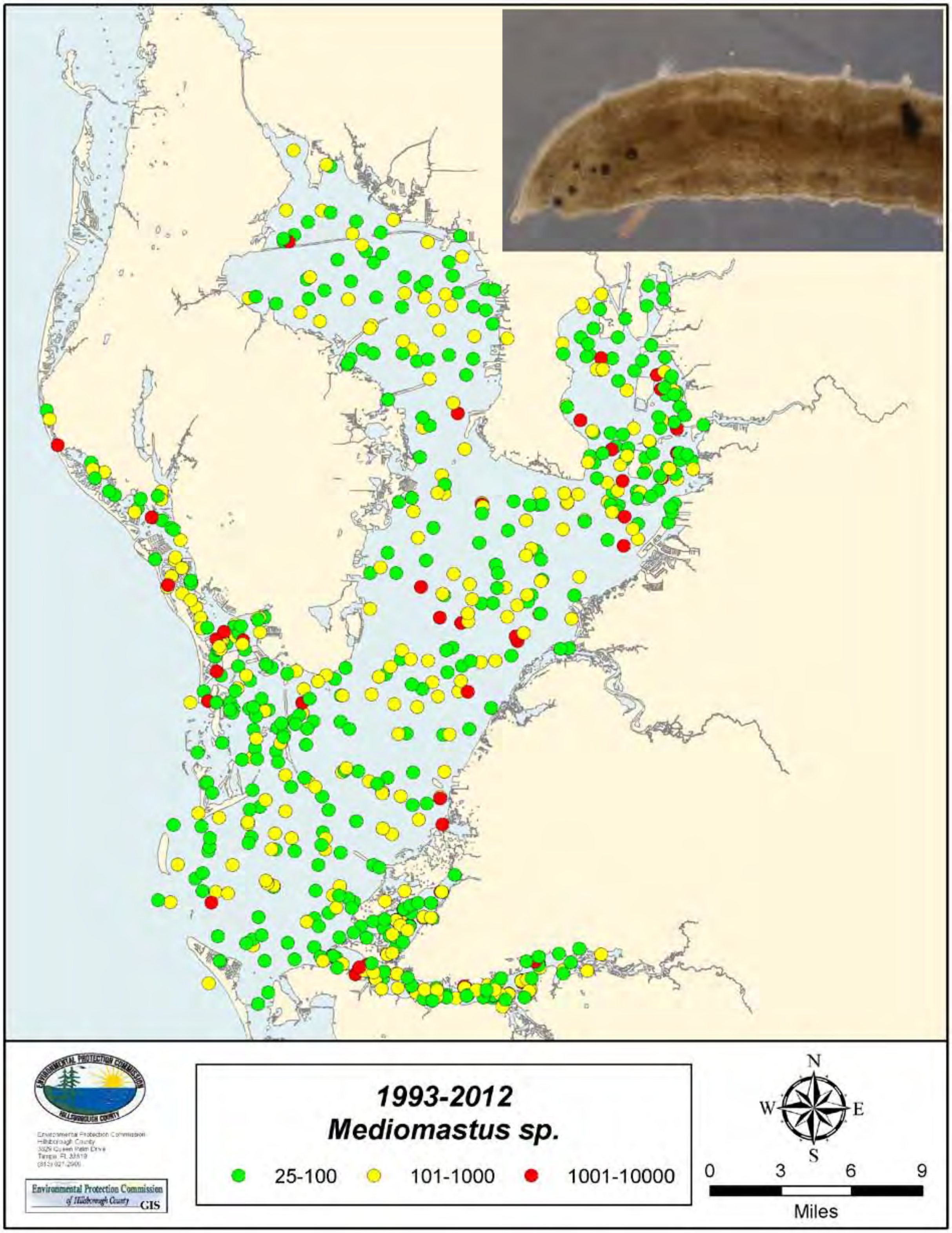


Figure 175. Late-Summer distribution of unidentified *Mediomastus spp.* in Tampa Bay (1993-2012).

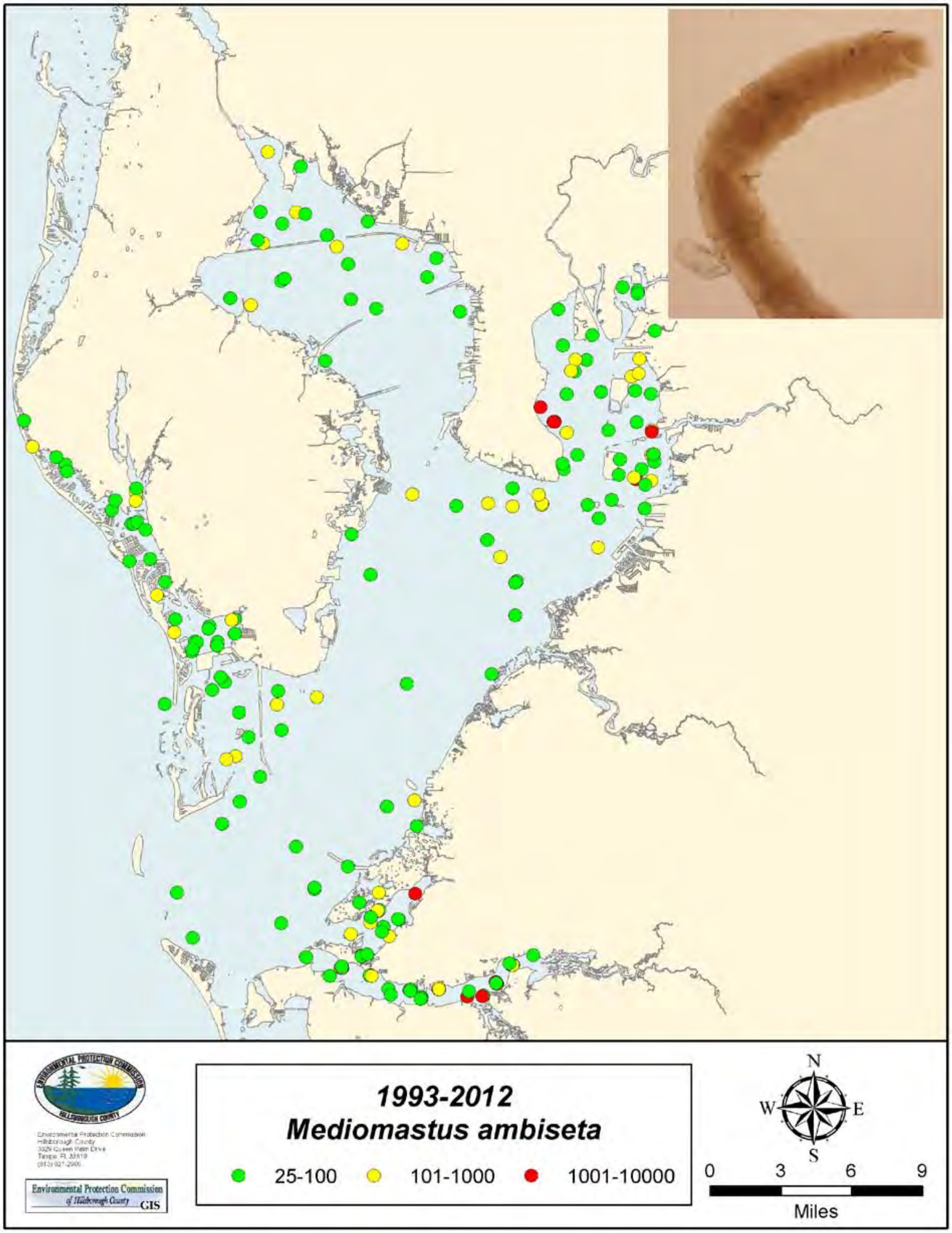


Figure 176. Late-Summer distribution of *Mediomastus ambiseta* in Tampa Bay (1993-2012).

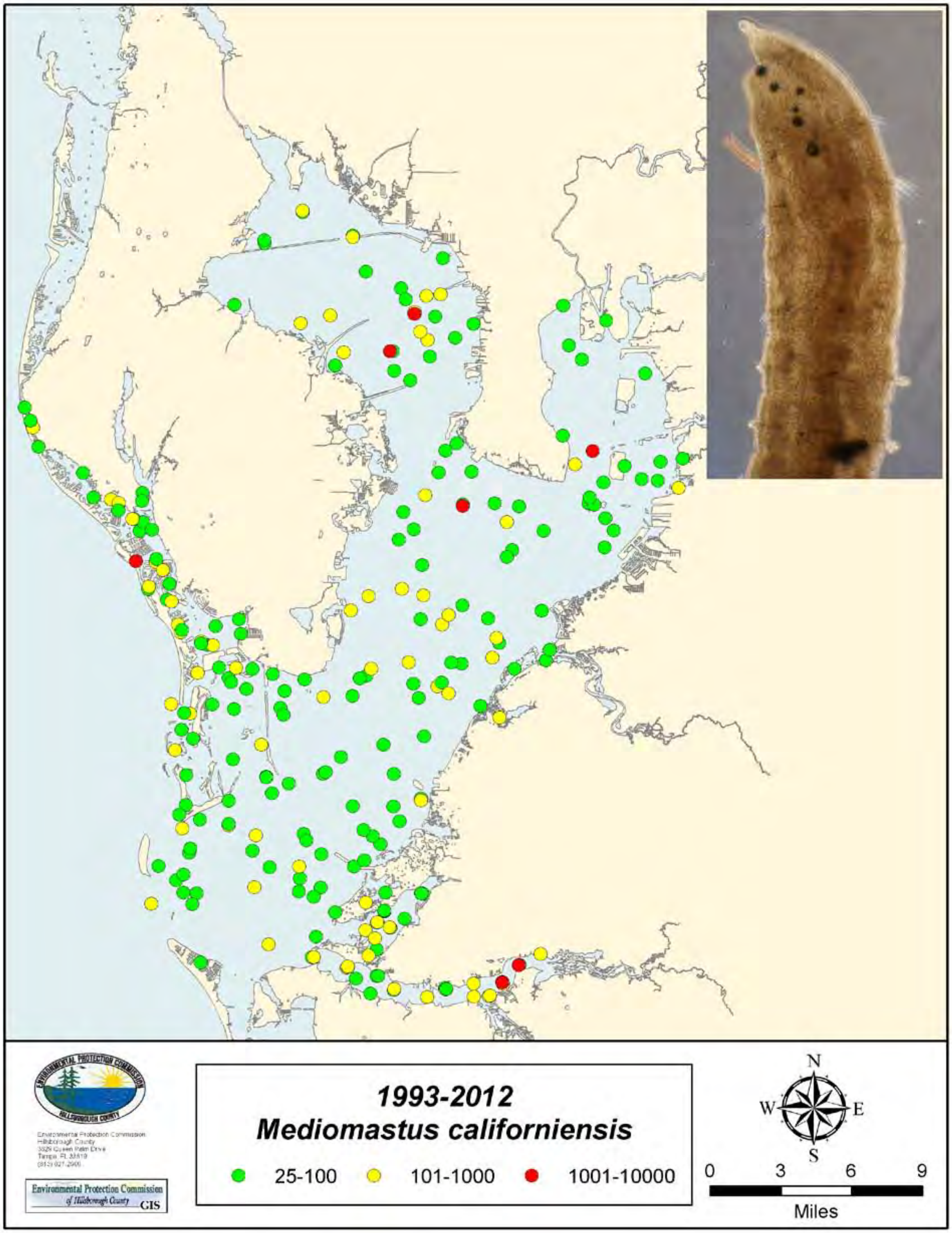


Figure 177. Late-Summer distribution of *Mediomastus californiensis* in Tampa Bay (1993-2012).

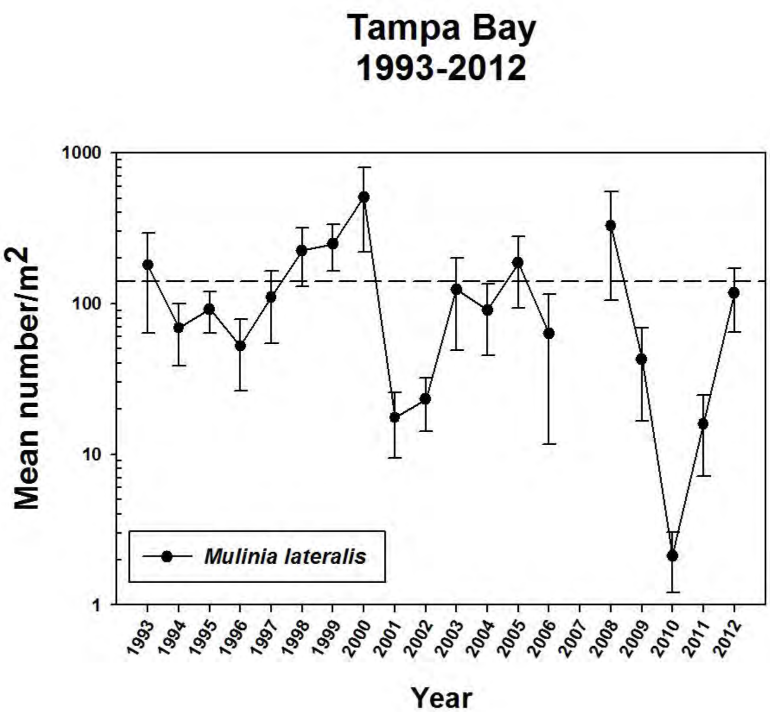


Figure 178. **Mean abundance of *Mulinia lateralis* by year. Error bars = 1 standard error, dashed line represents baywide mean value.**

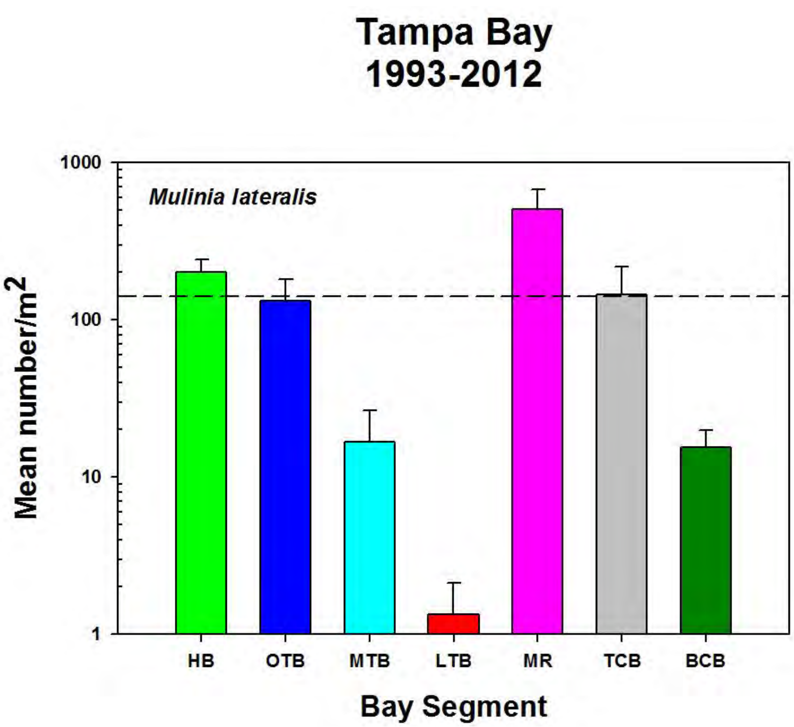


Figure 179. **Mean abundance of *Mulinia lateralis* by bay segment. Error bars = 1 standard error, dashed line represents baywide mean value.**

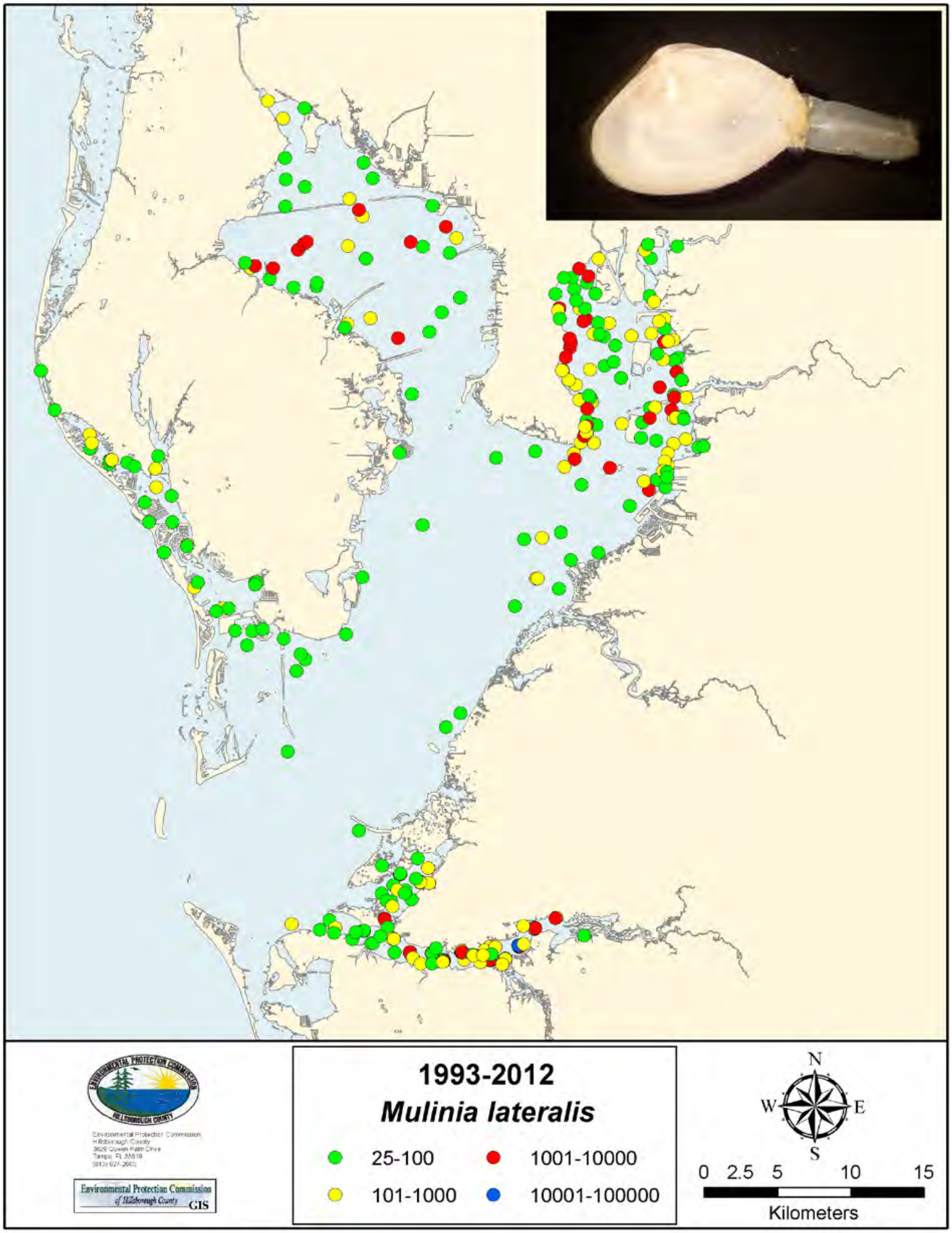


Figure 180. Late-Summer distribution of *Mulinia lateralis* in Tampa Bay (1993-2012).

Benthic Community Similarity Analysis

Cluster Analysis by sampling years

The Cluster Analysis between sampling years indicated that the Tampa Bay benthic community fell into five main temporal groupings: 1993 - 1997 (Group A); 1998-2002 + 2004 (Group B); 2006-2009 (Group C); 2003+2005 (Group D) and 2010-2012 (Group E) (Figure 181). SIMPER indicated that the Group A years had an average Bray-Curtis similarity of 62.91% among years and was characterized by *Branchiostoma floridae*, *Monticellina cf. dorsobranchialis* and *Caecum strigosum.* Group B had an average Bray-Curtis similarity of 64.12% among years and was characterized by *Branchiostoma floridae*, *Monticellina cf. dorsobranchialis*, and a high abundance of *Glottidia pyramidata*. Group C had an average Bray-Curtis similarity of 60.62% among years and was characterized by unidentified Tubificinae, the polychaete *Fabricinuda trilobata*, and bivalve *Mysella planulata* and having relatively lower abundances of *Branchiostoma floridae* and *Glottidia pyramidata*. Group D had an average Bray-Curtis similarity of 57.26% among years and was characterized by the bivalve *Amygdalum papyrium,* unidentified Tubificinae and *Monticellina cf. dorsobranchialis.,*. The Group D years also had a relatively high abundance of *G. pyramidata* and lower abundance of *B. floridae* contributing to the similarity. Group E had an average Bray-Curtis similarity of 56.55% among years and was characterized by unidentified Tubificinae, *Monticellina cf. dorsobranchialis* and the gastropod *Bittiolum varium*.

Group A can further be divided into two sub-groupings designated as A1 (1993 +1994) and A2 (1995+1996+1997). The similarity profile test (SIMPROF) indicated that there was no significant structure within the A1 group which means that the 1993 and 1994 benthic communities were different from each other designated by black lines (Figure181). The similarity profile test (SIMPROF) indicated that there was significant structure within the A2 group which means that 1996+1997 had similar benthic communities designated by red lines (Figure181). SIMPER analysis indicated that the A1 group had an average Bray-Curtis similarity of 64.48% and was characterized by high abundances of *Branchiostoma floridae, Monticellina cf. dorsobranchialis* and *Prionospio perkinsi*. SIMPER analysis indicated that the three years comprising the A2 group had an average Bray-Curtis similarity of 65% and was characterized by *Branchiostoma floridae*, Tubificinae oligochaetes, *Caecum strigosum*, and *Mysella planulata*. The average Bray-Curtis dissimilarity between the A1 and A2 was 38.43% with higher abundances of unidentified barnacles (Cirripedia) and the spirorbid polychaete *Janua steueri* in A2 and higher abundances of the capitellid polychaetes *Mediomastus spp and Mediomastus ambiseta* in A1 contributing to the difference between the two groups.

The SIMPROF test indicated that Group B had a distinct subgroup (designated as B1) which includes the sampling years 1998, 1999, and 2001 (Figure 181). The B1 group had an average Bray-Curtis similarity of 68% and was characterized by *Monticellina cf. dorsobranchialis, Caecum strigosum,* and *Branchiostoma floridae.* The B1 group had an average Bray-Curtis dissimilarity of 36.53% with the other years in Group B and differed mainly in lower abundances of *Glottidia pyramidata, Rudilemboides naglei* and *Ampelisca holmesi*.

TheSIMPROF test on Group C indicated that 2006+2007 and 2008+2009 formed two distinct subgroups designated C1 and C2 respectively (Figure 181). The C1 group had an average Bray-Curtis similarity of 62.24% and was characterized by *Rudilemboides naglei*, *Monticellina cf. dorsobranchialis*, *Branchiostoma floridae* and *Fabricinuda trilobata*. The C2 group had an average Bray-Curtis similarity of 63.51% and was characterized by *Mysella planulata*, *Mesokalliapseudes macsweenyi* (tanaid crustacean), unidentified Tubificnae and *Fabricinuda trilobata*. The C1 and C2 groups had an average Bray-Curtis dissimilarity of 40.5%, with higher abundances of *Exogone dispar* (syllid polychaete) and *Rudilemboides naglei* in C1 and higher abundances of *Mysella planulata* and *Mesokalliapseudes macsweenyi* in C2.

Cluster Analysis by bay segment

The Cluster Analysis performed on the average species assemblage by bay segment indicated that the Tampa Bay benthic community fell into two main spatial groupings: Group A with Hillsborough Bay, Old Tampa Bay, Terra Ceia Bay and the Manatee River) and Group B with Middle Tampa Bay, Lower Tampa Bay, and Boca Ciega Bay (Figure 182). SIMPER analysis indicated that Group A had an average Bray-Curtis similarity of 59.93% and was characterized by high abundances of *Ampelisca holmesi*, *Monticellina cf. dorsobranchialis*, *Mysella planulata*, *Mulinia lateralis*, Tubificinae oligochaetes and *Paraprionospio pinnata* (spionid polychaete). The Group B segments had an average Bray-Curtis similarity of 63.20% and was characterized by *Branchiostoma floridae*, unidentified Tubifincae oligochaetes, the spirorbid polychaete *Janua steueri*, *Clymenella mucosa* (maldanid polychaete or “bamboo worm”) and *Fabricinuda trilobata*.

Group A had two sub-groupings designated as A1 (Hillsborough Bay and Old Tampa Bay) and A2 (Manatee River and Terra Ceia Bay). SIMPROF analysis did not indicate that there was a significant structure in the A1 group while the A2 group had a significant structure (Figure 182). Group A1 had an average Bray-Curtis similarity of 64.32% and was characterized by *Mysella planulata*, *Ampelisca holmesi* and *Glottidia pyramidata*. Group A2 had and average Bray-Curtis similarity of 60.34% and was characterized by *Monticellina cf. dorsobranchialis*, *Ampelisca holmesi*, *Paraprionospio pinnata* and *Mulinia lateralis*. The A1 and A2 groups had an average Bray-Curtis dissimilarity of 41.87%. Group A1 had higher abundances of *Glottidia pyramidata*, *Rudilemboides naglei*, unidentified barnacles (Cirripedia) and *Mysella planulata*, while A2 had higher abundances of *Ampelisca abdita* and *Grandidierella bonnieroides* (amphipod).

Group B had a distinct subgroup (designated as B1) which contains Middle Tampa Bay and Lower Tampa Bay (Figure 182). The B1 group had an average Bray-Curtis similarity of 67.97% and was characterized by high abundances of *Branchiostoma floridae* and *Caecum strigosum*. There was 39.18% average Bray-Curtis dissimilarity between B1 and Boca Ciega Bay (designated as B2 in Figure 182). The B1 group had higher abundances of *Branchiostoma floridae*, *Caecum strigosum*, *Glottidia pyramidata*, and *Metharpinia floridana* (amphipod), while Boca Ciega Bay had higher abundances of *Pileolaria rosepigmentata* (spirorbid polychaete) and *Augeneriella hummelincki* (sabellid polychaete).

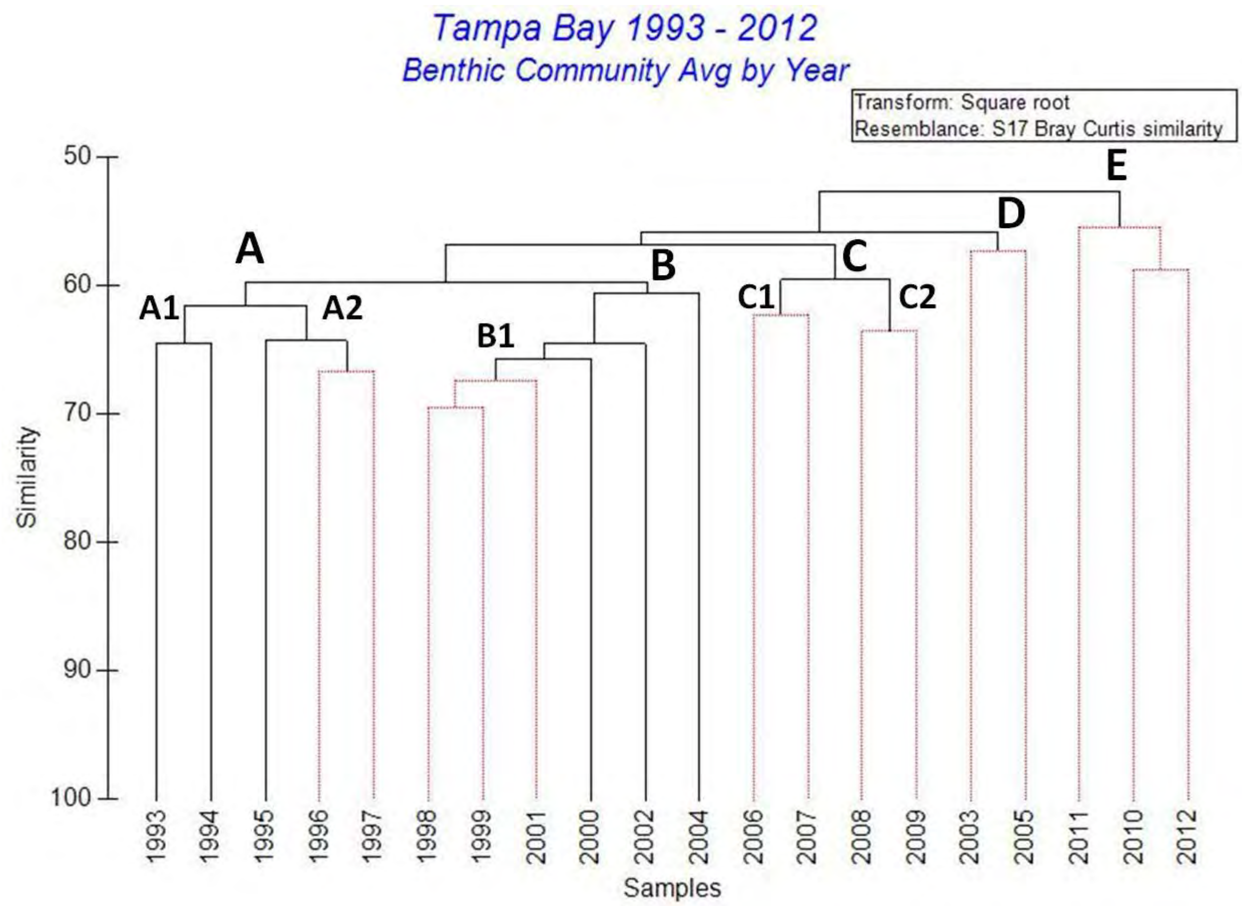


Figure 181. Cluster Analysis by sampling year.

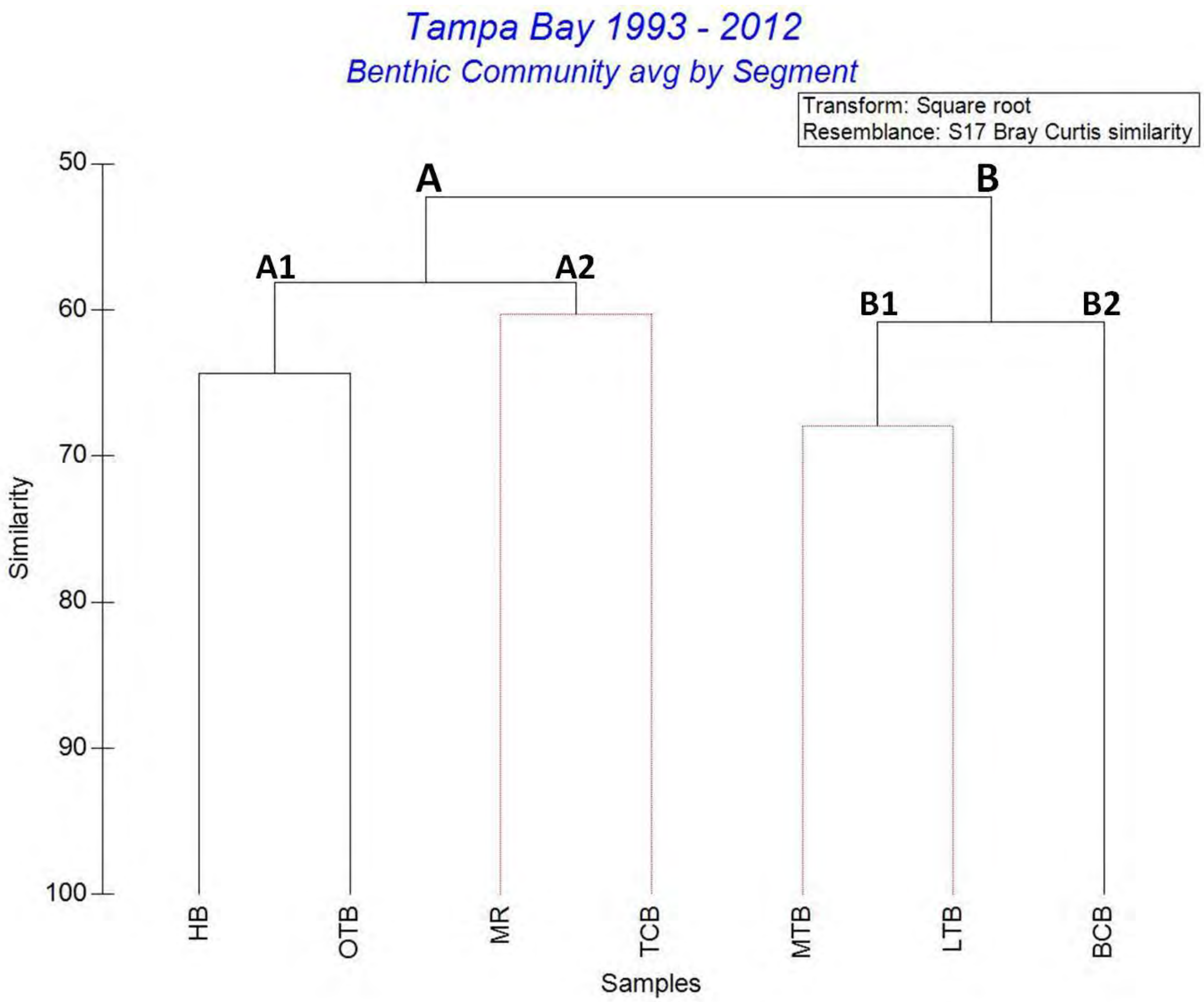


Figure 182. Cluster Analysis by bay segment.

Relating Biological and Environmental data

Multiple linear regression analysis of the benthic community indices versus hydrographic and sediment parameters are presented in Table 23. Salinity was positively correlated with species richness, abundance, Shannon Diversity (H') and Pielou's evenness *(J')*. Bottom dissolved oxygen was positively correlated with species richness, abundance, Shannon diversity, and the Tampa Bay Benthic Index. Bottom pH had a negative correlation with abundance. Percent silt+clay was negatively correlated with species richness, abundance, Shannon diversity and the TBBI, but it was positively correlated with evenness.

Spearman rank correlations between the benthic community indices and the hydrographic and sediment parameters are presented in Table 24. Species richness was positively correlated with salinity, bottom dissolved oxygen and pH. It was negatively correlated with temperature and percent silt+clay. Abundance and Shannon diversity were both positively correlated with salinity, dissolved oxygen, and pH. They were negatively correlated with % silt+clay. Evenness was positively correlated with salinity and % silt+clay. The Tampa Bay Benthic Index was positively correlated with depth, salinity, dissolved oxygen and pH. It was negatively correlated with temperature and % silt+clay.

The Spearman rank correlations between the benthic community indices and sediment metals are summarized in Table 25. Most of the indices were negatively correlated with metals with a few exceptions. Species richness was not significantly correlated with arsenic or tin. Abundance was not significantly correlated with antimony. Shannon diversity was not significantly correlated with arsenic selenium or tin. Evenness was not significantly correlated with most of the metals. It was positively correlated with arsenic, cadmium, silver and tin and negatively correlated with antimony. The Tampa Bay Benthic Index was not significantly correlated with arsenic or selenium, but it had a weak positive correlation with antimony.

The species richness, abundance, and TBBI were negatively correlated with all of low molecular weight PAHs (Table 26). Shannon diversity was negatively correlated with acenaphthylene, phenanthrene and total LMW-PAHs. Evenness was positively correlated with acenaphthene, fluorene, naphthalene and total LMW_PAHs. All high molecular weight PAHs and Total PAHs were negatively correlated with species richness, abundance, Shannon diversity, and the TBBI (Table 27). The other PAHs were negatively correlated with species richness, abundance, Shannon diversity and the TBBI. PAHs were positively correlated with evenness (Table 28). Shannon diversity was not correlated with retene (Table 28). Evenness was not correlated with benzo (B) fluoranthene (Table 28).

The community indices generally had negative, but weaker correlations with the pesticides (Table 29). Total DDT, total chlordane and PCBs were negatively correlated with all of the community measures except evenness. Eveness had a positive correlation with DDT and chlordane, but was not significantly correlated with PCBs. Several pesticides including endrin aldehyde, β-BHC, aldrin, and endosulfan I did not have significant correlations with any of the benthic community metrics (Table 29). Total PCBs had relatively strong negative correlations with the number of taxa, abundance, and diversity (Table 29). The TBBI was most negatively correlated with Total DDT as well as the DDT breakdown compounds DDD and DDE (Table 29).

Table 23. Multiple linear regression results of benthic community indices vs. physical parameters.

	Adj. R^2	Depth	Temp	Salinity	DO	pH	%Silt+Clay
S	0.391	NS (p=0.382)	NS (p=0.834)	+ (p<0.001)	+ (p<0.001)	NS (p=0.120)	- (p<0.001)
N	0.282	NS (p=0.930)	NS (p=0.230)	+ (p=0.009)	+ (p<0.001)	- (p=0.035)	- (p<0.001)
H'	0.277	NS (p=0.098)	NS (p=0.887)	+ (p<0.001)	+ (p<0.001)	NS (p=0.296)	- (p<0.001)
J'	0.017	NS (p=0.073)	NS (p=0.930)	+ (p<0.001)	NS (p=461)	NS (p=0.857)	+ (p<0.001)
TBBI	0.172	NS (p=0.728)	NS (p=0.524)	NS (p=0.122)	+ (p<0.001)	NS (p=0.384)	- (p<0.001)

Note: All parameters log(n+1) transformed for analysis

Table 24. Spearman rank correlation coefficients for benthic community matrices vs. environmental parameters.

		Depth	Temp	Salinity	DO	pH	%Silt+Clay
S	ρ	0.04	-0.05	0.35	0.32	0.25	-0.31
	p	0.143	0.040	0.000	0.000	0.000	0.000
N	ρ	-0.01	-0.02	0.06	0.21	0.11	-0.29
	p	0.703	0.416	0.010	0.000	0.000	0.000
H'	ρ	-0.01	-0.05	0.36	0.28	0.23	-0.23
	p	0.563	0.063	0.000	0.000	0.000	0.000
J'	ρ	-0.01	0.00	0.17	0.02	0.02	0.10
	p	0.599	0.957	0.000	0.514	0.399	0.000
TBBI	ρ	0.07	-0.08	0.16	0.28	0.22	-0.37
	p	0.005	0.002	0.000	0.000	0.000	0.000

Table 25. **Spearman rank correlations between benthic community indices and sediment metals.**

		Antimony	Arsenic	Cadmium	Chromium	Copper	Lead	Manganese	Nickel	Selenium	Silver	Tin	Zinc
S	**ρ**	-0.07	0.00	-0.14	-0.38	-0.40	-0.24	-0.17	-0.29	-0.08	-0.18	-0.03	-0.37
	p	0.051	0.940	0.000	0.000	0.000	0.000	0.000	0.000	0.014	0.000	0.201	0.000
N	**ρ**	-0.01	-0.10	-0.17	-0.26	-0.28	-0.20	-0.21	-0.25	-0.10	-0.22	-0.08	-0.28
	p	0.856	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.003	0.000
H'	**ρ**	-0.12	0.03	-0.09	-0.35	-0.35	-0.20	-0.16	-0.25	-0.05	-0.08	0.01	-0.31
	p	0.000	0.273	0.000	0.000	0.000	0.000	0.000	0.000	0.183	0.003	0.645	0.000
J'	**ρ**	-0.08	0.10	0.09	0.01	0.01	0.05	0.05	0.05	0.02	0.13	0.09	0.03
	p	0.026	0.000	0.001	0.707	0.829	0.052	0.118	0.074	0.525	0.000	0.000	0.202
TBBI	**ρ**	0.08	-0.04	-0.14	-0.33	-0.36	-0.23	-0.17	-0.22	0.04	-0.20	-0.09	-0.34
	p	0.023	0.159	0.000	0.000	0.000	0.000	0.000	0.000	0.298	0.000	0.000	0.000

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

		Acenaphthene	Acenaphthylene	Anthracene	Fluorene	Naphthalene	Phenanthrene	Total LMW PAHs
S	ρ	-0.15	-0.14	-0.09	-0.12	-0.18	-0.21	-0.23
	p	0.000	0.000	0.001	0.000	0.000	0.000	0.000
N	ρ	-0.23	-0.16	-0.10	-0.18	-0.27	-0.16	-0.25
	p	0.000	0.000	0.000	0.000	0.000	0.000	0.000
H’	ρ	-0.02	-0.07	-0.04	-0.02	-0.04	-0.19	-0.13
	p	0.539	0.026	0.143	0.573	0.173	0.000	0.000
J’	ρ	0.15	0.05	0.05	0.11	0.16	0.00	0.09
	p	0.000	0.105	0.104	0.000	0.000	0.920	0.002
TBBI	ρ	-0.22	-0.13	-0.13	-0.17	-0.25	-0.24	-0.29
	p	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 27. 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	-0.26	-0.25	-0.30	-0.32	-0.28	-0.33	-0.32	-0.31
	p	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
N	ρ	-0.27	-0.25	-0.29	-0.33	-0.27	-0.32	-0.33	-0.31
	p	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
H'	ρ	-0.16	-0.18	-0.20	-0.19	-0.21	-0.24	-0.22	-0.21
	p	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
J'	ρ	0.10	0.06	0.09	0.11	0.06	0.07	0.09	0.09
	p	0.000	0.041	0.003	0.000	0.047	0.021	0.001	0.002
TBBI	ρ	-0.32	-0.30	-0.34	-0.29	-0.33	-0.36	-0.38	-0.36
	p	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 28. Spearman rank correlations between benthic community indices and other measured PAHs.

		Benzo (B) Fluoranthene	Benzo (K) Fluoranthene	Indeno (1,2,3-C,D) Pyrene	Benzo(G,H,I) Perylene	Retene	Coronene
S	**ρ**	-0.26	-0.26	-0.25	-0.28	-0.21	-0.22
	p	0.000	0.000	0.000	0.000	0.000	0.000
N	**ρ**	-0.23	-0.28	-0.30	-0.33	-0.28	-0.21
	p	0.000	0.000	0.000	0.000	0.000	0.000
H’	**ρ**	-0.20	-0.15	-0.15	-0.14	-0.01	-0.11
	p	0.000	0.000	0.000	0.000	0.725	0.016
J’	**ρ**	0.05	0.11	0.12	0.14	0.21	0.13
	p	0.101	0.000	0.000	0.000	0.000	0.006
TBBI	**ρ**	-0.29	-0.32	-0.31	-0.32	-0.23	-0.26
	p	0.000	0.000	0.000	0.000	0.000	0.000

Table 29. Spearman rank correlations between benthic community indices and measured pesticides and total PCBs.

		p,p'-DDD	p,p'-DDE	p,p'-DDT	Σ DDT	Endrin	Endrin Aldehyde	Endrin Ketone	Methoxychlor	Mirex	α Chlordane	γ Chlordane	Σ Chlordane
S	ρ	-0.15	-0.18	-0.10	-0.23	-0.07	0.00	-0.10	-0.07	-0.11	-0.11	-0.11	-0.17
	p	0.000	0.000	0.000	0.000	0.020	0.961	0.000	0.023	0.000	0.000	0.000	0.000
N	ρ	-0.22	-0.18	-0.15	-0.24	-0.13	0.03	-0.08	-0.12	-0.17	-0.16	-0.14	-0.18
	p	0.000	0.000	0.000	0.000	0.000	0.342	0.006	0.000	0.000	0.000	0.000	0.000
H'	ρ	-0.02	-0.12	-0.01	-0.13	0.03	-0.01	-0.06	-0.01	-0.02	-0.02	-0.03	-0.09
	p	0.435	0.000	0.740	0.000	0.268	0.607	0.028	0.861	0.524	0.525	0.297	0.003
J'	ρ	0.16	0.05	0.12	0.10	0.11	-0.01	0.01	0.08	0.09	0.12	0.08	0.08
	p	0.000	0.072	0.000	0.000	0.000	0.738	0.835	0.005	0.004	0.000	0.007	0.008
TBBI	ρ	-0.17	-0.17	-0.18	-0.23	-0.11	-0.03	-0.03	-0.08	-0.10	-0.14	-0.13	-0.12
	p	0.000	0.000	0.000	0.000	0.000	0.290	0.233	0.005	0.000	0.000	0.000	0.000

Table 29 (Continued).

		α BHC	β BHC	δ BHC	Lindane	Aldrin	Dieldrin	Endosulfan 1	Endosulfan 2	Endo SO_4	Heptaclor	Heptaclor Epoxide	Total PCB
S	**ρ**	-0.09	0.01	-0.08	-0.05	-0.05	-0.11	-0.04	-0.08	-0.19	-0.06	-0.06	-0.15
	p	0.001	0.660	0.004	0.097	0.094	0.000	0.122	0.008	0.000	0.047	0.053	0.000
N	**ρ**	-0.15	-0.02	-0.12	-0.08	-0.04	-0.14	-0.04	-0.15	-0.21	-0.05	-0.06	-0.11
	p	0.000	0.598	0.000	0.004	0.134	0.000	0.121	0.000	0.000	0.087	0.047	0.000
H'	**ρ**	-0.01	-0.01	-0.03	0.00	-0.04	-0.06	-0.03	0.01	-0.09	-0.03	-0.05	-0.12
	p	0.640	0.852	0.387	0.877	0.148	0.050	0.324	0.636	0.001	0.233	0.077	0.000
J'	**ρ**	0.10	0.01	0.07	0.06	-0.01	0.06	0.00	0.12	0.08	0.00	-0.02	0.02
	p	0.000	0.620	0.013	0.044	0.785	0.039	0.966	0.000	0.006	0.865	0.538	0.540
TBBI	**ρ**	-0.12	-0.03	-0.07	-0.03	0.01	-0.06	0.01	-0.16	-0.14	-0.01	0.02	-0.09
	p	0.000	0.366	0.017	0.285	0.811	0.029	0.696	0.000	0.000	0.733	0.485	0.002

Non-metric Multi-dimensional Scaling (MDS) on the benthic community structure averaged by year and segment indicates that the benthic communities within individual bay segments were relatively distinct and consistent over time (Figure 183). There was an apparent gradation in the species composition along the north-south transect of Tampa Bay (except for the Manatee River and Terra Ceia Bay) with the benthic communites of Hillsborough Bay and Lower Tampa Bay being relatively distinct and consistent over time. Boca Ciega Bay also appeared to have a unique benthic community that was relatively consistant over time. The Manatee River and Terra Ceia Bay benthic communities appeared to be more variable which may be a result of the smaller sample size collected in these two segments.

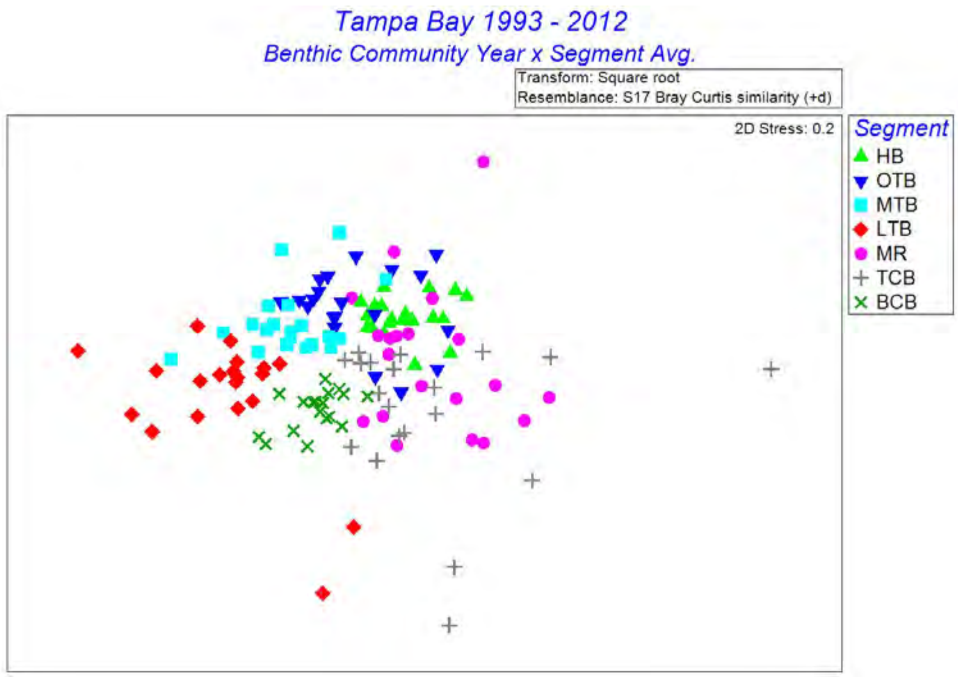


Figure 183. MDS plot of benthic species composition by bay segments, averaged by year.

Each site was categorized for the different physical parameters to illustrate that the benthic community composition is structured in part by depth (Figure 184), salinity (Figure 185), dissolved oxygen (Figure 186), and sediment type (Figure 187). The strong relationship between the percent silt+clay and benthic community composition is further illustrated as a “bubble plot” (Figure 188).

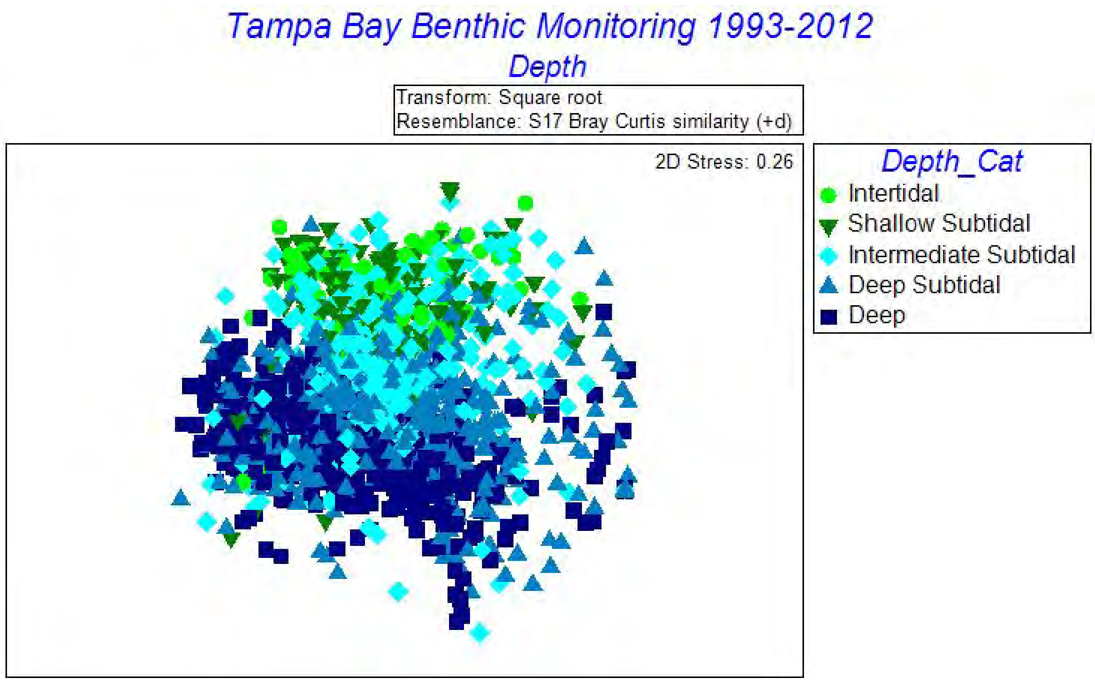


Figure 184. **MDS plot data coded by sample depth category - all sites shown.**

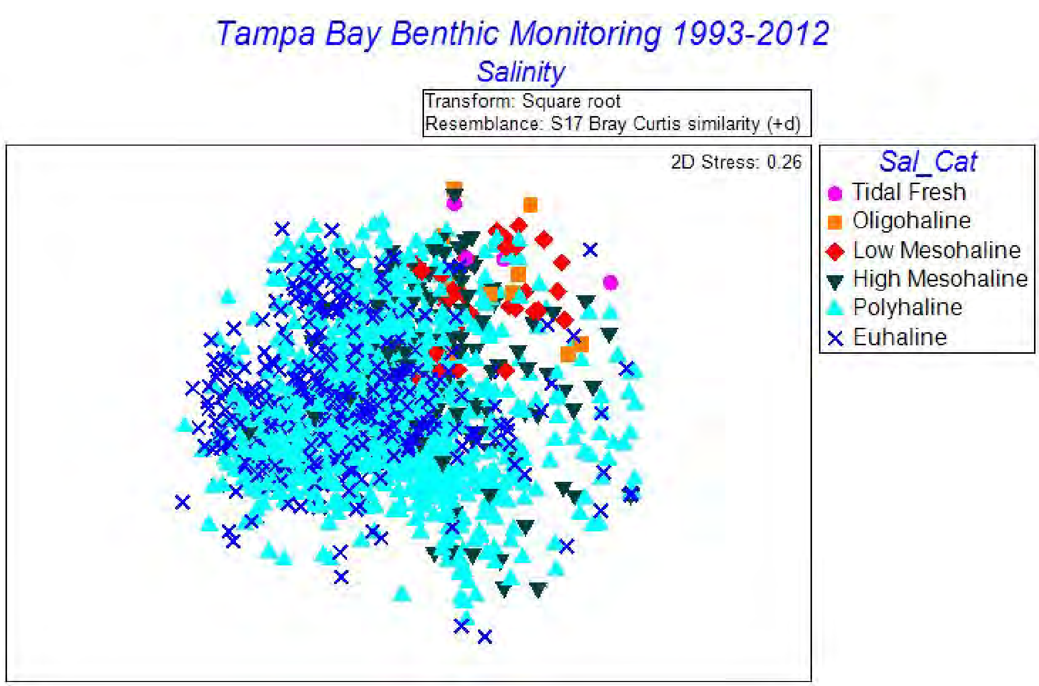


Figure 185. **MDS plot data coded by salinity category - all sites shown.**

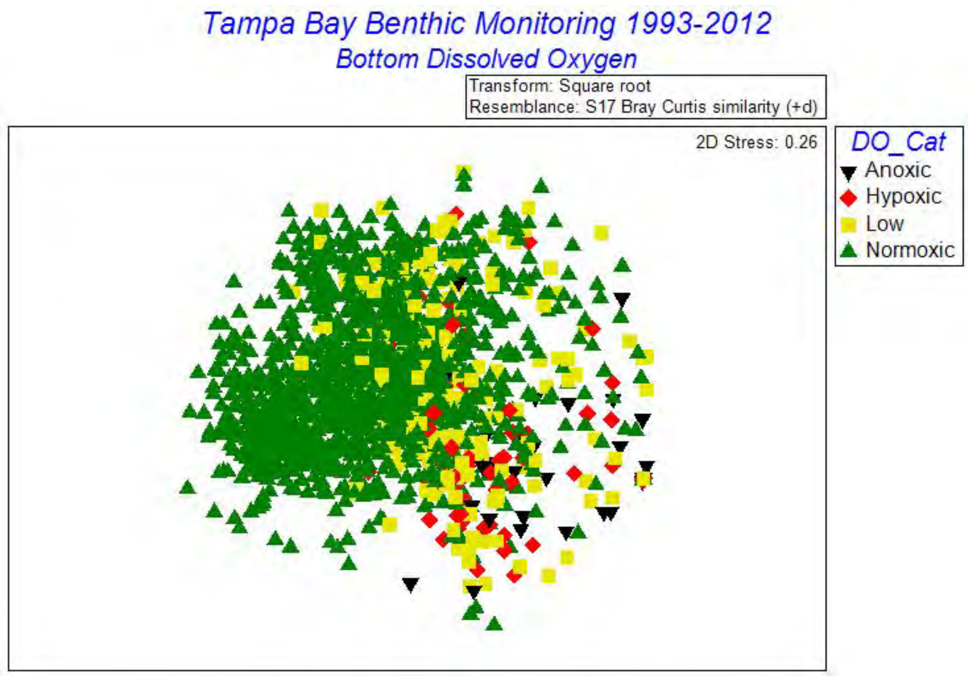


Figure 186. **MDS plot data coded by dissolved oxygen category - all sites shown.**

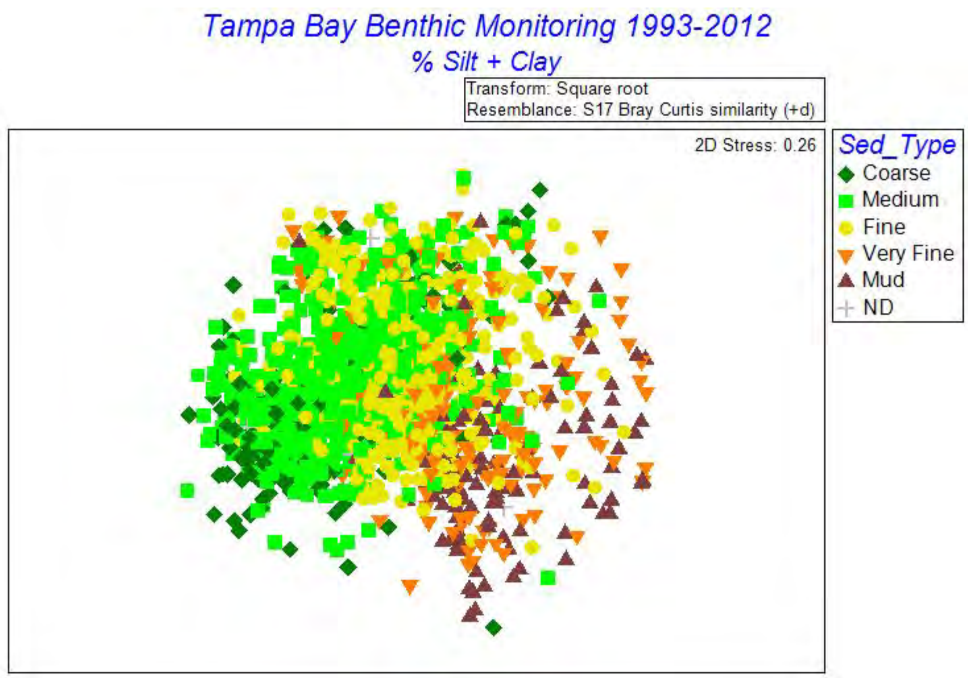


Figure 187. **MDS plot data coded by sediment category - all sites shown.**

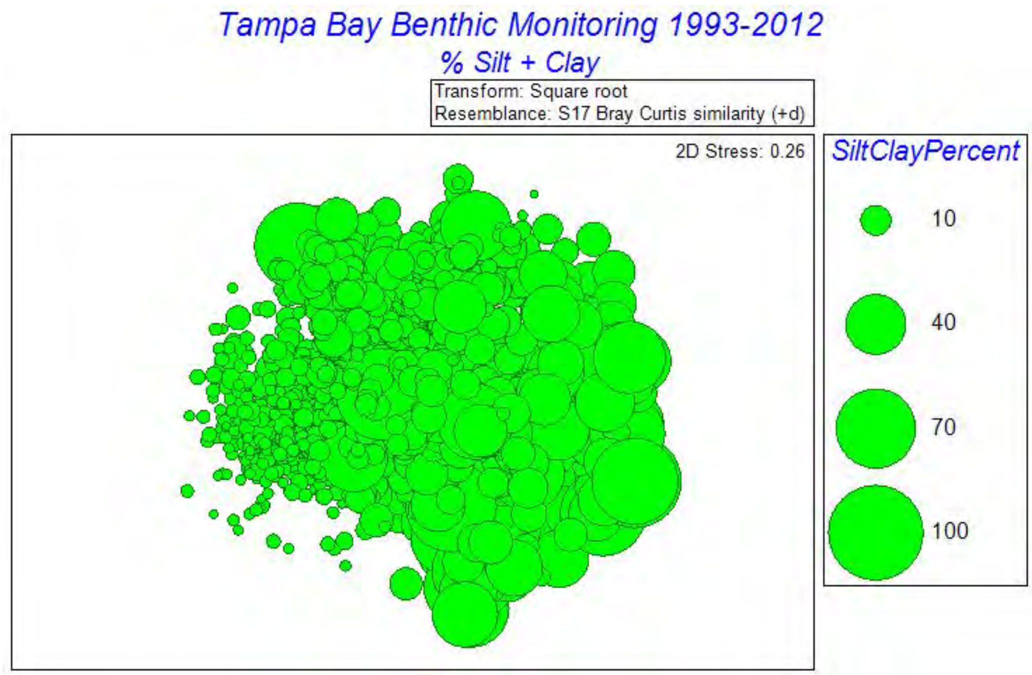


Figure 188. Bubble plot of percent silt+clay values on species similarity MDS plot.

The BIO-ENV analysis between the 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 ($\rho_s = 0.499$). The single variable with the highest correlation was percent silt+clay ($\rho_s = 0.388$) followed by dissolved oxygen ($\rho_s = 0.231$).

The SIMPER analysis results indicating which taxa contributed to the similarity among sites within each depth category are presented in Table 30. Tubificinae were among dominant taxa (at least 5%) across all depths. *Ampelisca holmesi* was more prominent at the Intertidal to Intermediate Subtidal sites. *Mysella planulata* was more prominent at the Shallow Subtidal to Intermediate Subtidal sites. *Branchiostoma floridae* were more prominent at the Intermediate Subtidal to Deep sites. *Glottidia pyramidata* was more prominent at the Deep Subtidal to Deep sites.

The SIMPER analysis results indicating which taxa contributed to the similarity among sites within each salinity category are presented in Table 31. There was an increasing trend in diversity and species richness with increasing salinity. There were only four freshwater sites and 10 oligohaline sites out of the 1,572 sites sampled. These salinity categories had few taxa and high percent contributions for each taxon. The Freshewater sites where characterized by *Polypedilum scalaenum* group (larval chironomid insects), *Laeonereis culveri* (nereid polychaete) and *Grandidierella bonnieroides* (amphipod). The Oligohaline sites were characterized by *Cyathura polita* (isopod) and Palaeonemertea sp. A of EPC (nemertean or ribbon worm). *Mediomastus* spp. was found from Low Mesohaline to Euhaline sites. This may be due to the fact that this taxon is a composite of two distinct species which may have different optimal salinity ranges. *Branchiostoma floridae* was associated with Polyhaline and Euhaline sites. *Glottidia pyramidata* was predominantly associated with Polyhaline sites.

The SIMPER analysis results indicating which taxa contributed to the similarity among sites within each dissolved oxygen category are presented in Table 32. There was an increasing trend in species richness and diversity with increasing dissolved oxygen. Taxa that are associated with Anoxic and Hypoxic sites are of particular interest since they tend to be more tolerant of anthropogenically degraded sites and may serve as potential indicator species. The Anoxic and Hypoxic sites where characterized by the polychaetes *Paraprionospio pinnata*, *Monticellina cf. dorsobranchialis* and *Sigambra tentaculata* and the unidentified hemichordate Enteropneusta, which was also found at the Hypoxic sites. *Paraprionospio pinnata* and *Monticellina cf. dorsobranchialis* both had a wide dissolved oxygen range and were present across all of the dissolved oxygen categories. *Prionospio perkinsi* and Tubificinae oligochaetes ranged from Hypoxic to Normoxic sites. *Ampelisca holmesi* and *Mysella planulata* ranged from Low to Normoxic sites. *Branchiostoma floridae* and *Glottidia pyramidata* were characteristic of Normoxic sites.

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). Periods of severe hypoxia or anoxia have caused complete defaunation in impacted areas (Santos and Simon 1980 a&b). Hypoxia can affect individual organisms by decreasing feeding, reducing their growth rates and inhibiting their immune systems resulting in higher mortality (Burnett and Stickle 2001). Tolerance for hypoxic conditions is variable across different taxonomic groups and ecological niches which influences the species composition. Crustaceans are sensitive to hypoxic conditions (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 cause behavioral responses in infaunal organisms including moving out of burrows or moving closer to the sediment surface which increases predation by fish (Diaz et al. 1992; Nestlerode and Diaz 1998).

The SIMPER analysis results indicate which taxa contributed to the similarity among sites within each sediment category (Table 33). There was an increasing trend in species richness and diversity with decreasing percent silt+clay and increasing sediment grain size from muds to medium-grained sediments. Coarse grained sediments had fewer taxa than Fine to Medium grained sediments. *Branchiostoma floridae* largely dominated in Medium and Coarse grained sediment. The Mud and Very Fine sediments were primarily dominated by polychaetes, Tubificinae oligochaetes and Enteropneusta. Most of these taxa were also associated with anoxic or hypoxic sites (Table 32). The spionid polychaetes *Paraprionospio pinnata* and *Prionospio perkinsi* were found in sediments ranging from Mud to Medium grained sediments, and the cirratulid polychaete *Monticellina cf. dorsobranchialis* ranged from Very Fine to Medium grained sediments. Other dominant taxa including *Mysella planulata* and *Glottidia pyramidata* were associated with Fine to Medium grained sediments while *Ampelisca holmesi* was found in Medium to Coarse grained sediments.

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). The distribution of dominant taxa within Tampa Bayis 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.

Table 30. SIMPER analysis by depth category; values = percent contribution to similarity. Taxa contributing 50% to similarity within category listed.

Intertidal		Shallow Subtidal		Intermediate Subtidal		Deep Subtidal		Deep	
Tubificinae	14.68	Tubificinae	13.14	Tubificinae	7.62	*Paraprionospio pinnata*	7.59	*Branchiostoma floridae*	7.13
Aricidea philbinae	6.15	*Ampelisca holmesi*	6.30	*Ampelisca holmesi*	6.71	*Monticellina cf. dorsobranchialis*	7.32	*Pinnixa spp.*	6.70
Laeonereis culveri	4.61	*Aricidea philbinae*	5.13	*Mysella planulata*	5.21	Tubificinae	5.47	*Prionospio (Minuspio) perkinsi*	5.33
Ampelisca holmesi	4.40	*Mysella planulata*	4.46	Tellininae	4.19	*Prionospio (Minuspio) perkinsi*	4.92	Tubificinae	5.10
Prionospio heterobranchia	3.77	*Capitella capitata* complex	4.15	*Acteocina canaliculata*	3.49	Tellininae	3.93	*Monticellina cf. dorsobranchialis*	4.93
Capitella capitata complex	3.65	*Prionospio heterobranchia*	3.07	*Monticellina cf. dorsobranchialis*	3.22	*Mediomastus spp.*	3.48	*Paraprionospio pinnata*	2.97
Acteocina canaliculata	2.77	*Magelona pettiboneae*	2.95	*Paraprionospio pinnata*	3.20	*Branchiostoma floridae*	3.35	*Mediomastus spp.*	2.80
Amygdalum papyrium	2.54	*Laeonereis culveri*	2.92	*Glycinde solitaria*	2.64	*Pinnixa spp.*	3.00	*Caecum strigosum*	2.54
Magelona pettiboneae	2.53	*Acteocina canaliculata*	2.90	*Mediomastus spp.*	2.63	*Mysella planulata*	2.74	*Nucula proxima*	2.54
Cymadusa compta	2.33	*Amygdalum papyrium*	2.29	*Branchiostoma floridae*	2.48	*Ampelisca holmesi*	2.63	*Phlyctiderma semiaspera*	2.32
Mysella planulata	2.25	*Kinbergonuphis simoni*	2.26	*Prunum apicinum*	2.14	*Glottidia pyramidata*	2.30	*Glottidia pyramidata*	2.21
Streblospio spp.	1.98	*Prunum apicinum*	1.92	*Amakusanthura magnifica*	2.13	*Nucula proxima*	2.22	Tellininae	2.20
				Haminoea succinea	2.09	*Glycinde solitaria*	2.02	*Amakusanthura magnifica*	2.14
				Amygdalum papyrium	1.88			*Sigambra tentaculata*	2.09
				Listriella barnardi	1.70				

Table 31. **SIMPER analysis by salinity category; values = percent contribution to similarity. Taxa contributing 50% to similarity within category listed.**

Freshwater		Oligohaline		Low Mesohaline		High Mesohaline		Polyhaline		Euhaline	
Polypedilum scalaenum group	15.84	Tubificinae	23.05	*Mediomastus spp.*	12.91	Tubificinae	9.22	Tubificinae	6.93	Tubificinae	7.48
Tubificinae	15.17	*Cyathura polita*	15.36	*Amygdalum papyrium*	7.44	*Paraprionospio pinnata*	8.74	*Monticellina cf. dorsobranchialis*	5.68	*Branchiostoma floridae*	5.17
Laeonereis culveri	14.71	Palaeonemertea sp. A of EPC	12.48	*Xenanthura brevitelson*	6.16	*Ampelisca holmesi*	8.68	*Prionospio (Minuspio) perkinsi*	5.00	Tellininae	4.53
Grandidierella bonnieroides	14.57			*Cyathura polita*	5.88	*Monticellina cf. dorsobranchialis*	4.96	*Paraprionospio pinnata*	4.43	*Mediomastus spp.*	4.00
				Mulinia lateralis	5.67	*Amygdalum papyrium*	4.89	*Branchiostoma floridae*	4.33	*Monticellina cf. dorsobranchialis*	3.75
				Tellininae	5.56	*Mulinia lateralis*	4.58	*Pinnixa spp.*	4.09	*Clymenella mucosa*	3.52
				Ampelisca abdita	5.24	*Mysella planulata*	4.49	*Ampelisca holmesi*	3.57	*Parvilucina crenella*	2.53
				Cyclaspis varians	5.16	*Glycinde solitaria*	3.47	*Mysella planulata*	3.18	*Listriella barnardi*	2.31
						Mediomastus spp.	2.81	Tellininae	2.86	*Paraprionospio pinnata*	2.06
								Glottidia pyramidata	2.71	*Jaspidella blanesi*	2.05
								Amakusanthura magnifica	2.40	*Nucula proxima*	1.83
								Mediomastus spp.	2.19	*Exogone (Exogone) dispar*	1.78
								Paranemertes cf. biocellatus	1.90	*Pinnixa spp.*	1.72
								Nucula proxima	1.75	*Angulus cf. versicolor*	1.66
										Amakusanthura magnifica	1.63
										Phascolion cryptum	1.56
										Fabriciola trilobata	1.45
										Phlyctiderma semiaspera	1.36

Table 32. **SIMPER analysis by dissolved oxygen category; values = percent contribution to similarity.. Taxa contributing 50% to similarity within category listed.**

Anoxic		Hypoxic		Low		Normoxic	
Paraprionospio pinnata	18.22	*Monticellina cf. dorsobranchialis*	15.30	Tubificinae	13.26	Tubificinae	6.62
Monticellina cf. dorsobranchialis	14.66	*Paraprionospio pinnata*	8.65	*Monticellina cf. dorsobranchialis*	9.50	*Branchiostoma floridae*	5.40
Enteropneusta	10.24	*Prionospio (Minuspio) perkinsi*	8.58	*Paraprionospio pinnata*	7.22	Tellininae	4.02
Sigambra tentaculata	8.34	Enteropneusta	7.13	*Prionospio (Minuspio) perkinsi*	6.17	*Monticellina cf. dorsobranchialis*	3.90
		Tubificinae	6.65	*Mysella planulata*	4.19	*Pinnixa spp.*	3.43
		Carazziella hobsonae	6.55	*Carazziella hobsonae*	3.36	*Paraprionospio pinnata*	3.29
				Ampelisca holmesi	3.21	*Mediomastus spp.*	3.25
				Podarkeopsis levifuscina	2.67	*Ampelisca holmesi*	3.21
				Pinnixa spp.	2.39	*Prionospio (Minuspio) perkinsi*	2.97
						Amakusanthura magnifica	2.66
						Mysella planulata	2.60
						Nucula proxima	1.96
						Listriella barnardi	1.81
						Paranemertes cf. biocellatus	1.73
						Glottidia pyramidata	1.65
						Glycinde solitaria	1.53

Table 33. SIMPER analysis by sediment category; values = percent contribution to similarity. Taxa contributing 50% to similarity within category listed.

Mud		Very Fine		Fine		Medium		Coarse	
Paraprionospio pinnata	13.66	*Monticellina cf. dorsobranchialis*	16.56	*Monticellina cf. dorsobranchialis*	9.80	*Branchiostoma floridae*	7.00	*Branchiostoma floridae*	19.05
Carazziella hobsonae	11.71	Tubificinae	10.40	Tubificinae	8.76	Tubificinae	6.43	*Caecum strigosum*	5.79
Prionospio (Minuspio) perkinsi	9.70	*Paraprionospio pinnata*	8.79	*Paraprionospio pinnata*	5.86	*Ampelisca holmesi*	4.36	*Amakusanthura magnifica*	5.55
Enteropneusta	9.49	*Prionospio (Minuspio) perkinsi*	7.67	*Prionospio (Minuspio) perkinsi*	3.98	Tellininae	3.69	*Metharpinia floridana*	5.50
Sigambra tentaculata	7.28	*Carazziella hobsonae*	5.58	Tellininae	3.65	*Amakusanthura magnifica*	3.20	*Acanthohaustorius uncinus*	3.41
		Podarkeopsis levifuscina	4.03	*Mediomastus spp.*	3.57	*Pinnixa spp.*	3.12	*Pinnixa spp.*	3.12
				Mysella planulata	3.10	*Mediomastus spp.*	3.09	*Eudevenopus honduranus*	3.07
				Pinnixa spp.	2.68	*Mysella planulata*	2.85	*Travisia hobsonae*	3.02
				Ampelisca holmesi	2.61	*Glottidia pyramidata*	2.29	*Ampelisca holmesi*	2.67
				Angulus cf. versicolor	2.20	*Paranemertes cf. biocellatus*	2.10		
				Podarkeopsis levifuscina	2.05	*Prionospio (Minuspio) perkinsi*	2.02		
				Glottidia pyramidata	1.79	*Monticellina cf. dorsobranchialis*	1.98		
						Nucula proxima	1.96		
						Paraprionospio pinnata	1.96		
						Listriella barnardi	1.83		
						Acteocina canaliculata	1.68		
						Ampelisca sp. C of LeCroy, 2002	1.59		

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 benthic diversity and abundance, particularly with amphipods.

BIO-ENV analysis on the metal sediment contaminant dataset found a combination of chromium, copper and zinc had the strongest correlation with the benthic assemblage (ρ_s = 0.364). Chromium being the highest ranked single metal (ρ_s = 0.322), followed by zinc (ρ_s = 0.308) and copper (ρ_s = 0.303).

The SIMPER analysis results for taxa associated with sites that exceeded the TEL and PEL for chromium, copper and zinc are in Table 34. Taxa associated with sites that exceeded the TEL or PEL for chromium were predominantly polychaetes, Tubificinae oligochaetes and Enteropneusta. Sites exceeding the TEL for copper were characterized by polychaetes and Tubificinae, while taxa associated with PEL exceedences for copper included *Listriella barnardi* (amphipod), *Mysella planulata* (bivalve) and *Phlyctiderma semiaspera* (bivalve). Taxa associated with sites that exceeded the TEL and PEL for zinc included the amphipods *Ampelisca abdita* and *Ampelisca holmesi*, *Pinnixa* spp. (pea crabs), Tubificinae oligochaetes and several polychaete species.

BIO-ENV analysis on the PAH dataset found the strongest correlation with the benthic assemblage was due to a combination of naphthalene, chrysene, fluoranthene and pyrene (ρ_s = 0.267). Pyrene being the highest ranked single PAH (ρ_s = 0.261) followed by fluoranthene (ρ_s = 0.239) and chrysene (ρ_s = 0.234).

The SIMPER analysis results for taxa associated with sites for that exceeded the TEL and PEL for naphthalene, chrysene, fluoranthene and pyrene are in Table 35. The polychaetes *Paraprionospio pinnata* and *Monticellina cf. dorsobranchialis* and Tubificinae oligochaetes were associated with TEL exceedences for all four contaminants. The spionid polychaete *Streblospio* spp. and Tubificinae were associated with sites that exceeded the PEL for chrysene, fluoranthene and pyrene.

BIO-ENV analysis on the chlorinated pesticides and PCBs found two combinations of five compounds that had equal correlation with the benthic community structure: a) Endosulfan 2, p,p'-DDD, p,p'-DDE, Total DDT, total PCBs; and b) Endosulfan 2, p,p'-DDD, p,p'-DDE, Total DDT, and total chlordane (ρ_s = 0.228). Total DDT had the highest correlation (ρ_s = 0.186), followed by p,p'-DDE (ρ_s = 0.154) and total chlordane (ρ_s = 0.140).

The SIMPER analysis results for taxa associated with sites that exceeded the TEL and PEL for p,p'=DDD; p,p'-DDE, total DDT, Total Chlordane and PCBs are in Table 36. Tubificinae and polychaetes including *Prionospio perkinsi*, *Paraprionospio pinnata* and *Monticellina cf. dorsobranchialis* were associated with sites that exceeded the TEL for most of the pesticides and PCBs. *Parastarte triquetra* (bivalve) was associated with sites exceeding the TEL for total chlordane. Enteropneusta, *Ampelisca abdita* and *A. holmesi* were associated with sites exceeding the TEL for PCB. *Ampelisca abdita*, Tubificinae and several polychaetes were also associated with sites exceeding the PEL for p,p'-DDD . Tubificinae oligochaetes were associated with sites exceeding the PEL for total chlordane.

Table 34. **SIMPER analysis by TEL and PEL exceedences for selected metals; values = percent contribution to similarity. Taxa contributing 50% to similarity within category listed.**

Contaminant	**>TEL; <PEL**		**> PEL**	
Chromium	*Paraprionospio pinnata*	14.17	*Prionospio (Minuspio) perkinsi*	21.10
	Enteropneusta	10.87	*Paramphinome sp. B* of Gathof, 1984	10.84
	Sigambra tentaculata	7.95	Tubificinae	10.19
	Monticellina cf. dorsobranchialis	7.67	*Sigambra tentaculata*	7.76
	Paramphinome sp. B of Gathof, 1984	7.57	*Carazziella hobsonae*	7.45
	Prionospio (Minuspio) perkinsi	7.24		
Copper	Tubificinae	14.05	*Laeonereis culveri*	13.76
	Paraprionospio pinnata	13.00	*Paraprionospio pinnata*	10.34
	Monticellina cf. dorsobranchialis	9.52	Tubificinae	8.73
	Podarkeopsis levifuscina	7.65	*Mysella planulata*	7.30
	Prionospio (Minuspio) perkinsi	6.78	*Listriella barnardi*	6.32
			Phlyctiderma semiaspera	5.77
Zinc	*Prionospio (Minuspio) perkinsi*	15.06	Tubificinae	30.12
	Carazziella hobsonae	13.63	*Pinnixa spp.*	10.27
	Gyptis crypta	6.91	*Ampelisca holmesi*	9.32
	Ampelisca abdita	6.71	*Paraprionospio pinnata*	7.01
	Tubificinae	6.32		
	Pinnixa spp.	6.27		

Table 35. SIMPER analysis by TEL and PEL exceedences for selected PAHs; values = percent contribution to similarity. Taxa contributing 50% to similarity within category listed.

Contaminant	>TEL; <PEL		> PEL	
Naphthalene	*Paraprionospio pinnata*	16.86		
	Ampelisca abdita	14.82		
	Tubificinae	11.43		
	Prionospio (Minuspio) perkinsi	4.80		
	Monticellina cf. dorsobranchialis	4.10		
Chrysene	Tubificinae	19.66	Tubificinae	47.96
	Paraprionospio pinnata	10.96	*Streblospio spp.*	24.17
	Monticellina cf. dorsobranchialis	10.43		
	Podarkeopsis levifuscina	7.98		
	Schistomeringos cf. rudolphii	6.42		
Fluoranthene	Tubificinae	28.37	*Streblospio spp.*	48.96
	Paraprionospio pinnata	11.21	Tubificinae	11.12
	Monticellina cf. dorsobranchialis	10.47		
Pyrene	Tubificinae	19.72	Tubificinae	38.27
	Paraprionospio pinnata	11.63	*Streblospio spp.*	32.15
	Monticellina cf. dorsobranchialis	9.35		
	Ampelisca abdita	6.97		
	Podarkeopsis levifuscina	6.76		

Table 36. **SIMPER analysis by TEL and PEL exceedences for selected pesticides and PCBs; values = percent contribution to similarity. Taxa contributing 50% to similarity within category listed.**

Contaminant	>TEL; <PEL		> PEL	
p,p'-DDD	Tubificinae	26.49	Tubificinae	17.32
	Prionospio (Minuspio) perkinsi	15.02	*Laeonereis culveri*	16.67
	Monticellina cf. dorsobranchialis	7.98	*Alitta succinea*	7.86
	Aricidea (Acmira) taylori	5.77	*Melinna maculata*	7.86
			Ampelisca abdita	7.86
p,p'-DDE	Tubificinae	25.44		
	Streblospio spp.	10.76		
	Paraprionospio pinnata	9.62		
	Monticellina cf. dorsobranchialis	7.88		
Total DDT	Tubificinae	29.97		
	Paraprionospio pinnata	13.86		
	Monticellina cf. dorsobranchialis	8.56		
Total Chlordane	Tubificinae	37.30	Tubificinae	54.96
	Parastarte triquetra	12.76		
PCB	Enteropneusta	12.21		
	Prionospio (Minuspio) perkinsi	11.46		
	Paraprionospio pinnata	10.97		
	Ampelisca abdita	8.59		
	Tubificinae	6.22		
	Ampelisca holmesi	6.14		

Conclusions and Recommendations

Tampa Bay has shown tremendous improvements in its water quality over the past 40 years; however, population growth and development continue to strain the environmental resources of the region (Karlen, 2014). Monitoring efforts such as the Baywide Benthic Monitoring Program are essential to assess the current environmental conditions in Tampa Bay, track long-term environmental trends and identify areas in need of remediation. The first 20 years of the Baywide 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 indicated that Tampa Bay is predominately a shallow estuary with a median depth of 2.7 meters. Salinities were generally 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 concentrations were generally high with a baywide median of 5.24 mg/L with nearly 78% of the samples above 4 mg/L. There were however several areas of hypoxia particularly in Hillsborough Bay and Old Tampa Bay. Hillsborough Bay had a larger percentage of sites that were either anoxic or hypoxic than the other segments of Tampa Bay.

Sediment contaminant concentrations were generally low at most sites with higher levels of contamination found in localized areas, particularly in Hillsborough Bay. Most metals had highest concentrations in Hillsborough Bay and the Manatee River. 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. 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.

Low and high molecular weight PAHs, as well as the overall total PAHs had relatively low concentrations throughout Tampa Bay except in isolated sites. Acenaphthene, acenaphthylene, and dibenzo (a, h) anthracene, however, were found at elevated levels (>TEL) at some sites. The number of taxa had a relatively strong negative correlation with PAHs, and pyrene had the strongest correlation with the benthic community structure.

Chlorinated pesticides and PCBs were found at low concentrations throughout the bay. Total PCB's, Lindane, total DDT and DDE had TEL exceedences at approximatly 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 had the strongest correlation with the benthic community structure.

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 dominate the overall abundance; seven taxa account for 25% of the relative abundance. The most abundant organism was the brachiopod *Glottidia pyramidata* which was found predominantly in fine to medium grained sediments. The benthic community had spatial and temporal variability between bay segments. Boca Ciega Bay, Lower Tampa Bay and Middle Tampa Bay had more similar benthic communities compared to Old Tampa Bay, Hillsborough Bay, Terra Ceia Bay and the Manatee River. Sediment composition had the strongest correlation with the benthic community structure, followed by dissolved oxygen. The Tampa Bay Benthic Index and the EPA's National Coastal Assessment rating scheme indicate that the overall condition of the benthic habitat in Tampa Bay is "Poor" to "Fair" despite the high diversity of benthic taxa**.** Hillsborough Bay, Boca Cieaga Bay, Terra Ceia Bay and the Manatee River generally had "Poor" to "Fair" ratings over the 20 year monitoring period. Old Tampa Bay rated as "Poor" during several years but generally rated as "Fair" to "Good." Middle Tampa Bay and Lower Tampa Bay typically rated as "Fair" to "Good."

The overall "Fair" to "Poor" ratings for the benthic communities emphasizes the continued need for benthic monitoring in Tampa Bay. Several recommendations that were intended to control increasing monitoring costs while maintaining the integrity of the program were made in the last Benthic Monitoring Report (Karlen et al. 2008). Their commendations were as follows: 1) reduce the overall annual sampling effort to a total of 44 baywide samples plus 20 additional samples directed towards selected "Special Study" sites, 2) combine Middle Tampa Bay and Lower Tampa Bay into a single reporting unit, and 3) increase the reporting period from four to five years in order to maintain long-term statistical power. These recommendations were adopted by the Tampa Bay Estuary Program retroactively to include the 2005 samples. The recommendation of this report is to maintain the current sampling design that has been in place since 2005, with the possibility of increasing the number of "Special Study" sites above the current 20 samples per year when needed. This would evaluate areas and issues of special concern to the Tampa Bay Estuary Program and regional bay managers.

Recommendations for additional future monitoring of sediments and benthic communities in Tampa Bay:

- Continue to focus on special study sites (i.e., areas of known or suspected environmental degradation or sites with anticipated future impacts, such as dredging or proposed mitigation sites). Also, consider revisiting past special study sites to assess any changes to conditions. These sites may include:
  - Port Tampa Bay (Ybor/Sparkman Channels, Garrison Channel; East Bay)
  - Clam Bayou
  - Bayboro Harbor
- Consider expanding laboratory analyses of sediment contaminants to include new or emerging contaminant concerns, for example:
  - Microplastics
  - PBDEs
  - Nanomaterials
  - Pharmaceuticals
  - Mercury
- Increase monitoring efforts in the major river systems (Hillsborough, Palm, Alafia and Little Manatee Rivers) and tidal stream areas since few low salinity areas are included in the current dataset. Previous benthic monitoring programs in the rivers including the EPC's Hillsborough Independent Monitoring Program (HIMP) and Tampa Bay Water's

Hydrobiolgical Monitoring Program (HBMP) have been discontinued due to recent budget cuts. 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. The program over the past 20 years has provided an extensive baseline of the status of benthic habitats and sediment conditions in Tampa Bay. These data 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. Hillsborough Bay has an increasing trend of hypoxia, and Old Tampa Bay has changes in the sediment composition. These trends emphasize the importance of benthic monitoring as a management tool, the need for long-term monitoring to track environmental changes, and to focus resources towards continuing restoration.

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