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Environmental Quality of the Pensacola Bay System: Retrospective Review for Future Resource Management and Rehabilitation

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by

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Notice

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Foreword

This report supports EPA's Sustainable and Healthy Communities Research Program. The objective of this Program is to assist community leaders make decisions that preserve the environment and the vital services they provide. The primary objective of this report is to provide an updated summary of the ecological condition of the Pensacola Bay System (PBS) and the value of its ecological goods and services. An updated summary is needed since a considerable amount of published and unpublished technical information has become available since the last summary published 15 years ago. This updated report serves as a technical resource for the public and the regulatory and scientific communities related to resource management. It provides a synopsis of the environmental database (1680-present) and the research needed to maintain and improve the environmental quality of the PBS.

The report is a collaborative effort. Authors are from the USEPA's Gulf Ecology Division Research Laboratory (Gulf Breeze, FL), West Florida Regional Planning Council (Pensacola, FL) and Escambia County Water Quality and Land Management Division (Pensacola, FL). The USEPA Gulf Ecology Division conducts ecological effects research to assess the sustainability of estuarine and coastal systems and determines the factors causing impacts in order to predict future risks. The mission of the WFRPC is to provide professional planning, coordinating and advisory services to local governments, state and federal agencies and to he public to preserve and enhance the quality of life in northwest Florida. Escambia County's Water Quality and Land Management Division serves the community through development and oversight of local environmental resource projects and programs for the county.

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Acronyms and Abbreviations

AFDW	Ash free dry weight
BL	Bay La Launch
CCA	Chromated copper arsenate
DDT	Dichloro-diphenyl-trichloroethane
ER-L	Effects range-low
ER-M	Effects range-median
GL	Grand Lagoon
MS	Mississippi Sound
NOAA	National Oceanic and Atmospheric Administration
OR	Old River
PAH	Polycyclic aromatic hydrocarbons
PBS	Pensacola Bay System
PCB	Polychlorinated biphenyl
PEL	Probable effects level
SAV	Submerged aquatic vegetation
SQAGs	Sediment quality assessment guidelines
SRE	Suwannee River Estuary
TEL	Threshold effect level
TMDL	Total Maximum Daily Loading
USEPA	U.S. Environmental Protection Agency
WRE	Withlacoochee River Estuary

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"If you don't synthesize knowledge, scientific journals become spare parts catalogues for machines never built."

Everglades conservationist, Arthur Marshall Jr.

Executive Summary

Biological and habitat diversity-The Pensacola Bay System (PBS) currently supports at least 1,400 estuarine plant and animal species identified from at least 85 natural resource surveys conducted during the last 50 years. The total does not include PBS-dependent wildlife. Seagrass meadows are largely limited to Santa Rosa Sound and Big Lagoon. Oyster reefs and tidal marshes dominate in East and Escambia Bays. The distribution, productivity, and condition of PBS biota are controlled by complicated and interdependent chemical, biological, and physical factors which are not well understood. As a consequence, attempts to establish a direct cause-effect relationship for the presence or absence of a species have been largely futile.

Environmental database-Environmental and physical observations for the PBS have been made for approximately 330 years beginning in the late 1600s. A relatively large bibliometric database is available but much data gathering has been reactive, unconnected, repetitive, and with an absence of central coordination and integration. Furthermore, much of the information is of limited accessibility and varied quality. Although some reports are available on-line, many are not which limits their value to the public and regulatory and scientific communities. Approximately 27% of 454 reviewed reports appear in the traditional peer-reviewed scientific literature. About 100 research topics have been investigated since the 1950s, including the effects of 22 natural and anthropogenic stressors. Environmental reports have been more common for Escambia Bay and Pensacola Bay (about 40% of all reports) and the least common for East and Blackwater Bays, Big Lagoon and Bayou Grande. The most diverse environmental database is for Bayou Texar.

Environmental condition- Environmental degradation of the PBS ecosystem became noticeable during the 1950s and its condition remained depressed until about the mid-1970s. As a result, the PBS became a less complex ecosystem with reduced resiliency to stress. Gradual improvement has occurred since the 1970s and considerable advancement for scientific understanding has occurred in recent years due in part to the presence of at least 30 management and restoration plans. However, the spatial, temporal, and experimental differences among many studies limit the ability to judge the environmental trend other than in general terms. The current extent and rate of improvement are uncertain for many environmental metrics and many assumptions for recovery and system-wide environmental gains are uncertain. It is currently unknown if environmental quality continues to improve, has stabilized or is declining and, if declining, is it reversible. Current monitoring programs are too infrequent and metric-limited to resolve this issue. The only available reported numerical judgement for condition of the PBS is for 1995-2000 during which 16%, 68%, and 16% of the PBS was considered in good, fair, and poor condition, respectively. No update is available. Stormwater runoff containing fecal bacteria, anthropogenic chemicals and suspended solids, and sediment contamination, and the increasing effects of global climate change are the dominant drivers of change for the near future.

Anthropogenic chemicals-The adverse effects of anthropogenic chemicals became a noticeable issue during the 1960s, particularly those contained in domestic and industrial wastewaters. Wastewaters, with few exceptions, are no longer of concern since direct discharges have been eliminated to all PBS areas except Santa Rosa Sound. In contrast, the fate and biological effects of PCBs, dioxins, atrazine (herbicide), and Irgarol (antifoulant) remain uncertain as well as those for more recent chemicals such as pharmaceuticals, endocrine disruptors, personal care products, veterinary products, nanomaterials (microbeads), anti-microbials, flame retardants, and anti-sticking agents. Currently, there is a lack or incomplete understanding of the toxic effects and no effect concentrations for the majority of PBS shoreline contaminants in water, sediment and biota. The first toxicity test conducted for the PBS was during 1958 (nutrients) and the first phytotoxicity test was conducted during 1982. Most toxicity information is for acute effects of contaminated sediments and relatively insensitive single species of benthic and infaunal invertebrates evaluated under the controlled conditions of the laboratory. The effects of environmental modifying factors (salinity and temperature) are unknown on chemical toxicity. As a result of the limited toxicity database, sensitive response parameters and pressure points are uncertain for most biota and their communities, and there is an inability to distinguish the effects of most natural and anthropogenic stressors alone and in combination on their condition.

Water quality: Chemical-There has been no long-term, multimetric, and consistently conducted monitoring effort to determine water quality trends for all but a few parameters. Surface water condition for the PBS is considered better than that for underlying sediments and has been ranked in the past between fair and good, including that for the Blackwater, Escambia and East Rivers. However, all chemical water quality judgments to date are based on an incomplete database and their conclusions are subject to wide interpretation. The effects and environmental concentrations for chemicals of past concern such as the highly phytotoxic atrazine and Irgarol and chemicals of recent or emerging concern are unknown. Water quality monitoring programs have been conducted independently by personnel of different technical skills ranging from high school students to environmental professionals. The Bream Fishermen Association has been conducting water quality measurements since 1968. Measurements have been often limited to routine physicochemical parameters and, to a lesser extent, concentrations of fecal coliforms, nutrients, chlorophyll *a,* and several trace metals. Nutrients have decreased to levels not thought by some to be problematic, including for seagrass, at least in relation to water clarity. PBS has a suspended solids problem that has been recognized since 1900. Suspended solids continue to degrade water quality but presumably to a lesser extent than in the past due to increases in water storage (retention) ponds, use of mechanical hydrodynamic separators, and more vegetative shoreline modifications. Chemically-contaminated groundwater from two Superfund sites will continue to enter the upper area of Bayou Texar for the next 70 years, the biological effects of which are still being evaluated and debated.

Water quality: Effects-based research-The direct and indirect effects of excessive nutrients have historically received more attention than those for non-nutrient contaminants. Only 2 of 11 symptoms of nutrient enrichment are present in the PBS, suggesting that nutrient concentrations have decreased from historically high levels. To some, current ambient nutrient concentrations are a suitable basis on which to establish numeric nutrient criteria. However, additional scientific confirmation is needed for verification. Mean autotrophic index values (ratio of biomass to chlorophyll *a*) for colonized algal-periphyton were 124, 260, 283, 442, and 244 for Pensacola Bay, Escambia Bay, Bayous Texar, Chico, and Grande, respectively, indicating the possibility of a high degree of organic enrichment. The toxic effect concentrations of most water-borne contaminants to PBS biota are unknown but toxicity is unlikely since most concentrations are low and below national water quality criteria for aquatic life. However, toxicity of combinations of water-borne non-nutrient contaminants in the presence of ambient nutrient concentrations under varying conditions of salinity and temperature, the more realistic condition, are possible and important to understand, particularly, for plankton and seagrass.

Sediment quality: Chemical-Contaminated sediments are and will continue to be one of the major impediments for environmental improvement for the PBS. Surficial sediments collected from many locations are chemically-contaminated and support only pollution-tolerant benthic communities. Approximately 16-49% of sediment samples analyzed in the past exceed proposed numerical chemical guidelines, suggesting a biological impact. However, exceedance of these guidelines is not a consistent indicator of a corresponding biological impact (30-60% accurate). As for the water column, concentrations of chemicals of emerging and more recent concern are unknown for sediments and not included in judgments for chemical quality.

Sediment quality: Effects-based research-Acute and chronic toxicity to benthic faunal species, genotoxicity, and phytotoxicity have been determined for at least 340 whole sediment samples collected from the PBS. Effects have been analyzed for 13 plant, animal and microbial test species. The frequency of toxicity observed for these sediments is 8% (acute toxicity), 33% (chronic toxicity), 20% (genotoxicity), and 57% (phytotoxicity). Sediments collected from various areas in Bayous Texar, Chico, and Grande have generally been more toxic. The most acutely toxic sediment was collected from upper Bayou Texar (lethal concentration to 50% of test species=3% contaminated sediment). There have been no known sediment toxicity identification evaluations conducted with PBS sediments to determine the specific cause(s) of toxicity and as a result, the Total Maximum Daily Loading (TMDL) process cannot be applied.

Dredging-Dredging has been conducted intermittently in the PBS to increase depth and remove contaminated sediments. Repetitive dredging has been needed for the same areas during the past 35 years due to the lack of control for the sources of suspended solids and contaminants to the waterbody. The ecological benefits of the intermittent dredging events, conducted more frequently in Bayous Texar and Chico, are uncertain. An overall positive benefit, other than for navigation, should not be assumed until supporting ecological information becomes available. The uncertain ecological value prevents calculation of cost-benefit ratios important to support cost-effective management. Noted as early as 1984, long-term ecological studies and control of contaminant and suspended solid sources are needed *prior to dredging* to prevent the costly repetitive dredging events.

Bioaccumulation-Chemical bioaccumulation has been determined for 30 faunal and floral species and 69 chemicals during the last 50 years. Many contaminants of current and historical concern are present in PBS biota, more so for faunal species than primary producers. The most consistent and long-term bioaccumulation monitoring (30 years) has been conducted for oysters in the PBS as part of NOAA's Mussel Watch Program.

Bioaccumulation: Public health-Some PBS biota contain concentrations of PCBs, dioxins, furans, DDT, mercury, Cd, Zn, and inorganic As that may pose public health risks. Exceedance frequency of reported numerical consumption guidelines, screening values, and benchmarks has been spatially, species, tissue, and guideline-specific. Consumption risk is lowest for shrimp. The health risk is greater for consumption of fish and blue crabs collected from Bayous Texar, Chico, and Grande, upper Escambia Bay, and lower Escambia River. Exceedance for numerical mercury criteria has been 27% or less of samples based on Federal guidelines of 0.3 ppm, 0.4 ppm and 1.0 ppm. However, for the more at risk population (women of child bearing age, children, and subsistence fishers), the lower thresholds of 0.1 ppm and 0.049 ppm have been exceeded by as much as 89% of samples. Exceedance of a screening value for inorganic As (0.01 ppm) in oysters and crabs was between 54%-100% of samples. PCB contamination in the PBS is considered serious. Florida Department of Health guidelines for tPCBs (<50 ppb to >500 ppb) were exceeded for 9 of 24 fish from Escambia Bay as part of a Florida Department of Health survey and up to 69% of samples from another survey. A USEPA screening level (20 ppb) was exceeded in all fish (five species, 21 samples) collected from Escambia Bay. There is a public health risk advisory for the consumption of PCB-contaminated striped mullet (skinless) collected from Escambia Bay. The public health risk of consuming seafood containing the human-harmful perfluorinated compounds (anti-sticking and waterproofing agents) and polybrominated diphenyl ethers (flame retardants) cannot be determined due to lack of information. In addition to the above, the presence of pathogens such as coliform bacteria and *Vibrio vulnificans* in surface water and oysters is also a public health risk. On-going monthly monitoring, TMDL implementation, and seasonal and spatial restriction of harvesting reduces the health risk of oyster consumption.

Bioaccumulation: Wildlife health-Published information describing the risk for wildlife consuming chemically-contaminated prey from the PBS could not be found. Based on a preliminary analysis, PBS wildlife may be at risk from consuming mercury and PCB-contaminated oysters, blue crabs, and fish. Exceedance of proposed wildlife protection guidelines for mercury (0.1 ppm, 0.077 ppm, and 0.033 ppm) was between 21-96% of samples based on a review of bioaccumulation databases for oysters, crabs, and fish. Exceedance of wildlife protection values (0.1 ppm and 0.016 ppm) for total PCBs and fish was 12% and 16% based on results of two studies.

Bioaccumulation: Organism health-The acute and sublethal effects of accumulated contaminants, alone and in combination, on the health or condition of dominant PBS biota including seagrass are unknown. This includes the incidence of possibly-related histopathological abnormalities.

Spatial environmental differences-The environmental quality of the PBS has been compared internally (across subunits) and externally (across regional and national estuaries). Environmental quality within the PBS usually increases seaward away from the shoreline contaminant sources and areas receiving river discharges. Peripheral bayous/bays act as settling basins removing many contaminants and, as a result, are environmentally degraded. Environmental degradation has been reported consistently for upper and mid-Escambia Bay, Pensacola Bay (harbor area), Bayous Texar, Chico, and Grande based on results for sediment contamination, contaminant bioaccumulation, and biotic diversity. These degraded areas overlap many of the State of Florida-listed impaired water segments for the PBS subject to the TMDL process. The outcomes of the many across-regional estuary comparisons that include the PBS are metric-specific, site-specific, time-dependent, and often based on the unproven assumption of watershed and coastal geomorphological similarity. The results of many comparisons are directionally mixed, qualitative, and indicate few supportable multimetric differences between the PBS and other northern Gulf of Mexico estuaries.

TMDLs-TMDLs are in progress for primarily public health issues (fecal bacterial contamination, mercury contamination in seafood) and excessive nutrients/chlorophyll *a*. The TMDL process is not in place to address major stressors such as sediment contamination and PCB contamination. Insufficient information for many water body segments of the Pensacola Basin prevents evaluation and verification of environmental condition, the precursor to the TMDL process.

Seagrass-Seagrass meadows are a keystone habitat for maintaining the biodiversity within the PBS. As a result, they have received much scientific interest and a diverse environmentally-related database exists. There have been at least 50 research-related reports, 12 reported summaries of status and coverage, and about 32 graphic and aerial surveys. The first aerial survey occurred during 1940. Surveys have been and continue to be sporadic, more so for those that include supporting ground truthing and condition analysis. Seagrass coverage during 1948 was extensive throughout the PBS, including Escambia and East Bays, but by 1972, these same areas were devoid of seagrass. Twenty reasons for the declines have been reported including the possible toxic effects of widely-used herbicides. Seagrass meadows have and continue to persist largely in Santa Rosa Sound and Big Lagoon but not without periodic declines. Total coverage during the past 30 years has been relatively steady between 4,100-4,700 acres relative to 9,530 acres for 1960. Coverage has increased about 8% since 2003.

Habitat coverage-Estimated coverage (acres) of the biodiversity-building seagrass meadows, oyster reefs, and salt marsh and tidal wetlands in the PBS are 4,462 (year of estimate=2010), 200-400 (2015), 6,697 (2010) and 8,579 (2014). Submerged aquatic vegetation is currently 3% of bay bottom relative to 8% 60 years ago. Seagrass coverage is currently estimated to be about 47% less than during 1960 (loss=5,068 acres), 72% less for oyster reefs (loss=471 to 631 acres) and 53-71% less for wetlands (loss=2,600 to 4,200 acres). Of these habitats, the future outlook is more promising for tidal marsh and salt marsh coverage, which has increased 19% (1995-2010) and is expected to further increase due to sea level rise if not restricted by anthropogenic barriers (roadways, armoured shorelines). In contrast, it is expected that the coverage of seagrass meadows and viable oyster reefs will decline in the future due to sea level rise, surface water acidification, and increased herbivory from invasive tropical species.

Economic evaluation-PBS diversity-building habitats provide environmental goods and services that have economic value. The estimated total value of these services combined for seagrass meadows, oyster reef complexes, and tidal wetland habitats is as much as $226 million per year. It can be argued that this total annual value is approximately half as much as that for the same habitats 50-60 years ago prior to their decline in coverage. For perspective, the current annual total habitat value exceeds the 2015 real estate tax collection for Escambia County ($112 million), the total tourist development tax collection ($9.1 million) and total toll revenue from the Bob Sikes Bridge ($3.9 million). The above habitat evaluations do not include values for tourism, recreational use, and seafood harvests. There are no locally validated models capable of predicting the effects of different levels of stressors on loss of ecological goods and services and their economic value.

Habitat restorations-Habitat restorations and creations have occurred for at least 40 years and continue within the PBS primarily for seagrass meadows and oyster reefs. Success has been mixed. A “learn by doing” approach has been typical of these efforts particularly for seagrass meadows. All restoration attempts to date are based on the unproven assumption that the ecological services of the destroyed natural habitats can be reversed and restored, and it is therefore, unknown what degree of replacement or creation is needed to compensate for the lost ecological services of the original habitat. The site-specific and aggregate contribution of all restorations to improving the overall environmental condition of the PBS is unknown. Oyster habitat has been successfully established in many areas at different scales including Bayous Texar, Chico, and Grande, Santa Rosa Sound, Pensacola Bay and East Bay. Significant oyster habitat creation is planned for 2016 in much of the PBS. Restoration of seagrass meadows has received considerable attention due to their historical reduction in most PBS areas. Restorations (transplantations) using primarily sods and seedlings of *Halodule wrightii* have been attempted for 40 years at different scales with limited or no long-term success in most previously-vegetated areas such as Escambia and East Bays. Despite some small-scale success in recent years, seagrass restoration should be considered in the trial and error stage until life-supporting requirements and locally sensitive biomarkers of condition become available. In a positive development, shoreline-vegetated and community-based restorations have increased in recent years, particularly along Pensacola Bay which include seagrass and saltmarsh plant revegetation and oyster reef creation. One notable example is Project GreenShores where 10,000 m^2 (2.5 acres) of seagrass (*Ruppia maritima*) has been added to Pensacola Bay.

Variability-The natural variability for many chemical and biological measurements reported for the PBS is unknown since single measurements predominate the database. Initial indications are that temporal variability in results can be as great as one order of magnitude for measurements of biodiversity, bioaccumulation, and sediment toxicity. The effect of this variability on conclusions for chemical risk assessments, monitoring programs, habitat restoration efforts, and resource management decisions is unknown but important to consider.

Climate change-Understanding and adapting to the effects of global climate change is the primary challenge for maintaining the current environmental condition and future improvement of the PBS.

Consequently, many research needs for filling data gaps and updating information in the historical database are important but secondary to those for identifying, adapting, and minimizing the increasing impacts of this stressor. Sea level rise, an influx of tropical species (i.e., lionfish), changes in salinity zones, acidification of water column, shoreline alteration and reduced coverage and condition for seagrass meadows and oyster reefs are some effects to be expected.

Future research focus-Information gains for future research and monitoring conducted in Escambia Bay, Bayou Texar, and Chico will be less than those for environmental studies conducted in areas less studied in the past, such as Big Lagoon and East and Blackwater Bays. Likewise, additional uncoordinated and non-focused chemical monitoring for sediment and water quality (physicochemical parameters, trace metals, chlorophyll *a,* and nutrients) should be reduced since the information gain will be minimal. The same applies to benthic community analysis and measurements of chemical quality. Research and monitoring effort needs to be redirected to the technical areas identified from this summary for which information is lacking but needed for environmental improvement. These include increased understanding for the effects of dredging, sediment chronic toxicity, specific cause(s) of sediment toxicity/degradation, environmental concentrations and biological effects for chemicals of more recent concern, sensitive indicators for biotic condition and economic value of local biodiversity-building habitats.

Bottom line-Identifying the current condition of the PBS and preventing further chemical and biological deterioration is an achievable goal but pragmatically any measureable improvement will occur incrementally over the long-term in the shadow of the increasing effects of climate change. If noticeable improvement is expected, research modelling, habitat restorations, and system monitoring will need proactive, long-term and enhanced multi-organizational coordination and financial commitment. Specific action steps are provided in the 20 recommendations resulting from our review.

1 Introduction

Nineteen of the 37 major estuaries in the U.S. are located along the northern Gulf of Mexico coast (Isphording et al. 1987), including the subtropical Pensacola Bay System (PBS), also known as the “Pensacola estuary” (Cooley 1970, 1978) and “Escarosa” (Hopkins 1973). The PBS is included in the Panhandle Bioregion for Florida and in the Group 4 Basin for the 5 year cycle of the Florida Watershed Management approach (FDEP 2014). It is a shallow and unstable Coastal Plain riverine and estuarine system partially blocked by a barrier island. It includes several interconnected sub-estuaries such as Pensacola, Escambia, East, and Blackwater Bays (Fig. 1.1). Also included for this review are two marine lagoons that parallel the PBS and Gulf of Mexico, Santa Rosa Sound, and Big Lagoon (Fig. 1.1). Big Lagoon, not usually included in PBS environmental summaries, is a bay barrier bar that connects Perdido Bay and Pensacola Bay. It is part of the Big Lagoon Florida State Park. A portion of the east-west orientated Santa Rosa Sound is within the Naval Live Oaks-Gulf Islands National Seashore. Sections of Big Lagoon, Santa Rosa Sound, and the Blackwater Bay are classified as Florida Outstanding Waters, the highest protection offered to a waterbody in Florida. The Blackwater Bay system has been considered the most threatened in the PBS (FDEP 1998). Escambia Bay is a priority site for conservation (Beck et al. 2000).

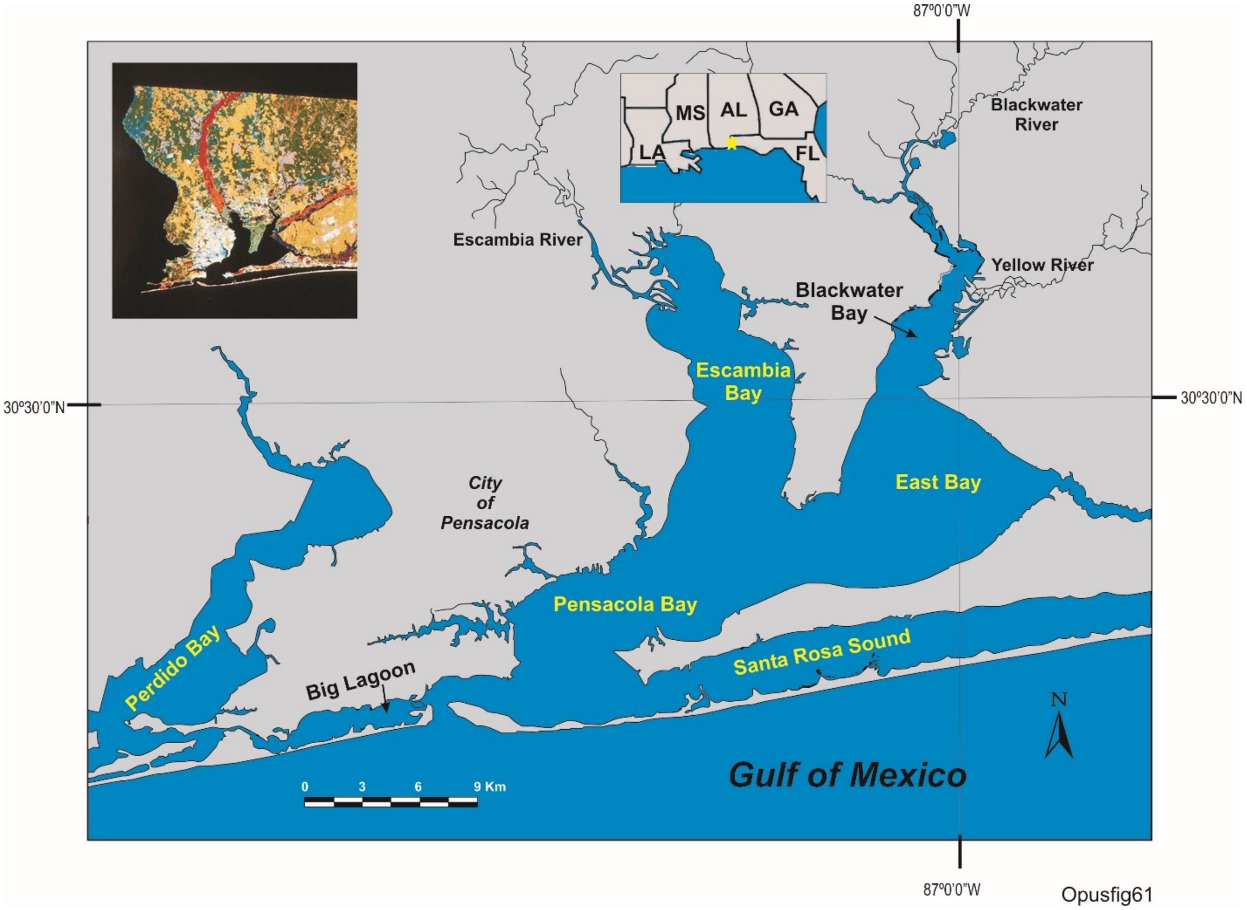


Figure 1.1 Location of the Pensacola Bay System adjacent to the Gulf of Mexico in northwest Florida. Subunit focus for summary includes Pensacola, Escambia, East and Blackwater Bays, Santa Rosa Sound, and adjacent Big Lagoon.

The PBS is the fourth largest estuary in Florida with a surface area of 373 km^2, 889 km of coastline, and an approximate 18,000 km^2 watershed. A 0.8 km wide pass opens to the Gulf of Mexico and flushing times have been estimated as 18 d and 200 d (Olinger et al. 1975; Thorpe et al. 1997). The geomorphological characteristics of the PBS have been reported on numerous occasions (examples, Barnett and Gunter 1985; Lewis 1986; Jones et al. 1992; BARC et al. 1998; FDEP 2007; 2012a; WFRPC et al. 2005) and have been compared to those for other U.S. estuaries (NOAA 1990). Spatial overviews or contours are available for several chemical and biological characteristics such as seagrass coverage, oyster contaminants, salt marsh coverage, sediment contaminants, organic carbon, nutrients in water and sediment, salinity, light penetration, wastewaters and Superfund sites, and benthic fauna. For examples, see Olinger et al. (1975); Cantillo et al. (2001); Von Appen and Winter (2000); DeBusk et al. (2002); Macauley et al. (2005); FDEP (2007); Liebens et al. (2006); Lewis and Devereaux (2007); Mohrherr et al. (2006, 2008, 2009, 2012); Murrell et al. (2009); and Reynolds, Smith and Hills Inc. (2014).

The PBS is a shared resource with federal, state, regional and local jurisdictional organizations responsible for its environmental condition. It is one of the many several northern Gulf of Mexico estuaries that have been impacted by the effects of increasing population growth. Population growth increased about 500% between 1950 and 2000 (FDEP 2007) and is projected to further increase 20% and 64% by 2020 for Escambia and Santa Rosa Counties, respectively (Zwick and Carr 2006). Environmental quality of the PBS has been observed for over 250 years (Table 3.1). Although pollution had been a problem since 1900, scientific and public concern increased during the 1950s (examples, Patrick et al. 1953; Murdock 1955) and has continued thereafter. The period between the 1950s and mid-1970s was a period of relatively few environmental regulations for coastal waters and a period when declines in harvested fish and shellfish and numerous fish kills became obvious. For example, there were 166 fish kills between 1970-1974 (Olinger et al. 1975) including 41 in Escambia Bay and 32 in Pensacola Bay (NWFWMD 1990). Approximately 2,000 to more than 10 million fish died in Mullato Bayou between 1970 and 1971 (Hopkins 1973). The fish kills paralleled a 98% reduction in the shrimp fishery during 1968 -1971 (Lewis 1986). Smaller summer fish kills continued intermittently during the 1990s in some areas such as Bayou Texar largely due to anoxic/hypoxic conditions (Fig. 1.2) As a result of population increases, many of the biota-supporting habitats of the PBS have been degraded, fragmented, or destroyed resulting in ecological simplification and a reduction in resiliency to environmental stress. The PBS has been considered a heavily-impacted estuary (Seal et al 1994; Von Appen and Winter 2000; Livingston 2005) and by one estimate has the lowest biological quality of several Florida estuaries relative to fish and infaunal invertebrate biomass (Livingston 2010). Macauley et al. (2005) reported ecological condition as good, fair, and poor for 16%, 68% and 16% of the surface area for 1995-2000. No update is available.

Figure 1.2 Summer kill of Gulf menhaden (*Brevoortia patronus*) in Bayou Texar.

The objective of this report is to summarize the scattered environmental information for the PBS which is essential for understanding its current environmental condition and trend and needed for future cost-effective and science-based resource management. The management and regulatory response to the on-going influx of anthropogenic contaminants, the effects of episodic events (hurricanes, oil spills) and the effects of climate change depend upon technically-based information such as that contained in a current state-of-the-science synthesis report. Many environmental reviews are available for the PBS (examples, Pratt et al. 1990; Thorpe et al. 1997; BARC et al. 1998; WFRPC et al. 2005) but many are limited in scope, most are outdated, and none have been published in the peer-reviewed literature. This review provides an updated and critical appraisal of the environmental condition of the PBS based on consolidation and integration of historical, recently published, and unpublished information reflective of current chemical and biological assessment methodologies. The review also includes summaries for ecological information lacking or under-reported in previous reviews. This includes information for biodiversity, non-nutrient contaminant concentrations in surface water and sediment, sediment phytotoxicity and genotoxicity, bioaccumulation, use of colonized periphyton as bioindicators, organism and wildlife health, economic value for ecological services, climate change, and temporal variability of environmental measurements.

In addition to the above, there have been multiple across-estuary comparisons reported with the intent to judge or rank the environmental condition of the PBS. Several of these comparisons scattered in the literature are summarized in this report. In a parallel effort, comparisons of unpublished results from identical chemical and biological analyses conducted for the PBS and six potential reference areas are made to provide an additional regional perspective. These sites were chosen as potential reference sites based on results from the USEPA's Estuarine Monitoring and Assessment and National Coastal Assessment Programs, which indicated minimal anthropogenic impact. These areas were Old River (OR), Bay La Launch (BL), Grand Lagoon (GL), Mississippi Sound (MS), Withlacoochee River (WRE), and the Suwannee River (SRE) estuaries (Fig. 1.3). Bay La Launch connects Perdido Bay with Wolf Bay (Alabama). Old River and Grand Lagoon are partially enclosed portions of the Gulf of Mexico located near Orange Beach (AL) and Panama City (FL), respectively. Geographic coordinates for sampling stations appear in Lewis et al. (2006).

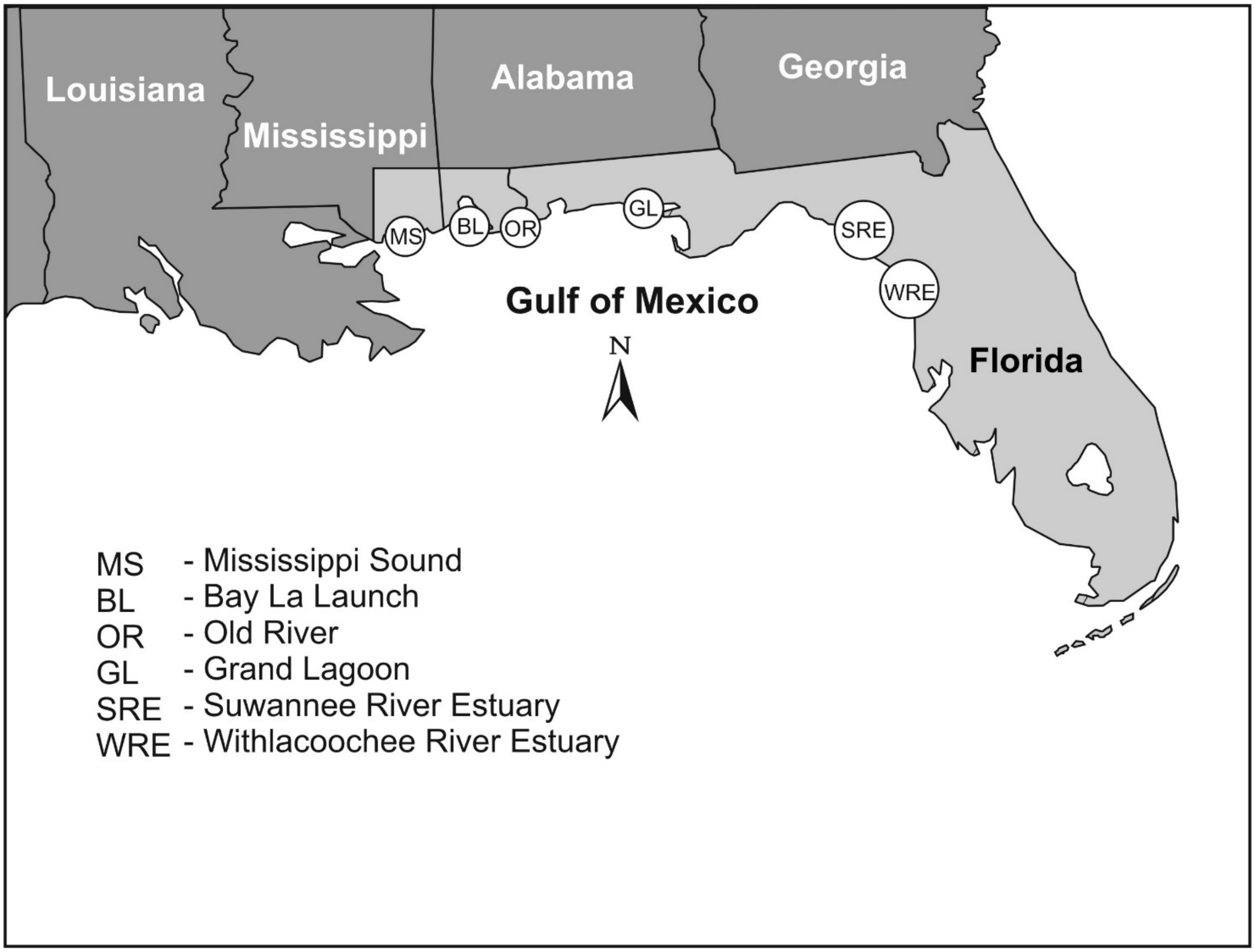


Figure 1.3 Relative locations of proposed reference sites for which environmental quality of the Pensacola Bay System is compared within the summary. Geographic coordinates for sampling stations available in Lewis et al. (2006).

2 Historical Database

Environmental observations and measurements for the PBS have been made since 1680 but more commonly after 1960. At least 454 reports are available describing environmental results excluding those for aquatic animal diseases, shoreline stabilization, off-shore surveys, flood plains, beach conditions, marina sittings, taxonomic guides, groundwater availability, quality and use, surface water availability, flood control, erosion, soil surveys, and natural resource descriptions for upper non-tidal reaches of tributaries. Some technical and overview environmental information for tributaries appears in Von Appen and Winter (2000) and WFRPC (2005). The Blackwater, Escambia, and Yellow Rivers were listed priority conservation sites in 1999 by the Nature Conservancy. The environmental reports have been produced by diverse sources including federal, state, regional and local regulatory agencies, academic institutions, industry, and volunteer environmental groups. The information appears in internal reports, workshop and symposium proceedings, academic theses, state and county technical reports, environmental impact statements, file memos, reviews, bibliographies (examples, Eubank 1975; USEPA 1979; Burch 1981; Mahadevan et al. 1984; Lewis 1986; Bream Fishermans Association 1987; Jones et al. 1992; USDOI 1996a; SAIC 1996; Von Appen and Winter 2000), and in book chapters (examples, Livingston 2000, 2003, 2005, 2014). The reports are a mix of limited or no review publications. Publication in the peer-reviewed scientific literature has been uncommon until the last 30 years. Only 112 of 438 reviewed reports (27%) appear in this format. Periodic summaries of national monitoring studies such as NOAA's Status and Trends Program (Mussel Watch and Bioeffects) (Kimbrough et al. 2008, 2009) and the USEPA's Environmental and Monitoring Assessment, Regional Environmental and Monitoring Assessment and National Coastal Condition Assessment Programs (examples, Macauley et al. 2005; USEPA 2012) also contain environmental information for the PBS.

The environmental database consists of results for many short-term studies, many of which are reactive, unconnected, often repetitive and, until recently, conducted independently of a watershed management plan. The quality of the historical environmental reports and results vary and their inadequacies have been reported by Collard (1991a). Some reports contain large amounts of information not analyzed. In others, statistical analysis, quality assurance and control procedures are often absent as are descriptions of experimental techniques, analytical methodologies, detection limits for chemical analyses, and geo-referencing of sampling sites.

Environmental research objectives for the PBS have been biologically, chemically, spatially, and temporally diverse (Table 2.1). At least 100 research topics have been the subject of investigation since the 1950s, which include the determination of the effects of 22 natural and anthropogenic stressors on prokaryotic and eukaryotic organisms. Examples of these stressors appear in Fig. 2.1 and include atmospheric deposition of mercury, fecal bacterial contamination, drought, flooding, wastewater discharges, groundwater contamination from hazardous waste sites (Superfund sites), chemical spills (polychlorinated biphenyls), stormwater runoff, excessive sedimentation, contaminated sediments, hydraulic dredging, anoxia and hypoxia, CCA-treated lumber, oil drilling, by-catch from shrimp harvesting, and episodic weather events. The chemical effects of these stressors have been determined for the microbial community, benthic macroinvertebrates, indigenous and transplanted oysters (*Crassostrea virginica*), seagrass, phytoplankton, picophytoplankton, microphytobenthos, zooplankton, colonized periphytic-algae, surface biofilms, blue crabs (*Callinectes sapidus*), and several fish.

Figure 2.1 Examples of natural and anthropogenic stressors, or “drivers of change”, for the Pensacola Bay System.

The reported environmental information for the PBS is spatially uneven. Seventy percent of the 285 site-specific research reports are for Escambia Bay (22% of total studies), Pensacola Bay (20%), Bayou Texar (14 %), and Santa Rosa Sound (14%) (Fig. 2.2). Environmental analysis, at least that reported, has been considerably less for Big Lagoon (1% of studies), Bayou Grande (5%), Blackwater Bay (6%), and East Bay (8%). The scarcity of information for East and Blackwater Bays has been previously recognized (Jones et al. 1992). Although Escambia Bay has been the subject of most reported studies over a longer time period, many are similar in topic. The more diverse and comprehensive environmental data sets are for the residential Bayou Texar and the industrialized Bayou Chico as reported in numerous reports such as those by De Sylva (1955); Moshiri et al. (1972, 1974, 1976, 1978a, b, 1979); Moshiri and Crumpton (1978a, b); Raney (1980); Moshiri (1981); NWFWMD (1988a, 1993); Morgan and Stone (1989); Stone and Morgan (1989, 1990, 1991, 1992); Stone et al. (1990, 1991); Moshiri and Elewad (1990); Wood and Bartel (1994); Waller et al. (1998); Lewis et al. (2001a, d, e, 2010); Butts and Lewis (2002); Mohrherr et al. (2005, 2008); Liebens et al. (2006, 2007, 2011); FDEP (2011); URS (2012); and Liebens and Mohrherr (2015). Bayou Texar has a repair kit (West Florida Regional Planning Council/Bayou Texar Foundation 2002). The history of Bayou Chico and early environmental quality has been reported (Keltner no date).

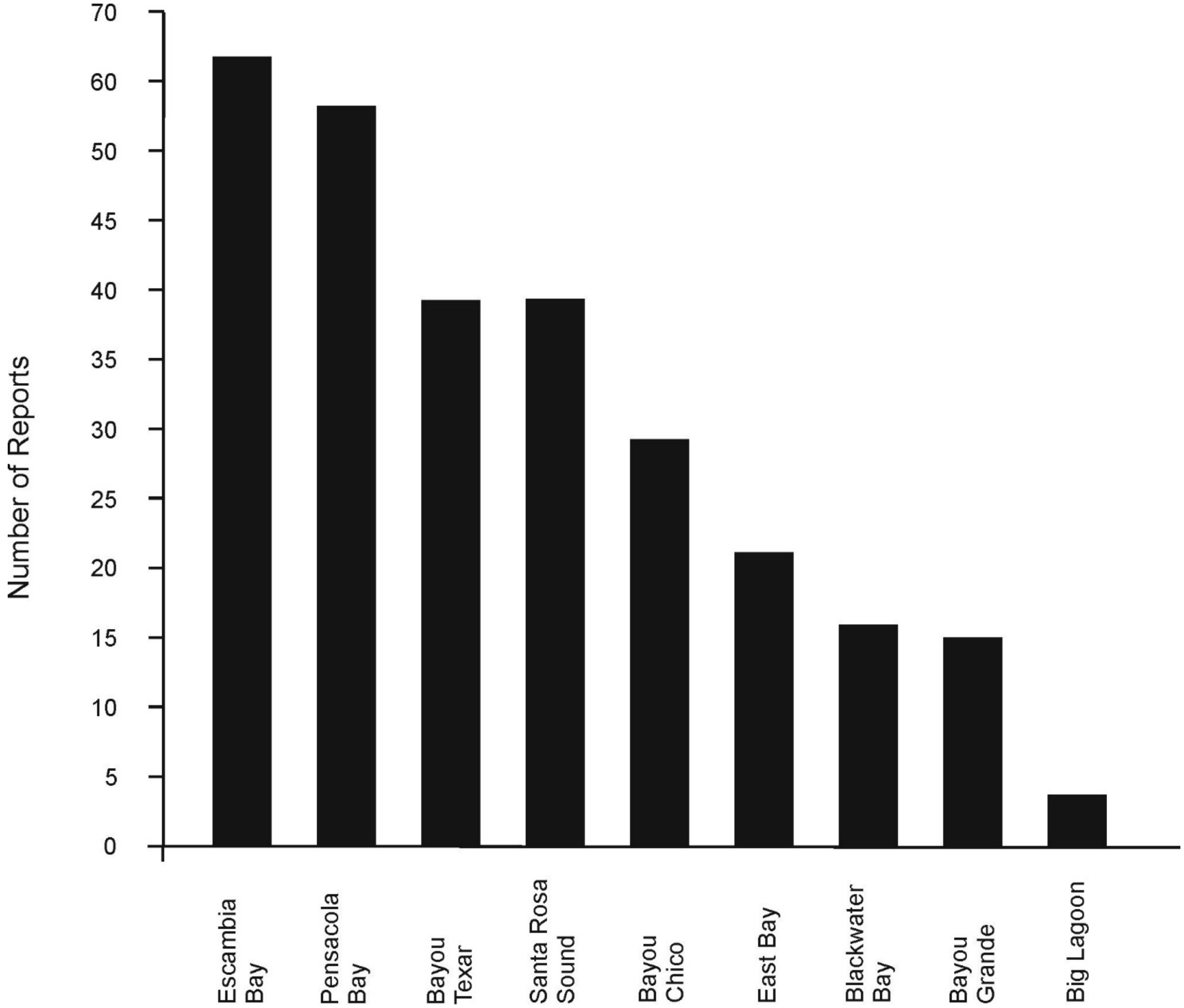


Figure 2.2 Distribution of spatially-specific environmental reports/publications published since 1950. Total number of reviewed reports-290.

Several research topics and highlights for the PBS appear in chronological order in Table 2.1. Early keystone publications are those of Butler (1973), who first reported DDT uptake in mollusks from East Bay, and Cooley (1978), who reported the first and still the most comprehensive natural resource characterization for the PBS. Other noteworthy reports are those of U.S. Department of the Interior (USDOI 1970) and Olinger et al. (1975). The Olinger et al. report is probably the most significant early publication as related to pollution for the PBS and continues to serve as a useful benchmark or baseline for conditions 40 years ago, as well as serving as the current sole source of data for several PBS subunits (see Lewis FG 2010). DeBusk et al. (2002) provided the first in-depth summary for sediment toxicity and chemical quality for the PBS. Mohrherr et al. (2006, 2008, 2009) and Liebens et al. (2006, 2007) provide the most recent and detailed contaminant sediment survey for the PBS. The most current public health assessments for seafood safety are those of Karouna-Renier and Snyder (2007); Snyder and Rao (2008); and Snyder and Karouna-Renier (2009). The most recent overview for nutrients is that by FDEP (2012b, c). Reviews of ecological condition specific to PBS subsystems include those of Hopkins et al. (1973); Ross and Jones (1979); Lewis T (1986); Jones et al. (1992); Collard (1991a, b); Northwest Florida Water Management District (1991b); Livingston (1999, 2005); Von Appen and Winter (2000); DeBusk et al. (2002); Anderson et al. (2005); Macauley et al. (2005); Caffrey (2010); Hall et al. (2010);

Lewis FG (2010); and Geselbracht et al. (2013). In addition, comprehensive water quality status reports specific to the PBS (FDEP 2004, 2007) are available. Less specific for the PBS are the biannual series of integrated assessment water quality reports focused on the State of Florida and the TMDL process (the latest FDEP 2014).

A generalized resource management plan is available to improve the environmental condition for the northern Gulf of Mexico coastal areas (Gulf of Mexico Alliance 2009). Many of the elements are paralleled in the 20 resource management, protective strategy and habitat restoration plans that have been published during the past 40 years by several of the federal, state, regional, county, and city agencies that have jurisdictional and regulatory oversight of the environmental quality of the PBS. Many of these plans have been largely paper exercises due to underfunding of the recommended action steps. The impact of these plans on improving environmental conditions, therefore, has usually been limited. The plans have been for specific media (surface water), habitats (oyster reefs, seagrass meadows, coastal wetlands), PBS subunits (Pensacola Bay, Escambia Bay, Bayou Texar, Bayou Chico), and proposed aquatic preserves. Examples of early comprehensive plans include those of Hennington et al. (1975) and Glassen et al. (1977). Reports by Thorpe et al. (1997), and to a greater extent, those by BARC et al. (1998), the West Florida Regional Planning Council (WFRPC et al. 2005), and the National Park Service (2014) form the "current" basis for watershed management activities.

The impetus for much of the environmental information for the PBS is the result of the Surface Water Improvement and Management Act (SWIM) which was implemented to restore degraded water bodies and protect endangered systems using a watershed management approach. It served as a platform for multiple management strategies, research needs, funding strategies, and water and sediment quality summaries for the PBS (i.e., NWFWMD 1988b, 1991a, b; Pratt et al. 1990; Thorpe et al. 1997; Collard 1991a; Jones et al. 1992). Funding for SWIM and the Pensacola Bay System ended in 1997/1998 and accomplishments of the Program were summarized for 1990-1996 by Thorpe et al. (1997). An updated SWIM management plan funded by the National Fish and Wildlife Foundation is scheduled for 2017 (Northwest Florida Water Management District-SWIM Plan Updates 2015-2017; accessed 2016 July 14).

Table 2.1 Chronology and examples of the diversity of environmental observations, research topics and resource management plans for the Pensacola Bay System.

1686	First physical description of Pensacola Bay
1693	First description of Bayou Chico and appearance on a map
1763	Fish observations in Pensacola Bay
1784	Air and water quality observations
1827	Wetland plant description
1882	Fish surveys in PBS and Escambia River
1880	First numerical record of fish harvest
1883	First map for oyster coverage (East and Blackwater Bays)
1898	Oyster production reported
1931	SAV description (navigational charts)
1933	Oyster reef investigations

Table 2.1 (continued)

1940 First seagrass aerial photograph (Santa Rosa County)

1941 First seagrass aerial photographs (Escambia County)

1948 Checklist of algae of northern Florida

1953 Lower Escambia River/Bay pollution survey (first of many)

1954 Fishes from the Escambia River with ecologic and taxonomic notes

1955 First report for seagrass loss; pollution conditions in lower Escambia River; Bayou Chico pollution and fish kill investigation

1957 Escambia Bay fish kills; pollution surveys for wastewaters in Escambia Bay

1958 First bioassay (nutrients)

1960 Aerial seagrass survey

1963 Pollution survey of Escambia River

1964 Ecological survey of Escambia River

1965 First resource management plan; pesticide effect evaluations begin, first with DDT in tidal marsh

1968 Sedimentology of the Pensacola Bay System

1969 Hydraulic oil (PCB) entry to Escambia River discovered; Escambia River fish kills investigated

1970 Effects of pollution on water quality Escambia River and Bay**;** detection of PCBs (Aroclor 1254) in biota; sediment and water of Escambia Bay; significance of DDT residues in aquatic life

1971 Mass oyster mortality; Escambia Bay oyster epizootic investigations; nitrogen fixation studies in Escambia Bay and Mulatto Bayou; survey report for Blackwater River/Bay and East Bay; benthic characterization studies Escambia Bay

1972 Bayou Chico dredging impact evaluation; N-P budget, phytoplankton and primary productivity investigations for Bayou Texar; effects of dredging in Mulatto Bayou; fish and oyster mortalities in Escambia Bay–relation to water quality; comprehensive planning analysis for shoreline and beach

1973 Marine ecology in Escarosa (summarizes market value of seafood and habitat distributions); Gulf Power thermal wastewater evaluation; assimilative capacity for wastewaters in Pensacola Bay; zooplankton description for East Bay; water quality management plan for Pensacola urban area, cost of water pollution to Pensacola, DDT residues in fish, wildlife and estuaries; one of the most in-depth oyster restoration; nitrogen fixation in salt marshes

1974 First documented red tide; first large seagrass restoration attempt (Escambia Bay), system models and simulations for Escambia Bay; Aroclor 1254 accumulation in grass shrimp; effects of ground application of malathion on a salt marsh; tropical fishes from Pensacola; seagrass loss summary for the PBS (1949-1974); nitrogen-phosphorus budget for Bayou Texar

1975 Environmental and recovery studies of Escambia Bay and the Pensacola Bay System (large wastewater driven study); Bayou Texar restoration plan; seagrass loss summary for Pensacola Bay 1949-1974; water quality management plan for Escambia and Santa Rosa Counties; summary of environmental condition for Escambia Bay, algal bloom problems; checklist of research 1965-1975 for Escambia and Santa Rosa Counties; analysis of sea foam; summary of the loss of submerged aquatic vegetation (1949-1974)

1976 Ecology, resource, rehabilitation and fungal parasitology of commercial oysters

Table 2.1 (continued)

1977 Bayou Chico restoration study; microbial interactions with pesticides in surface films; ecology of the Blackwater River System

1978 Most comprehensive estuarine faunal survey for the Pensacola Bay System**;** Bayou Texar fish kills; seagrass evaluation for Santa Rosa Sound; sediment redox potentials for East Bay; nutrient relationships in Bayou Texar; persistence of Aroclor 1254 in the Pensacola Bay System

1979 Biological aspects of water quality in Escambia Bay and seven other basins (biodiversity summary 1973-1978); East Bay oil drilling impact; limiting nutrient algal bioassays

1980 Water quality studies in Santa Rosa Sound (nutrients and phytoplankton), dredging and stormwater investigations for Bayou Chico; water quality methodology for Bayou Texar; seagrass survey for Pensacola Bay system; ecology of the Yellow River System

1981 Bioassays for wastewaters; environmental recommendations for dredging**;** shellfish bed coverage; Pensacola Bay nutrient monitoring study; biology and water quality study in Yellow and Blackwater Rivers; water quality and biological assessment of Bayou Chico (impacts of dredging, stormwater runoff, hazardous waste site); recovery studies for Escambia Bay; American Creosote Works closed after 80 years1983. American Creosote Work site designated a Superfund site

1982 First phytotoxicity test (herbicides)

1983 American Creosote Co. listed as a National priority clean-up site

1984 Pensacola Bay Water Quality Monitoring Program–review and assessment

1985 Comprehensive shellfish growing area survey with bacteriological and bioaccumulation measurements; infectious and noninfectious diseases in oysters and fish

1986 The Pensacola Bay System analysis of estuarine degradations and relationship to land management practices (large summary); biological and physicochemical assessments of Santa Rosa Sound, Pensacola Bay and Escambia River (water quality, sediment, habitat, benthic assemblages)

1987 SWIM Management and Action Plan**;** environmental bibliography for northwest Florida 1900-1985; surface and near surface zooplankton survey for Escambia and East Bays; biological and physicochemical assessment for Santa Rosa Sound

1988 Surface Water and Improvement and Management Program-Pensacola Bay System (SWIM); documentation of oyster mortalities in Escambia and East Bays, biological quality of the Pensacola Bay System; seasonal changes in standing crop and chlorophyll content in seagrass

1989 Comparative effects of toxics on 25 drainage areas**;** dredging recommendations for Bayou Texar; monitoring project basin surveys for Pensacola Bay and Santa Rosa Sound; comprehensive shellfish harvesting surveys; Agrico-Chemical Company listed as a National priority clean-up site

1990 Physical, Biological and Environmental Studies of Bayou Texar (first of five volumes), Pensacola Bay System SWIM Plan for Restoration and Preservation of the Pensacola Bay System**;** oyster resource summary for Pensacola Bay System, Santa Rosa Sound water quality monitoring program; first of multiple detailed biological assessments for wastewaters

1991 Pensacola Bay System; biological trends and current status (SWIM); point source assessment for the Pensacola Bay System (SWIM); management options for the Pensacola Bay System: value of seagrass and oyster restorations (SWIM); Yellow River aquatic preserve management plan; heavy metals in Bayou Chico sediments ; Pensacola Harbor benthic communities

1992 First evaluation of the effects of wastewaters on periphyton photosynthesis; aerial seagrass coverage,

Table 2.1 (continued)

literature based review of physical, sedimentary and water quality in Pensacola Bay System (SWIM); sediment flux and bathymetric changes in Bayou Chico

1993 Research needs for toxic substances and pesticides in the Gulf of Mexico: a strategy**;** uptake of metals from chromated-copper-arsenate treated lumber by epibiota

1994 Florida coastal sediment atlas; Escambia Treating Company listed as a National clean-up site; Bayou Chico sediment and water quality report

1995 Gill net ban initiated

1996 Evaluation of sediment quality guidelines for Florida coastal areas; spatial extent of sediment toxicity for the Pensacola Bay System; comprehensive survey for shellfish harvesting areas

1997 Magnitude and extent of sediment toxicity in four estuaries includes Pensacola Bay; Pensacola Bay Surface Water Improvement and Management Plan (SWIM); bacteria and microflagellate production in Santa Rosa Sound

1998 Pensacola Bay Watershed Management Guide (with action plans); most comprehensive evaluation of the ecological condition of Bayou Chico; first detailed comparison of local wastewater in-situ impacts including phytotoxicity; sediment denitrification rates

1999 New benthic condition index; Pensacola Bay System environmental study

2000 Biological monitoring in the Pensacola Bay System 1990-2000 (Summary); first sediment phytotoxicity evaluation; Mapping and monitoring of submerged aquatic vegetation in Escambia Bay; aerial seagrass coverage; sediment quality and toxicity below Pensacola Bay System wastewater discharges

2001 Seagrass Management Plan for Big Lagoon and Santa Rosa Sound; first sediment genotoxicity tests conducted; first evaluation of the ecological impact of a golf complex within the Pensacola Bay System (follow-up 2002, 2004); first evaluation of sediment genotoxicity**;** periphyton bioaccumulation as indicator of wastewater impact; biological and chemical impact of dredging in Bayou Texar; Project Greenshores

2002 Sediment quality in the Pensacola Bay System (summary); first use of genotoxicity as an indicator of sediment quality (follow-up in 2006); most comprehensive study for zooplankton dynamics , chemical quality, sediment toxicity and benthic communities in Bayous Texar, Chico, and Grande; macroinvertebrate comparison in bayous; P nutrient limitation for Pensacola Bay System;**);** survey of dioxin and furans in Florida panhandle systems (Pensacola Bay and Santa Rosa Sound) with estimate of risk to birds; first local evaluation for the effects of local golf courses on water quality and nutrient bioavailability

2003 Last reported aerial seagrass survey with mapping for Pensacola Bay System**;** bacterioplankton dynamics; relation of contaminant uptake and hemocyte activity in oysters

2004 Water Quality Draft Status Basin Report: Pensacola Bay (large summary; also in 2007); TMDL development initiated (list of impaired waters updates: 2006, 2010), phytoplankton and zooplankton seasonal dynamics

2005 Pensacola Bay Watershed Management and Action Plan (includes environmental summaries for subunits and six plans); Ecological Condition Report for Pensacola Bay; aerial mapping of chlorophyll *a* concentrations; importance of seagrass epiphytes in Big Lagoon; microbial biofilms as environmental sensors; profiles of diverse contaminants in Bayou Texar; zooplankton, phytoplankton and nutrient relationships; natural resource summary for Gulf Islands National Seashore; cyanobacterial abundance in three Gulf of Mexico estuaries (includes Pensacola Bay)

2006 Effects of Hurricane Ivan on water quality; spatial patterns for phytoplankton and periphyton growth as indicators of environmental condition; marsh shoreline protection and wetland mitigation management plan;

Table 2.1 (continued)

analysis of fecal loadings to bayous; benthic nutrient flux; Bayou Chico sediment and water quality report; pollution in Bayou Texar

2007 Survey for trace metals and PCBs in fish and shellfish and risks to humans; first seagrass habitat chemical evaluation; Pensacola Bay Water Quality Assessment Report (large summary); Seagrass status and trends in Gulf of Mexico and Pensacola Bay**;** pollution pathways and petroleum hydrocarbons in Bayou Chico; enhancement of recruitment and nursery function by habitat creation in Pensacola Bay; susceptibility to hypoxia evaluated

2008 Most current summary of historical changes in seagrass coverage for Pensacola Bay System**;** trace metals and PCBs in fishers of Escambia Bay; nutrient limitation of phytoplankton growth and physiology; an approach for nutrient criteria; mercury concentrations in flora and fauna near contaminant sources; environmental assessment for Bayou Grande

2009 Detailed analysis of contaminant bioaccumulation in fish and shellfish for northwest Florida region; detailed analysis of sediment chemical contamination of Escambia Bay and River**;** hypoxia and benthic processes in Pensacola Bay; summary of nutrient inputs, responses and impacts in Pensacola Bay; effects of humans and weather on nitrogen dynamics

2010 Horizon oil spill, seagrass mapping**,** final verified list of impaired waters, atmospheric deposition of mercury and other trace elements; seasonal and spatial fish community dynamics in Bayous Texar, Chico, and Grande pre- and post hurricanes; Escambia and Blackwater Bays and Yellow River baseline resource characterizations; Bayou Chico Action Management Plan; aerial imagery for seagrass conducted but no mapping; screening for contaminants in Escambia Bay

2011 Annual report for Agrico-Chemical Superfund site on Bayou Texar; Basin Management Action Plan in Bayou Chico (TMDL implementation)

2012 Support document for establishing numeric criteria for Pensacola Bay; **f**inal TMDL report: fecal coliforms in Escambia River, Bayou Texar and Carpenter Creek; support document for Escambia Bay TMDL models; detailed analysis of PCBs in Escambia Bay sediments

2013 Modelling and abating the impacts of sea level rise for the Pensacola Bay System**;** seagrass mapping and monitoring program report No. 1 for Pensacola Bay, Santa Rosa Sound and Big Lagoon; final TMDL report-Bayou Chico and middle Pensacola Bay; coastal response to storms and sea level rise in Santa Rosa Island; discussions for RESTORE-funded research projects begin

2014 Most current-Integrated water quality assessment for Florida 2012 305(b) report and 303(d) list update (available biannually); seagrass assessment; Gulf Islands National Seashore Management Plan; proposals for RESTORE funding available

2015 RESTORE funded oyster reef and community-based shoreline modifications/Bayou Chico dredging approved

2016 First private commercial oyster farm established (Escambia Bay); Florida Oyster Clutch Placement Project; Marine Fisheries Hatchery and Enhancement Center approved; historical nutrient summary for PBS

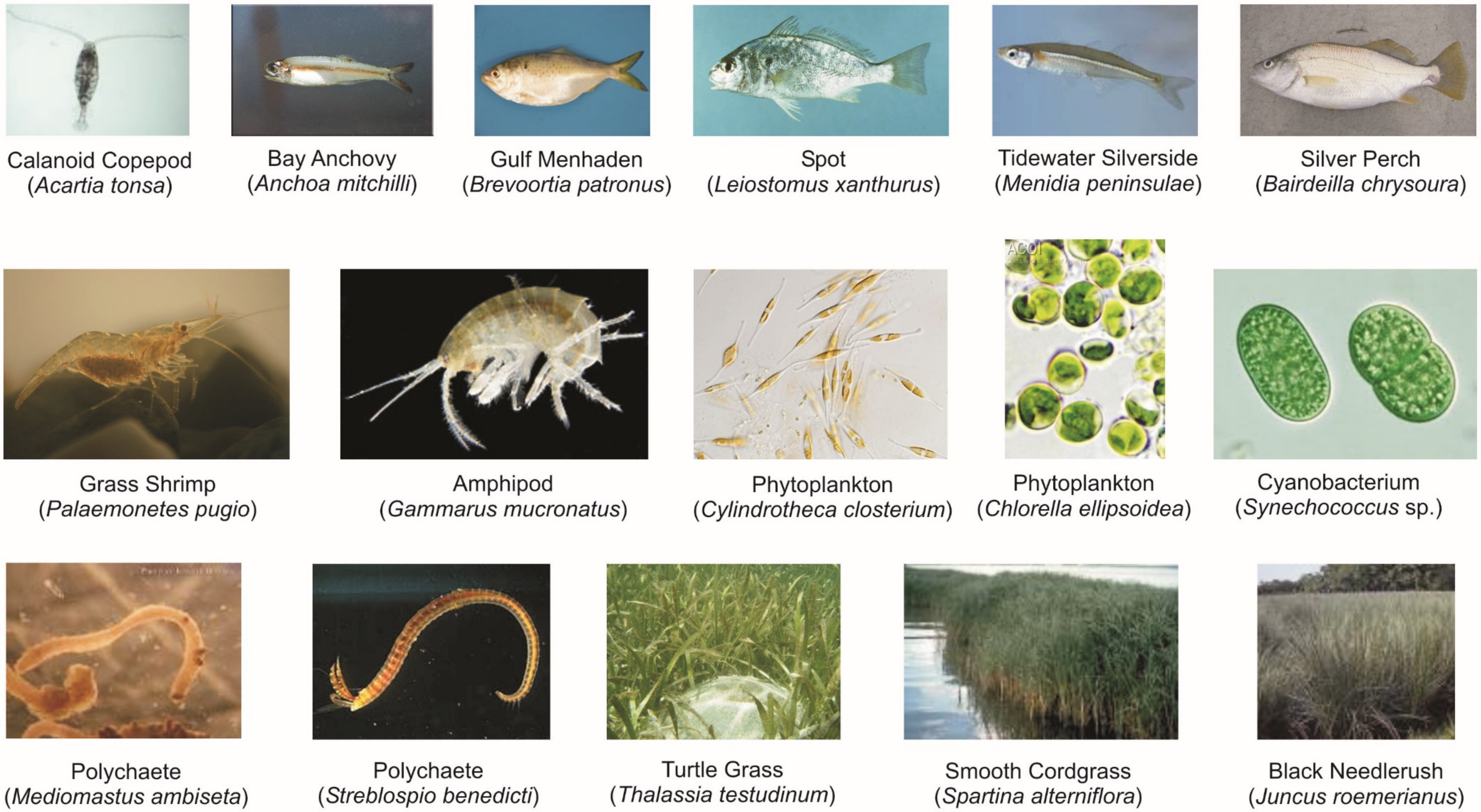
2017 Updated Surface Water Management Plan (Northwest Florida Water Management District)

3 Natural Resource Inventories (Biodiversity)

3.1 History/Overview

Understanding the biodiversity of estuarine flora and fauna in the PBS is necessary for environmental management and improvement. The more abundant species largely control the rates and directions of many community and ecosystem processes. Demographic information for biota became available as early as 1763 for fish (Roberts 1763) and 1827 for wetland vegetation (Williams 1976). However, the more detailed and useful taxonomic investigations began post-1950, beginning with those for the lower Escambia River (Patrick et al. 1953; Murdock 1955). The in-depth taxonomic surveys of Cooley (1970; 1978); USDOI (1970); Hopkins (1973); Olinger et al. (1975); Ross and Jones (1979); Moshiri et al. (1980); McAfee (1986); and Barnett and Gunter (1985) followed. Of these, the studies of Cooley (1970, 1978) and Olinger et al. (1975) are the more notable. Ross and Jones (1979) reported biotic diversity for eight drainage basins, including Escambia Bay. Biological trends for major biotic groups for 1980-1988 were summarized by Collard (1991a). One of the few mussel surveys for the major rivers entering the PBS was reported by the National Biological Survey (1995). Twenty-eight species of freshwater mussels were reported for the Escambia River, 14 species in the Yellow River, and none for the Blackwater River. More recent natural resource investigations are available for Pensacola Bay (Thorpe et al. 1997; FDEP 2007), Blackwater River watershed (Hall et al. 2010), East and Blackwater Bays (Lewis FG 2010), and the Gulf Islands National Seashore associated with Santa Rosa Sound (Anderson et al. 2005; Cooper et al. 2005). The trophic organization of the PBS has been presented by Livingston (2010), and food webs for *Juncus* marsh and submarine meadows are available from Hopkins (1973).

The PBS supports at least 1,400 aquatic species based on results from at least 85 biological surveys conducted during the past 130 years. The total does not include PBS-dependent wildlife. The fauna and flora represent a mix of communities regulated in part by the highly variable gradients of river inflows, tides, light, temperature, salinity, dissolved oxygen, and sediment and water chemical quality. Many species are dependent upon the presence of seagrass meadows which are found primarily in Santa Rosa Sound and Big Lagoon, and oyster reefs and tidal marshes which dominate in Escambia and East Bays. McAffee (1986) reported that oyster beds had the highest number of species, diversity, and biomass of any habitat in Escambia Bay, and grass beds were the second most productive habitat. Described taxa for the PBS include benthic macroinvertebrates, microphytobenthos, seagrass, bivalves, phytoplankton, picophytoplankton, zooplankton, periphyton, macroalgae, and fish. Several dominant species appear in Fig. 3.1 and the maximum species number by location based on a compilation of historical reports appears in Fig. 3.2. The total number of different species reported for the macrobenthos, phytoplankton and periphyton, zooplankton, and fish are 187, 402, 110, and 200, respectively. Cooley (1978) reported the results of a 1961-1963 survey for which 704 species of benthic and planktonic species collected from Pensacola, Escambia and Little Sabine Bays, and Santa Rosa Sound were identified. The total included 91 species of annelid worms, 100 species of arthropods, 225 species of mollusks, and 182 species of bony fishes. Brief summaries and representative reports for major taxa follow.



Calanoid Copepod (*Acartia tonsa*)

Bay Anchovy (*Anchoa mitchilli*)

Gulf Menhaden (*Brevoortia patronus*)

Spot (*Leiostomus xanthurus*)

Tidewater Silverside (*Menidia peninsulae*)

Silver Perch (*Bairdeilla chrysoura*)

Grass Shrimp (*Palaemonetes pugio*)

Amphipod (*Gammarus mucronatus*)

Phytoplankton (*Cylindrotheca closterium*)

Phytoplankton (*Chlorella ellipsoidea*)

Cyanobacterium (*Synechococcus* sp.)

Polychaete (*Mediomastus ambiseta*)

Polychaete (*Streblospio benedicti*)

Turtle Grass (*Thalassia testudinum*)

Smooth Cordgrass (*Spartina alterniflora*)

Black Needlerush (*Juncus roemerianus*)

Figure 3.1 Examples of abundant biota inhabiting the Pensacola Bay System. Species not shown to scale. Photos by author or courtesy of Encyclopedia of Life (Encyclopedia of Life; accessed 2016 July 14).

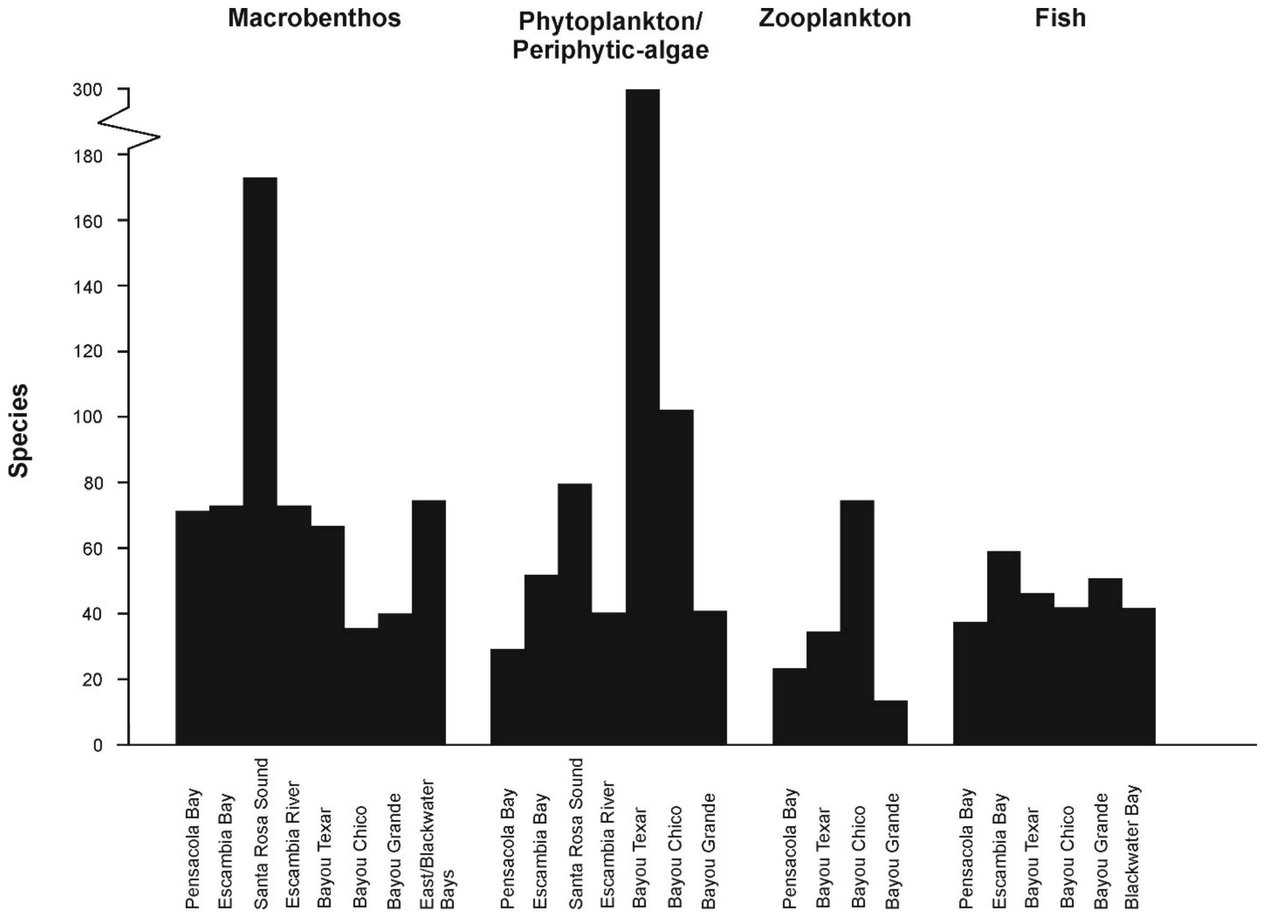


Figure 3.2 Maximum number of species reported since 1970 by location.

3.2 Fish

The diversity of the fish community was of early interest and was first described in the late 1800's (Goode 1879; Jordan and Gilbert 1882; Jordan 1884, 1885, 1886). Many surveys have followed, including those of Haburay et al. (1968), Hopkins (1973); Olinger et al. (1975); Bass and Hitt (1977); Cooley (1978); Lewis T (1986); Livingston (1999); FDEP (2007, 2012b); Lewis FG (2010); and Lewis et al. (2010). Based on these surveys, at least 200 species of fish and shellfish (FDEP 2007) have been reported. However, the community is dominated by relatively few species such as *Leiostomus xanthurus* (Spot), *Anchoa mitchilli* (Bay anchovy), *Brevortia patronus* (Gulf menhaden), *Micropogonias undulatus* (Atlantic croaker), and *Bairdiella chrysoura* (Silver perch). More recently, the top ten species collected from minimally-impacted areas in Pensacola Bay included *A. mitchilli*, *B. chrysoura*, *Membras martinica* (Rough silverside), *Anchoa hepsetus* (anchovy), *Lagodon rhomboides* (pinfish), and *Menidia* spp. (silversides) (FDEP 2012b). The PBS fish assemblage is similar to those for several nearby coastal areas (Table 3.1) and also for fish collected from multiple locations along the northern coast of the Gulf of Mexico during 2000-2004, where *A. Mitchilli*, *L. xanthurus*, and *M. undulatus* comprised 69% of all fish (Lewis et al. 2015).

Table 3.1 Species diversity and relative abundance (%) of fish reported for river-dominated estuaries of the northern Gulf of Mexico. T=trawl, S=seine. Adapted from Lewis et al. (2011).

	Bayous[1]		Pensacola Bay Estuary[2]	Escambia Bay[3]		Apalachicola Bay[4]	Perdido Bay[5]		St. Andrew Bay[6]	Mobile Bay[7]		Bayou La Batre[8]	Northern Gulf of Mexico[9]
	T	S	T	T	S	T	T	S	T	T	S	T	T
Lagodon rhomboides	4	3	16	1		1	8	2	3				4
Micropogonias undulatus		1	15	31	5	31	1		15	36	1	3	5
Anchoa mitchilli	22	2	3	41	15	41	5	21		50	40	89	53
Leiostomus xanthurus	49	12	40	3	2	3	82	8	10	11	4	5	10
Arius felis				1		1				2			3
Chloroscombrus chrysurus					3		1		2				4
Cynoscion arenarius				9		9						1	2
Brevoortia patronus	19	53	9		58			21			51	1	1
Bairdiella chrysoura			3	1		1						1	7
Bagre marinus			1										
Eucinostomus argenteus	1	1											
Anchoa hepsetus			3										
Mugil cephalus		4						26			3		
Anchoa nasuta	2												
Menidia beryllina		4		1	10	1		5			1		
Menidia peninsulae		17						8					
Fundulus similis		3											
Harengula jaguana				2									
Menticirrhus americanus				2		2							
Polydactylus octonemus									46				
Symphurus urospilus									3				
Stenotomus caprinus									2				

[1] Bayous Texar, Chico, and Grande, n = 585,000, June 1993-December 1998

[2] Cooley (1978), n = 21,052, January, April, August, November 1961-1963

[3] Olinger et al. (1975), n = 79,373, October 1973-September 1974

[4] Livingston (1976), n = 40,870, March 1972-April 1974

[5] USEPA (unpublished data), n = 45,027, March 1990-February 1991

[6] Ogren and Brusher (1977), n = 207,447, September 1972-August 1973

[7] Swingle (1971), n-no data, January 1969-March 1969

[8] Swingle and Bland (1974), n-no data, January 1971-May 1972

[9] USEPA (unpublished data), n = 149,000, 993 sites, 2000-200

Monthly and annual variability were reported for total abundance, total species, and diversity (Fig. 3.3) in a multiyear fish survey conducted during 1993-1998 for Bayous Texar, Chico, and Grande (Lewis et al. 2010). *B. patronus*, *Menidia peninsulae (*Tidewater silverside*)*, and *L. xanthurus* were dominant in seines and *L. xanthurus* and *A. mitchilli* were dominant in trawls. *A. mitchilli* was most abundant of all taxa comprising about 52% of the total catch from the Bayous. Lists of fish species for Blackwater, Escambia, Shoal, and Yellow Rivers reported by Bass (1993) are summarized in Lewis FG (2010). Blackwater bay supports 42 fish species (Lewis FG 2010). The Escambia River supports 81 species of fish, the most for any Florida river (Boning 2007). Shannon-Weaver diversity index values for fish collected from the PBS have usually been 1.0 or less. Olinger et al. (1975) reported 0.54 and 1.1 for seasonal fish collections during 1973 and 1974. Diversity was greatest during June.

A related matter for fish abundance and diversity is the future presence of the Marine Fisheries Hatchery and Enhancement Center. This $19 million facility of the Florida Fish and Wildlife Conservation Commission, will produce 5 million fingerlings of primarily recreationally and commercially-important species annually. The effects of this production-scale hatchery, the first for Florida, on the PBS fishery is unknown.

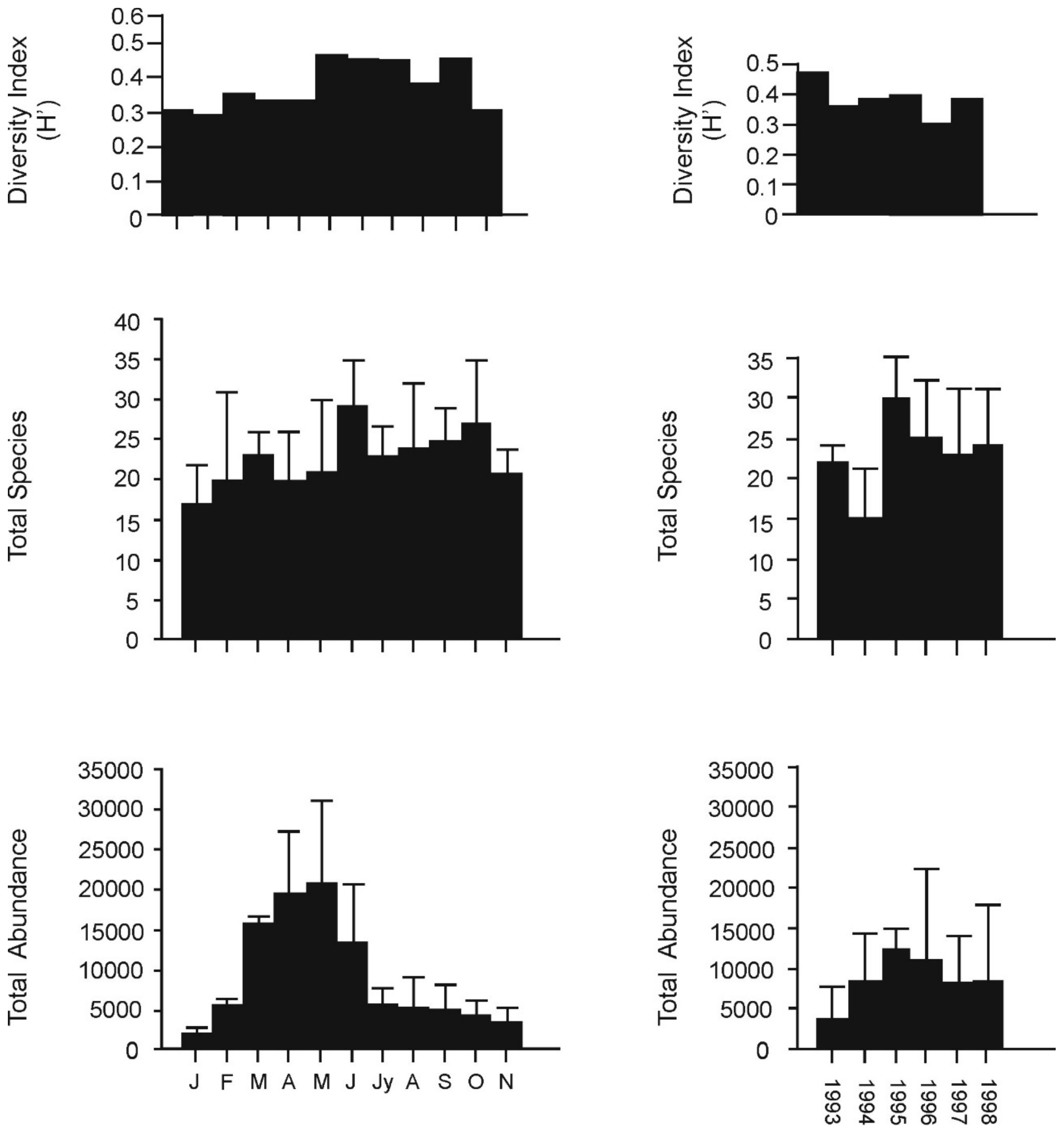


Figure 3.3 Annual and monthly variability for a diversity index (Shannon and Weaver 1949), total species and abundance of fish collected from Bayous Texar, Chico, and Grande using seines and an otter trawl during 1993-1998. Values represent means (±1 SD) for all sites and Bayous. Adapted from Lewis et al. (2010).

3.3 Macrobenthos

Composition of the benthic macroinvertebrate community has been reported by among others, the U.S. Department of the Interior (USDOI 1970); Ross and Jones (1979); Keltner (1979); Brinson and Keltner (1981); McAfee (1986); Butts (1990a, b); Moshiri and Elewad (1990); Collard (1991a); Stone et al. (1991); USEPA (1991) (harbor area); Livingston (1999); Butts and Lewis (2002); and FDEP (2012b). The most detailed early taxonomic analysis of the benthos appears in Olinger et al. (1975). It was reported that northern Escambia Bay had greater numbers and biomass than for southern areas of the Bay. One hundred and eighty seven species of benthic fauna were identified; 89 species in Escambia Bay, 75 species in East and Blackwater Bays, and 97 species in Santa Rosa Sound. Butts (1990a) reported 169 species of benthic fauna during winter months (1986) for Santa Rosa Sound. Biomass, species numbers and numbers of individuals increase from mud to sand stations (McAfee 1986).

Primarily, stress-tolerant, near-surface infaunal species are favored in most of the PBS (Collard 1991a), such as polychaetes and nemertean worms in mud substrates. These include the mud bottom, deposit feeding polychaetes *Mediomastus ambiseta* (Family Capitellidae) and *Streblospio benedicti* (Family Spionidae) (Fig. 3.1). Both species are tolerant of organic enrichment and comprised the bulk of the benthic macroinvertebrates in Bayous Texar, Chico, and Grande during 1993 and 1994 (Table 3.2). Seasonal density and abundance of benthic macroinvertebrates were reported for Bayou Texar (Moshiri and Elewad 1990). *Leptochelia rapax*, a tanaidacean crustacean, was the most abundant species comprising 39% of total abundance. Distribution maps for numbers of infaunal and epibenthic invertebrates are available from Livingston (1999).

Table 3.2 Macrobenthic fauna that exceeded 1% abundance for Bayous Texar, Chico, and Grande during 1993-1994. Sediments were collected using a petite Ponar grab sampler. Total abundances ranged from 81% to 91%. Unpublished results (USEPA, Gulf Breeze, FL.)

Bayou Texar		Bayou Chico		Bayou Grande	
Mediomastus ambiseta	42.2	*Streblospio benedicti*	50.8	*Streblospio benedicti*	68.9
Streblospio benedicti	24.5	*Mediomastus ambiseta*	10.4	*Mediomastus ambiseta*	6.3
Hobsonia florida	5.5	*Capitella capitata*	7.9	*Tetrastemma sp.*	3.0
Oligochaeta sp.	2.5	*Oligochaeta sp*	5.1	*Polydora sp.*	1.2
Polydora sp.	2.3	*Cyclaspis varians*	3.1	*Leitoscoloplos fragilis*	1.2
Acanthohaustorius intermedius	2.3	*Edotea montosa*	3.0		
Tetrastemma candidum	2.3	*Leitoscoloplos fragilis*	2.8		
Carinoma tremaphoros	1.8	*Mulinia lateralis*	1.8		
Macoma tenta	1.4	*Spiochaetopterus costarum*	1.7		
Neanthes succinea	1.2	*Tetrastemma candidum*	1.1		
Capitella capitata	1.0	*Acteocina canaliculata*	1.1		
		Cossura delta	1.1		
		Sayella fusca	1.0		

3.4 Phytoplankton

Seasonal abundance, species composition, and spatial differences have been reported since the 1970s for PBS phytoplankton (Olinger et al. 1975; Adams 1972; Hannah 1972; Conklin 1976; Moshiri et al. 1980; McAfee 1986; Stone et al. 1991; Livingston 2001, 2003; Murrell and Lores 2004; Murrell et al. 2002a; Wagner 2006; Smith and Caffrey 2009). The phytoplankton, like the zooplankton, have a bimodal pattern of abundance; greater during Spring and Fall. Murrell and Lores (2004) reported 21 abundant taxa for Escambia Bay during 1999-2001. Seventy percent of total abundance was dinoflagellates in January, largely *Procentrum minimum*. In contrast, diatoms comprised 50% of total abundance during summer months. Eighty genera of phytoplankton, primarily diatoms, were identified for Santa Rosa Sound and Little Sabine Bay for collections during 1977-1979 (Moshiri et al. 1980). Livingston (2001) reported low species richness dominated by bloom forming species *Cyclotella choctawhatcheeana*, *P. minimum*, and *Heterosigma akashiwo*; the center for primary productivity was upper Escambia Bay (Livingston 2010).

Factors impacting phytoplankton distribution and production have been reported (Murrell 2003; Murrell et al. 2007; Juhl and Murrell 2005, 2008). No imbalance was noted for the PBS phytoplankton community relative to reactions to excess nutrients (Hagy et al. 2008; Livingston 2010). Spatial differences for structural characteristics of the phytoplankton community have been reported within the PBS as well as across other estuaries. Escambia and East Bays had similar rates of primary production, phytoplankton cell counts during 1973-1975 (Olinger et al. 1975). Carbon fixation and phytoplankton diversity were greater for Little Sabine Bay than Santa Rosa Sound (Moshiri et al. 1980). Eighty genera were identified from both areas. Primary productivity in Escambia Bay was reported less than that for Port Royal Sound, SC (Olinger et al. 1975). Mean cyanobacterial abundance for the PBS was intermediate to those for Apalachicola Bay (FL) and Weeks Bay (AL) (Murrell and Caffrey 2005). Nutrient assimilation in Escambia Bay was greater than that in Perdido Bay (Livingston 1999). See Fig. 3.4 for examples of diversity index values.

3.5 Zooplankton

Composition of the zooplankton community has been reported less frequently than that for the phytoplankton. Important reports are those of Olinger et al. (1975); McAfee (1986); Dye (1987); Moshiri and Elewad (1990); Lores et al. (2002); and Murrell and Lores (2004). The dominant species has consistently been the marine calanoid copepod, *Acartia tonsa* (Fig. 3.1) which is one of the most ubiquitous copepods along the northern Gulf of Mexico coast. A total of 80 zooplankton species were identified in Pensacola Bay, Bayous Texar, Chico, and Grande (Lores et al. 2002). *A. tonsa* comprised 82% of the total abundance relative to species of *Oithona* (11%), *Podon* (3%) and *Balanus* (1%). Shannon-Wiener diversity index values (Shannon and Weaver 1949) averaged 1.1 (Pensacola Bay), 0.91 (Bayou Grande), 0.92 (Bayou Chico), and 1.1 (Bayou Texar). Diversity values varied spatially and seasonally (Fig. 3.4). The diversity index values were similar to those for the zooplankton collected from proposed reference areas, 1.2 (Mississippi Sound, Bay La Launch), 1.9 (Grande Lagoon), and 1.6 (Old River) (Unpublished results, USEPA, Gulf Breeze, FL). Livingston (1999) reported 35 taxa in Bayou Texar and 75 in Bayou Chico. Reported zooplankton abundances have been 3.1 L^{-1}, 38 L^{-1}, and 17 L^{-1} (Dye 1987; Lores et al. 2002; Murrell and Lores 2004) relative to an average of 2 L^{-1} in nearby Perdido Bay (Livingston 2001). Zooplankton abundance in East and Escambia Bays was considered similar 40 years ago (Olinger et al. 1975)

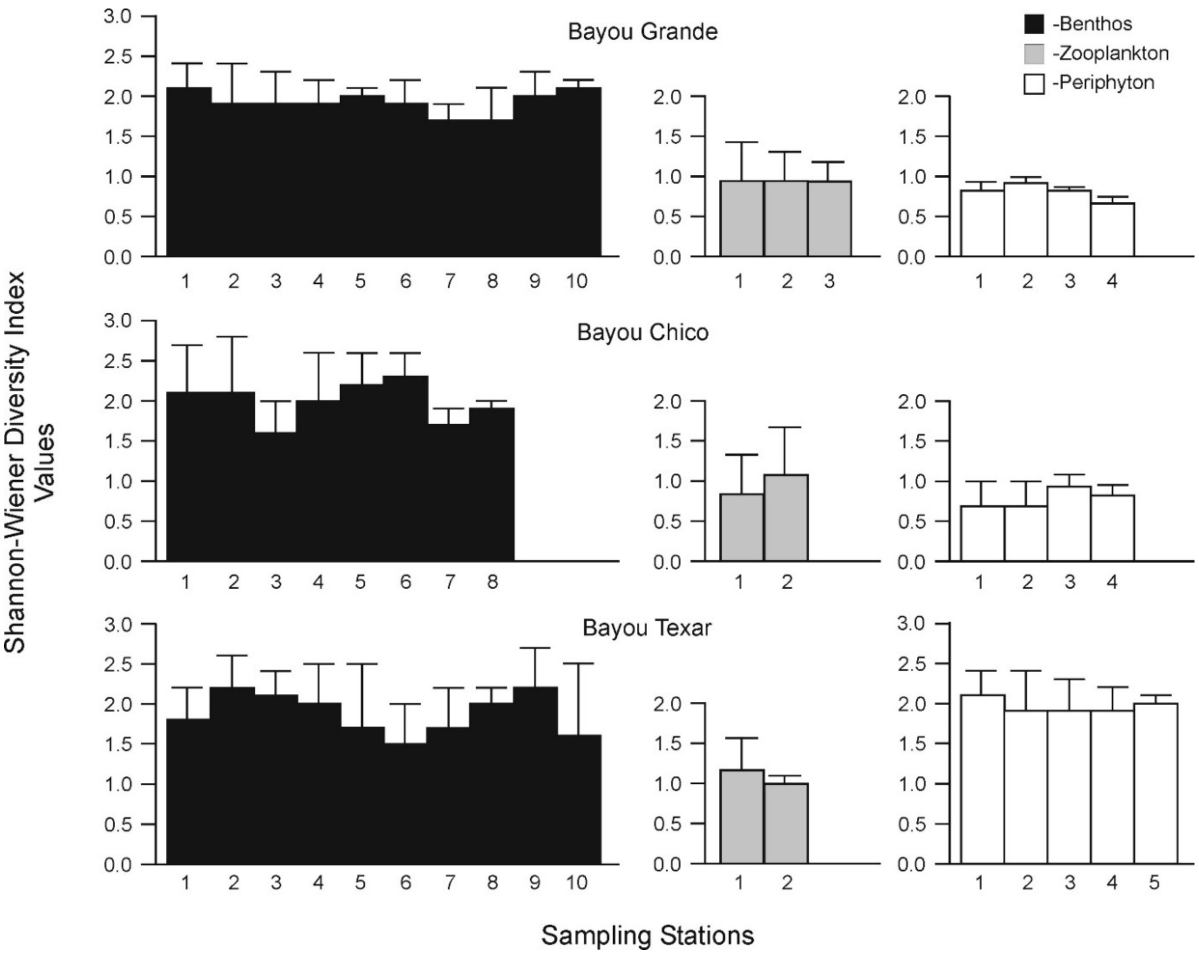


Figure 3.4 Temporal and spatial variation for a diversity index (Shannon and Weaver 1949) determined for benthic macroinvertebrates, zooplankton and the algal-periphyton. Results are for samples collected at least four times during the same year (1993-2000) at multiple sites in Bayous Texar, Chico, and Grande. Values represent means (±1 SD). See Butts and Lewis (2002) and Lores et al. (2002) for additional details.

3.6 Periphytic Algae

Approximately 400 taxa of periphytic-algae have been identified for the PBS. These unpublished taxonomic results are for seasonal colonizations during the 1990s. A comparison of the relative abundances of the periphyton appears in Table 3.3. The chlorophyte, *Chlorella ellipsoidea*, (Fig. 3.1) dominated in Bayous Texar, Chico, and Grande (relative abundance range= 23-37%), the filamentous cyanobacteria, *Lyngbya* and *Oscillatoria,* dominated taxa in a salt marsh adjacent to Santa Rosa Sound (48%), and the diatoms, *Nitzschia longissima*, *Cylindrotheca closterium* and *Mastogloia* sp. (56%) were more abundant in Santa Rosa Sound. The total numbers of identified periphytic-algal species were 44 (Bayou Texar), 102 (Bayou Chico), 41 (Bayou Grande), 52 (Escambia Bay), 40 (lower Escambia River), 30 (Santa Rosa Sound), and 46 (salt marsh). The mean numbers of fish species colonized on each acrylic substrate were 23 (SD=10,range=2-41, n=122), 31 (SD=16, range=15-46, n=3), 17 (SD=7, range=7-28, n=17), and 15 (SD=7, range=8-36, n=30), respectively, for Bayous Texar, Chico, and Grande, Santa Rosa sound, Pensacola Bay, and Escambia Bay (Unpublished results, USEPA, Gulf Breeze, FL). For comparison, the number of colonized periphytic-algae for the proposed reference areas (Fig. 1.3) using identical colonization and taxonomic methodologies averaged between 17 and 30 and ranged from 16-31 (Unpublished results, USEPA, Gulf Breeze, FL). Periphyton diversity like for zooplankton varies seasonally (Fig. 3.4).

Table 3.3 Periphytic-algae taxa identified after 21-day colonization on acrylic substrates in the Pensacola Bay System during summer months of 1993-1995 (Bayous) and 1997 (saltmarsh, Santa Rosa Sound and adjacent residential canal). Total abundance in parenthesis.

Salt Marsh (76%)	**Santa Rosa Sound** (86%)	**Residental Canal** (100%)
Lyngbya sp.	*Mastogloia spp.*	*Amphora tenerrima*
Oscillatoria sp.	*Cylindrotheca closterium*	*Schizomeris sp.*
Scenedesmus bijuga	*Nitzschia longissima*	*Achnanthes brevipes*
Merismopedia glauca	*Tabularia waernii*	*Licmophora hyalina*
Merismopedia tenuissima	*Nitzschia sp.*	*Nitzschia sp.*
Coelastrum sphaericum	*Nitzschia areolata*	*Cylindrotheca closterium*
Ankistrodesmus spiralis	*Navicula spp.*	*Amphora tenerrima*
Navicula spp.	*Melosira nummuloides*	*Schizomeris sp.*
Chroococcus disperses	*Campylodiscus innomiasatu*	
Crucigenia tetrapedia	*Striatella interrupta*	
Bayou Texar (78%)	**Bayou Chico** (76%)	**Bayou Grande** (86%)
Chlorella ellipsoidea	*Chlorella ellipsoidea*	*Chlorella ellipsoidea*
Fragilaria sp.	*Navicula sp.*	*Navicula sp.*
Navicula sp.	*Nitzschia sp.*	*Nitzschia sp.*
Chlorella sp.	*Chlorella sp.*	*Chlorella sp.*
Chlorococcum sp.	*Gloeothece sp.*	*Fragilaria sp.*
Nitzschia sp.	*Fragilaria sp.*	*Closterium acerosum*
Pinnularia sp.	*Pinnularia sp.*	*Synedra sp.*
Chlorococcum sp.	*Amphiprora sp.*	*Fragilaria sp.*
Nitzschia sp.	*Cyclotella sp.*	
Pinnularia sp.	*Synedra sp.*	
	Chlorella sp.	

3.7 Tidal Wetland Vascular Plants

Kurtz (1953) provides one of the earliest and most comprehensive descriptions of tidal marsh vegetative zonation in northwest Florida relative to soil characteristics and salinity. Other early marsh vegetation surveys were conducted by Stith et al. (1984) and Ross and Jones (1979). See Collard (1991a) for a summary. Dominant species in coastal marshes include *Juncus roemerianus* (Fig. 3.1, black needlerush), *Spartina patens* (salt meadow cord grass), *Spartina alterniflora* (Fig. 3.1, smooth cord grass), and *Cladium jamaicense* (saw grass). Minor species are *Borrichia frutescens* (sea oxeye), *Fimbristylis cymosa* (hurricane grass), *Sporobolus vagrancies* (coastal dropseed), and *Distichlis spicata* (salt grass). The environmental interest in coastal plants is currently largely restricted to their use in shoreline restoration projects. Their environmental requirements will become more of interest in the future due to the expected effects of sea level rise that will result in either their submersion or expansion in upshore areas.

3.8 Biodiversity Differences

The sometimes large differences for species diversity and abundances reported for the same and different sampling locations are not unusual. The frequency and duration of sampling, level of taxonomic identification, level of quality assurance, life stage of organisms, method of collection (sampling gear, mesh size), and season of collection have often differed among studies which impacts results. Furthermore, the ecological stability, substrate requirements, and sensitivities of most biota and their communities to the mix of natural and man-induced factors add to the observed differences.

4 Anthropogenic Contaminants

The PBS has served for at least 65 years as a repository for anthropogenic chemicals that enter from a variety of sources including the atmosphere, ground water, tributaries, municipal and industrial wastewaters, and stormwater runoff. Efforts to determine their fate and distribution among water, sediment, and biota have been the subject of numerous studies. It was recognized 50 years ago that the PBS was susceptible to the adverse effects of nutrients, trace metals, and pesticides. As a consequence, efforts began to determine their environmental concentrations and adverse effects, including the use of toxicity tests which became an early important diagnostic tool. The first reported toxicity test for the PBS was an Escambia Bay bioassay (Florida State Board of Health 1958). Other early toxicity studies are those of USEPA (1973); Tagatz (1974); and FDER (1979) for limiting nutrients, pesticides, and thermal effluents. The first phytotoxicity test was conducted in 1982. Personnel at the USEPA's Gulf Breeze Lab analyzed the effects of pesticides on phytoplankton carbon assimilation, oyster shell deposition, and shrimp equilibrium (USFWS 1965). Despite these and other efforts, it was recognized that there was an increasing need to better understand the impact of toxicants. The stimulus for this need is attributable in part to the first report for national water quality standards in 1976 (USEPA 1976). A chemical risk overview for northern Gulf of Mexico drainage basins (Brecken-Folse 1989) and 27 consensus research needs for chemical risk assessments (Gulf of Mexico Program 1993) are available that are pertinent for the PBS.

Anthropogenic contaminants contained in wastewaters have had a major impact on the PBS. Assessing their environmental safety has been a resource management objective since the 1950s. Early studies are those of Patrick et al. (1953), Florida State Board of Health (1958); Hall (1972); USEPA (1973); Baseline Inc. (1973); Hopkins and Schomer (1975); and the FDER (1981, 1984). Barnett and Gunter (1985) investigated wastewater effects on oyster harvesting areas. More detailed wastewater evaluations occurred during the 1990s (Butts and Frydenburg 1991, 1992a, b, c; NWFWMD 1991a; Woodward and Clyde Assoc. 1997; Lewis and Weber 1998). More recent investigations included a varied multimetric approach (Fig. 4.1) that included measures of chronic toxicity, bioaccumulation, and sediment quality in the wastewater mixing zones (Lewis et al. 2000; Lewis et al. 2001a, c; 2002b). Many of the large volume domestic and industrial wastewaters which were centers of attention in the past are no longer directly discharged into the PBS but enter indirectly as runoff after passing through wetlands or from spray irrigation. For example, a golf complex near Gulf Breeze, FL, is the recipient of about 600,000 gpd of treated wastewater that eventually enters Santa Rosa Sound (personal communication, South Santa Rosa Utilities System, November 2015) (Fig. 4.2). Treated wastewater from the relatively small-volume Pensacola Beach and Navarre sewage treatment plants applied to the golf complex ultimately ends into Santa Rosa Sound.

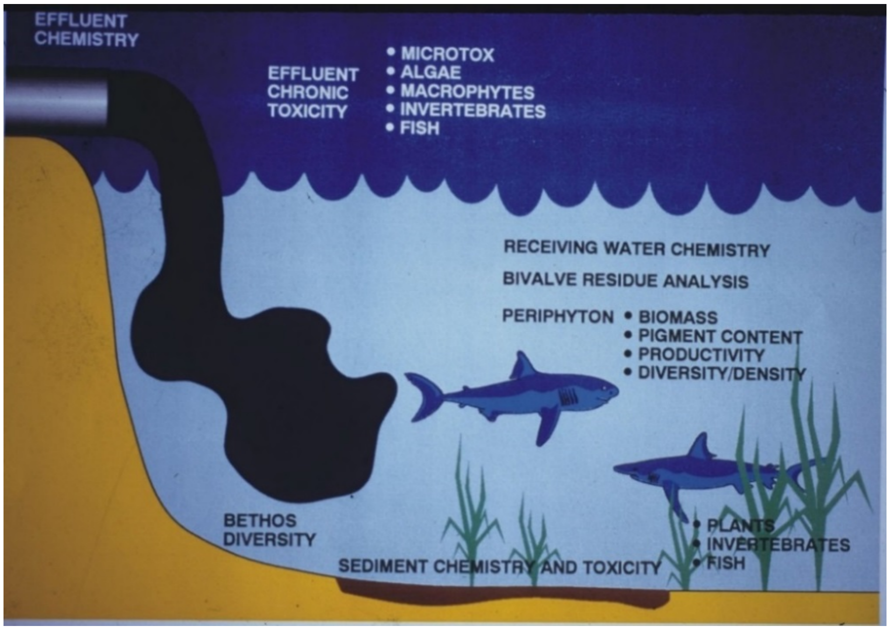


Figure 4.1 Chemical and biological measurements used to determine the impacts of industrial, domestic and thermal wastewaters discharged during the 1990s to Pensacola and Escambia Bays, Santa Rosa Sound, and the Escambia River.

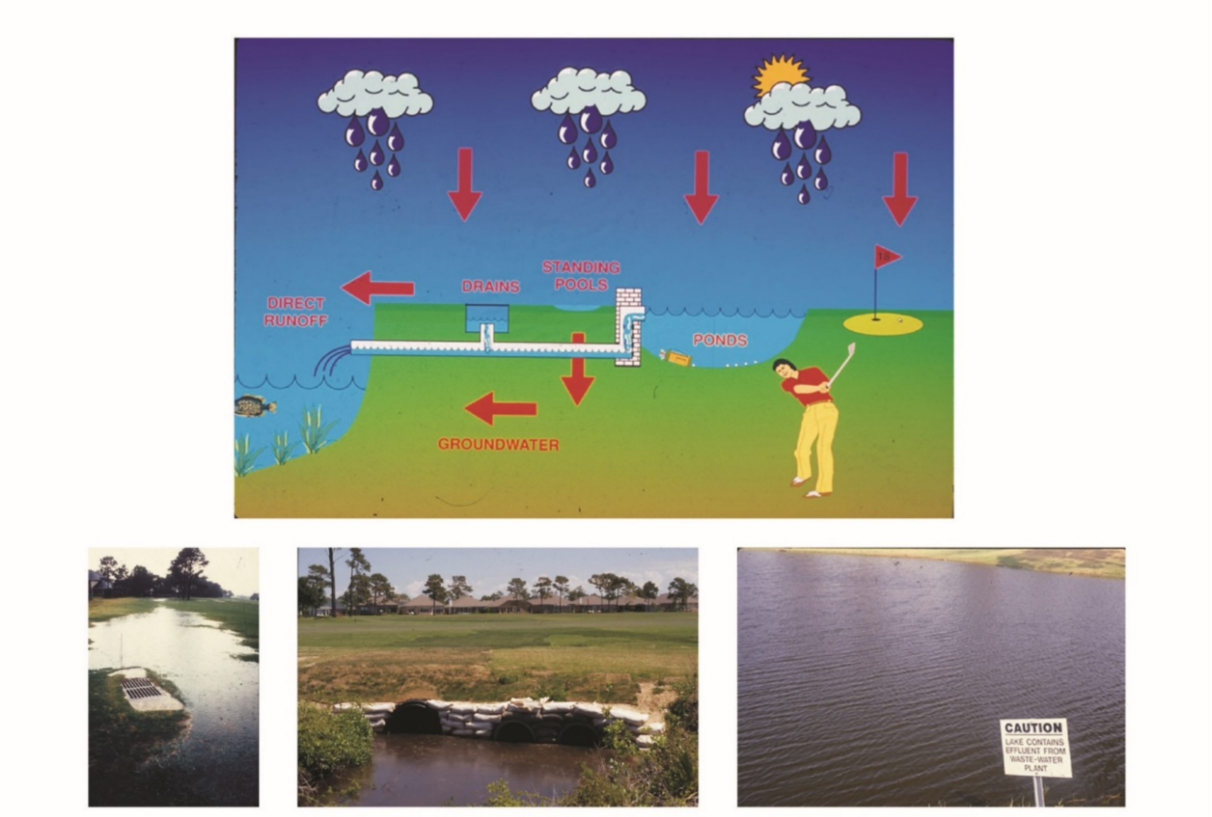


Figure 4.2 Routes of stormwater runoff to Santa Rosa Sound from the Tiger Point golf complex. Runoff contains contaminants from course maintenance and spray-irrigated wastewater. More detail in Lewis et al. (2001b, 2002b, 2004).

5 Groundwater Quality/Superfund Sites

Contaminated surface and groundwater has entered Bayous Texar, Chico, and several adjacent areas of Pensacola Bay as a result of three abandoned hazardous waste sites: the Escambia Treating Co. (26 acres, wood treatment facility, closed 1991), Agrico Chemical Co. (35 acres, fertilizer producer, closed 1979), and American Creosote Works (18 acre, wood treatment facility, closed 1981). The sites were listed on the USEPA's National Priorities List between 1983-1994 as part of Superfund or the Comprehensive, Environmental Response, Compensation Act of 1980 (EPA Superfund Comprehensive, Environmental Response, Compensation Act of 1980; accessed 2016 July 13). Chemicals of concern in the plumes were primarily arsenic, lead, dioxins, PCBs, PAHs, creosote, fluoride, and pentachlorophenols. Goerlitz et al. (1985) reported 12 PAH compounds and 16 phenolic compounds in groundwater associated with the American Creosote Works site. Clean-up has reduced surface contamination. However, natural attenuation is the current course of action (or inaction) for the groundwater plume containing a combination of contaminants from the Agrico Chemical Co. and Escambia Treating Co. sites that will continue to enter Bayou Texar for the next 70 years. Several of the environmental effects of these hazardous waste sites have been evaluated (Liebens et al. 2006, 2007). Mean fluoride concentrations were about ten times greater in Bayou Texar sediments collected from the groundwater entry zone (100.8 mg/kg) relative to sediments collected from other Bayou Texar areas (10.2 mg/kg) (Liebens et al. 2006). The mean total mercury concentration was six times greater, 1.9 mg/kg versus 0.3 mg/kg, respectively, for the same areas. Annual and five-year update reports are available for the groundwater intrusion into Bayou Texar (examples, URS 2012; E^2 Inc. 2010).

6 Surface Water Quality

Good water quality is important to maintain public, aquatic organism, and wildlife health. Since chemical quality is temporally and spatially dynamic, it is best described with frequent and long-term, coordinated sampling using consistent techniques. Water quality results for the PBS have varied for the same locations, in part, because of differences for the collection technique (grab, composite), frequency, depth, time of collection, preservation and storage conditions, sample preparation (filtration), method of chemical analysis, and detection limits. Additionally, quality assurance and control measures have often been absent or unreported.

Water quality for the PBS has been evaluated as part of compliance monitoring, enforcement actions, national environmental assessment programs, emergency response operations, and pollution identification surveys. Symptoms of deteriorated water quality include the effects of eutrophication (anoxia, hypoxia, algal blooms, fish kills) and chemical contamination of sediments and biota, all of which have occurred in the PBS. The longest continuous water monitoring program for the PBS has been conducted since 1968 by the Bream Fishermen Association, although for limited parameters. Water quality has been determined in response to drought (Butts and Ray 1987) and groundwater contamination (Rostad and Periera 1987; Elder and Dresler 1988). Seafoam quality has been reported (Landry 1974). Current and past water quality monitoring programs have centered on measuring traditional physicochemical parameters such as salinity, pH, dissolved oxygen, temperature and nutrient-related parameters, and several trace metals. Fecal coliform bacteria and indicators of pathogens are monitored frequently in water quality samples because of the public health risk, which intermittently occur (Fig. 6.1) because of inadequately maintained septic tanks, domestic sewage overflows/spills, and urban stormwater runoff. In contrast, concentrations of non-nutrient contaminants have been reported less commonly such as for petroleum hydrocarbons (aliphatic and aromatic compounds), persistent organic pollutants (chlorinated and organophosphorus pesticides), polychlorinated biphenyls (PCBs), and the phytotoxic atrazine and Irgarol. These compounds are relatively insoluble; nevertheless, confirmation is needed. Their presence can impact the commercial quality of shellfish and finfish, and pesticides/herbicides can have severe effects on non-target organisms, including plant-dominated ecosystems for which commercially important faunal species depend upon for their survival. Examples of reports containing results include Olinger et al. (1975); Ross and Jones (1979); Moshiri et al. (1980); McAfee (1986); Lewis T (1986); Rodriguez and Hunner (1994); FDEP (2004, 2005, 2007, 2008, 2012a); Macauley et al. (2005); Lewis FG (2010); and Hall et al. (2010).

Water quality for the PBS has been considered in need of improvement (FDEP 1998), fair (Jones et al. 1992), good (WFRPC 2005), and 30% good (Macauley et al. 2005). Water quality of the Blackwater River has been judged better than that for the Escambia and Yellow Rivers, although quality was considered good for all (Boning 2007). No technical information was provided to support this conclusion. Judgments of water quality have been based on uneven databases and all do not include information for contaminants listed previously and, of more recent concern, that are persistent in the environment and have severe consequences to public health. These include pharmaceuticals, antimicrobials, and endocrine disruptors and concentrations of the human harmful polybrominated diphenyl ethers (flame retardants) and perfluorinated compounds (anti-sticking and waterproofing agents) (USEPA 2013a, b). Furthermore, information is not available for plastic microbeads, which are common in the marine environment and can adsorb waterborne contaminants and leach toxic additives (Derraik 2002; Cole et al. 2011). These plastic particles are used as abrasives in facial scrubs, toothpaste, and soap. There will be phased out beginning in 2017 due to Federal mandate to protect fish and wildlife.

Figure 6.1 Examples of posted public health warnings for surface water contact with Bayou Texar and Santa Rosa Sound. Warnings are due to unusually high rainfall and resultant stormwater entry containing elevated coliform bacteria. Warnings have occurred intermittently for 30 years but are decreasing annually

6.1 Nutrients

The determination of the fate and effects of nutrients contained in wastewaters and stormwater runoff has been a major historical research focus for the PBS. Research topics have included determining the extent of anoxia and hypoxia, algal blooms, nutrient flux, denitrification rates, nutrient limitations, nutrient budgets, and development of local numeric nutrient water quality criteria. Nitrogen limitation (Juhl and Murrell 2008), phosphorus limitation (Murrell et al. 2002b; Livingston 2003), and their co-limitation (Juhl and Murrell 2008) have been reported for Pensacola Bay. Overviews of seasonal hypoxia occurrence and causes are available (Committee on Environment and Natural Resources 2010; Caffey and Murrell 2015). It should be noted that hypoxia is not always caused by elevated nutrients and can be the result of changes in wind and circulation patterns, stratification and upwelling. An average of 25% of the Bay bottom experienced hypoxia in 2008. Flemer et al. (1998) reported its effect on the macrobenthic community. Algal blooms have been recognized as a periodic problem since at least 1975 (FDER 1975; Young 1986). Summertime blooms in Escambia Bay are comprised largely by the pico-phytoplankton *Synechococcus* (Caffery and Murrell 2015).

Nutrient concentrations in Pensacola Bay are low relative to eutrophic estuaries (Bricker et al. 2007). Nutrient and chlorophyll *a* concentrations have been routinely reported for approximately 45 years. Early reports are those of Bohannon (1971); Simmons (1972); Moshiri et al. (1972, 1974); Olinger et al (1975). Useful and more recent studies include those of Murrell et al. (2002a, b); Murrell and Lores (2004); Han and Jordan (2005); DiDonato et al. (2006); Hagy and Murrell (2007); Juhl and Murrell (2008); Hagy et al. (2008); Hagy (2009); Hayes (2010); FDEP (2012b); Livingston (2014); and Caffery and Murrell (2015). Han and Jordan (2005) reported chlorophyll *a* concentrations (µg/l) for Escambia Bay (mean=11.2, range=4.1-23.2), Pensacola Bay (mean=2.3, range=1.1-3.3), East Bay (mean=5.9, range=4.7-6.9) and Santa Rosa Sound (one value=5.9). Murrell and Lores (2004) reported that chlorophyll *a* for Escambia Bay during 1999-2001 averaged 6.8 (SD=5.8, range= 1-26) µg/l. Concentrations in Santa Rosa Sound over grass beds during the past 27 years have been between 0.8 and 8.0 µg/l (FDEP 2012b). Harvey et al. (2015) reported the range of mean chlorophyll *a* concentrations over grass beds as 2.8 to 7.8 µg/l for 2011 and 2014. In addition to published information, a large unpublished USEPA database (Gulf Breeze, Florida) is available for chlorophyll *a*, DIN and DIP for 1992-2003 (Fig. 6.2). Mean chlorophyll *a* concentrations ranged from 3.5-6.4 µg/l for 1156 samples. Mean DIN concentrations were between 0.0-0.03 mg/l (N=2,562) and between 0.011-0.022 mg/l (N=798) for DIP. When compared to guidelines used for National Coastal Assessment Program (USEPA 2012), chlorophyll *a* concentrations on average were “good” (<5 µg/l) for most of the PBS but “fair” (5-20 µg/l) in Escambia Bay. All mean DIN concentrations were in the good category (<0.1 mg/l). In contrast, DIP concentrations were usually “fair” (0.01-0.05 mg/l) except for Santa Rosa Sound where concentrations were indicative of good water quality. A spatial comparison of the unpublished results appears in Fig. 6.2. Escambia Bay on average contained more chlorophyll *a* (6.4, SD=5.4), dissolved inorganic phosphorus (0.022, SD=0.028), and dissolved inorganic nitrogen (0.076, SD=0.074). The higher concentrations for Escambia Bay parallels previous findings (Olinger et al. 1975; Han and Jordan 2005; FDEP 2007, 2012b). Nutrient concentrations in East Bay were reported to be similar to those in Escambia Bay (Caffery and Murrell 2015).

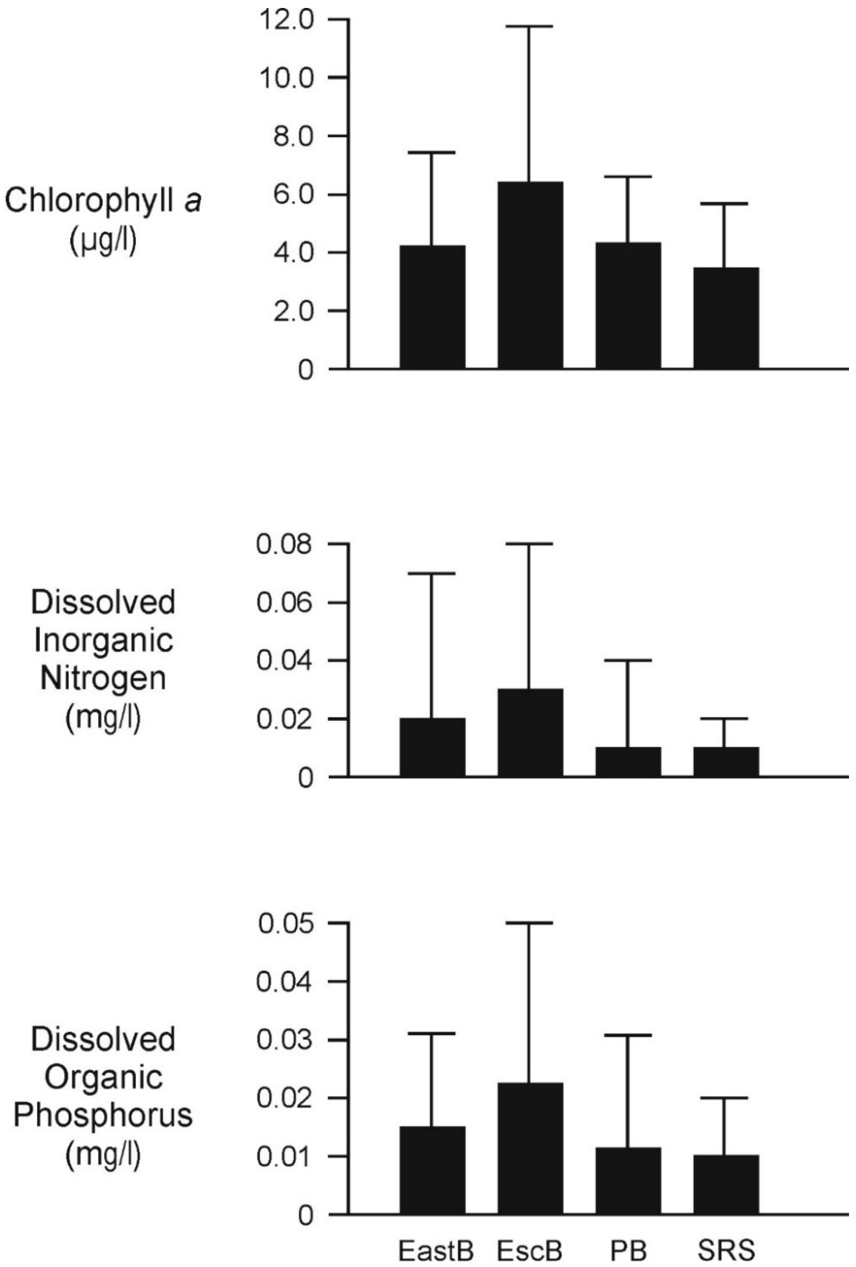


Figure 6.2 Summary of chlorophyll *a* (µg/l), dissolved inorganic nitrogen (mg/l) and dissolved organic phosphorus (mg/l) concentrations in surface waters collected during 1992-2003. Values represent means (±1 SD). EastB=East Bay, EscB=Escambia Bay, PB=Pensacola Bay, SRS= Santa Rosa Sound. Total samples approximates 2,000.

Presumably, nutrient concentrations have declined for the PBS and, to some, they are currently below concentrations of concern at least for submerged aquatic vegetation based primarily on chlorophyll *a* concentrations (FDEP 2012a). The State of Florida water quality criterion for chlorophyll *a* and aquatic life designated use is ≤20 µg/l (FDEP 2010b), which is well above most measured concentrations for the PBS. Although portions of Escambia Bay, East Bay, and Bayou Chico are considered impaired by nutrients (FDEP 2007), current thinking is that only 2 of 11 symptoms of nutrient enrichment occur in the PBS and the only impacted area is upper Escambia Bay. See FDEP (2012b) for a nutrient enrichment checklist and status. It has also been concluded that water quality criteria for nutrients can be based on current ambient concentrations which were reported not detrimental to submerged aquatic vegetation. This conclusion was based in part on the suitability of current chlorophyll *a* concentrations to support seagrass beds in Big Lagoon and Santa Rosa Sound (FDEP 2012b). However, long term condition of these grass beds is uncertain. Coverage declined in both areas during 1993-1995 (Heck et al. 1996) and 2003-2010 (Harvey et al 2015). Therefore, additional information is needed to support the acceptability of current nutrient concentrations, including their effect on the phytotoxicities of non-nutrient contaminants to phytoplankton and seagrass.

6.2 Trace Metals

Trace metal concentrations have been reported in waters adjacent to different stressor sources in a series of papers to provide a worst case scenario of their presence in the PBS (examples, Lewis et al. 2002a, b, 2007; Lewis and Chancy 2008). The order of concentrations based on results for multiple studies for the PBS appears in Table 6.1. The concentration order and magnitude of the concentrations were metal-specific when compared to results for areas considered to be reference areas (Table 6.2). Concentrations of As, Cr, Cd, Cu, Ni, Pb, Zn, and Hg were detected in 12% (Pensacola Bay), 15% (Bayou Texar), 12% (Bayou Chico), 16% (Bayou Grande) and 46% (Santa Rosa Sound-adjacent to a golf course) of 177 water samples. Exceedance of national and Florida water quality criteria to protect aquatic life (USEPA 2014; FDEP 2010b) was infrequent. Concentrations of As, Hg, Zn, Se, and atrazine did not exceed corresponding Florida and National acute and chronic criterion values. In contrast, continuous chronic concentrations for Cu and Cr (Bayous Texar, Chico, Grande), Ni (Bayous Texar, Chico, Grande, Pensacola, and Escambia Bays), Pb (Santa Rosa Sound, Escambia, and Pensacola Bays), and Cu (Pensacola Bay, Bayous Texar, Chico, Grande) were exceeded based on mean concentrations of these trace metals in surface water. Exposure to continuous chronic concentrations are assumed to affect long-term survival, growth and reproduction of the biota. Most mercury concentrations were less than Florida human use water quality criterion of <0.025 µg/l for predominately marine waters based on fish consumption (FDEP 2010b). The higher total mercury levels found were in Santa Rosa Sound at two locations adjacent to a coastal golf course where they averaged 0.11 (SD=0.02) µg/l and 0.07 (SD=0.07) µg/l (Lewis et al. 2002b).

Table 6.1 Contaminant concentrations in decreasing order for media collected from Pensacola Bay System and proposed reference areas (Fig. 1.3). Results from multiple studies conducted during 1990-2010. Not all analytes were measured at all locations.

Surface Water	
Bayou Texar	Cr>Ni>Cu>Zn>Cd>Pb
Bayou Chico	Cr>Ni>Zn>Cu>Cd>Pb
Bayou Grande	Zn>Cu>Ni>Cr>Cd>Pb
Pensacola Bay	Cr>Cu>Zn>Ni>Cd>Pb
Santa Rosa Sound	Pb>Zn>Ni>As>Cu>Cd>Cr
Surficial Sediment	
Escambia Bay	As>tPCB>Cr>Ni>Cd>Pb>Zn>tDDT>Cu>Hg
Pensacola Bay	As>Ni>Cr>Pb>Cd>tPCB>tPAH>tDDT>Hg>Zn>Cu
East Bay	As>Ni>Cr>Pb>>Zn>Cd>Cu
Bayou Texar	Zn>Cu>Pb>Cr>Ni>tPAH>Cd>tDDT>tPCBs
Bayou Chico	Zn>Cu>Pb>Cr>Ni>Cd>tDDT>tPCBs

Table 6.1 (continued)

Bayou Grande	Cr>Zn=Pb>Cu>Ni>Cd>tPAH>tPCBs>tDDT
Santa Rosa Sound	Zn>Cr>Pb>As>Cu>Cd=Ni>Hg
Reference Areas	Zn>Cr>Pb>Ni>Cu>As>Cd>Hg>tPAH>tDDT>tPCBs
Colonized Algal-Periphyton	
Escambia River	Zn>Cr>Ni>Cu>Pb>Cd
Pensacola Bay	Zn>Cr>Ni>Cu>Pb>Hg
Escambia Bay	Zn>Cr>Ni>Cu>Pb>Hg
Bayou Texar	Zn>Pb>Cu>Cr>Ni>Cd
Bayou Chico	Zn>Pb>Cu>Cr>Ni>Cd
Bayou Grande	Zn>Cr>Pb>Cu>Ni>Cd
Santa Rosa Sound	Zn>Cr>As>Cu>Pb>Ni>Cd>Hg
Reference Areas	Zn>Cu>Cr>Ni>Ni>Pb>Se>As>Cd>Ag>Hg
Transplanted Caged Oysters	
Bayou Texar	Zn>Cu>As>Cd>Ni>Cr>Pb>Hg
Bayou Chico	Zn>Cu>As>Ni>Cd>Cr>Pb>Hg
Bayou Grande	Zn>Cu>As>Cd>Cr>Ni>Pb>Hg
Reference Areas	Zn>Cu>As>Se>Cd>Ni>Cr>Ag>Pb>Hg
Indigenous Oysters[1]	
Bayou Chico	Zn>Cu>As>tPAH>Cd>Ni>Pb>tPCBs>Hg
East Bay	Zn>Cu>As>Cd>Ni>Cr>Pb>Hg>tPAH>tPCBs
Indian Bayou	Zn>Cu>As>Cd>Ni>Pb>Hg=Sn
	PCBs>PAHs>DDT>dieldrin>lindane>mirex>hexachlordane
Seagrass Roots[2]	Zn>Cu>As>Fe>Pb>Ni>Cr>Cd>Hg
Seagrass Leaves[2]	Zn>Cu>As>Fe>Ni>Pb>Cd>Cr>Hg
Whole Seagrass [3]	Zn>Cu>As>Cr>Pb>Ni>Cd>Hg
Blue Crabs[4]	Zn>Cu>As>Cd>Cr>Pb>Ni>Hg
Mussels[5]	Zn>Cu>Cr>As>Pb>Ni>Cd
Fish[5]	
Bayous	Zn>Ni>As>Cu>Cd>Pb>Cr
Pensacola Bay	Zn>As>Ni>Pb>Cd>Cu>Cr

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[1] *Crassostrea virginica*

[2] *Testudinum wrightii*

[3] *Ruppia maritima*

[4] *Callinectes sapidus*

[5] multiple species from lower Escambia River

Table 6.2 Comparison of trace metal concentrations (µg/l) in grab samples of filtered surface water collected from the Pensacola Bay System and proposed coastal reference areas (Fig. 1.3). Results from Lewis et al. (2006). Values represent means (±1 SD).

Analyte	Pensacola Bay System[1]	Suwannee Estuary	Withlacoochee Estuary	Mississippi Sound	Bay La Launch	Old River	Grand Lagoon
Arsenic	3.3	16.7	45.0	87.0	74.2	74.0	112.4
	(0.1)	(14.4)	(51.3)	(88.2)	(75.5)	(68.8)	(119.8)
Cadmium	10.1	4.1	<0.5	<0.5	<0.5	<0.5	0.68
	(6.1)	(8.2)	-	-	-	-	(1.4)
Chromium	23.8	16.2	60.3	74.4	58.7	70.5	83.3
	(17.5)	(18.6)	(67.8)	(89.7)	(83.2)	(102.5)	(120.3)
Copper	13.8	0.7	19.4	47.1	41.0	42.9	60.9
	(9.7)	(1.6)	(29.4)	(42.2)	(38.3)	(39.0)	(56.7)
Lead	7.5	0.8	2.8	0.55	<0.6	1.0	0.7
	(10.8)	(1.0)	(4.3)	(0.64)		(1.2)	(0.83)
Nickel	19.4	3.7	25.0	20.3	14.8	14.8	21.3
	(12.0)	(3.9)	(29.7)	(22.7)	(14.4)	(14.6)	(19.8)
Zinc	22.9	20.2	11.3	19.5	10.9	25.9	34.2
	(13.3)	(24.2)	(7.9)	(17.1)	(7.6)	(27.0)	(38.7)

[1] For Santa Rosa Sound, Pensacola Bay, Bayous Texar, Chico, and Grande

6.3 Persistent Non-Nutrient Organics

The few reported concentrations of persistent pesticides and PCBs have usually been less than 1 µg/l or below method detection limits. For example, the concentrations of 16 pesticides and 18 PCB congeners were below detection in waters affected by wastewaters in Pensacola Bay, Escambia Bay, and Escambia River (Lewis et al. 2002a). Low concentrations would be expected since most persistent non-nutrient organic chemicals are relatively insoluble in water and settle to the sediment attached to particulate matter. Reported concentrations of atrazine, one of the more widely used herbicides locally, are surprisingly uncommon for the PBS. Concentrations ranged between 0.024-0.037 µg/l in Santa Rosa Sound adjacent to a golf course and National Seashore (Lewis et al. 2002b).

6.4 Effects-Based Research

The biological effects of water-borne contaminants have centered historically on determining the effects of wastewater-diluted surface water (discussed previously) and indirect and direct effects of excessive nutrients. The toxic effects of locally relevant non-nutrient contaminants on dominant PBS biota have not been determined frequently. Their usual low concentrations, less than Florida and national water quality criteria, suggest that toxicity of their presence alone is unlikely. It is important to note, however, that national water quality criteria are largely based on information for temperate species for which sensitivity is less than that for subtropical species (Kwok et al. 2007). The use of application factors were discussed in that report to remedy this situation. Furthermore, the toxicities of water-bourne chemicals in combination with PBS ambient nutrients under the influence of different salinities and temperatures may occur and needs attention.

7 Sediment Quality

Sediments serve as reservoirs of particle-sorbed contaminants which continually threaten the condition of the benthos, rooted plants, fish, wildlife, and public health. The PBS is considered by some to be the most polluted estuarine system in Florida due to sediment contamination (Seal et al. 1994; Livingston 2005). PBS sediments are biologically and chemically degraded generally near stressor sources and upper reaches of bayous such as for Bayou Texar (Fig. 7.1). DeBusk et al. (2002) presented an overview of hot spots. Areas of greater contamination based on that summary are in Bayou Chico, upper Bayou Texar, lower Bayou Grande, mid- and upper-Escambia Bay, and the Pensacola Bay waterfront. It is unknown if the contamination is static, increasing, or decreasing since determining the trend is complex. Sediment physical and chemical properties (example, Jones et al. 1992) and contamination are more spatially heterogeneous (patchy) than water-born contaminants impacting efforts to quantify quality. Nevertheless, by one estimate, sediment quality has been reported as poor (8% of the area), fair (60%), and good (32%) during 1995-2000 (Macauley et al. 2005).

Figure 7.1 Contaminated sediment collected from Bayou Texar prior to analysis for chemical quality, toxicity, and benthic community composition. Sediment collected with a Petite ponar grab sampler to a depth of 13 cm or less.

Concern for sediment contamination occurred during the 1960's (Jones et al. 1992). The first extensive evaluation of sediment chemical quality was by Olinger et al. (1975). Sediment quality has been consistently monitored at three PBS stations (Sabine Point, Indian Bayou, Pensacola public harbor) for 30 years as part of the NOAA's National Bioeffects and Mussel Watch Programs. Publications by Long et al. (1997), Cantillo et al. (2001), and Kimbrough et al. (2008, 2009) summarize many of the chemical results from this program. Von Appen and Winter (2000) summarized sediment condition for the PBS (1990-2000). Sediment investigations have been conducted for determinations of chemical quality, exceedance frequency, and predictive ability of proposed numerical guidelines, acute toxicity (faunal), chronic toxicity (faunal), genotoxicity, phytotoxicity, benthic community metrics (univariate, multimetric), effects of dredging, reference conditions, and spatial and temporal variability in condition. Engle and Summers (1998, 1999) describe a benthic diversity index developed in part for use within the PBS. These assessment techniques comprise the weight-of-evidence approach recommended for contaminated sediment risk assessments (Chapman 1990). This approach has not always been followed for the PBS where individual components of the triad have been conducted independently of the others.

7.1 Chemical Quality

Chemical quality has been determined frequently for PBS sediments and the results have often been compared to proposed sediment quality assessment guidelines (SQAGs) to determine the expected biological response. Unlike for surface waters, there are no consensus national numeric quality criteria for sediments to protect aquatic life. However, proposed numerical guidelines are available including those for Florida (Long and Morgan 1990; MacDonald et al. 1996; Long and MacDonald 1998; Long et al. 1998). The effect-based guidelines are intended to be used as benchmarks below which the risk from contamination is expected to be minimal. The more common guidelines include the TEL (threshold effect level), PEL (probable effects level), ER-L (effects range low), and ER-M (effects range median) values.

Sediments collected from at least 128 sites within the PBS have been analyzed for a variety of chemicals, including those in Table 7.1. Concentrations for trace metals dominate the database and their order of concentration by analyte appears in Table 6.1 for several PBS subsystems. Arsenic, zinc, and copper typically have been the major contaminants. Of the many reports for sediment quality, the more recent studies are for Bayous Texar, Chico, and Grande and Escambia Bay/River (Liebens et al. 2006, 2007; Mohrherr et al. 2006, 2008, 2009, 2012). Concentrations for as many as 14 trace metals were reported in these studies.

Of the trace metals, the presence of mercury in sediments is of more concern due to its methylation to methyl mercury which, when accumulated in some biota, can become a public health issue. Methylmercury and total mercury concentrations are usually considered equivalent due to the cost of measuring methylmercury. Consequently, total mercury is the analyte usually reported for PBS sediments. A frequency distribution of total mercury concentrations in PBS sediments appears in Fig. 7.2. Mean total mercury concentrations (ng/g dry wt.) have averaged 564.5 (SD=169.6), 13.7 (SD=28.5), 54.1 (SD=63.4), 8.5 (SD=7.4), respectively, in sediments collected from urban-impacted bayous, Santa Rosa Sound adjacent a golf course, Pensacola and Escambia Bays near wastewater outfalls, and under Santa Rosa Sound seagrass beds. Mercury averaged 0.22 (range=<0.001-0.79) mg/kg in Bayou Chico (Liebens et al. 2007) and 0.7 mg/kg in Escambia Bay (Mohrherr et al. 2009). Concentrations were between 0.003-3.4 mg/kg for Bayou Texar (Liebens et al. 2006). Mercury concentrations ranged from 0.1-0.17 µg/g dry wt. during 2004/2005 (Kimbrough et al. 2008) and 0-0.6 µg/g dry wt. during 1991-1996 (Cantillo et al. 2001) for three PBS stations determined as part of NOAA's Mussel Watch Program. For comparison, mean mercury concentrations (ug/g dry wt.) in sediments collected from six proposed reference coastal areas were between 0.002 and 0.090 (Lewis et al. 2006). Of the 187 determinations for mercury reviewed for this summary, 89% were less than the TEL value (0.13 ppm) and 10% were between the TEL and the PEL guidelines (0.13-0.7 ppm). No concentrations exceeded the PEL guideline.

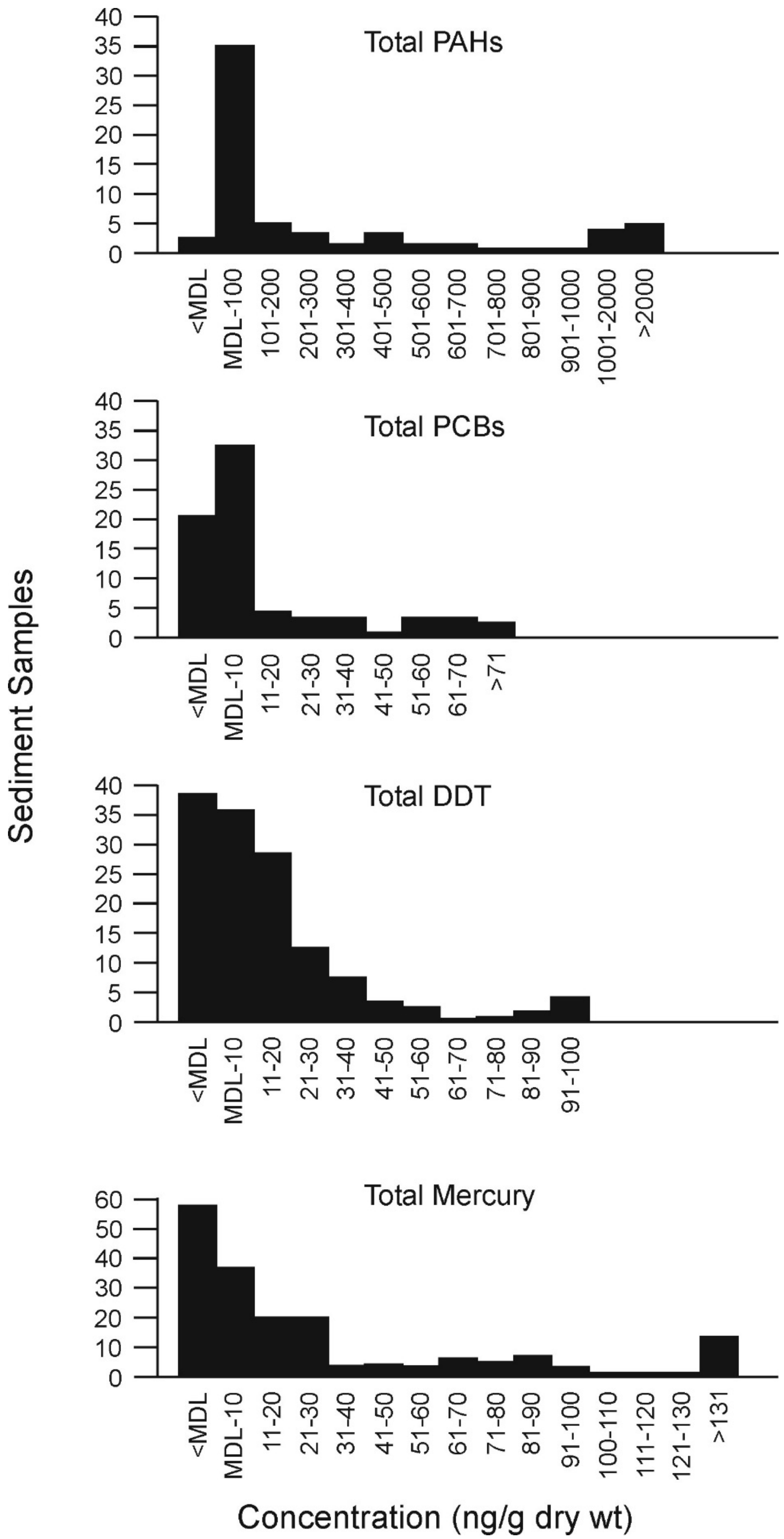


Figure 7.2 Frequency distributions for four persistent and bioaccumulative contaminants in sediments collected during the 1990s from the Pensacola Bay System. Adapted from Lewis (2005).

Concentrations of non-nutrient organic contaminants in PBS sediments have been evaluated less frequently than for trace metals. Frequency distributions for concentrations of four highly bioaccumulative and persistent contaminants appear in Fig. 7.2, and a PBS subsystem and across-estuarine comparison of mean concentrations appears in Fig. 7.3 for three of the four. It is apparent that concentrations, on average, are greater in the PBS and these chemicals, banned at least 35 years ago, still persist in some PBS areas, particularly for PCBs in Escambia Bay/River. Chlorinated pesticide concentrations have been reported for Bayous Texar, Chico, and Grande. Mean concentrations (ng/g dry wt.) for sediments in the three Bayous were from 1.3-9.2 (chlordane), BD-7.0 (dieldrin), 6.9-24.2 (DDE), 7.6-18.2 (DDD), and 1.2-6.8 (DDT) (Lewis et al. 2001e). The maximum concentrations (ng/g dry wt.) were 30.3, 18.4, 40.5, 40.7, and 9.8, respectively for the same order of chemicals. Endosulfan (I and II) was detected in 7 of 78 samples. Concentration ranges were 0.8-5.8 (endosulfan I) and 1.5-10.9 (endosulfan II). DDT and total chlordane concentrations in PBS sediments as part of the Mussel Watch Program were between 0-40 ng/g dry wt. and 0-5 ng/g dry wt., respectively (Cantillo et al. 2001). In the same study, dieldrin and aldrin in sediments collected from the public harbor area in Pensacola Bay were in the upper 15% of those measured nationwide (Cantillo et al. 2001). DDT concentrations were below detection in Escambia Bay but were detected in the lower areas of Escambia River (Mohrherr et al. 2009). In the only reported study found, the concentration of flame retardants (PBDEs) in one sediment sample collected from Pensacola Bay was 0.1 ng/g (Kimbrough et al. 2009).

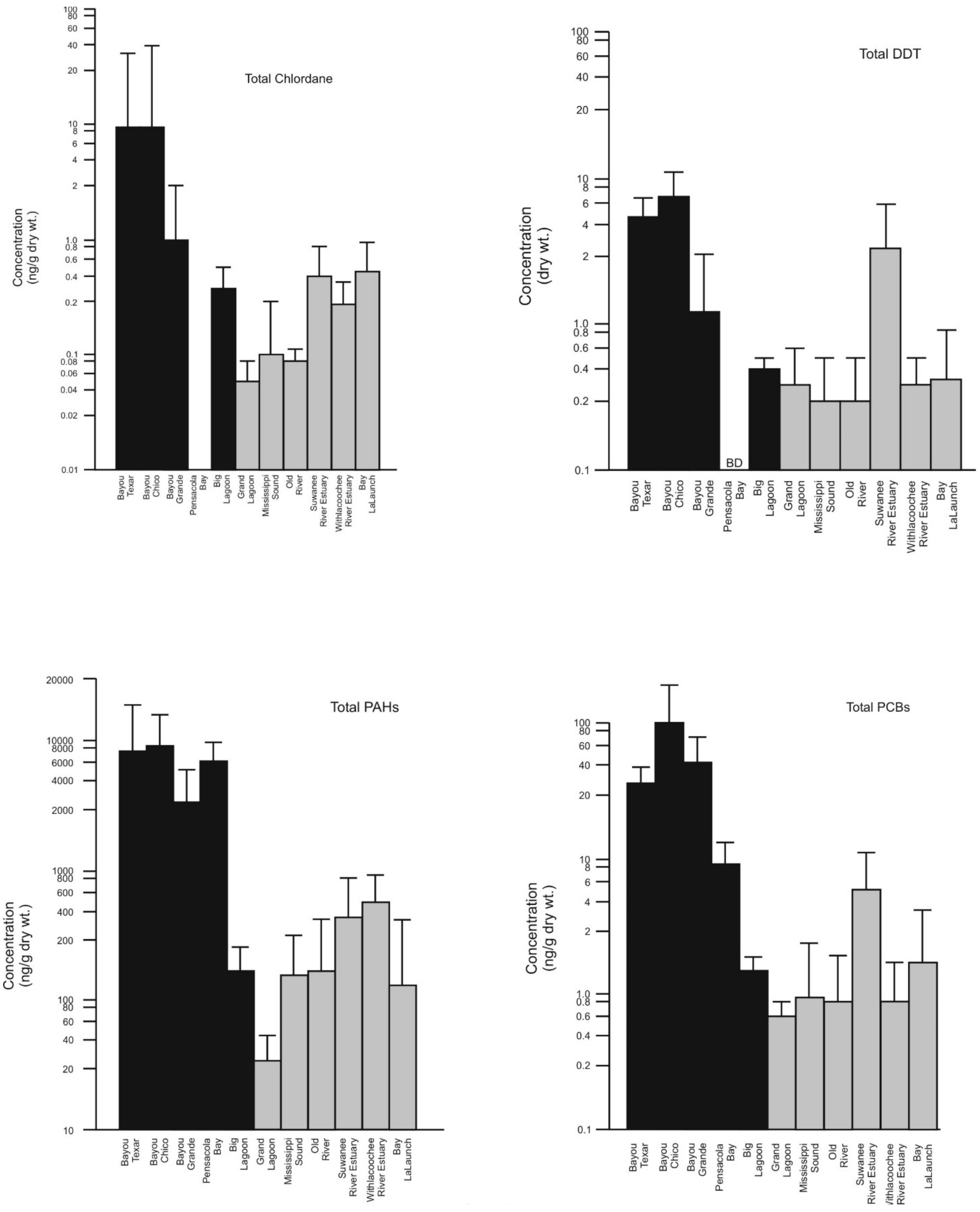


Figure 7.3 Concentrations (ng/g dry wt.) of total chlordane, total DDT, polycyclic aromatic hydrocarbons (total PAHs) and polycyclic biphenyls (total PCBs) in sediments collected during 1995-2002 from the Pensacola Bay System and proposed reference areas (Lewis et al. 2006). Values represent means (±1 SD).

Most studies for sediment-bound polycyclic aromatic hydrocarbons (PAHs) and total petroleum hydrocarbons concentrations have been conducted in Bayous Texar, Chico, and Grande. Reports by

Liebens et al. (2006, 2007) represent the more recent and detailed studies and were conducted partly in response to concern for the effects of nearby Superfunds sites. Total petroleum hydrocarbons ranged from 6-730 mg/kg dry wt. and total PAHs ranged 0-291,940 µg/kg in Bayou Chico and near its entry to Pensacola Bay including the Sanders Beach area (Liebens et al. 2007). TELs were exceeded at four sites for low molecular weight PAHs and at 6 sites for high molecular weight PAHs. Total PAHs in Bayou Texar ranged from 117-14,430 µg/kg for samples collected during 2003-2004 (Liebens et al. 2006). Total PAH concentrations in sediments (ng/g dry wt.) collected during 1993/94 from multiple sites in Bayous Texar, Chico and Grande ranged from 1,638-22,122, 3,243-16,199, and 29-7,057, respectively (Lewis et al. 2001e; Butts and Lewis 2002). The concentrations exceeded the TEL guideline of 1,684 ppb in 23 of 39 samples and 1 of 39 samples for the PEL guideline of 16,770 ppb. PAH concentrations for sediment from three sites in the PBS during 1986-1996 were between approximately 4,000-6,000 ng/g dry wt. (Cantillo et al. 2001). One value was in the upper 15% percentile for estuaries nationwide. Mohrherr et al. (2009) reported PAH concentrations were usually below Florida SQAG guidelines and averaged 238.2 (range=2.4-2,859) µg/kg for sediments collected from Escambia Bay during 2007-2008.

Table 7.1 Examples of anthropogenic contaminants determined for sediments collected from the Pensacola Bay System.

Trace Metals	Chlorinated Pesticides	Polycyclic Aromatic Hydrocarbons	PCB Congeners[1]	
Ag	Aldrin	Acenaphthene	2, 4’-CL2	8
As	Endrin	Acenaphthylene	2, 2’, 5-CL3	18
Cd	Dieldrin	Anthracene	2, 4, 4’-CL3	28
Cu	Alpha-Chlordane	Benzo (a) anthracene	2, 2’, 3, 5’-CL4	44
Cr	Gamma-Chlordane	Benzo (a) pyrene	2, 2’, 5, 5’-CL4	52
Hg	Oxychlordane	Benzo (b) fluoranthene	2, 3’, 4, 4’-CL4	66
Ni	Cis-Nonachlor	Benzo (e) pyrene	2, 2’, 4, 5, 5’-CL5	101
Pb	Trans-Nonachlor	Benzo (g, h, i) perylene	2, 3, 3’, 4, 4’-CL5	105
Ra	Heptachlor	Benzo (k) fluoranthene	2, 3’, 4, 4’, 5-CL5	118
Sb	Heptachlor Epoxide	Chrysene	2, 2’, 3, 3’, 4, 4’-CL6	128
Se	Chlorpyriphos	Dibenzo (a, h) anthracene	2, 2’, 3, 4, 4’, 5’-CL6	138
Sn	2, 4’-DDD	2, 6-Dimethylnapthalene	2, 2’, 4, 4’, 5, 5’-CL6	153
Th	4, 4’-DDD	Fluoranthene	2, 2’, 3, 3’, 4, 4’, 5-CL7	170
Zn	2, 4’-DDE	Fluorene	2, 2’, 3, 4, 4’, 5, 5’-CL7	180
	4, 4’-DDE	Indeno (1, 2, 3, c, d) pyrene	2, 2’, 3, 4’, 5, 5’, 6-CL7	187
	2, 4’-DDT	1-Methylnapthalene	2, 2’, 3, 3’, 4, 4’, 5, 6-CL8	195
Organophosphorus	4, 4’-DDT	2-Methylnaphthalene	2, 2’, 3, 3’, 4, 4’, 5, 5’, 6-CL9	206
Pesticides	Hexachlorobenzene	1-Methyphenanthrene		
	Lindane (gamma-BHC)	Naphthalene		
Phorate	Alpha-BHC	Perylene		
Diazinon	Mirex	Phenanthrene		
Chlorpyrifos	Endosulfan I	Pyrene		
Methyl Parathion	Endosulfan II	1, 6, 7-Trimethylnaphthalene		
Fenthion	Beta-BHC			
Malathion	Delta-BHC			
Parathion				

[1] up to 209 congeners have been determined (Mohrherr et al. 2012)

The history of polychlorinated biphenyl (PCB) monitoring in PBS sediments and biota is presented in Snyder and Karouna-Renier (2009). Many reported concentrations in the past have been for total PCBs. The number of congeners analyzed (209 possible) and summed as "total" PCBs has varied among reports which needs to be considered for a cross-study comparisons. Total PCBs (ng/g dry wt.) in sediments collected from different sites in Bayous Texar, Chico, and Grande ranged from BD-44, 34-288, and 4-92, respectively (Butts and Lewis 2002). The total PCB concentrations in the Bayous exceeded the TEL guideline value of 21.6 ppb for 22 of 34 samples but only once for the PEL guideline of 189 ppb. Total PCBs concentrations for three sites in Pensacola Bay (1986-1996) were between 0-200 ng/g dry wt. (Cantillo et al. 2001). Hemming et al. (2003) reported the results of a sediment survey (1992-2001) conducted for dioxins and furans in six panhandle bay systems including Pensacola Bay and Santa Rosa Sound. The dioxin toxicity equivalents at the two sites were below levels posing a risk to sensitive fish but sediment from Pensacola Bay was thought to be a possible risk to sensitive birds and additional sampling was recommended. In the same study, the mean dioxin toxicity equivalent (a dioxin compounds toxicity relative to 2,3,7,8- TCDD) for Perdido Bay sediments was almost twice that for Pensacola Bay and the toxicity equivalent for Pensacola Bay was greater than equivalents for sediments collected from Choctawhatchee, St. Andrew, St. Joe, and Apalachicola Bays.

Recent detailed descriptions of PCBs, dioxins-furans, and dioxin-like PCBs concentrations in sediments are available for Bayous Chico and Grande from Mohrherr et al. (2006, 2008). It was concluded that the sediments were very contaminated based on exceedance of numerical guidelines and that the indigenous seafood likely represented a public health risk due to PCB bioaccumulation. PELs for total PCBs were exceeded for 5 of 17 samples and 13 of 17 samples exceeded the TEL guidelines in Bayou Chico. Liebens et al. (2011) reported concentrations of dioxins/furans and dioxin-like PCBs in sediments and blue crabs from Bayous Texar, Chico, and Grande. Sediments were more contaminated in Bayou Chico and uptake profiles were different between sediment and crab.

PCBs have been detected in sediments (and biota) from Escambia Bay for over 45 years due to largely a chemical release. Hydraulic oil containing PCBs was first detected entering the Escambia River in 1969 from the Monsanto Company's nylon plant. The more recent and detailed reports related to this contamination are by Mohrherr et al. (2009, 2012) and Liebens and Mohrherr (2015). Concentrations exceeded Florida numerical guidelines in 12 of 57 sediment samples. Total PCBs averaged 17.9 (range=0.9-125.9) µg/kg dry wt. and dioxin/furans averaged 186.4 (range=22-11,004) ng/kg dry wt. (Liebens and Mohrherr 2015). The mean concentration for the northern Bay was 26.7 mg/kg relative to a mean of 11.9 mg/kg for sediment collected from the lower Bay. A useful sediment PCB profile for multiple stations in Escambia Bay based on five data bases is available from the Mohrherr et al. (2009) report. Sediment-sorbed PCBs did not affect sediment nutrient dynamics in Escambia Bay during 2005 after storm events (Smith and Caffrey 2009).

7.2 Sediment Quality Assessment Guidelines Exceedance

Contaminant concentrations were below proposed numerical sediment quality assessment guidelines for approximately 50% (TEL) and 80% (PEL) of total sediment samples collected during 1993-2000 as reported in multiple studies (Fig. 7.4). The number of guidelines exceeded and exceedance frequency for specific analytes by stressor source and location appear in Tables 7.2 and 7.3, respectively, as determined for 171 and 165 sediment samples, respectively. It is obvious that sediment chemical quality was less in the Bayous, areas impacted by urban runoff (Table 7.2). TEL exceedances occurred for 31% of total samples collected from East and Escambia Bays, 17% (Pensacola Bay), and 11% (Santa Rosa Sound). Five-67% of sediment samples collected from various sites within Bayous Texar, Chico, and Grande exceeded TEL guidelines and 0-36% exceeded the PEL guideline concentrations. The number of measured chemicals of concern (those exceeding the TEL and less than PEL) were 17 (Bayous Texar and Chico), 14 (Bayou Grande), and 12 (Pensacola Bay). The more commonly exceeded guidelines in decreasing order based on percent of total samples analyzed was As>Cr>Ni>Pb>Cd>Zn>Cu=Hg>tPAH>tDDT>tPCBs for Pensacola, East, and Escambia Bays. In the most recent survey for Escambia Bay and River (Mohrherr et al. 2009), PELs were not exceed for As, Cd, Cr, Cu, Pb, Hg, and Zn. In contrast, results for 99 of 434 analyses exceeded a TEL in the following sequence: As>Ni=Cd>Cr>Pb>Zn>Cu>Hg. In the same study, 25% of DDT concentrations exceeded a SQAG value, usually the PEL. TELs were exceeded for As, Cr, Cu, Hg, and Ni and PELs were exceeded for Cd, Pb, and Zn in Bayou Grande sediments collected during 2006 (Mohrherr et al. 2008). TELs were exceeded for As, Cr, Cu, Hg, and Ni, and PELs exceeded for Cd, Pb, and Zn for sediments collected from Bayou Chico during 2005 (Mohrherr et al. 2008).

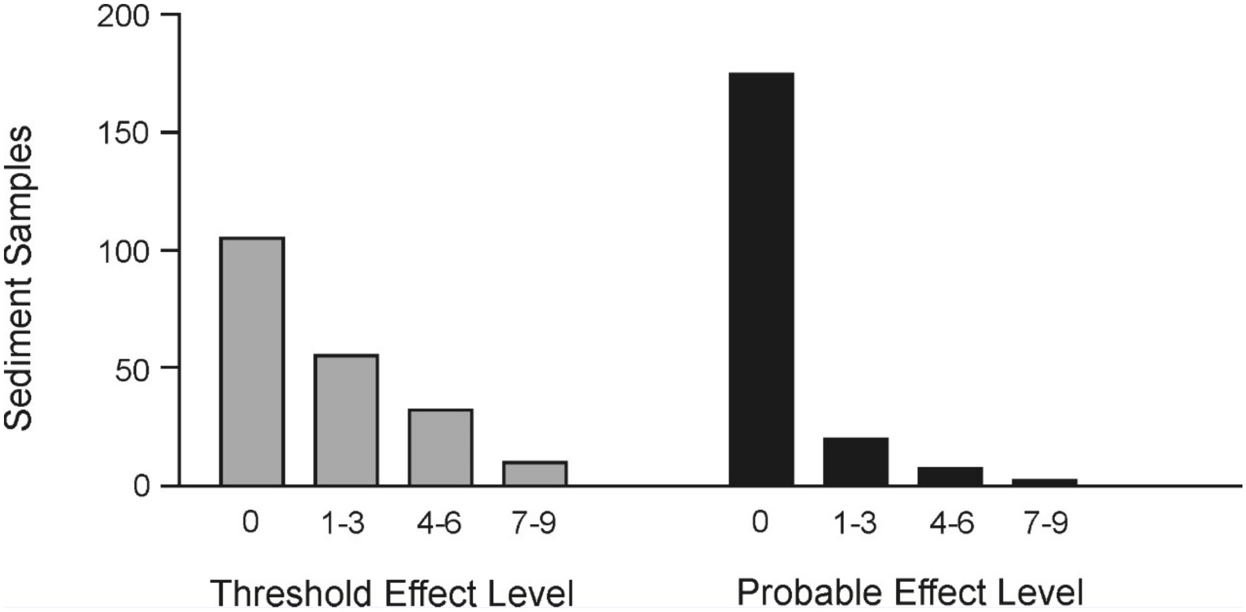


Figure 7.4 Exceedance of numerical, effects-based sediment quality assessment guidelines (SQAGs) proposed by MacDonald et al. (1996) for Florida coastal waters. Values based on sediment samples collected from the Pensacola Bay System during 1993-2000. Adapted from Lewis (2005). Threshold effect level: concentration below which no effects are expected to occur frequently; Probable effect level: concentration for which effects are expected to occur frequently.

Table 7.2 Number of proposed sediment quality assessment guidelines (SQAGs) exceeded for sediments collected from the Pensacola Bay System impacted by different contaminant sources, proposed reference areas (Fig. 1.3) and sediments attached to seagrass. Values represent the number of sediment samples for which result was observed. N - total number of samples. TEL - Threshold effects level; PEL-Probable effects level. SQAGs from MacDonald et al. (1996).

Guidelines	SQAG Guidelines Exceeded	Urban Stormwater Runoff[1]	Golf Course Runoff[2]	Treated Wastewater[3]	Seagrass Meadows[4]	Proposed Reference Areas
TEL	0	6	18	43	13	3
	1-3	5	10	27	1	3
	4-6	17	1	6	2	4
	7-9	9	1	0	0	2
PEL	0	11	24	75	16	12
	1-3	15	6	1	0	0
	4-6	9	0	0	0	0
	7-9	2	0	0	0	0
N		37	30	76	16	12

[1] Bayous Texar, Chico and Grande

[2] Santa Rosa Sound

[3] Pensacola and Escambia Bays

[4] Santa Rosa Sound

Table 7.3 Exceedance of sediment quality assessment guidelines (SQAGs) by analyte and sediment source. Values represent percent exceedance of total analyses based on threshold and probable effect levels (in parenthesis) from MacDonald et al. (1996). N=number of samples per analyte.

Analyte	Urban Stormwater Runoff[1]	Golf Course Runoff[2]	Treated Wastewater[3]	Seagrass Meadows [4]	Proposed Reference Areas[5]
As	7 (0)	2	5	8	8
Cd	59 (11)	7	14	0	8
Cr	30 (10)	2	19	0	8
Cu	46 (26)	7 (2)	21	8	0
Ni	24 (0)	0	11	8	0
Pb	34 (47)	0	0	0	0
Zn	19 (49)	2	2	0	0
Hg	---	5	8	0	8
N	118	44	63	12	12
Chlordane	5 (15)[1]	6 (6)	0	0	0
Dieldrin	13 (21)	6	0	0	0
DDD	23 (36)	15 (9)	9 (1)	0	0
DDE	67 (0)	30	7	0	0
DDT	5 (5)	3 (6)	0	0	8
TPCB	51 (3)	0	19	0	0
TPAH	56 (5)	0	1	0	8
N	39	33	69	12	12

[1] Bayous Texar, Chico, and Grande

[2] Santa Rosa Sound

[3] Escambia and Pensacola Bays

[4] Santa Rosa Sound

[5] see Fig. 1.3

An additional analysis using SQAGs can be used to judge sediment quality. Contaminant concentrations in the same sediment sample can be divided by the corresponding SQAG values and then summed to produce a quotient value (SQAQs) (Long et al. 2006). The greater the quotient value the greater likelihood of an adverse biological effect occurring. SQAQs were determined for about 790 sediment samples collected from the PBS and proposed reference areas and the results are summarized by location in Fig. 7.5. It is obvious that sediment contamination based on this metric is greater for Bayous Texar, Chico, and Grande. The average TEL quotient values for the PBS are between 0.3 (Santa Rosa Sound) and 20.7 (Bayou Chico). The average PEL quotient values are between 0.05 (Santa Rosa Sound) and 4.9 (Bayou Texar).

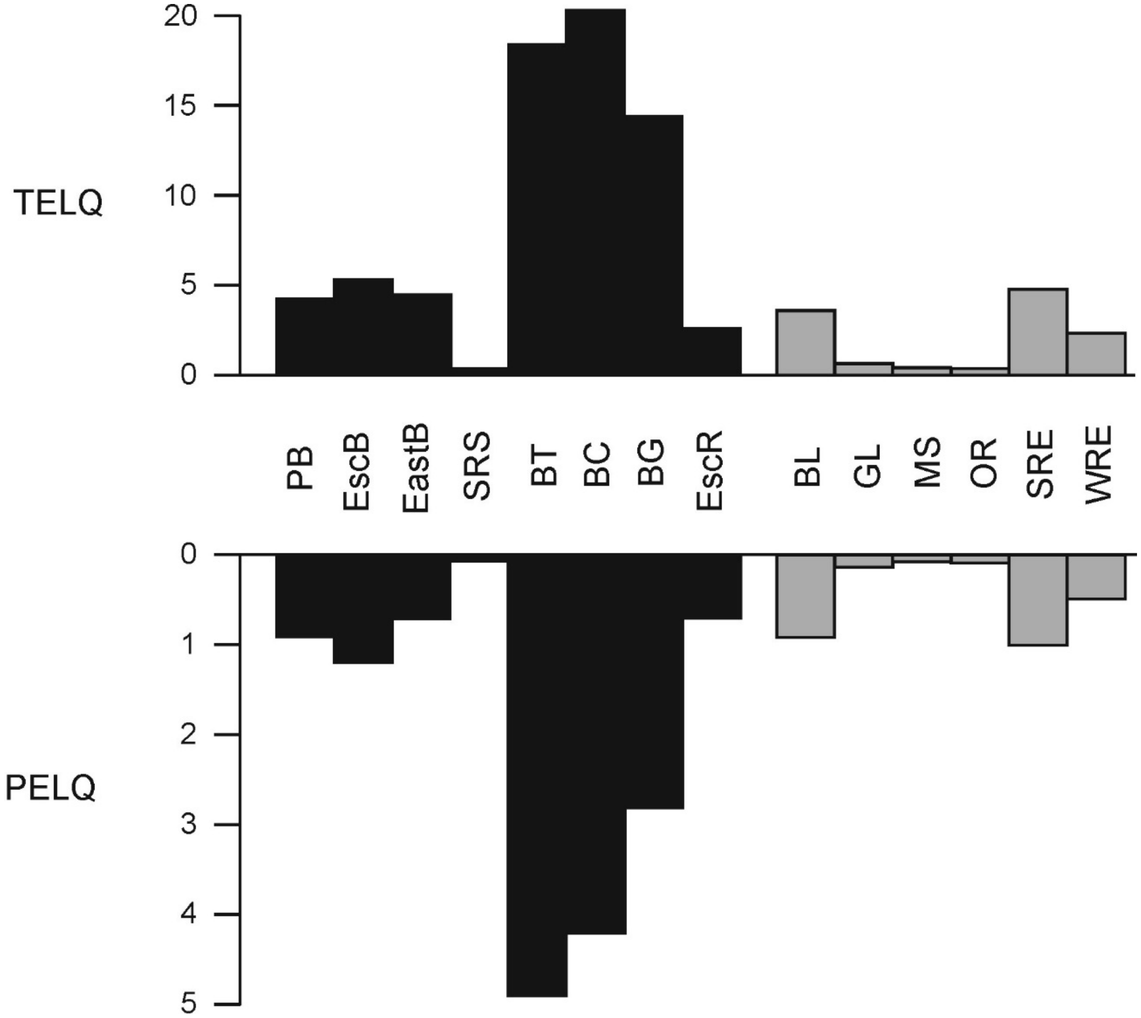
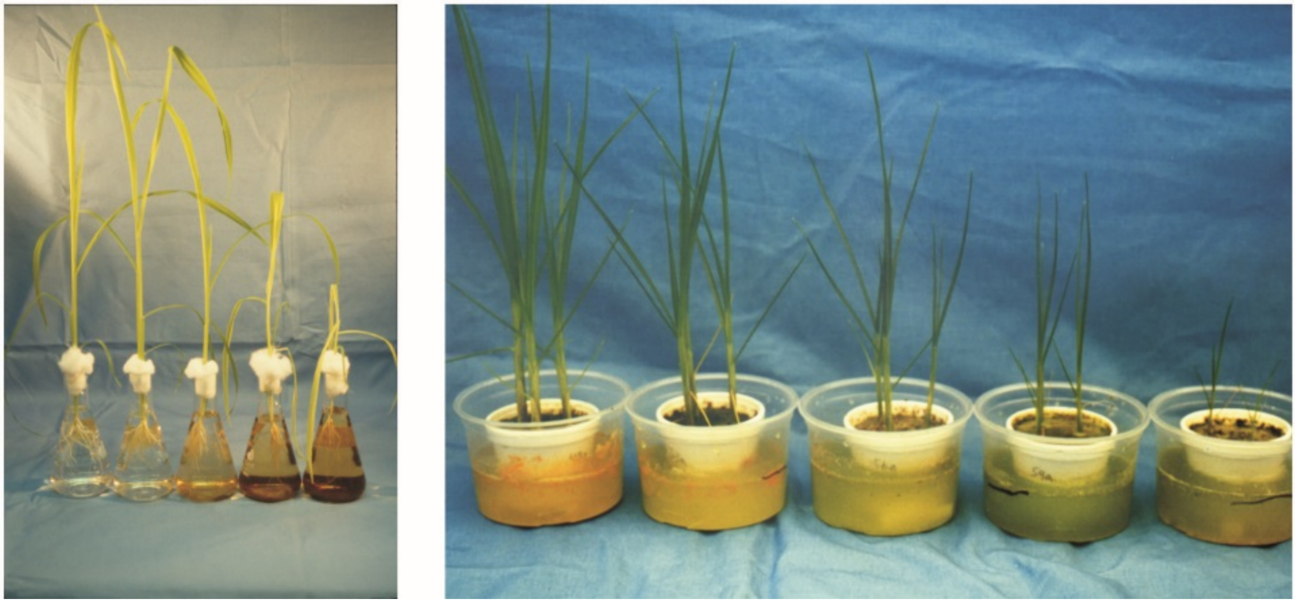


Figure 7.5 Sediment quality assessment quotients (Long et al. 2006) for Pensacola Bay System sub-units and proposed reference areas (Lewis et al. 2006). Values are based on chemical results for 792 sediment samples reported in DeBusk et al. (2002) and Lewis et al. (2007b). The concentrations of individual chemicals in all sediment samples collected from a subsystem were averaged and divided by the corresponding numerical guideline concentration and the fractions summed to form the composite quotient values. TELQ-threshold effect level quotient; PELQ-probable effect level quotient. Location descriptions from Fig. 1.3. PB=Pensacola Bay, EscB=Escambia Bay, EastB=East Bay, SRS=Santa Rosa Sound, BT=Bayou Texar, BC=Bayou Chico, BG=Bayou Grande, EscR= Escambia River.

7.3 Toxicity (Fauna)

Several PBS sediments have been found acutely and chronically toxic to epibenthic and infaunal macroinvertebrates, wetland plants, and the microbial community. Approximately, 500 toxicity tests have been conducted with PBS sediments since the early 1990s to determine the differences in species sensitivities, response parameter sensitivities, pore water versus whole sediment toxicities, relevance of assessment guidelines, frequency of toxicity relative to contaminant sources, and relationship to bioaccumulation. Initial studies were often limited to acute tests (Fig. 7.6) using an insensitive infaunal amphipod, *Ampelisca abdita* (Fig. 7.7) as the test species. However, 13 species and a bacterium (Table 7.4; Fig. 7.7) have been used since to determine toxicity after exposure periods of 0.5 h-28 days. Methods for many tests appear in Lewis et al. (2006). Effects on survival, young production, shoot and root biomass, seed germination and photosynthetic activity, mutagenicity, sea urchin fertilization, and bacterial bioluminescence have been determined. Tests have been conducted with whole sediments, pore waters, and contaminated sediments diluted with reference sediments. However, most toxicity tests have been conducted with undiluted whole sediment which negates the determination of LC50 values-the basic calculation for acute toxicity tests that identifies concentrations lethal to 50% of test species.

Acute Toxicity Tests



Phytotoxicity Tests

Figure 7.6 Examples of a laboratory whole sediment acute toxicity test conducted for 10 days with the infaunal amphipod, *Ampelisca abdita*, and phytotoxicity tests conducted with wetland plant seedlings such as the smooth cordgrass, *Spartina alterniflora*. Plants exposed for 21-28 days to either water-borne contaminants or contaminated whole sediment.

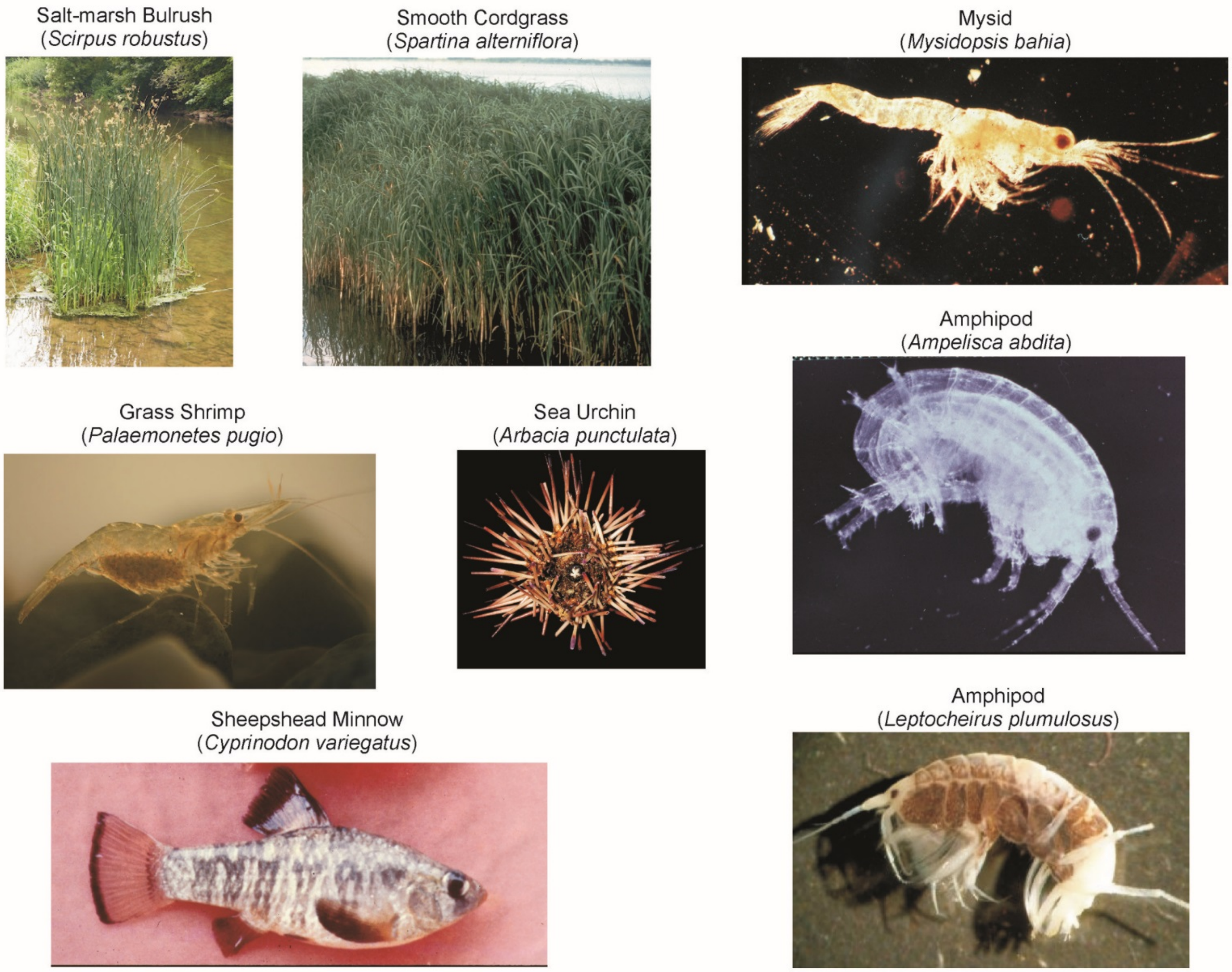


Figure 7.7 Examples of test species exposed to whole and diluted sediments collected from the Pensacola Bay System and their associated pore waters in laboratory acute and chronic toxicity tests. Test durations were 0.5 hours to 28 days. Species not shown to scale. Photos by author or courtesy of Encyclopedia of Life (Encyclopedia of Life; accessed 2016 July 14).

Table 7.4 Test species used in acute and sublethal toxicity tests conducted with whole and diluted sediments and interstitial pore waters collected from the Pensacola Bay System.

Flora

Echinochloa crusgalli - Barnyard grass

Scirpus robustus - Salt marsh bulrush

Sesbania macrocarpa - Yellow bladder pod

Spartina alterniflora - Smooth cordgrass

Fauna

Americamysis bahia - Mysid shrimp

Ampelisca abdita - Benthic estuarine amphipod

Arbacia punctulata - Sea urchin

Brachionus calaflorus - Freshwater rotifer

Cyprinodon variegatus - Sheepshead minnow

Hyalella azteca - Freshwater epibenthic amphipod

Leptocheirus plumulosus - Benthic estuarine amphipod

Palaemonetes pugio - Grass shrimp

Thamnocephalus platyurus - Beaver-tail fairy shrimp

Vibrio fischeri - Bioluminescent bacterium

The only published LC50 value (concentration lethal to 50% of test species) reported is for a contaminated whole sediment collected for one site in upper Bayou Texar (Norton et al. 1999). The LC50 value was as low as 3% contaminated sediment (diluted with reference sediment). This, to our knowledge, is the most acutely toxic sediment identified to date for the PBS. The probable sources of toxicity are from the considerable stormwater runoff and contaminated groundwater from nearby Superfund sites that enter the Bayou.

The peak of sediment toxicity testing for the PBS occurred during the 1990s. Acute toxicity has generally been low (high survival) based on results of 340 whole toxicity tests conducted during this period with PBS sediments (Fig. 7.8). Toxicity occurrence (control-corrected) as a percent of total tests conducted was 8% (acute toxicity) and 33% (chronic toxicity). Of 78 acute-chronic comparisons, 48 sites had no acute and chronic toxicity and 30 sites had no acute toxicity but had chronic effects. The usual lack of high mortality combined with the occurrence of sublethal effects suggests that chronic toxicity should be the focus for future toxicity tests conducted with sediments. It is important to note that there has been no known attempt to determine the specific cause (and source) of toxicity in contaminated PBS sediments despite an available method for a toxicity identification analysis (USEPA 2007). The lack of this information combined with the absence of numerical, effects-based toxic concentrations for benthic species and most sediment-sorbed chemicals precludes the use of the TMDL approach for contaminated sediment remediation.

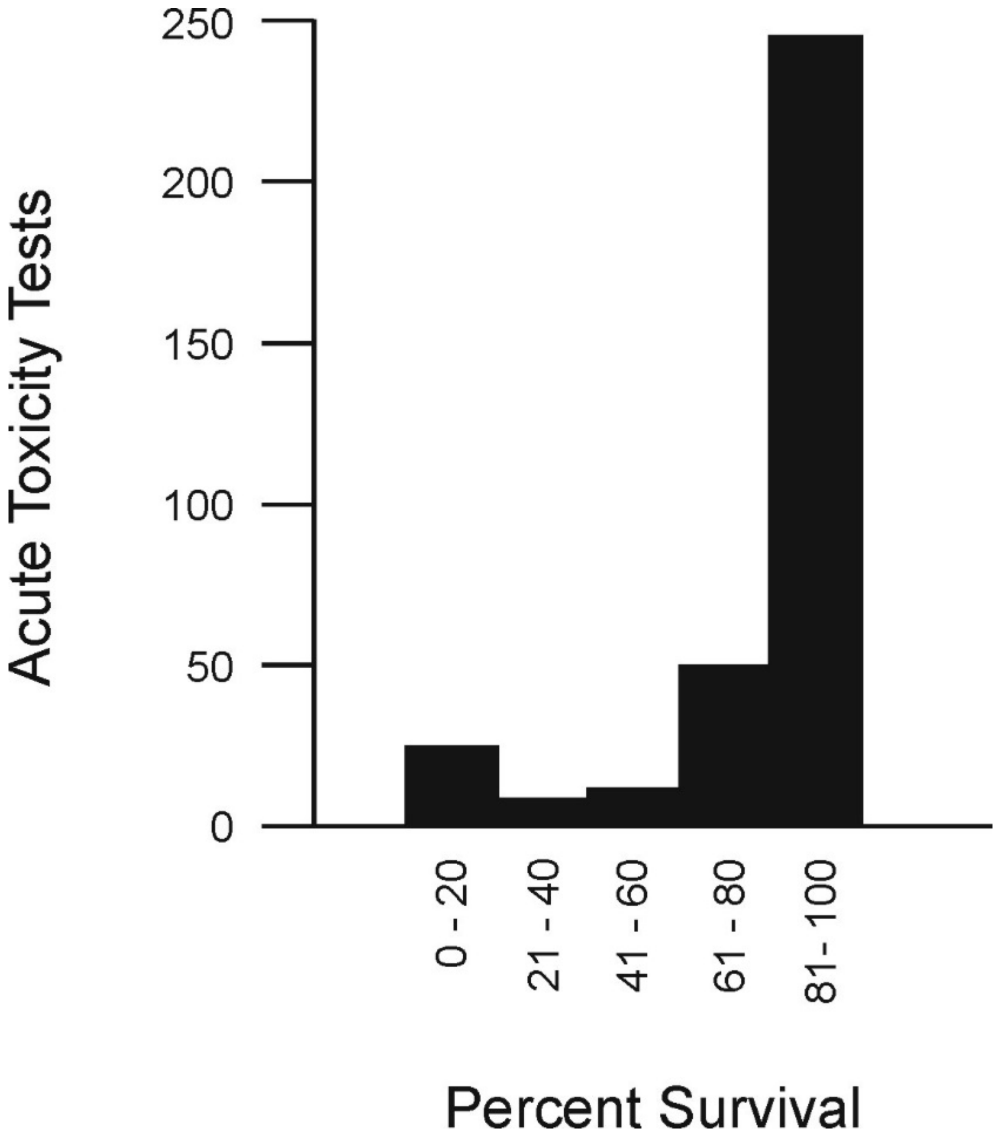


Figure 7.8 Survival (%) of epibenthic and infaunal test species after their 4-10 days exposure to the Pensacola Bay System contaminated whole sediments. Total toxicity tests conducted=340.

Interspecific differences in sensitivities have been minor based on acute toxicity results (Fig. 7.9). Mean survival after exposure to the same whole sediment (52 toxicity tests) collected from PBS areas receiving treated wastewater was 95%, 83%, 83%, and 87% for *M. bahia*, *Cyprinodon variegatus*, *A. abdita*, and *Leptocheirus plumulosus*, respectively. Mean survival (%) of *Ampelisca abdita* after exposure to Bayou Texar, Chico, and Grande sediments (70 tests) was 75 (SD=33), 86 (SD=15), and 84 (SD=31), respectively. Mean survival for *L. plumulosus* exposed to sediments collected from Bayous Texar and Grande was 78 (SD=32) % and 82 (SD=26) %, respectively. Mean survivals (%) for *A. abdita*, *L. plumulosus*, *Hyalella Azteca*, and *C. variegatus* exposed up to 11 times to a sediment from Perdido Bay and used as the control sediment in many toxicity tests conducted with PBS contaminated sediments were 96 (SD=5), 95 (SD=10), 98 (SD=4), and 95 (SD=4), respectively (Unpublished results, USEPA, Gulf Breeze, FL).

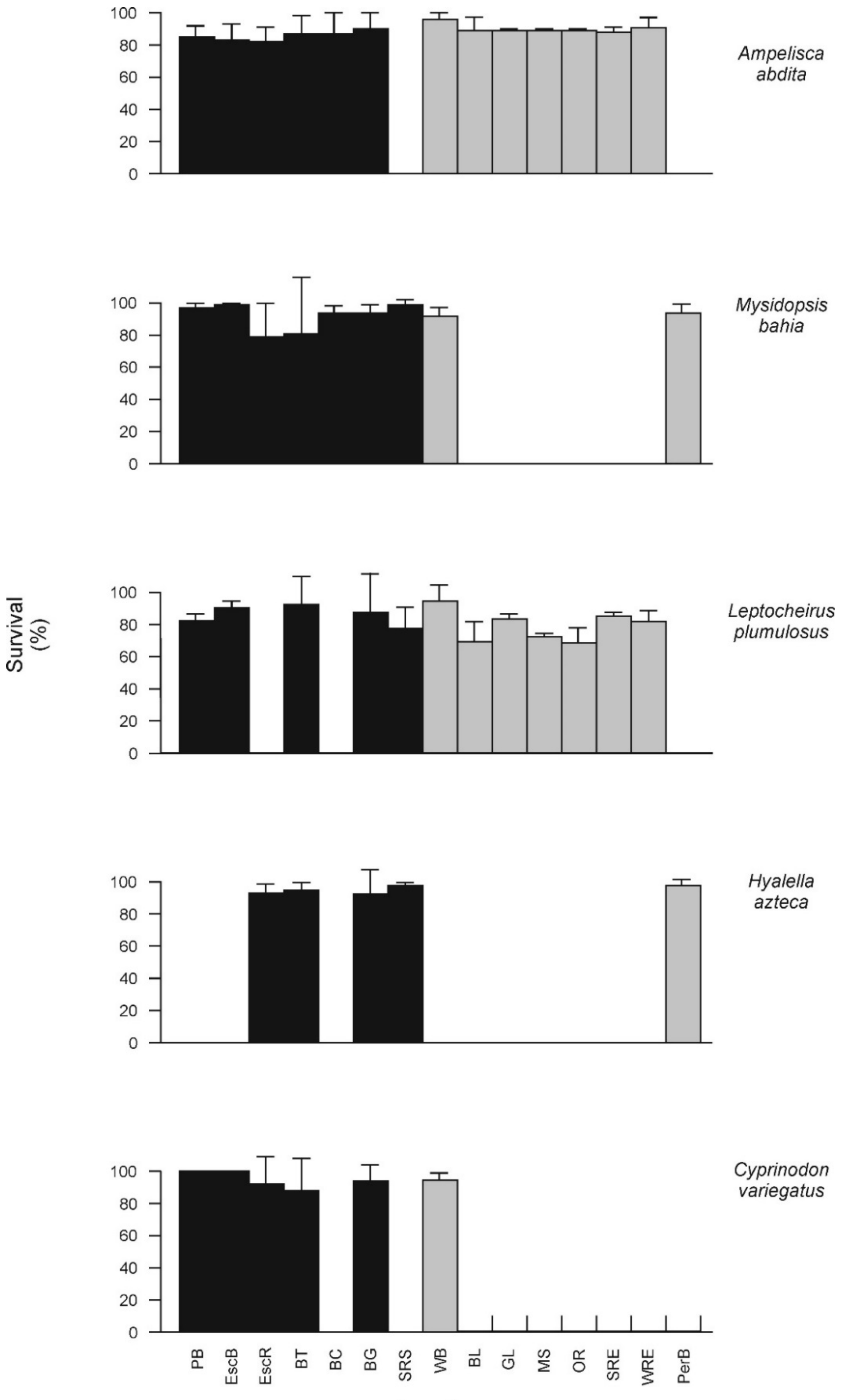


Figure 7.9 Species- and site-specific differences for survival of five test species exposed to whole sediments collected from the Pensacola Bay System, nearby bays and proposed reference areas (Lewis et al. 2006). See Figures 1.3 and 7.5 for site designa tions. PerB=Perdido Bay; WB=Weeks Bay.

Results of acute toxicity tests with sediments have been spatially similar (Fig. 7.9). For example, mean survival (%) was 70 (SD=40), 94 (SD=5), 93 (SD=16), 94 (SD=3), and 94% for Bayous Texar, Chico, and Grande, Santa Rosa Sound, and Escambia and Pensacola Bays, respectively, based on approximately 133 sediment toxicity tests conducted with *M. bahia*. These results are similar to those for *M. bahia* exposed to sediments collected from nearby Perdido Bay, Florida (mean=94%, SD=3%) and Weeks Bay, Alabama (mean=92%, SD=3%).

As stated previously, sublethal toxicity to benthic-dwelling faunal species has been reported less frequently than acute toxicity. The extent of sublethal toxicity based on results of 40 toxicity tests (sea urchin fertilization test, pore water, one hour test duration) and reported as a percent of study area was estimated as great as 14.4 km^2or 5.3% (Long et al. 1996). In contrast, only 0.015% of the study area was estimated to be acutely toxic to the amphipod, *A. abdita*. Toxicity tests using bioluminescence bacteria and organic extracts of sediments were also reported by Long et al. (1997). All samples from Bayou Grande, Bayou Chico, and inner Pensacola harbor were highly toxic in that study. Samples from Escambia Bay, East Bay, and Bayou Texar were not toxic. In an unpublished USEPA study (Gulf Breeze, Fl), effects of whole sediments collected from Pensacola and Escambia Bays and the Escambia River were determined in 7-d tests monitoring survival, weight and fecundity of *M. bahia.* There were no locational differences in weight. In contrast, fecundity was reduced in decreasing order for sediments collected from the lower Escambia River>Escambia Bay>Pensacola Bay.

7.4 Phytotoxicity

The sensitivities of indigenous aquatic plants (vascular and non-vascular) to anthropogenic contaminants and natural stressors associated with the PBS are almost unknown despite the well-documented biodiversity-building and phytoremediation properties of near-shore plant-dominated ecosystems and the availability of in-situ methods (Durako et al. 1995) and laboratory test methods (Walsh 1991). The earliest known phytotoxicity investigation is that of Grigsby (1982). In that study, the effects of three herbicides were evaluated on *Ruppia maritima*. In a more recent and in-depth study, several PBS sediments were found phytoinhibitory or phytostimulatory. Early seedling shoot and root growth was determined in 70 toxicity tests (Fig. 7.6) conducted with salt marsh bulrush (Fig. 3.1, *Scirpus robustus*) and salt marsh cordgrass (Fig. 3.1, *Spartina alterniflora*) and sediments collected from 15 sites in Bayous Texar, Chico, and Grande (Lewis et al. 2001d). Sediment phytotoxicity was common and species-specific. Phytotoxic effects were observed at 12 of 15 sites but invertebrate mortality occurred at only two sites. Stimulation was more common than phytoinhibition likely reflecting a nutrient reservoir in the sediments. It was concluded that phytotoxicity provides useful information not available if only the traditional faunal species are used. It remains to be seen if this is true for seagrass for which sediment phytotoxicity may be a determinant for their survival and for which no local information is available.

7.5 Genotoxicity

Pore waters extracted from several PBS sediment sites have been found to be genotoxic, including those impacted by golf course runoff, urban runoff, hydraulic dredging, and treated wastewaters (Long et al. 1997; Lewis and Daniels 2006). All pore water samples collected from Bayou Chico in 1994 were found to be genotoxic using the commercial microbial Mutatox^{tm} assay (Long et al. 1997). Pore waters from PBS sediments in areas receiving 10 different wastewaters discharged into Escambia and Pensacola Bays and the lower Escambia River were assayed using a similar mutagenicity assay (*Vibrio fischeri*-M169) before and after activation using rat liver microsome mix (Lewis and Daniels 2006). Direct and indirect genotoxic effects were observed for 14% and 32% of the 37 tests conducted, respectively. Both direct and activated responses were observed for the same sediment sample in 5% of the tests. One in six pore water samples from Santa Rosa Sound adjacent to a golf course and one in five samples in dredged areas of Bayou Texar were genotoxic (direct). Genotoxicity occurred more frequently than acute toxicity to the benthic amphipod *A. abdita*.

7.6 Macrobenthic Community Metrics

The herbivorous infaunal biota are the base of the primary estuarine food web and are important to secondary production (Livingston 1999). The PBS has a faunally-diminished benthic community, low secondary productivity, and benthic respiration rate (Livingston 1999, 2005). Furthermore, the infaunal invertebrate biomass is lower than that for other Gulf of Mexico bays (Livingston 2010). The low abundance has been attributed to habitat limitation, hypoxia and low phytoplankton production (Livingston 2005). In another appraisal for 1995-2000, the benthic community was considered poor (16% of area), fair (13%), and good (58%) (Macauley et al. 2005).

The structural and, to a lesser extent, functional characteristics (Rakocinski 2011) of the benthic community in the PBS have been analyzed frequently since the 1970s (examples, Olinger et al. 1975; Livingston 1999, 2005; Murrell et al. 2009; Smith and Caffrey 2009; FDEP 2012b). An early in-depth analysis (1973-1978) is available for 250 sites (Ross and Jones 1979). Frequency distributions for numbers of taxa and organisms and density determined for PBS sediments collected between 1993 and 2000 appear in Fig. 7.10. The majority of samples contained 20 or less taxa, 300 or less organisms and 3,000 organisms/m^2 or less. Based on Florida guidelines, 13% of samples were in the poor category (<200 orgs/m^2), 25% were of marginal quality (200-500 orgs/m^2) and 62% in the good category (>500 orgs/m^2).

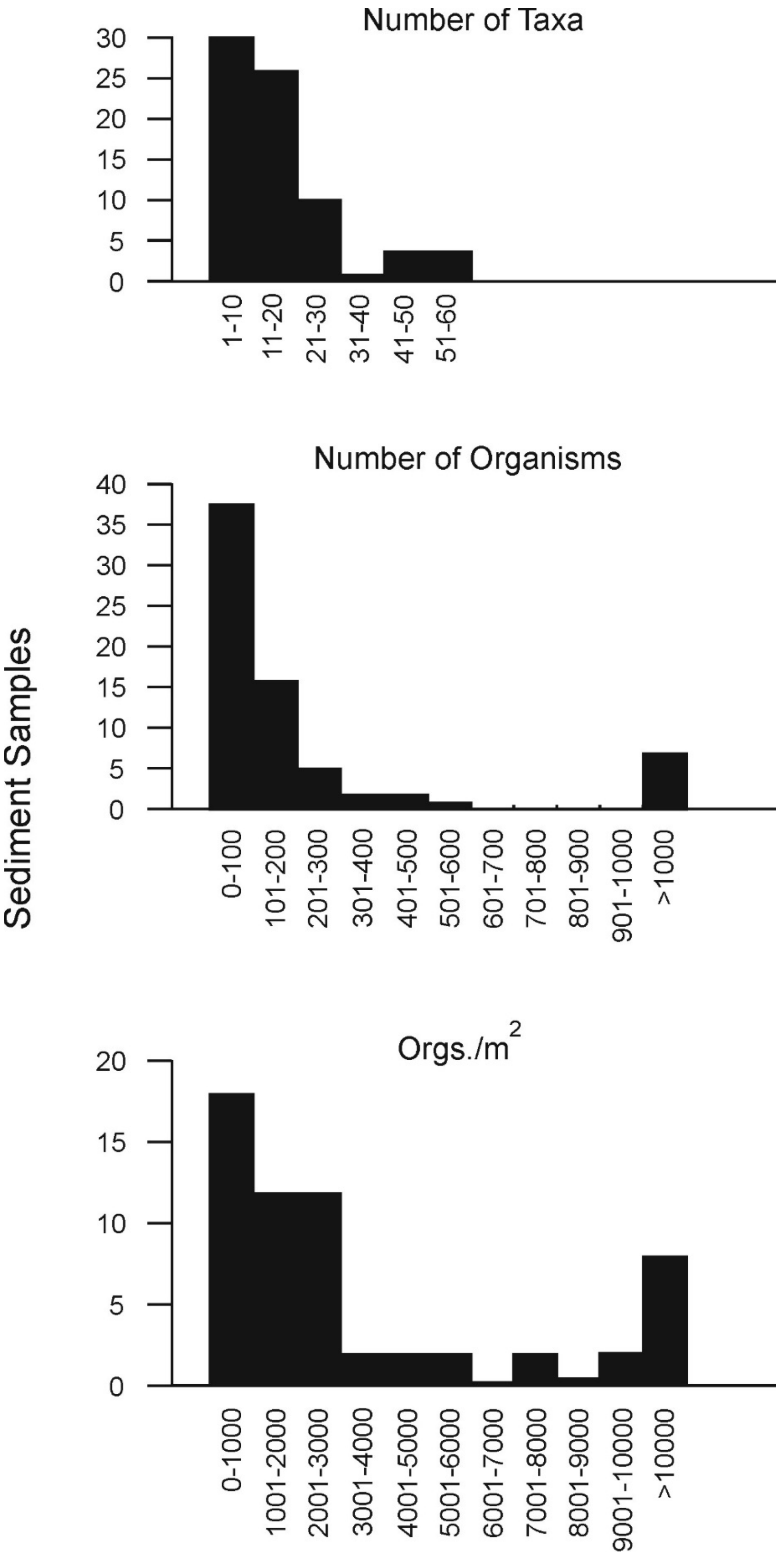


Figure 7.10 Frequency distributions for structural characteristics of the benthic macroinvertebrate community in sediments collected during 1993-2000 from the Pensacola Bay System. Number of analyses=203. Adapted from Lewis (2005).

Benthic diversity index values represent a single number summary of the health of the macroinvertebrate community. The most commonly used measure of diversity is that of Shannon and Weaver (1949) commonly referred to as the Shannon-Wiener Index. Values usually range between 1 and 4; the lower the value the more simplistic the community. A frequency distribution of results for this Index and three other indices for PBS benthos appear in Fig. 7.11 based on taxonomic results for about 1,000 sediment samples. Approximately 60% of the samples had Shannon-Wiener Index values between 2.0-3.0 and 27% below 2.0. Ninety percent of the 400 sites evaluated using a different benthic index were found to be degraded during 1991-1994 (Engle and Summers 1999). The definitive cause of the low benthic diversity commonly observed in the PBS, like for toxicity, is unknown. Salinity was not a factor in the Engle and Summer's study.

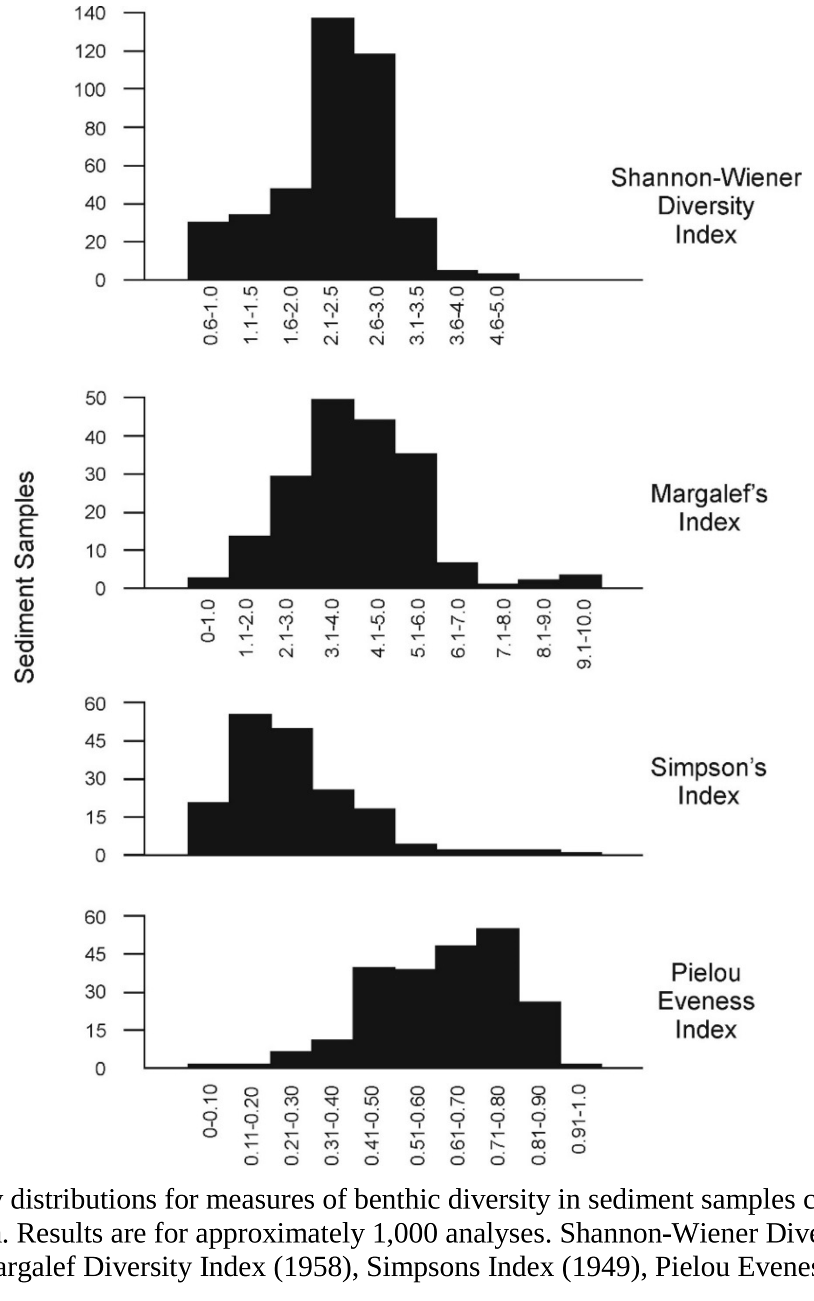


Figure 7.11 Frequency distributions for measures of benthic diversity in sediment samples collected from the Pensacola Bay System. Results are for approximately 1,000 analyses. Shannon-Wiener Diversity Index (Shannon and Weaver 1949), Margalef Diversity Index (1958), Simpsons Index (1949), Pielou Eveness Index (1966).

7.7 SQAG Predictive Ability

The ability of the proposed sediment quality assessment guidelines (SQAGs) to predict adverse biological effects based on chemical measurements alone has been evaluated (Long et al. 1997; Lewis et al. 2001b, d, e; Lewis and Daniels 2006). Comparisons for results of multiple tests for acute and chronic toxicity, genotoxicity, and phytotoxicity and analyses of community diversity have been made to the number of SQAG guidelines exceeded for the same sediment sample. Results are summarized in Table 7.5 and an example is provided in Fig. 7.12 for co-occurrence of acute toxicity and phytotoxicity (plant biomass) in 15 Bayou sediments. The results for this comparison as well as others are inconsistent, and the chemical-biological concordance depends upon the measured biological effect. The predictive ability (SQAG exceedance = biological effect or no SQAG exceedance=no biological effect) has been about 60% (acute toxicity), 58% (microbial genotoxicity), 56% (low benthic diversity), and 65% (phytotoxicity). Thus, reliance on chemical measurements alone will lead to misleading conclusions on sediment biological quality, which supports the use of a weight-of-evidence approach for sediment contaminant evaluations in the PBS.

Table 7.5 Exceedance of sediment quality assessment guidelines (SQAGs), MacDonald et al. 1996) and concomitant occurrence of toxicity and low benthic diversity for the same Pensacola Bay System sediment sample. Values represent percent of comparisons where outcome was observed. Adapted from Lewis (2005).

	Acute Toxicity[1]	Genotoxicity[2]	Phytotoxicity[3]	Benthic Macroinvertebrate Diversity[4]
SQAG exceedances and biological effects	9	20	53	31
SQAG exceedances and no biological effects	39	20	32	13
No SQAG exceedances and biological effects	1	22	3	31
No SQAG exceedances and no biological effects	51	38	12	25
Number comparisons	350	40	38	62
Acute toxicity and biological effects	-	5	11	4
Acute toxicity and no biological effects	-	7	5	3
No acute toxicity and biological effects	-	44	45	45
No acute toxicity and no biological effects		44	39	48
Number comparisons	-	40	38	78

[1] Survival 20% or less (control-corrected) for *Americamysis bahia, Ampelisca abdita, Palaemonetes pugio*.

[2] Direct or activated response observed (Lewis and Daniels 2006)

[3] Statistically significant phytoinhibition or phytostimulation.

[4] Shannon-Wiener diversity index value < 2.0. (Shannon and Weaver 1949)

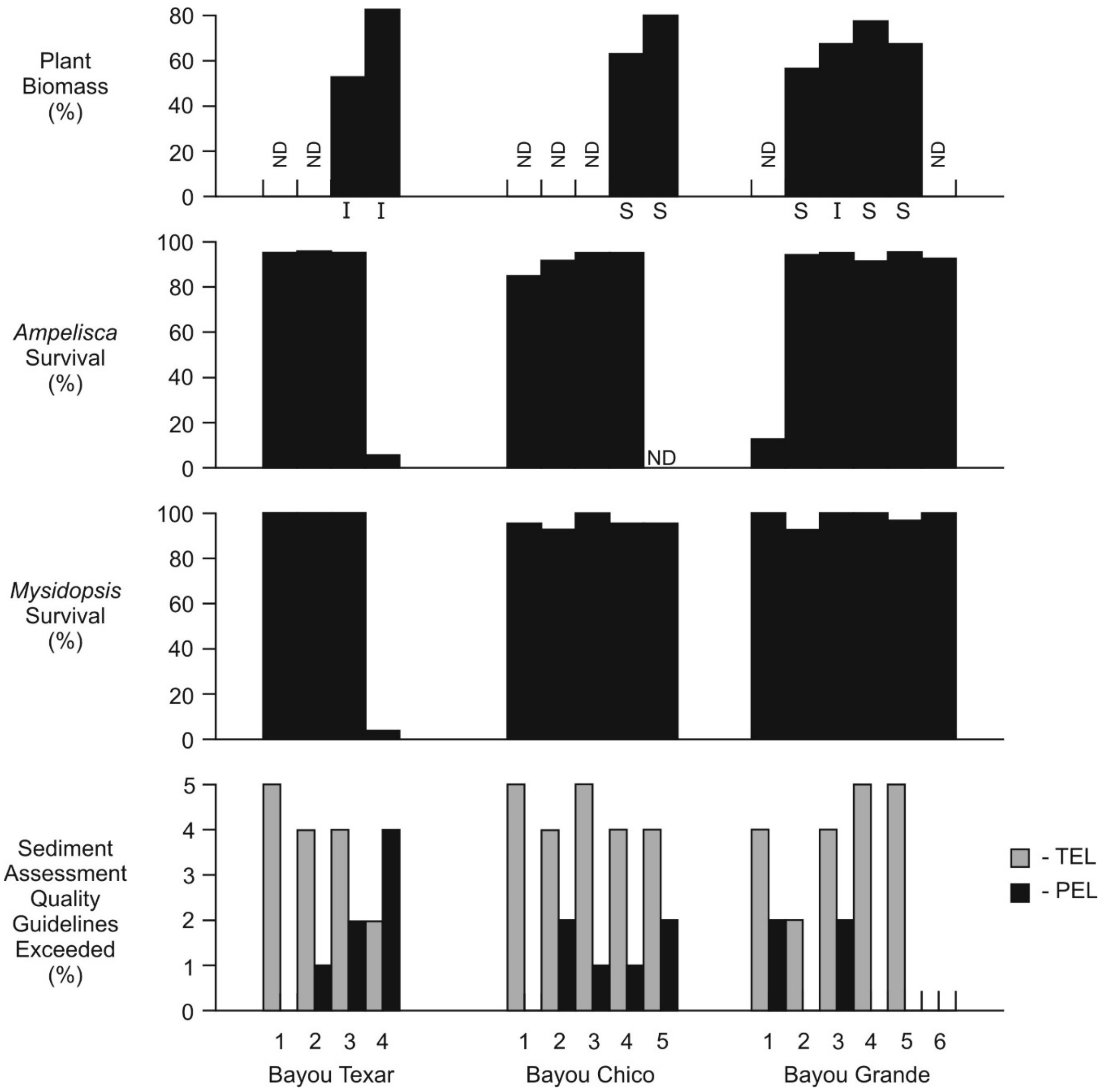


Figure 7.12 Comparison of exceedance of sediment quality guidelines (MacDonald et al. 1996) and results of toxicity tests conducted with the same whole sediments collected from 15 locations in Bayous Texar, Chico and Grande. Test species were *Mysidopsis bahia* and *Ampelisca abdita*, and seedlings of the wetland plants *Sesbania macrocarpa* and *Echinochloa crusgalli*. ND-no data; I-inhibition and S-biomass increase (stimulation) relative to plant biomass in control.

7.8 Spatial Comparisons of Sediment Quality

Sediment chemical quality has been compared within the PBS and also to other coastal areas. Quality varies between and within Bayous Texar, Chico, and Grande as shown in Fig. 7.3 and 7.13 based on reports of Lewis et al. (2001d, e); Butts and Lewis (2002) and Macauley et al. (2005). See Mohrherr et al. (2005) and Liebens et al. (2006, 2007) for relatively recent spatial profiles of metals, pesticides, and PAHs within Bayous Texar and Chico and Escambia Bay (Mohrherr et al. 2009). Macauley et al. (2005) ranked sediment contamination in decreasing order as Bayou Grande>Bayou Chico>Bayou Texar. Olinger et al. (1975) reported that the order of copper and nickel contamination was Pensacola

Bay>Escambia Bay>East Bay>Blackwater Bay. Comparisons for 12 trace metals in sediments across as many 16 coastal areas were provided in that report. For example, copper and nickel concentrations in sediments from Escambia Bay were less than in sediments from Chesapeake and Galveston Bay. Mean tPAH, tPCB and mercury concentrations were usually greater for Pensacola Bay than in other Florida panhandle bays (Long et al. 1997). Concentrations of dioxins/furans in sediments in decreasing order were Perdido Bay>Pensacola Bay/Santa Rosa Sound>Choctawhatchee Bay>St Joe Bay>St Andrew Bay>Apalachicola Bay (Hemming et al. 2003). An excellent comparison of nine organic and nine trace metal concentrations for Pensacola Bay (three sites) during 1986-1996 relative to three other Florida panhandle estuaries appears in Cantillo et al. (2001). Although site-specific, concentrations of mercury, lead, mirex, lindane, dieldrin, chlordane, DDT, and PCBs were generally less in the PBS. Escambia Bay was ranked 6th of 25 estuarine drainage areas for pesticide contamination; it was considered more susceptible to chemical contamination than Mobile Bay but less so than Perdido Bay (Brecken-Folse 1989).

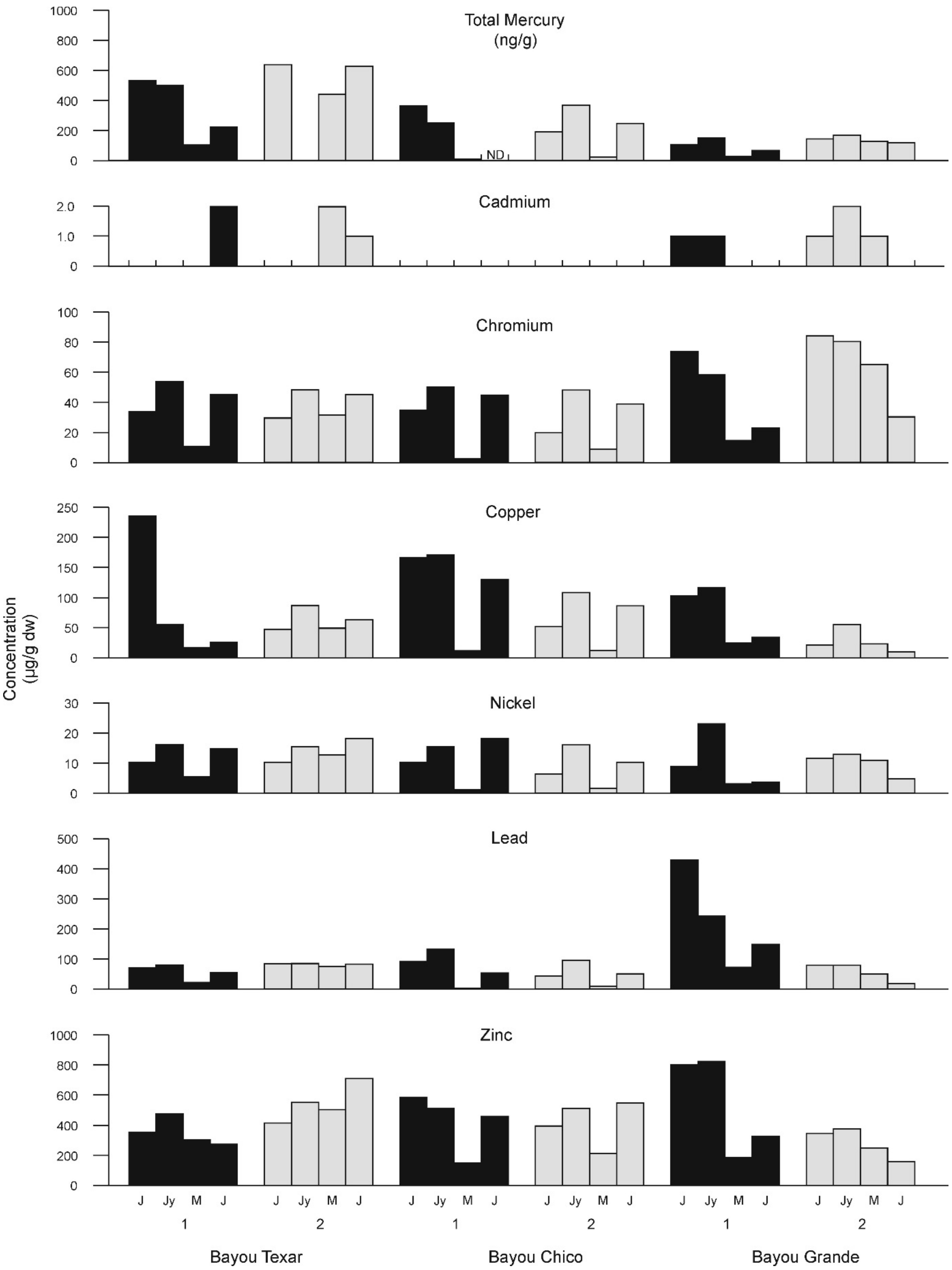


Figure 7.13 Temporal and spatial variation for trace metal concentrations (µg/g dry wt.) in sediments collected four times at two locations in each of Bayous Texar, Chico, and Grande. See Lewis et al. (2001e) and Butts and Lewis (2002) for more detail.

Sediment acute toxicity has been generally low within the PBS (Fig. 7.9) except for a few hot spots as shown for two bayous (examples, Fig. 7.14). The similarity in toxicity results also extends to that observed for the PBS and other estuaries (Fig. 7.9). In contrast, spatial differences for sublethal toxicity have been reported and found at times to be test species-specific as demonstrated by the results from Long et al. (1997). In that study, toxicity based on sea urchin fertilization in decreasing order was for sediments collected from Apalachicola Bay>Choctawhatchee Bay>Pensacola Bay>St. Andrew Bay. In the same study, the geographical order of decreasing effects was Choctawhatchee Bay=St. Andrew Bay>Apalachicola Bay>Pensacola Bay based on reductions in microbial bioluminescence. Sediment toxicity including genotoxicity in Bayou Chico was greater than that in most other sites located in Choctawhatchee, St. Andrew, and Apalachicola Bays (Unpublished results, USEPA, Gulf Breeze, FL).

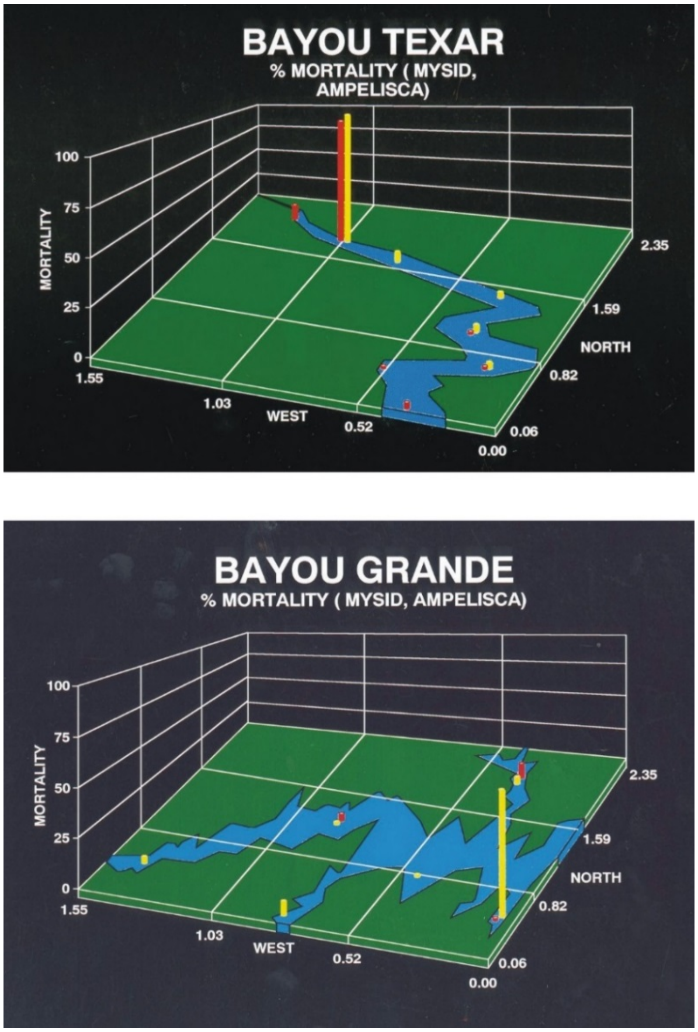


Figure 7.14 Spatial differences for mortality of two macrobenthic test species exposed to whole sediments collected from multiple stations in Bayous Texar and Grande. Yellow-*Mysidopsis bahia*; red-*Ampelisca abdita*.

Many spatial comparisons have been made within the PBS and across regional estuaries for the macrobenthos. Shannon-Weiner Index values for benthic macroinvertebrates were similar in Escambia, East, and Pensacola Bays (1981-1986), and values for Escambia Bay were less than those Hillsborough and Galveston Bays (McAfee 1986). Escambia Bay had lower biomass of infaunal and epibenthic invertebrates than other regional river-dominated estuaries (Livingston 2010). Escambia and Pensacola Bays had lower biomass, secondary production and species richness than Apalachicola, Choctawhatchee and Perdido Bays (Livingston 2005, 2010), and lower mean benthic abundance than Tampa, Charlotte and St. Andrew Bays (FDEP 2012b). The benthos in Santa Rosa Sound was more diverse and had greater biomass and number of individuals than assemblages in Escambia Bay and East Bay (Olinger et al. 1975). Escambia and East Bays also had relatively low macroinvertebrate diversity during 1979 (Ross and Jones 1979). Upper Escambia Bay and Blackwater Bays had the highest biomass of infauna and the high salinity areas of Pensacola Bay and mid-Escambia Bay had the highest diversity (Livingston 1999; FDEP 2012b).

7.9 Stressor Source Comparisons for Sediment Quality

One of the major goals of aquatic resource managers and urban planners is to understand the magnitude of the effects of the various urban stressors impacting the local resource in order to prioritize the allocation of often-limited research and remediation funds to mitigate their effects. Reported attempts to rank the severity of the impacts of common sources of chemical stressors for the PBS began in the late 1990s and extended to the 2000s (examples, Lewis et al. 2000, 2004, 2006; Lewis and Chancy 2008). The chemical and biological impacts of urban stormwater (Bayous Texar, Chico, and Grande), 11 wastewaters (Pensacola and Escambia Bays, Santa Rosa Sound) and golf course runoff (Tiger Point-Santa Rosa Sound) were evaluated in a multiyear study using identical diagnostic techniques. Some results appear in Tables 7.2 and 7.3 and a ranking summary appears in Table 7.6. The results are metric-specific but urban stormwater runoff and municipal and industrial wastewaters were at the time more detrimental than golf course runoff containing chemicals from course maintenance (pesticides, fertilizers) and treated municipal wastewater (spray irrigation). Since this evaluation 15 years ago, direct wastewater discharges have been reduced to the PBS and the golf complex has been reduced in size due to economic and climatic factors. Consequently, this has reduced their significance as stressors. In contrast, stormwater runoff although more controlled than in the past, still remains a major determinant of environmental quality.

Table 7.6 Relative ranking of stressor sources for severity of contaminated sediment quality. Identical assessment methods used for all areas. US = urban storm water runoff (Bayous Texar, Chico, Grande). WW=11 treated municipal and industrial wastewaters (Escambia and Pensacola Bays). GC=runoff from two golf courses (Santa Rosa Sound). AG=south Florida Water Management District canals and entry points into Florida Bay. Decreasing trend for all parameters. Adapted from Lewis (2005).

Metric	Ranking
TEL exceedances (>TEL≤PEL)	US > WW > GC>AG
PEL exceedances	US > GC > WW>AG
Trace metal enrichment[1]	US = WW > GC>AG
Acute Toxicity[2]	GC > US > WW
Chronic toxicity[3]	GC > WW>AG
Genotoxicity (pore water)	US > WW > GC
Benthic diversity index[4]	GC>AG>US>WW
Macroinvertebrate abundance[5]	US=AG>GC>WW
Number of taxa[6]	AG>GC>US>WW

[1] Based on total number of trace metals after normalization to aluminum (Windom et al. 1989).

[2] Based on total number of toxicity tests for *Americamysis bahia*, *Ampelisca abdita*, and *Palaemonetes pugio* where mortality was 20% or more (after control corrections).

[3] Not determined for sediments affected by urban storm water, based on results for *L. plumulosus* and *Americamysis bahia*.

[4] Based on Shannon-Wiener diversity index values of 2.0 or less.

[5] Based on 500 orgs/m^2 or less.

[6] Based on 20 taxa or less.

8 Dredging

The environmental impacts of dredging are variable, site-specific, and influenced by the magnitude and frequency of activity, methodology, intertidal area, tidal range, rate of mixing, and presence and sensitivity of animal and plant communities. Predicting effects with any degree of confidence is uncertain without this information. Near-field and far-field detrimental effects include decrease in density and diversity of the benthic community, increase in bioaccumulation of contaminants, redistribution of contaminated sediments far-field, increase in suspended solids, decrease in light penetration (may lead to hypoxia), clog gills of fish and oysters, release of organic substances which may decrease dissolved oxygen and cause algal blooms. Positive effects are restoration of water depth and flow and removal of contaminated sediments.

Repetitive dredging continues to occur in the PBS primarily for Bayous Texar and Chico due to the inadequate control of the particulate solids and contaminants entering from their increasing urbanized and industrialized watersheds. The efficacy and practicability of these continuous dredging events has been debated for years (WFRPC 2005). The more recent dredging events are those in Bayou Texar (2015) to remove sediment from a flooding event (10,000 cubic yards, cost=$670,000) and in Bayou Chico (2016; cost=$360,000) to remove contaminated sediments. The environmental effects of these dredging events are not known. In contrast, several of those for previous dredging events have been investigated sporadically (Livingston 1971; Brinson and Keltner 1981; Morgan and Stone 1989; Moshiri and Elewad 1990; EA Engineering Science and Technology 2000; Lewis et al. 2001a). Dredging operations in Mulatto Bayou (1965-1970) resulted in changes in circulation patterns and dredged pits with high levels of nutrients and low dissolved oxygen and fish kills (Livingston 1971). Chlorophyll *a* and nutrients increased in the water column and there was no long-term benefit to the benthos after navigational dredging in Bayou Chico (Brinson and Keltner 1981). It was concluded that future removal of sediments be conducted only after assurance that water quality would improve and that other sources of pollution are controlled. The environmental effects of dredging on sediment toxicity (faunal and genotoxicity), benthic community composition, colonized periphyton composition, and contaminant uptake and light penetration were evaluated in one of the few pre- and post-dredging studies conducted in Bayou Texar (Lewis et al. 2001a). Hydraulic dredging reduced the diversity of the benthic community and light penetration and altered the composition of the periphyton. Dredging reduced mercury bioavailability to the periphyton by 65% at multiple sites in Bayou Texar (Fig. 8.1); Cr, Zn, Cu, Pb, Cd, and Ni concentrations were reduced between 4-44% eight months after dredging. Acute toxicity was not altered but genotoxic activity was particularly high in recently dredged areas in Bayou Texar where effect levels (% porewater) were 22 (SD=9, range=2-44) and 20 (SD= 22, range=2-70) for direct and indirect effects, respectively. It was concluded for this small-scale dredging event that the environmental impact was localized and of short-term consequence based on the 8 mos. study duration. It was noted however that additional studies would be needed for larger-scale dredging events to validate this conclusion. Based on the above, the long-term chemical and biological effects of local dredging events are uncertain and additional supporting evidence is needed before their environmental benefit can be assumed.

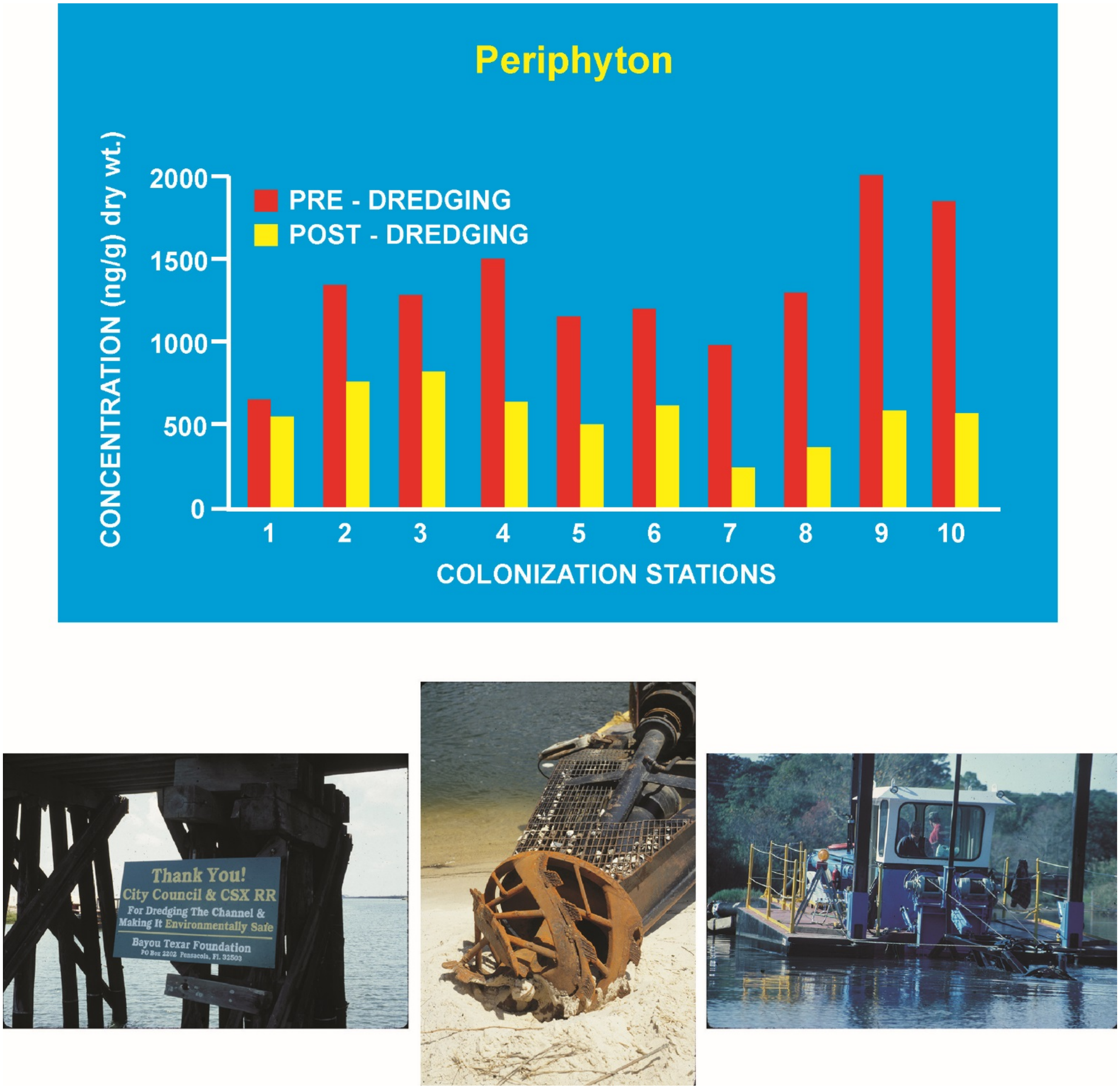


Figure 8.1 Concentrations of total mercury (ng/g dry wt.) in algal-periphyton colonized for 21 days at 10 locations in Bayou Texar prior to hydraulic dredging and 8 eight months post-dredging. Dredging occurred during 1993-1994; about 22,800 m3 sediment removed. See Lewis et al. (2001a) for more details.

9 Bioaccumulation (Contaminant Bioavailability)

Field bioaccumulation studies conducted within the PBS have been used to determine the bioavailability of at least 69 contaminants (examples, Table 9.1) for as many as 30 species of flora and fauna (Table 9.2). Bioaccumulation assessments began in earnest during the early 1970s and centered on DDT and PCBs (Duke et al. 1970; Hansen and Wilson 1970; Nimmo et al. 1971a, b; Butler 1973). The more recent and detailed studies are those of Karouna-Renier et al. (2007), Snyder and Rao (2008), and Snyder and Karouna-Renier (2009) for trace metals, furans, and dioxins in oysters, blue crabs, and fish with accompanying reports for sediments (Mohrherr et al. 2009; Liebens et al. 2011; Liebens and Mohrherr 2015). Most determinations have been for field-collected specimens although caged fish, caged oysters (Fig. 9.1), and colonized periphyton (Fig. 9.1) have been used on occasion (Hopkins and Schomer 1975; Lewis et al. 2001a, c, 2002b, 2004). Study objectives in addition to public health concerns have included determination of spatial, temporal, and species differences, and understanding the availability of chemicals associated with chromated copper arsenate (CCA)-treated wood, hydraulic dredging, wastewater discharges, urban runoff, golf course runoff, hazardous waste sites, and agriculture runoff. Accumulations of the same chemical in the above studies have been species-specific as shown for total mercury (Fig. 9.2) and chemical-specific as shown for seagrass (Fig. 9.3) and colonized algal-periphyton (Fig. 9.4). This is not unexpected, since bioconcentration patterns are influenced by as many as 22 physicochemical factors (Rai 2009) that impact biotransformation and membrane transfer kinetics, and partitioning between storage and structural lipids. Biological factors include organism type, size, age, gender, life stage, life mode, mobility, type of diet, sample preparation (skin on/off), and lipid content.

Table 9.1 Examples of anthropogenic contaminants determined in tissues of biota collected from the Pensacola Bay System.

Trace metals	PCB congeners	PCB congeners continued	Chlorinated Pesticides	Polycyclic aromatic hydrocarbons
Aluminum	8	126	Aldrin	Acenaphthalene
Arsenic	18	138	*cis*-chlordane	Anthracene
Barium	28	153	g-Chlordane	Benzo (a) anthracene
Cadmium	29	154	Dieldrin	Benzo (a) pyrene
Chromium	44	170	Lindane	Benzo (b) fluoranthene
Copper	50	180	Heptachlor	Benzo (g,h,I) perylene
Iron	52	187	Heptachlor epoxide	Benzo (k) fluoranthene
Lead	66	188	Hexachlorobenzene	Benzo (e) pyrene
Manganese	77	195	Mirex	Chrysene
Mercury	87	201	Trans-nonachlor	Dibenz (a,h) anthracene
Nickel	101	209	2,4′ –DDE	Fluoranthene
Selenium	104		2,4′ –DDD	Fluorene
Silver	105		2,4′ –DDT	Indeno (1,2,3-c,d) pyrene
Tin	118		4,4′ –DDD	Napthalene
Zinc			4,4′ –DDE	2-Methylnapthalene
			4,4′ –DDT	1-Methylnapthalene
				2,6 Dimethylnaphthalene
				2,3,5-Trimethylnapthaline

Table 9.2 Thirty species of flora and fauna collected from the Pensacola Bay System which have been analyzed for anthropogenic contaminants.

Common Name	Scientific Name
Turtle Grass	*Thalassia testudinum* Banks ex Konig
Shoal Grass	*Halodule wrightii* Aschers
Widgeon Grass	*Ruppia maritina* Linnaeus
Mussels (freshwater)	*Utterbackia imbecillis*
	Lampsilis straminea
	Lampsilis claibornesis
	Villosa villosa
Seaweed	*Ceramium* sp.
Colonized algal periphyton	
Eastern oyster	*Crassostrea virginica* Gemlin
Brackish clam	*Rangia cuneata* Gray
Barnacle	*Balanus eburneus*
Mussel	*Brachydontis recurvis*
Shrimp	*Farfantepenaeus* spp.
Blue crab	*Callinectes sapidus* Rathbun
Hardhead catfish	*Arius felis* Linnaeus
Channel catfish	*Ictalurus punctatus* Rafinesque
Atlantic croaker	*Micropogonias undulatus* Linnaeus
Bluegill	*Lepomis macrochirus* Rafinesque
Bluefish	*Pomatomus saltatrix*
Flounder	*Paralichthys* spp.
Jack crevalle	*Caranx hippos* Linnaeus
Largemouth bass	*Micropterus salmoides* Lacepede
Pompano	*Trachinotus carolinus*
Red drum	*Sciaenops ocelatus*
Sheepshead	*Archosargus probatocephalus*
Spotted seatrout	*Cynoscion nebulosus*
Striped mullet	*Mugil cephalus*
Spot	*Leiostomus xanthurus* Lacepede
White trout	*Cynoscion arenrius*
Oyster drill snail	*Thais haemostoma*

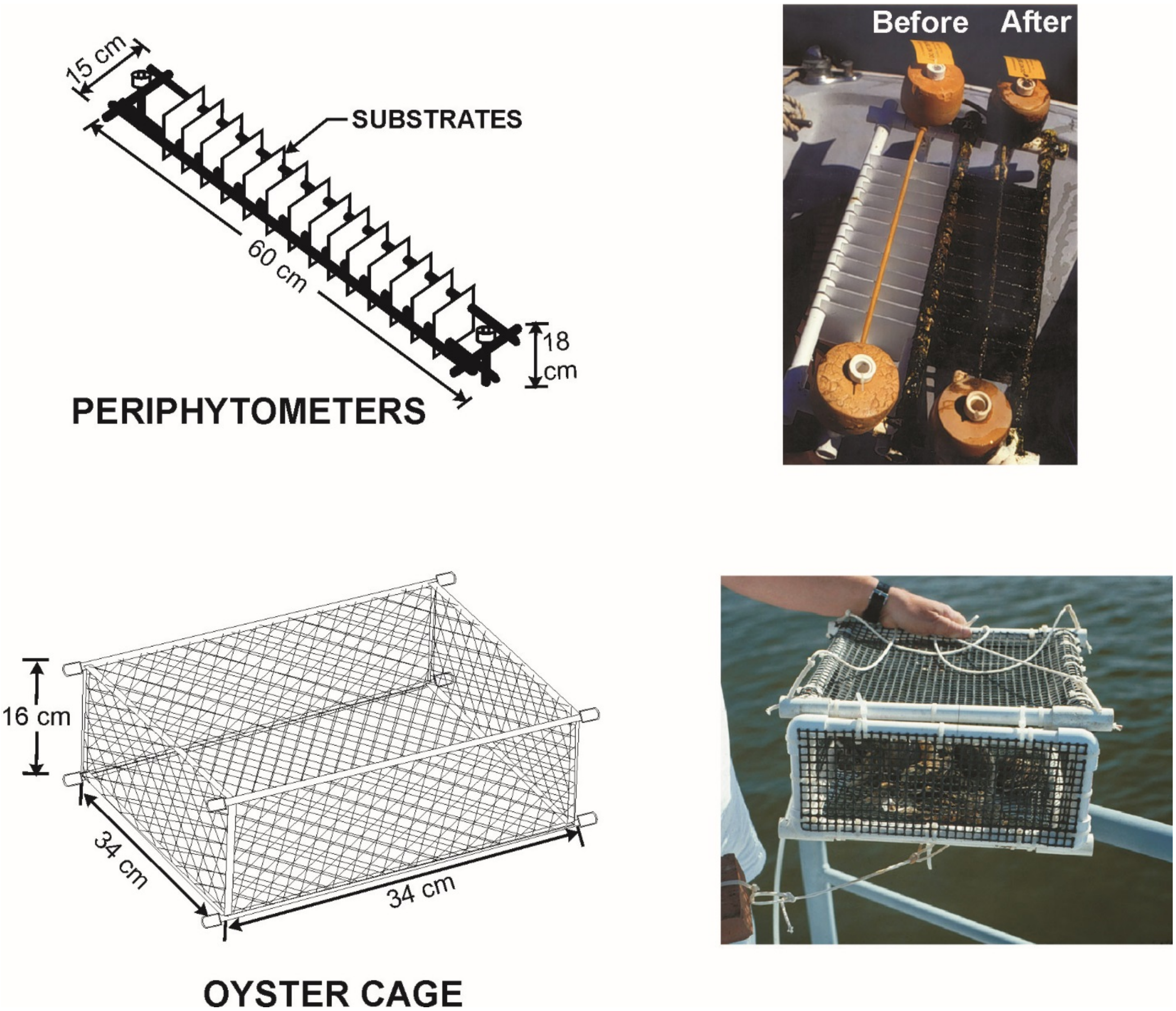


Figure 9.1 Oyster cage and periphytometer containing acrylic substrates used to determine structural parameters and contaminant bioavailability in the Pensacola Bay System. Periphytometers are shown before and after 21 day in-situ colonization period.

9.1 Trace Metals (Sans Mercury)

The fate of trace metals, including the biologically non-essential Cd and Pb, and the essential Cu and Zn, have been the focus of multiple bioaccumulation studies. The descending order of trace metal accumulations in periphyton, oysters, seagrass, blue crabs, mussels, and fish appears in Table 6.1. Much of the database consists of information for mollusks, particularly the Eastern oyster, *Crassostrea virginica*. Trace metal concentrations (ppm wet wt.) for this species collected from approved shellfish harvesting areas in Escambia and East Bays ranged from 0.08 (Pb) to 433.8 (Zn) and in decreasing order were Zn>Fe>Cu>Al-Mn>As>Cd>Ni>Se>Cr>Pb (Barnet and Gunter 1985). Oysters collected from Pensacola Bay have been analyzed for trace metals since 1986 as part of the National Mussel Watch Program (NOAA National Status and Trends Program) and the results have been periodically summarized (FDEP 1998; Cantillo et al. 2001; Kimbrough et al. 2008, 2009). In a more recent Mussel Watch Program report, concentrations of As, Ni and Pb in oysters collected during 2004-2005 from Sabine Point, Indian Bayou and the public harbor area of Pensacola Bay were judged regionally high (Kimbrough et al. 2008). Oliver et al. (2003) reported concentrations of 16 trace metals, including tributyl tin in oysters collected from East Bay and Bayou Chico and compared them to internal defense mechanism activity. Oysters collected from Bayou Chico were approximately three-times more contaminated (total metal concentration) than those collected from East Bay. The mean total metal concentration (µg/g dry wt., 16 trace metals) was 15,706 (Bayou Chico) and 5,142 (East Bay). Defense mechanism activity increased with increasing contaminant concentrations. Karouna-Renier et al. (2007) reported the concentrations for 10 trace metals in oysters and blue crab muscle and hepatopancreas collected from 23 stations from the PBS. Weis et al. (1993) analyzed Cu, Cr and As in an alga (*Ceramium* sp.), barnacle (*Belanus eburneus*), and mussel (*Brachidontes recurvus*) collected from CCA treated wood in Santa Rosa Sound. The metals were elevated in all cases, particularly on treated wood less than one year old. Freshwater mussels (*Villosa villosa*, *Lampsilis straminea*, *Lampsilis teres*, *Uterbacki embicillis*) were collected from seven locations in the lower Escambia River during 1995/96 and analyzed for trace metals (Unpublished results, USEPA, Gulf Breeze, FL). Copper (range= 0.5-3.7) and zinc (range= 9.5-63.6) were concentrated in greater concentrations (µg/g wet wt.). Snyder and Rao (2008) reported that concentrations of As, Cd, Cu, and Pb were low in five fish species collected from Escambia Bay near the I-10 bridge.

The bioaccumulation potential for primary producers in the PBS is less understood than that for faunal species. Lewis et al. (2004, 2007) reported trace metal concentrations in above and below ground tissues of seagrass (Fig. 9.2) and colonized periphytic-algae (Lewis et al. 2001a, c, 2002b, 2004) (Fig. 9.3). Concentrations in seagrass were relatively low and less than those in their rooted sediments and in colonized periphyton. Mean bioconcentration factors (concentration in biota/concentration in water) for eight trace metals in biota collected from Santa Rosa Sound ranged between 519-26,467 (periphyton) and 26-11,033 (seagrass) relative to 44-8,718 (blue crabs) and 87-162,625 (oysters) (Lewis et al. 2004).

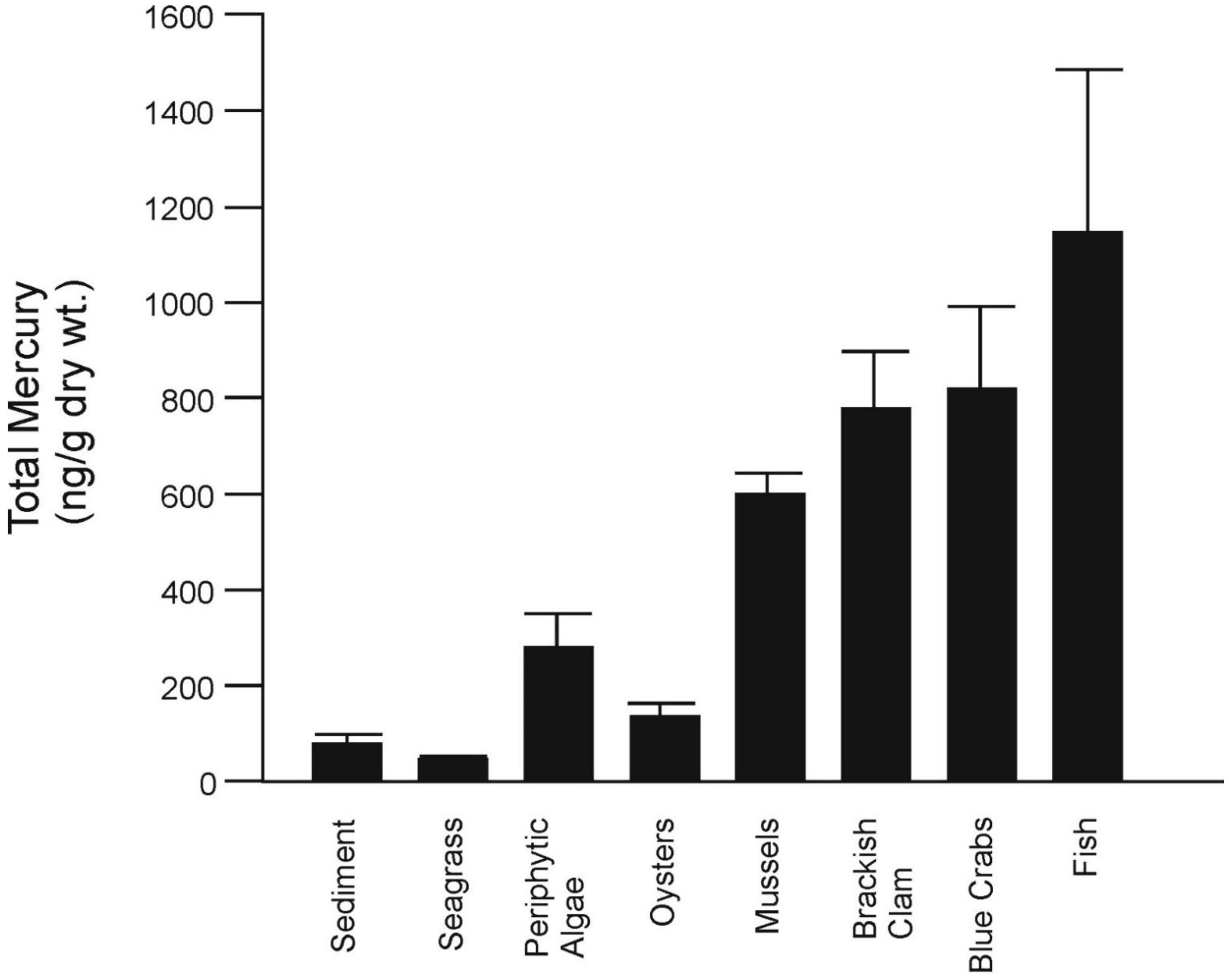


Figure 9.2 Total mercury concentrations (ng/g dry wt.) in sediment and various biota collected from the Pensacola Bay System during 1993-2001. Values represent means (±1 SD). Sample sizes ranged 7-262. From Lewis and Chancy (2008).

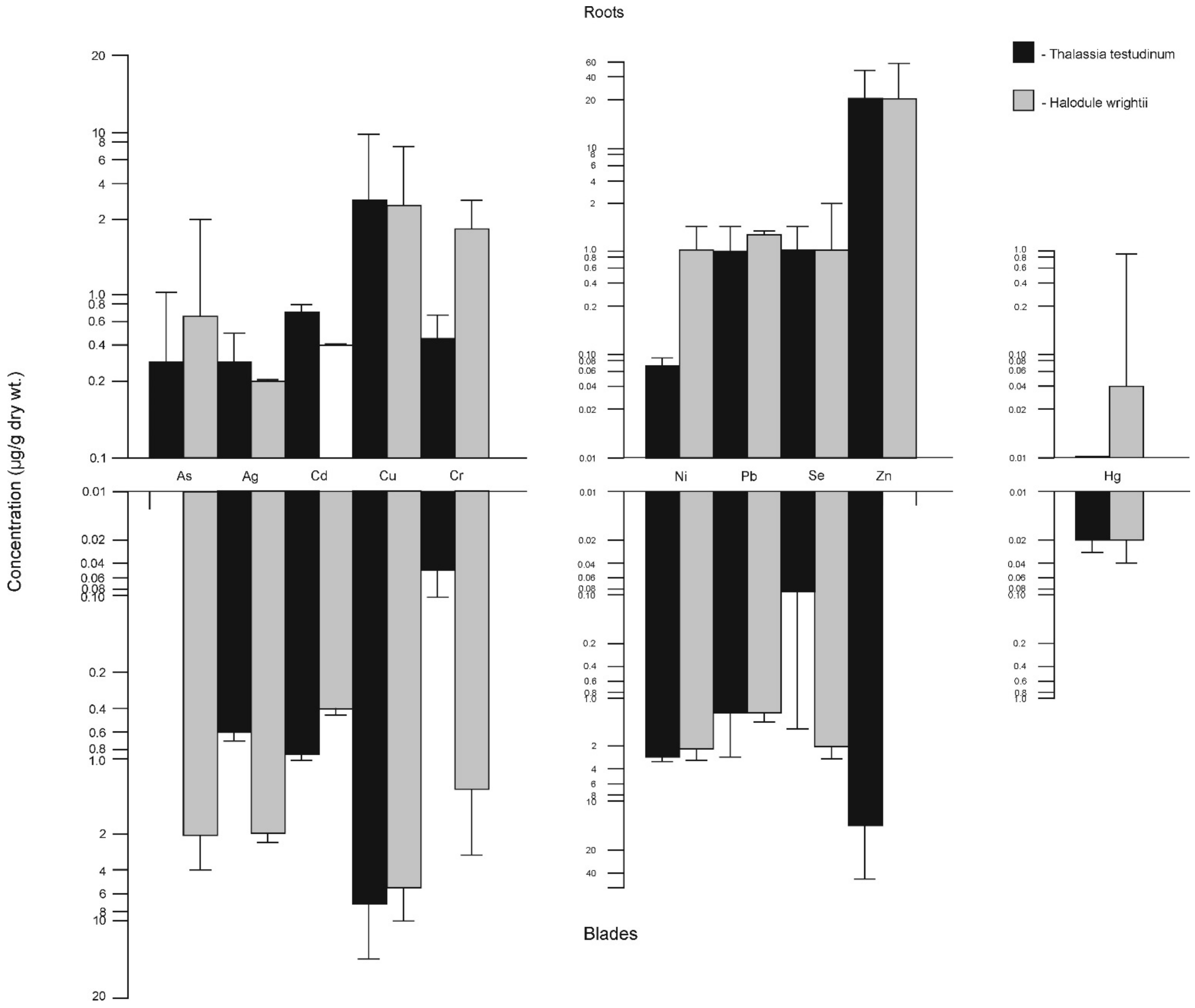


Figure 9.3 Trace metal concentrations (µg/g dry wt.) in roots and blades of the seagrass *Thalassia testudinum* (turtle grass) and *Halodule wrightii* (shoal grass) collected from the Pensacola Bay System. Values represent means (±1 SD). Results from Lewis et al. (2007b).

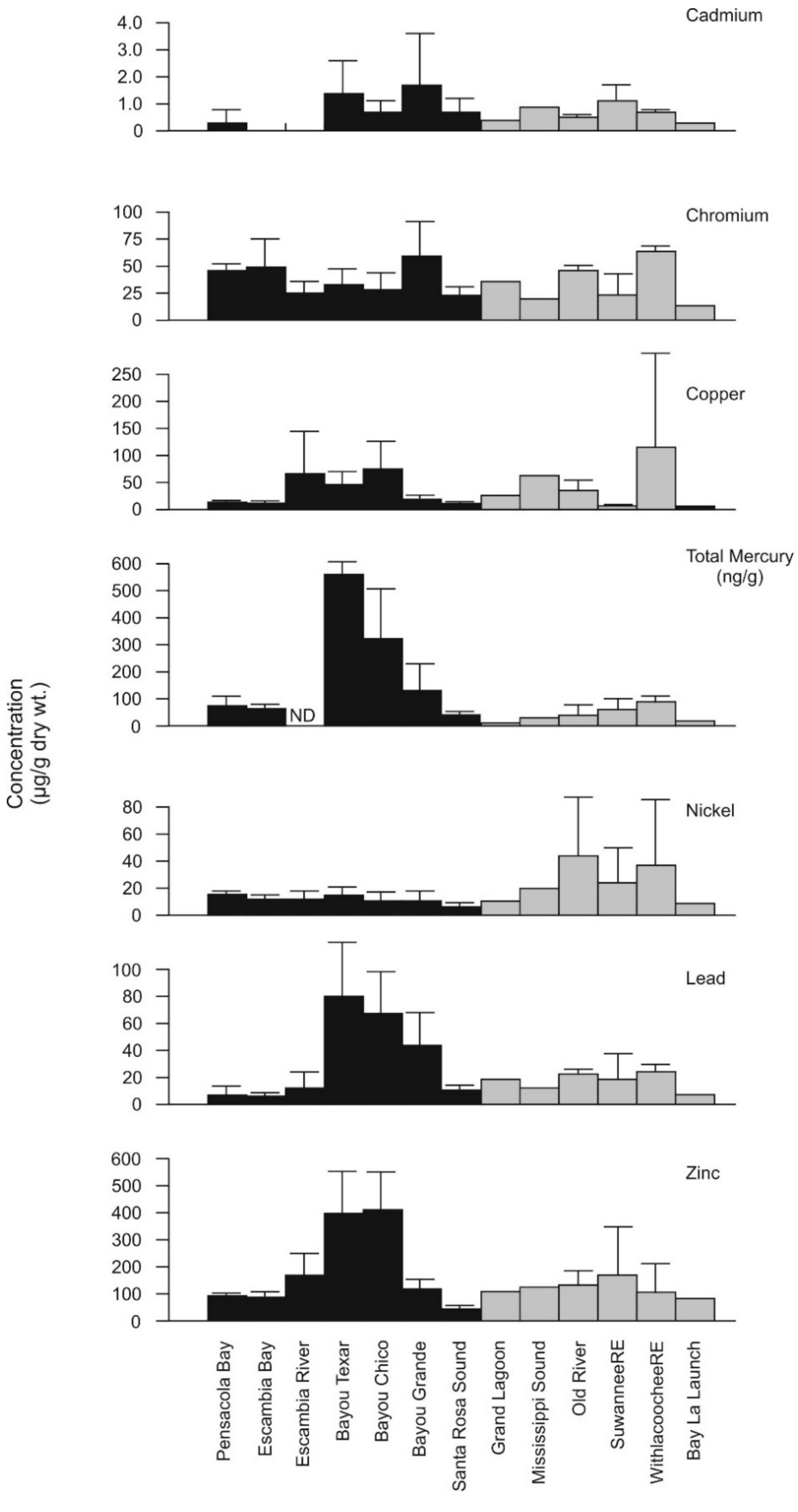


Figure 9.4 Trace metal concentrations (µg/g dry wt.) in the algal-periphyton after 21 days colonization in the Pensacola Bay System and proposed reference areas (Fig. 1.3) during 1993-1996. Values represent means (±1 SD). Unpublished results (USEPA, Gulf Breeze, FL).

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9.2 Non-Nutrient Organic Chemicals

Bioaccumulation information for persistent organic pollutants such as polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins and furans, polycyclic aromatic hydrocarbons, and the organochlorine pesticides DDT, toxaphene, chlordane, and lindane is less common than that for trace metals. This information is important since these chemicals magnify in the food chain, do not degrade readily, and several can have public and wildlife health consequences. The importance of understanding their biological uptake was first reported for DDT (Hansen and Wilson 1970; Butler 1973). DDT metabolites in East Bay oysters ranged from 10-26 ppb (Butler 1973). Total pesticides (ng/g dry wt.) averaged 83.8 (SD=81.6) in oysters from Bayou Chico and 6.9 (SD=3.1) in those from East Bay (Oliver et al. 2003). Total PAH concentrations (ng/g dry wt.) in the same study averaged 6,225 (SD=1973.8) and 69.3 (SD=36.9) for oysters from Bayou Chico and East Bay, respectively. Total pesticide concentrations in Atlantic croaker (*Micropogonias undulatus*) and spot (*Leiostomus xanthurus*) collected from Pensacola Bay, Bayou Texar, and Bayou Grande averaged for all collection sites were between 2.7 and 9.7 ng/g wet wt. (Unpublished results, USEPA, Gulf Breeze, FL). Long-term information is available from the Mussel Watch Program. Cantillo et al (2001) reported that tDDT concentrations in oysters from three locations in the PBS during 1986-1996 were usually 60 ppb or less. Concentrations at the same sites during 2004-2005 were between 7.9-20.0 ppb (Kimbrough et al. 2008). The order of accumulation in oysters collected from Sabine Point, Indian Bayou, and the public harbor area of Pensacola Bay during 2004-2005 was PAHs>PCBs>DDT>butyltins=chlordane>dieldrin (Kimbrough et al. 2008). Concentrations ppb of PCBs in oysters ranged from 28-83 in the same study. Downward trends were reported for butyltins, total chlordane, total DDT, dieldrin, PAHs, and PCBs. Across-regional comparisons are available for pesticide concentrations in oysters and fish collected from the PBS and other Florida, Gulf of Mexico, and U.S. coastal areas (Cantillo et al. 2001; Kimbrough et al. 2008).

The bioaccumulation of contaminants originating from an on-shore Superfund hazardous waste site has been evaluated. Excess preservative fluid containing creosote and pentachlorophenol were stored for up to 80 years in unlined ponds which eventually entered Bayou Chico and adjacent nearshore areas of Pensacola Bay. The bioaccumulative effects of PAH-contaminated groundwater and runoff from the wood-treatment facility, American Creosote Company, was determined by Rostad and Pereira (1987) and Elder and Dresler (1988). Tissues for the field collected oyster drill snails (*Thais haemastoma*) and caged oysters were analyzed for 13 PAHs, 7 nitrogen heterocycles, 2 sulfur heterocycles, and an oxygen heterocycle. Total PAH concentrations (µg/kg wet wt.) in snails ranged from 1-194. Accumulation of fluoranthene, pyrene, and phenanthrene, but not napthalene, were up to ten times greater than for both species collected from control sites located across Pensacola Bay.

10 Public Health Risk

Shrimp, oysters, blue crabs, and fish are harvested from the PBS for human consumption, more so in the past than currently. Many reports describing the size and economic value of the harvests are available for 1964-2009 (Olinger et al. 1975; Hopkins 1983; Lewis T 1986; FDEP 1998; Snyder and Karouna-Renier 2009; Lewis FG 2010). Annual landings (approximate values in lbs.) have ranged from 66,000-4,600,000 (fish), 400-137,000 (blue crabs, *Callinectes sapidus*), 0-492,000 (Eastern oysters, *Crassostrea virginica*), and 43,000-906,000 (penaeid shrimp). Snyder and Karouna-Renier (2009) estimated 2008 seafood landings (individuals) for Escambia and Santa Rosa Counties as approximately 18,900 (*C. virginica*), 133,000 (brown shrimp, *Farfantepenaeus azteca*), 137,000 (*C. sapidus*), and 380,000 mullet (*Mugil cephalus*). Total combined landings for spot (*Leiostomus xanthurus*), spotted seatrout (*Cynoscion nebulosus*), black drum (*Pogonias cromis*), Atlantic croaker (*Micropogonias undulatus*), white trout (*Cynoscion arenius*), flounder (*Paralichthys* spp.), and sheepshead (*Archosargus probatocephalus*) was about 454,000 individuals.

The public risk of consuming chemically-contaminated seafood collected from the PBS, like that for the presence of pathogens, is of concern and has been the focus of many bioaccumulation surveys particularly for the presence of methylmercury, PCBs, and dioxins/furans. Methylmercury impairs brain development in developing fetuses of pregnant mothers exposed to the toxin and impacts hearing, vision, and muscle coordination in adults. Polychlorinated biphenyls (PCBs), a group of 209 chemicals, are probable carcinogens and can affect hormone functions, development, and the immune system in humans (Carpenter 1998). The public health risk from consuming biota containing trace metals such as Cd and Zn (example, Mohrherr et al. 2009) has also been reported. In contrast, concentrations of other potentially harmful contaminants to humans such as the persistent, toxic, and broadly distributed perfluorinated compounds (PFCs) have not been reported for PBS biota (USEPA 2013a, b). Also, scarce are reports for polybrominated diphenyl ethers (PBDEs, flame retardant chemicals). Concentrations in oysters collected from the PBS during 1996-2007 in the only known report were between 1.8 and 6.7 ng/g (Kimbrough et al. 2009).

10.1 Mercury

Methylmercury contamination in some fish is the leading cause of water quality impairment in Florida's estuaries (FDEP 2014). The primary source of mercury to the PBS is the atmosphere (Landing 2010; Caffrey 2010; Caffrey et al. 2010). Mercury advisories have been issued for Escambia, Blackwater, and Yellow Rivers and largemouth bass (*Micropterus salmoides*) and seaward for species such as King mackerel (*Scomberomorus cavalla*) and Spanish mackerel (*Scomberomorus maculatus*) that enter the PBS. As a result, TMDLs (total maximum daily loads) for mercury in fish and shellfish have been issued for several PBS areas (FDEP 2010a).

Mercury concentrations have been reported in many edible and non-edible biota collected from the PBS. Concentrations in non-edible species provides information on trophic transfer. Total mercury, not methylmercury, has been the usual form of mercury reported for seafood safety studies since the analysis for methylmercury is less economically feasible. It has been assumed that methylmercury and total mercury concentrations are equitable. This assumption is a conservative approach, however, since methylmercury concentrations represent about 75 to 95% of total mercury in aquatic biota (Bloom 1992; Lasorsa and Allen-Gil 1995; Kannan et al. 1998).

10.1.1 Fish

Total mercury usually occurs at low concentrations for many levels of the PBS food chain (Table 6.1) but not so for fish and blue crabs (*C. sapidus*) (Fig. 9.2). Rider and Adams (2000) reported that the mean concentration of mercury in 89 spotted seatrout (*C. nebulosus*) collected from Pensacola Bay (1993-1996) was 0.4 (SD=0.15, range=0.11-0.88, median=0.39) ppm. The more recent evaluations for mercury contamination are those of Snyder and Karouna-Renier (2009) for 23 estuarine fish species and Snyder and Rao (2008) for five fish species. Concentration ranges (µg/g wet wt.) for several common PBS species were 0.025-0.092 (sheepshead, *A. probatocephalus*), 0.1-0.64 (spotted seatrout, *C. nebulosus*), 0.12-0.26 (white trout, *C. arenrius*), 0.07-1.1 (red drum, *Sciaenops ocelatus*), 0.017-0.059 (Atlantic croaker, *M. undulatus*), 0.14-0.21 (flounder, *Paralichthys* spp.), and 0.008-0.026 (Striped mullet, *M. cephalus*) (Snyder and Karouna-Renier 2009). Total mercury (µg/g wet wt.) in fish collected near wastewater outfalls in Pensacola Bay averaged 0.24 (SD=0.06, range=0.08-0.47) and 0.48 (SD=0.2, range=0.29-0.68) for Escambia Bay (Lewis et al. 2002c).

10.1.2 Blue Crabs

Karouna-Renier and Snyder (2007) reported total mercury concentrations in *C. sapidus* collected from 23 PBS stations during 2003-2004. The concentrations (µg/g) in muscle and hepatopancreas samples ranged from 0.07 to 0.23 and 0.02 to 1.1, respectively. Total mercury concentrations (µg/g) in edible tissues of blue crabs collected during the 1990s averaged 0.17 (SD=0.038), 0.14 (SD=0.13), 0.053.0 (SD=0.023), 0.088 (SD=0.017), and 0.19 (0.14), respectively, for Bayous Texar, Chico, and Grande, and Escambia Bay and Santa Rosa Sound (Unpublished results, USEPA, Gulf Breeze, FL).

10.1.3 Oysters/Mussels

Eastern oysters (*C. virginica*) have been commonly analyzed for total mercury. Oysters collected 30 years ago from approved harvesting areas in Escambia and East Bays contained on average 0.02 (range=0.01-0.03) µg/g wet wt. of mercury (Barnett and Gunter 1985). Mercury in oysters collected from the PBS during 1986-1996 were 0.3 ppm or less (Cantillo et al. 2001). Total mercury concentrations averaged 0.19 (SD=0.04) and 0.42 (SD=0.09) µg/g dry wt., respectively for Bayou Chico and East Bay oysters (Oliver et al. 2003). Oysters collected from 23 PBS stations contained total mercury ranging from 0.006-0.075 µg/g wet wt. (Karouna-Renier et al. 2007). For comparison, concentrations in oysters collected from the proposed reference areas (Fig. 1.3) averaged 0.01 (SD=0.003) µg/g wet wt. In an unique evaluation, total mercury concentrations in five species of mussels (Table 9.1) collected from seven locations in the lower Escambia River during 1995 ranged from 0.027-0.123 µg/g wet wt. (Unpublished results, USEPA, Gulf Breeze, FL).

10.1.4 Exceedance of Consumption Guidelines

The mercury concentrations reported above have been compared to various numerical screening levels and consumption guidelines to protect public health. Consumption guidelines are not regulations but recommendations. Guidelines commonly used include the USEPA maximum advisable methylmercury fish tissue concentration of 0.3 ppm to protect human consumers (USEPA 2001), the State of Florida Total Maximum Dailey Load thresholds of 0.3 ppm (general population) and 0.1 ppm total mercury (women of child-bearing age and children) (FDEP 2013a), the Food and Drug Administration action level of 1.0 ppm methylmercury (USFDA 2011), and the USEPA risk-based screening levels of 0.4 ppm (recreational fishers) and 0.049 ppm (subsistence fishers) (USEPA 2000b). The two screening concentrations are used to estimate contaminant risk for consumers of non-commercially caught fish and are intended to be used by local, state and regional health officials responsible for issuing human health consumption advisories.

The exceedance frequency of consumption guidelines for humans varies (Fig. 10.1) due to differences for species-, tissue-, location-, and consumption frequency and portion size. Generally, risk is least for shrimp and greater for blue crabs and fish. Mercury concentrations in soft tissues of oysters and shrimp did not exceed any consumption guideline based on results of multiple studies reviewed for this summary. No mercury concentrations in fish, oysters, blue crabs, and freshwater mussels collected by the USEPA personnel from 98 sites in the PBS during 1993-2000 exceeded the USFDA action limit of 1.0 ppm based on a compilation of previously reported and unreported data. However, 5 of 41 (12%) blue crab samples, and 24 of 89 (27%) fish samples exceeded the USEPA criterion value of 0.3 ppm. The EPA screening levels for subsistence fishers (0.049 ppm) was exceeded for 42 of 47 (89%) oyster and blue crab samples and 2 of 47 (4%) samples exceeded the recreational fishers guideline of 0.4 ppm. Using published databases (Karouna-Renier et al. 2007; Snyder and Rao 2008; Snyder and Karouna-Renier 2009), exceedance of the mercury guidelines/thresholds of 0.3, 0.4, and 1.0 ppm was between 1-5% for total samples of oysters, blue crabs, and fish. In contrast and for the same studies, 50% of the samples exceeded the subsistence fisher guideline of 0.049 ppm. About 45% of 88 fish samples (seven species) and 88% of blue crab muscle samples exceeded the 0.1 ppm State of Florida threshold for women of child-bearing age and children. Thirty-two blue crab tissue and hepatopancreas samples exceeded the screening value of 0.15 ppm mercury used by Karouna-Renier et al. (2007). None of the oyster samples exceeded the screening value but 34 of 53 samples for striped mullet, Atlantic croaker, flounder, red drum, sheepshead, speckled trout, and white trout did (Snyder and Karouna-Renier 2009).

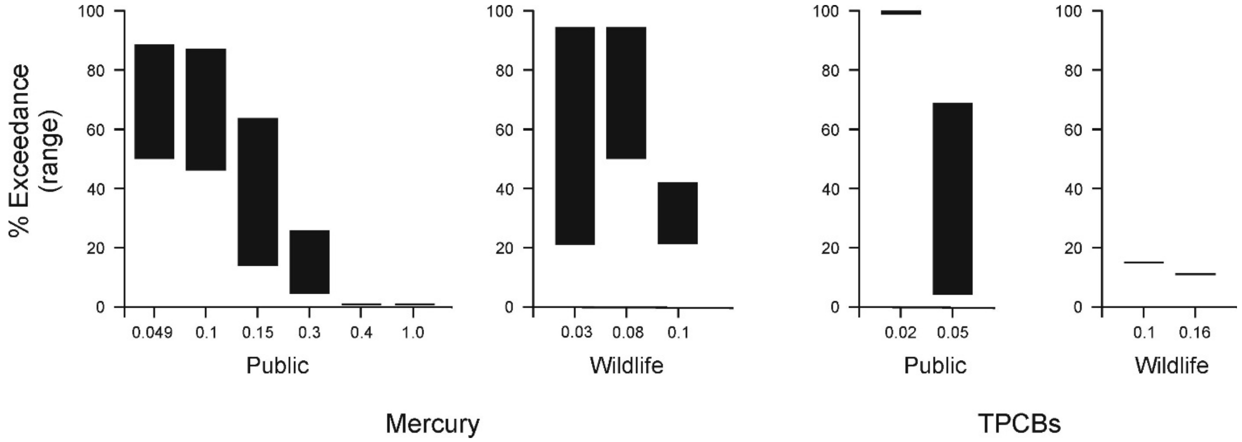


Figure 10.1 Exceedance of consumption advisory levels for mercury and total PCBs for protection of public health and wildlife consumers of aquatic life. Values represent exceedance range based on the comparisons of multiple guidelines (ppm) and bioaccumu lation results from primarily Snyder and Karouna-Renier (2009), Karouna-Renier et al. (2007) and Snyder and Rao (2008) for shrimp, oysters, blue crabs and fish.

The health risk of consuming mercury-contaminated seafood may be overstated in those cases where concentrations have exceeded consumption benchmarks. As previously stated, methylmercury concentrations are often considered equivalent to those for total mercury, which is not the case (usually 10-20 % less). In addition, a possible mitigating health factor is the co-occurring presence of selenium (Ralston 2005, 2008; Ralston et al. 2008). Molar ratios of Se/Hg greater than one are thought by some to reduce the toxicity of methylmercury (Ralston et al. 2008). Co-occurring selenium concentrations have not been reported in mercury-focused studies conducted in the PBS. Consequently, Se-Hg ratios and the related Selenium Health Benefit Values (Ralston 2008; Berry and Ralston 2008; Rezayi et al. 2012) are not available. However, results for other northern Gulf of Mexico areas are available that suggest lower risk (Lewis and Harwell 2016 Draft). The mean Se:Hg ratios for about 500 samples of fish and shrimp collected during 2000-2006 from northern Gulf of Mexico near-shore areas including the PBS was 191 (whole fish and shrimp, range=7-493) and 59 (filleted fish, range=4-191). The analyses were for fish commonly collected in the PBS such as spot (*L. xanthurus*), Atlantic croaker (*M. undulatus*), and pinfish (L. *rhomboides*). Selenium Health Benefit Values averaged 47 (fish fillets, range=1-184) and 86 (whole fish and shrimp, range= 4-550) suggesting minimal risk of human consumption.

Only one study has reported a public health risk for trace metals (inorganic As, Cd, Zn) other than mercury (Karouna-Renier et al. 2007). Of these, exceedance of screening values was more frequent for inorganic As (concentrations converted from total As). The USEPA screening value of 0.01 mg/kg as was exceeded for 100% (crab hepatopancreas), 93% (edible crab tissue), 54% (crab muscle), and 96% (oyster) of samples. Arsenic, cadmium, and zinc pose a health risk to human consumers of seafood collected from Escambia Bay and River (Mohrherr et al. 2009). Exposure to high concentrations of As, Cd and Zn can result in cancer, kidney, lung and bone diseases, reduced nerve development, and immunity and growth problems.

10.2 PCBs (Polychlorinated Biphenyls) and Dioxin Furans

Reported PCB concentrations in PBS media are not all equivalent which needs to be considered in across-study comparisons for their presence in PBS biota. The commonly reported measure of “total PCBs” often represents different numbers of congeners. Concentrations of single congeners, groups of congeners, and all 209 congeners have been reported.

A historical perspective on PCB accumulation in biota from the PBS and the Gulf of Mexico is available from Snyder and Karouna-Renier (2009). PCB residues were first detected in shrimp in Escambia Bay in 1969 (Terrebonne 1973) and have been reported in other PBS biota thereafter (Duke et al. 1970; Nimmo et al. 1971a, b; Hopkins 1975; Butler 1973; Wilson and Forester 1978; FDEP 1998; Rider and Adams 2000; Kimbrough et al. 2008). Dioxins/furans and dioxin-like PCBs have been reported in seafood from Bayous Texar, Chico, and Grande (Mohrherr et al. 2006, 2008; Liebens et al. 2011). PCBs in oysters have been determined for 30 years as part of NOAA’s Mussel Watch Program. Of the three sites in the PBS, total PCB concentrations (18 congeners) were greater for oysters from Indian Bayou (Escambia Bay), which ranged from 300-800 ng/g dry wt. (Casillo et al. 2001). Mean concentrations of total PCBs (18 congeners; ng/g dry wt.) in oysters collected from Bayou Chico in 1998 averaged 368.1 but were below detection in East Bay oysters (Oliver et al. 2003). Concentrations of dioxins/furans and dioxin-like PCBs were determined for oysters (*C. crassostrea*) and male blue crabs (*C. sapidus*) collected from 24 sites in the PBS (Karouna-Renier et al. 2007). The USEPA recreational screening value of 0.098 pg/g was exceeded at all locations for dioxins/furans and dioxin-like PCBs. Areas of the higher carcinogenic and non-carcinogenic health risks were Bayous Texar, Chico, and Grande and western Escambia Bay. Oysters from Escambia and East Bays and crabs from East and Blackwater Bays generally contained lower levels of contaminants.

The most detailed and current analysis of PCBs and PCB-like chemicals in fish is that reported by Snyder and Karouna-Renier (2009). Concentrations of 17 dioxin/furans and 12 dioxin-like PCB congeners (as well as Hg) were reported for shrimp and 24 fish species. Mullet (*Mugil cephalus*) contained the highest total PCB concentrations of all fish (range=2-1,580 µg/kg), particularly those collected from upper and west Escambia Bay-areas impacted by the hydraulic fluid/PCB discharge to the Escambia River discovered in 1969. It was concluded that dioxins/furans and dioxin-like PCBs were elevated throughout the PBS and that “serious PCB contamination” exists. The exceptions were Blackwater and East Bays, lower Pensacola Bay, and Santa Rosa Sound, which were considered “green areas” relative to tissue quality. In another study, the mean concentration for mullet collected near the I-10 bridge (upper Escambia Bay) were between 284-1,580 µg/kg and most fish tissues exceeded the

USEPA and Florida threshold concentrations of 20 ng/ and 50 ng/g total PCBs, respectively (Snyder and Rao 2008). As a follow-up to the Snyder reports, 60 *M. cephalus* were collected from Escambia, East and Pensacola Bays, and Santa Rosa Sound and analyzed for 19 of 209 PCB congeners (Goff 2009). The decreasing spatial order of accumulation was for fish collected from upper Escambia Bay>lower Escambia Bay>Pensacola Bay>East Bay=Santa Rosa Sound. Concentration ranges (ng/g) for mullet were 24-88 (upper Escambia Bay), 18-109 (lower Escambia Bay), 12-48 (Pensacola Bay), and below detection (East Bay and Santa Rosa Sound).

PBS biota contain PCBs above State of Florida health advisory concentrations. Total PCB concentrations (tPCB) reported by Goff (2009), Snyder and Rao (2008) and Snyder and Karouna-Renier (2009) for fish are compared below to Florida Department of Health advisory concentrations for tPCBs based on consumption of an 8 ounce meal. These health advisory concentrations are <50 ppb unlimited; 50-100 ppb one meal per week; 110-500 ppb one meal per month; and >500 ppb do not eat. Exceedance of these advisory levels for 177 fish samples was, respectively, about 69%, 14%, 12%, and 3%. Goff (2009) reported that of the 24 fish collected from Escambia Bay, eight contained total PCBs between the 50-100 ppb advisory concentration and one fish contained in excess of 100 ppb. Based on these results, it was concluded that the consumption of skinless striped mullet (*M. cephalus*) collected from upper and lower Escambia Bay should be limited to one 8-ounce meal per week. In contrast, unlimited amounts of fish could be eaten from Pensacola Bay, East Bay, and Santa Rosa Sound. Snyder and Rao (2008) reported that 21 fish samples representing five species exceeded a USEPA screening threshold of 20 ng/g tPCBs. Mohrherr et al. (2009) discusses the cancer risk of consuming PCB-contaminated seafood from upper Escambia Bay and lower Escambia River.

10.3 Fecal Coliform Bacteria and Pathogens

Although not chemically-related and not discussed in detail for this summary, the presence of high numbers of coliform bacteria in surface water and some biota is an indication of the possible presence of disease causing bacteria, viruses, and protozoa. Stormwater runoff containing fecal coliforms, largely a result of high rainfall, enters the PBS. Unsafe swimming conditions were reported as early as 1973 for Bayous Chico and Texar, Sanders Beach (Pensacola Bay), upper Escambia Bay, and Blackwater Bay (Terrebonne 1973). Periodic warnings continue to be issued for these areas (Fig. 6.1). The most recent for Bayou Texar occurred in 2015. A Bayou Chico Basin Management Action Plan to reduce fecal coliform bacteria has been in place since 2011. Nevertheless, exceedance of State criterion levels were about 23% and 32% of the approximately 650 water samples collected from two Bayou areas during 2009 and 2015. The most acute public health issue for Bayou Grande are fecal coliforms in surface water (Mohrherr et al. 2008). Consumption of fecal contaminated oysters is controlled in part by seasonally and spatially limiting the oyster harvest areas. The limitation can be severe. Escambia County had no approved harvesting areas from 1951-1986 (Lewis T 1986). Currently, oyster harvesting is seasonally permitted in middle and lower Escambia Bay and East Bay. In addition to coliform bacteria, the elevated presence of the pathogen *Vibrio vulnificus* (biotype 1) in estuarine water (entry through pre-existing wounds and in under cooked shellfish and blue crabs) is of particular concern since it is the number one cause of seafood-borne death from any food source in Florida (Hlady et al. 1993) and cause of 95% of all seafood deaths in the U.S. (Oliver 2005). To date (August, 2015), 17 cases (7 deaths) have occurred in Florida due to its presence (South Marion Citizen; accessed 2016 July 13). Consequently, the presence of pathogens is more of a public health issue than consumption of chemically-contaminated seafood.

11 Organismal Health Risk

Tissue-accumulated chemicals can have no, reversible, or irreversible adverse effects on the organism depending on measures of metabolism, partitioning to target and non-target sites, and excretion. Determinations of their impact on organism health have not been published often due to the lack of threshold internal lethal and sublethal concentrations for most common shoreline chemicals and coastal flora and fauna. Consequently, there are few consensus regional and national numerical guidelines to which tissue contaminant concentrations can be compared to. Thus, the effects of the reported accumulated chemicals, alone and in combination, on physiological mechanisms, histopathological disorders such as tumors (Fig. 11.1) and loss of reproductive potential are unknown for most PBS biota. There is no reported summary of tumor occurrence for PBS biota. To our knowledge, the toxicological and physiological significance of accumulated contaminants have been evaluated only twice: for oysters and indicators of stress (Oliver et al. 2003; Fisher et al. 2003) and for colonized periphyton and biomass and pigment content (Unpublished results, USEPA, Gulf Breeze, FL). There was a connection in the Oliver et al. (2003) report but there were no obvious relationships between chemical residues and structural characteristics of the same periphyton colonized in Bayous Chico and Grande (Fig. 11.2). The inability to determine organismal impact represents a historical and ongoing hindrance that limits the value of most field bioaccumulation studies conducted in the PBS. More visible than chemical impacts on organism health are non-chemical impacts (Fig. 11.3) due to anthropogenic negligence.

Figure 11.1 Fibrosarcoma on mullet. From Overstreet (1988).

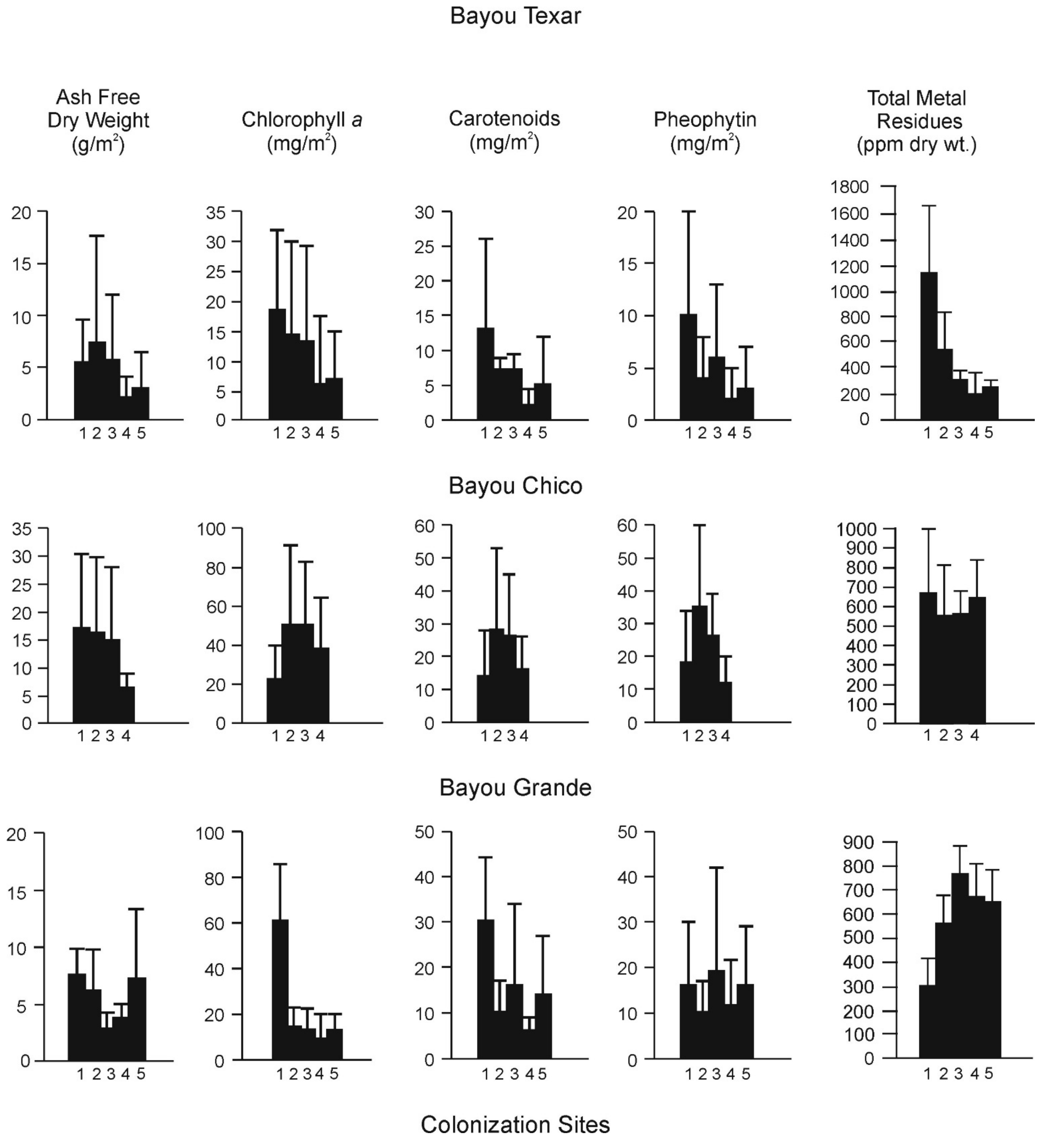


Figure 11.2 Spatial comparison of ash free dry weight (g/m^2) and pigments to total trace metal accumulation for the same algal-periphyton colonized for 21 days at multiple stations in Bayous Texar, Chico and Grande. Values represent means (±1 SD). Unpublished results (USEPA, Gulf Breeze, FL).

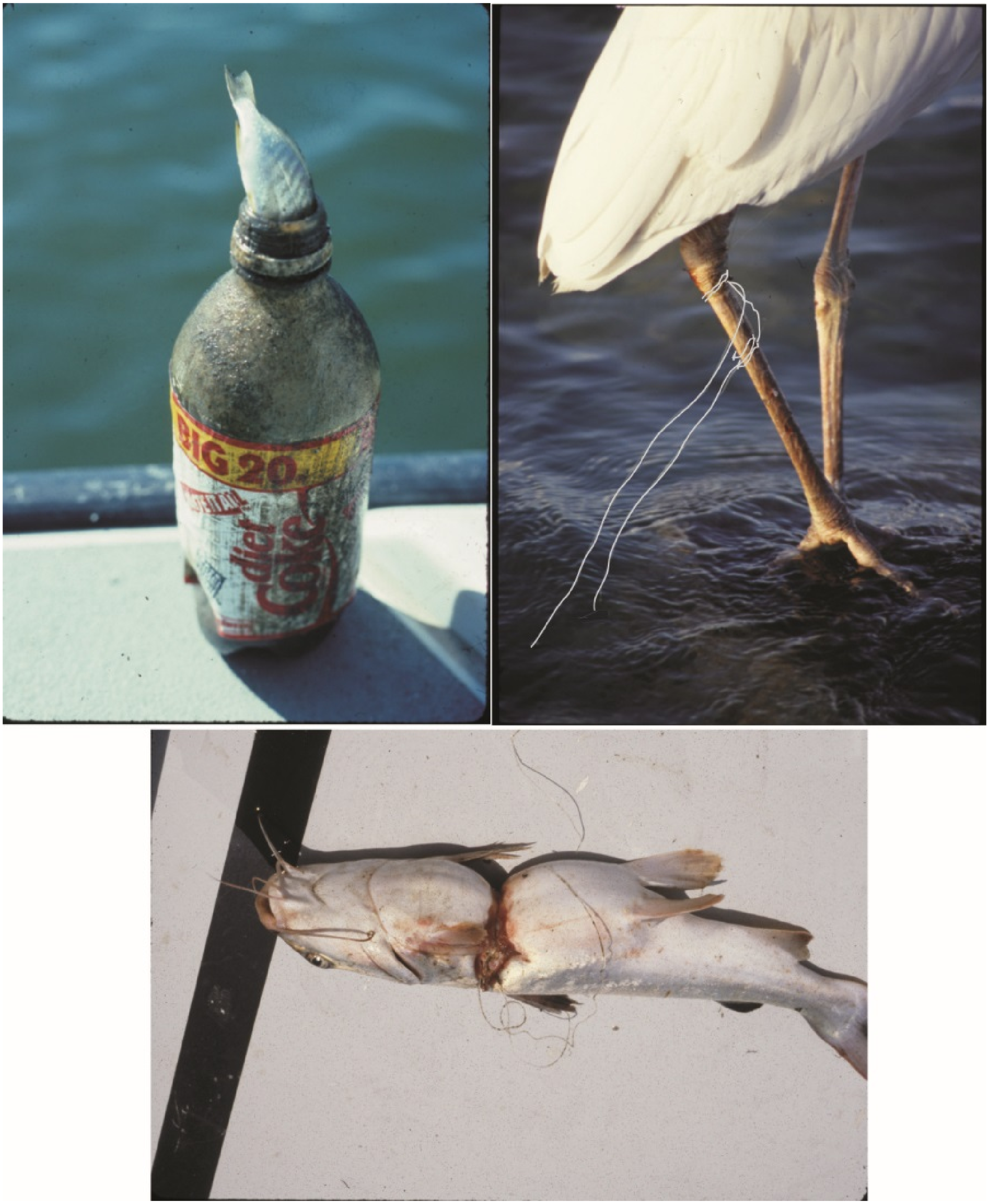
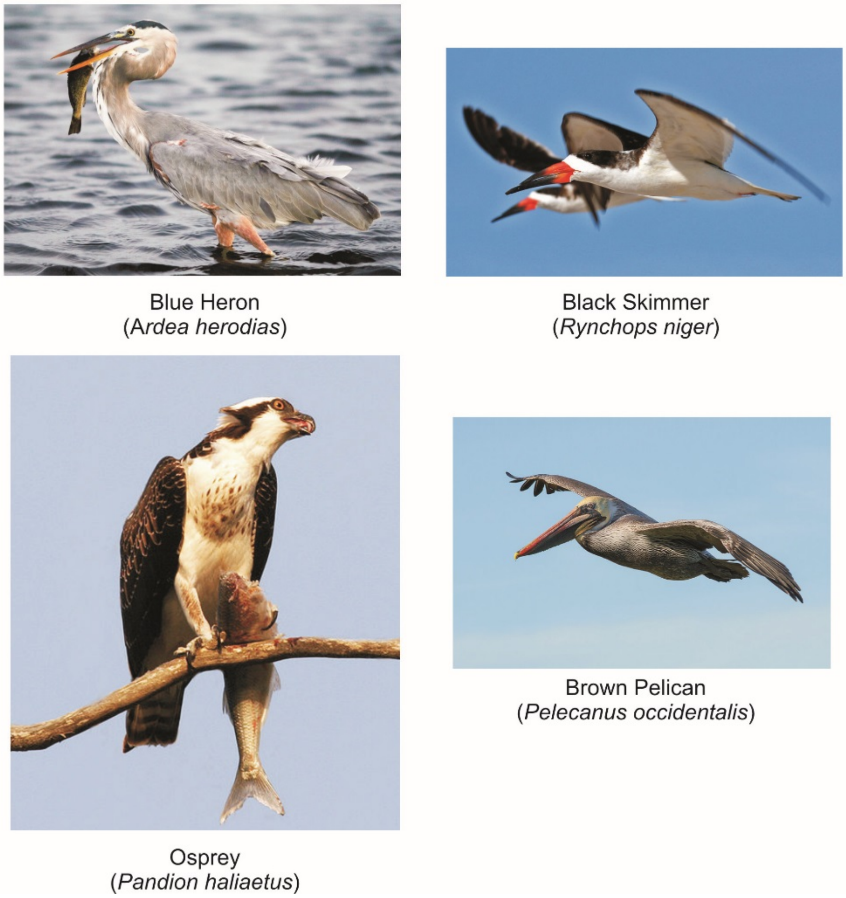


Figure 11.3 Examples of non-chemical anthropogenic hazards for PBS biota. Photos from the corresponding author.

12 Wildlife Health Risk

Wildlife species are bioindicators of the environmental condition of aquatic ecosystems. PBS-dependent wildlife such as resident and migratory birds may be at risk from consuming chemically-contaminated prey. Barnett and Gunter (1985) provide a listing of wildlife that utilize waters, tidal flats, beaches, salt marshes, and swamps for their feeding, nesting, and resting. This includes a variety of wading birds, waterfowl, shorebirds, and raptors (examples, Fig. 12.1). Salt marshes in Florida support 23 threatened birds and 14 threatened mammals (Florida Fish and Wildlife Commission 2012) and 13 species of common waterfowl winter in Pensacola Bay salt marshes (Lewis 1986). A detailed discussion of the effects of environmental contaminants in wildlife consumers of aquatic organisms is available for aquatic birds including raptors (Beyer et al. 1996). However, there apparently has been only one reported local risk assessment for PBS wildlife. Hemming et al. (2003) determined the risk of dioxin and furans in sediments collected from Pensacola Bay and Santa Rosa Sound to birds. A sediment sample from Pensacola Bay represented low risk and a sample collected from Santa Rosa Sound was of no risk. To provide additional insight, tissue-accumulated chemicals reported in PBS biota are compared below to several proposed protective benchmarks. The results of this comparison, which should be considered preliminary, indicate a potential for adverse effects.



Blue Heron
(*Ardea herodias*)

Black Skimmer
(*Rynchops niger*)

Osprey
(*Pandion haliaetus*)

Brown Pelican
(*Pelecanus occidentalis*)

Figure 12.1 Examples of common piscivorus birds vulnerable to contaminated prey from the PBS. Photos courtesy of Encyclopedia of Life (Encyclopedia of Life; accessed 2016 July 14) and Wikipedia (Wikipedia; accessed 2016 July 14).

Numerical tissue-based contaminant criteria for wildlife associated with the Gulf of Mexico are not available. However, spatially-non-specific benchmarks and criteria have been published for mercury. These include, for example, a criterion of 0.1 ppm in whole fish for fish-eating birds and wildlife (Eisler 1987) and 0.077 ppm for piscivorous wildlife (USEPA 1997). The recommended criteria of 0.1 ppm and 0.077 ppm were exceeded for 42% and 50% of 109 skinless samples, respectively, for locally-important Atlantic croaker (*M. undulatus*), flounder (*Paralicthyes* spp.), striped mullet (*M. cephalus*), red drum (*S. ocelatus*), sheepshead (*A. probatocephalus*), speckled trout *(C. nebulosus*), and white trout (*C. arenarius*) as reported by Snyder and Rao (2008) and Snyder and Karouna-Renier (2009). When compared to results from Karouna-Renier et al. (2007), the two guidelines were not exceeded for oysters but were exceeded for blue crabs (21% and 96% of samples).

In addition to the above, a Canadian tissue residue guideline is available for methylmercury (33 ng/g) which is intended to protect wildlife consumers of aquatic life in estuarine and marine waters (Canadian Council of Ministers of the Environment 2001). Exceedance of the guideline using the results of Karouna-Renier et al. (2007) was 29% (oysters), 100% (blue crab muscle), and 96% (blue crab hepatopancreas). Exceedance was 61% of 109 fish samples (eight species) based on the combined results of Snyder and Rao (2008) and Snyder and Karouna-Renier (2009).

A wildlife protection value of 0.16 ppm has been recommended for PCBs (USEPA 1997). Exceedance of this protection value was 12% when compared to the results for 180 fish samples (8 species) reported by Snyder and Rao (2008), Snyder and Karouna-Renier (2009), and Goff (2009). The Great Lakes Water Quality agreement recommends that the total PCB concentration in fish tissues should not exceed 0.1 ppm for the protection of birds and wildlife which consume fish (EPA Great Lakes; accessed 2016 July 13). The 0.1 ppm protection value was exceeded for approximately 16% using the same three databases. Neither guideline was exceeded when applied to the concentration range of 28-83 ppb reported in oysters by Kimbrough et al. (2008). It is important to note that the exceedance of PCB benchmarks may be underestimated when based on results for skinless fish, which contain less PCBs than skin-on whole fish and is the form normally consumed by wildlife.

The negative effects of DDT in coastal birds as a result of fish consumption was noted in the 1950s, and its effect on egg shell thinning and reproductive success led in part to its almost total ban in 1972. Its presence in PBS biota was a concern during the 1960s. Butler (1973) was one of the first to measure its presence in PBS biota (oysters from East Bay) during 1965-1972. Hansen and Wilson (1970) reported DDT residues in PBS fish collected during 1965-1966. The residues were usually less than 0.1 ppm and did not exceed 1.3 ppm. Cantillo et al. (2001) and Kimbrough et al. (2008) report more recent information. Wildlife protection benchmarks for DDT have been generally been between 6-200 ng/g (USGS Types and Sources of Water-Quality Benchmarks for Pesticides; accessed 2016 July 13). The Canadian guideline is 14 ng/g (Canadian Council of Ministers of the Environment 2001). These guidelines were exceeded frequently during the 1960s, for example, when based on the results of Hansen and Wilson (1970). In contrast, concentrations in PBS biota have decreased. Only one of three oyster samples collected during 2004/05 as part of NOAA's Mussel Watch Program (Kimbrough et al. 2008) exceeded the Canadian guideline. It was noted in that report that DDT levels in oysters from the PBS have declined since 1986.

13 Transplanted Oysters

Filter-feeding oysters (*C. crassostrea*) are sessile and are commonly used as indicators of environmental conditions. Their presence in the PBS is dependent upon the availability of hard substrate, which is not common. Therefore, transplanted oysters and other mollusks have been used to determine contaminant bioavailability in areas generally absent of these mollusks (Elder and Desler 1988; Oliver et al. 2003; Fisher et al. 2003). Oliver et al. (2003) and Fisher et al. (2003) determined the response of transplanted oysters (hemocyte count and bactericidal activity) to contaminated conditions in Bayous Texar and Chico. Enhanced defense activity was observed in several cases with increased tissue concentrations of contaminants. Elder and Dresler (1988) reported the effects of surface and groundwater contamination from a wood treating facility on tissue quality of caged oysters near the entrance of Bayou Chico to Pensacola Bay.

In addition to the above, caged oysters and brackish water clams (*Rangia cuneata*) were used to assess contaminant bioavailability in areas impacted by golf course runoff (Santa Rosa Sound), wastewaters (Escambia and Pensacola Bays), urban stormwater runoff (Bayous Texar, Chico, and Grande), and also in proposed reference areas (Fig. 1.3). For these unpublished USEPA studies (Gulf Breeze, Florida), oysters were obtained from Bayou Labatre (AL) and maintained for a month in a seawater flow-through system, prior to placement in cages constructed of aquaculture plastic netting (Fig. 9.1) for in-situ deployment. A subset of the oysters (soft tissues) were analyzed for inorganic and organic analytes prior to deployment. The oysters (14-17 per cage) were exposed three to four times at the same station for one year. Exposures were for 3w and occurred at multiple locations. Oyster survival, gaping, and growth were monitored weekly at several locations to ensure their viability. Uptake was spatially-specific as shown for exposures in the reference areas and bayous (Table 13.1) and the order of accumulation was generally similar to that for indigenous oysters (Table 6.1). It was concluded that the technique was useful but labor intensive.

Table 13.1 Trace metal residues in soft tissues of oysters (*Crassostrea virginica*) after 21 days exposure in enclosures (Fig. 9.1). Exposures during 1993/-1994 (Bayous) and 2000/-2001 (proposed reference areas; Fig. 1.3). Baseline results are for commercially-obtained oysters prior to field deployment. Values represent mean (±1 SD) in µg/g dry wt. ND-not determined, BD-below detection. Unpublished results (USEPA, Gulf Breeze, FL).

Location	Trace Metals									
	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
Bayou Texar	ND	8.4	5.6	3.6	2.3		4.3	0.6		5686
		(2.3)	(2.7)	(5.5)	(147)	BD	(4.5)	(1.5)	BD	(4148)
Bayou Chico	ND	9.1	2.5	1.8	234		2.6	0.4		5495
		(5.8)	(1.2)	(1.8)	(231)	BD	(2.4)	(1.5)	BD	(3843)
Bayou Grande	ND	9.8	6.4	4.2	229		4.0	3.1		3520
		(2.8)	(3.2)	(3.0)	(172)	BD	3.7	(4.6)	BD	(2406)
Bay La Launch	1.9	12.4	4.2	1.7	104.2	0.55	3.5	0.56	5.2	1612.6
	(0.5)	(2.6)	(1.2)	(1.1)	(22.2)	(0.012)	(2.0)	(0.24)	(0.9)	(472.6)
Grand Lagoon	2.6	36.7	4.3	1.3	151.8	0.043	2.4	0.58	5.2	1889.6
	(0.9)	(12.4)	(1.2)	(0.6)	(46.9)	(0.015)	(0.8)	(0.24)	(1.0)	(639.1)
Mississippi Sound	2.1	13.9	5.7	1.3	104.3	0.049	2.2	0.62	5.6	1317.2
	(0.1)	(6.9)	(2.0)	(0.5)	(21.7)	(0.014)	(0.5)	(0.21)	(1.0)	(550.9)
Old River	1.8	19.2	3.5	1.1	94.3	0.059	2.9	0.56	5.2	1450.3
	(0.5)	(5.9)	(1.1)	(0.3)	(32.4)	(0.007)	(1.7)	(0.31)	(0.6)	(614.5)
Baseline	1.7	6.9	5.2	1.0	117.9	0.033	437	0.34	4.7	1364.0
	(0.1)	(0.3)	(1.0)	(0.5)	(44.2)	(0.006)	(1.7)	(0.09)	(0.3)	(525.0)

14 Colonized Periphyton

The autotrophic and heterotrophic components of the periphyton serve as a food source for higher trophic levels. The use of colonized periphyton provides a useful multimetric in-situ response of an important biotic community over a defined exposure period to environmental conditions. Periphyton have been commonly used as an indicator of environmental condition in freshwater for over 75 years and a rapid periphyton survey is currently used in freshwaters of the PBS watershed (FDEP 2013b). In contrast, the use of colonized periphyton in estuarine waters of the PBS has been uncommon. The first documented use was by Ross and Jones (1979) followed 20 years later (1995-2002) by a series of studies, including those of Lewis et al. (2001a, c, 2002a, b, 2004), Snyder et al. (2005), and Wagner (2006). The objectives of the Lewis et al. (2001a, c, 2002a, b, 2004) studies, conducted intermittently during 1993-2001, were for method development and environmental assessment. Seasonal and spatial differences were evaluated for measurements of post-colonization community composition, biomass, pigment content, phaeophytin and contaminant residues. The relationship between contaminant residues and structural community changes was determined also. Periphyton were colonized bimonthly on multiple acrylic plexiglass plates (surface area one side= 0.01m^2) contained in a periphytometer (Fig. 9.2) for 3w and 6w at an approximate depth of 10.0 cm. Colonizations occurred at 135 sites in Escambia and Pensacola Bays, Bayous Texar, Chico, and Grande, and Santa Rosa Sound, as well as at 31 external coastal sites for comparison. Focus was for areas receiving treated wastewater (Lewis et al. 2002a), pre- and post-hydraulic dredging (Lewis et al. 2001a), and areas impacted by stormwater runoff from a coastal golf course (Lewis et al. 2002b). In addition, 120 colonizations were conducted quarterly during 1993-1994 in the urbanized Bayous Texar, Chico, and Grande to determine seasonal variability for chemical uptake and structural parameters (Unpublished results, USEPA, Gulf Breeze, FL).

14.1 Bioaccumulation

The periphyton serve as a source of anthropogenic chemicals to the grazing community (herbivores) in the PBS. Trace metals have been commonly detected in local periphyton but not PAHs, PCBs, or chlorinated pesticides. Zinc, chromium, copper, and lead are accumulated in greater concentrations (Tables 6.1, 14.1). Metal uptake is spatially and temporally variable as shown during 1993/94 for Bayous Texar, Chico, and Grande (Table 14.1; Fig. 14.1). Trace metals were more concentrated in periphyton colonized in urban and industrial-impacted areas such as Bayous Texar, Chico, and Grande (Table 14.1). Using total mercury as an example, concentrations (ng/g dry wt.) averaged 71 (SD=22, range=15-152), 59 (SD=35, range=17-133), 401 (SD=269, range=22-988) for areas impacted by golf course runoff (Santa Rosa Sound), wastewaters (Pensacola and Escambia Bays), and urban runoff (Bayous Texar, Chico and Grande), respectively. The mean mercury concentration for proposed reference areas (Fig. 1.3) was 75 (SD=16, range=16-102) ng/g dry wt. The BCF values (concentration in periphyton/concentration in surface water) have ranged from 355-16,843 (Cr), 1,432-16,927 (Cu), 2,019-1,653 (Ni), 735-5,656 (Pb), 13,132-61,071 (Zn), and 2,663-53,634 (Hg) for periphyton colonized seasonally at 12 sites in Bayous Texar, Chico, and Grande. As previously noted, dredging in Bayou Texar reduced trace metal bioavailability to colonized periphyton (Lewis et al. 2001a).

Table 14.1 Comparisons of ash free dry weight (AFDW), chlorophyll *a*, trace metal residues, and Shannon-Weaver Diversity Index values for the same algal-periphyton colonized 21 days at each location. Values represent mean (±1 SD) for multiple colonizations (excludes residues) and ranges for Shannon-Weaver Diversity Index values. Only one diversity index value available for proposed reference sites. Residue concentrations in µg/g dry wt. and ng/g dry wt. (mercury). ND-not determined. BD-below detection. Unpublished results (USEPA, Gulf Breeze, FL).

Location	AFDW (g/m^2)	Chlorophyll *a* (mg/m^2)	Mean Trace Metal Residues								Diversity Index
			As	Cd	Cr	Cu	Hg	Ni	Pb	Zn	
Bayou Texar	5.1 (4.1)	18.2 (15.8)	ND	1.4	33	48	0.57	15	80	399	0.5 – 2.6
Bayou Chico	13.7 (9.5)	30.8 (18.1)	ND	0.7	28	74	0.3	11	63	412	0.7 – 3.0
Bayou Grande	6.6 (2.3)	27.3 (9.0)	ND	2.0	60	20	0.13	11	44	121	0.7 – 2.0
Pensacola Bay	2.6 (1.2)	20.8 (6.9)	15	0.7	17	32	0.06	9	13	86	0.7 – 1.1
Escambia Bay	2.6 (1.6)	14.8 (9.8)	BD	BD	42	10	0.06	13	9	104	0.5 – 1.3
Santa Rosa Sound	6.2 (0.4)	8.8 (4.0)	20	1	24	17	0.05	7	11	79	2.2 – 3.0
Bay La Launch	0.28 (0)	9.1 (2.4)	9.5	0.29	14.4	7.9	0.02	9.0	7.8	83	1.5
Grand Lagoon	0.87 (0)	10.1 (0)	23.5	0.36	36.1	27.3	0.01	11.2	19.4	110	2.3
Mississippi Sound	0.48 (0.09)	3.4 (1.5)	16.5	0.86	22.8	61.5	0.03	19.8	11.8	125	2.1
Old River	0.28 (0.04)	3.4 (3.4)	9.3	0.74	69.0	12.4	0.09	10.8	24.1	50	1.5
Suwannee River Estuary	0.48 (0.24)	23.4 (12.2)	3.7	0.39	8.0	7.9	0.02	6.2	4.6	28	2.4
Withlacoochee River Estuary	0.41 (0.08)	5.3 (3.6)	9.3	0.73	69.0	12.4	0.09	10.8	24.1	50	1.5

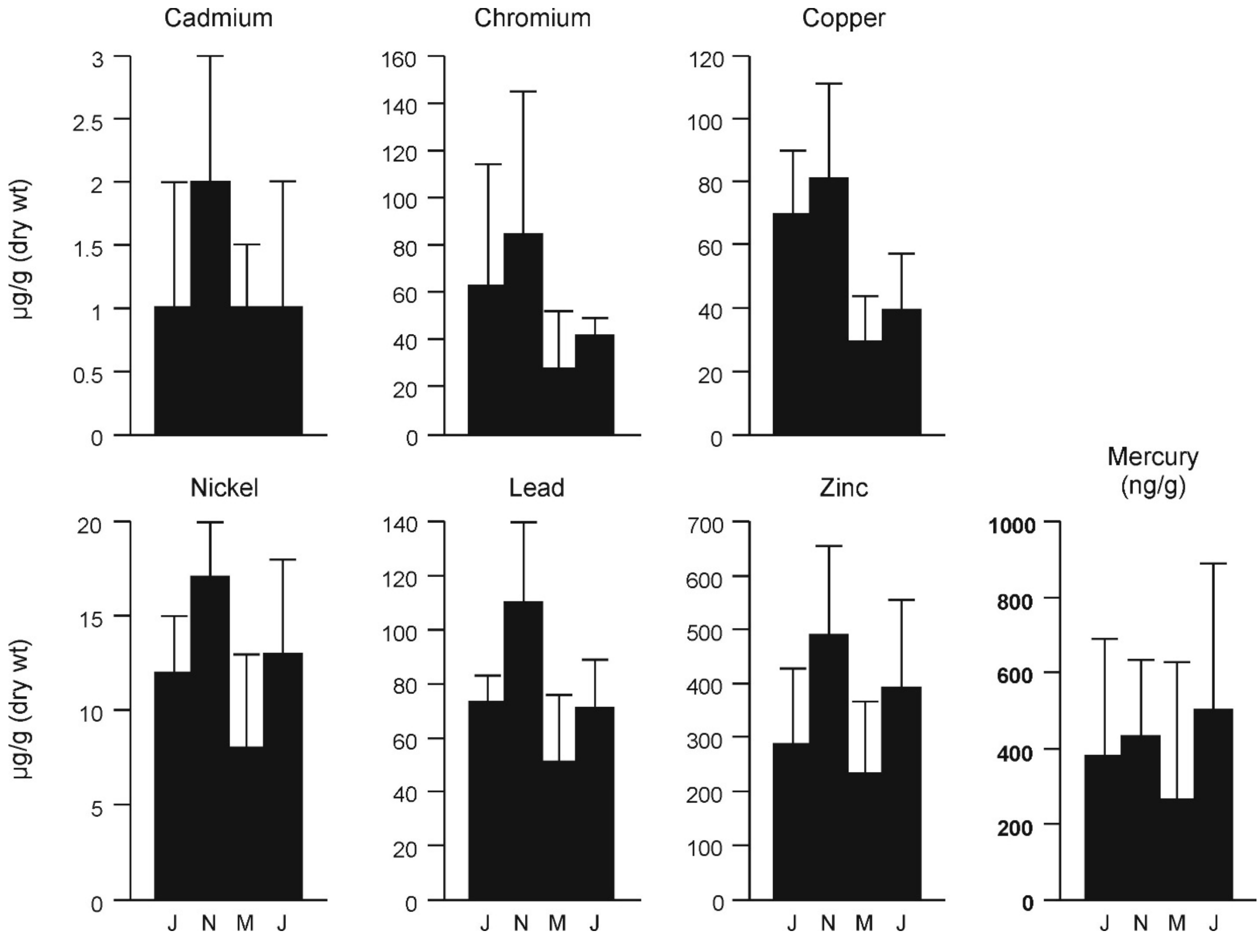


Figure 14.1 Temporal and spatial variation for trace metal concentrations (µg/g dry wt.) in the algal-periphyton colonized 21 days at five sites in Bayou Texar. J-June (1993), N-November (1993), M-March (1994), J-June (1994). Values represent means (±1 S D). Unpublished results (USEPA, Gulf Breeze, FL).

14.2 Biomass and Pigment Content

Structural characteristics of the algal-periphyton varied monthly (biomass and pigments) (Fig. 14.2) within and between bayous (Lewis et al. 2001c, 2002a, b, 2004). Mean ash free dry weight (AFDW, g/m^2) in decreasing order by colonization location was: Bayou Chico>Bayou Grande>Bayou Texar>Santa Rosa Sound>Pensacola Bay=Escambia Bay. Mean chlorophyll *a* concentrations (mg/m^2) in decreasing order were: Bayou Chico>Bayou Grande, Pensacola Bay>Bayou Texar>Escambia Bay>Santa Rosa Sound (Table 14.1). Mean biomass and chlorophyll *a* for periphyton colonized in the three urban-impacted bayous, was usually greater than that for the proposed reference areas (Table 14.1). No obvious relationship was observed between biomass and pigment content and total metal residues for the nine colonization sites in Bayous Chico and Grande (Fig. 11.2). In contrast, biomass, pigment content and metal residues declined in almost parallel for colonization sites in Bayou Texar.

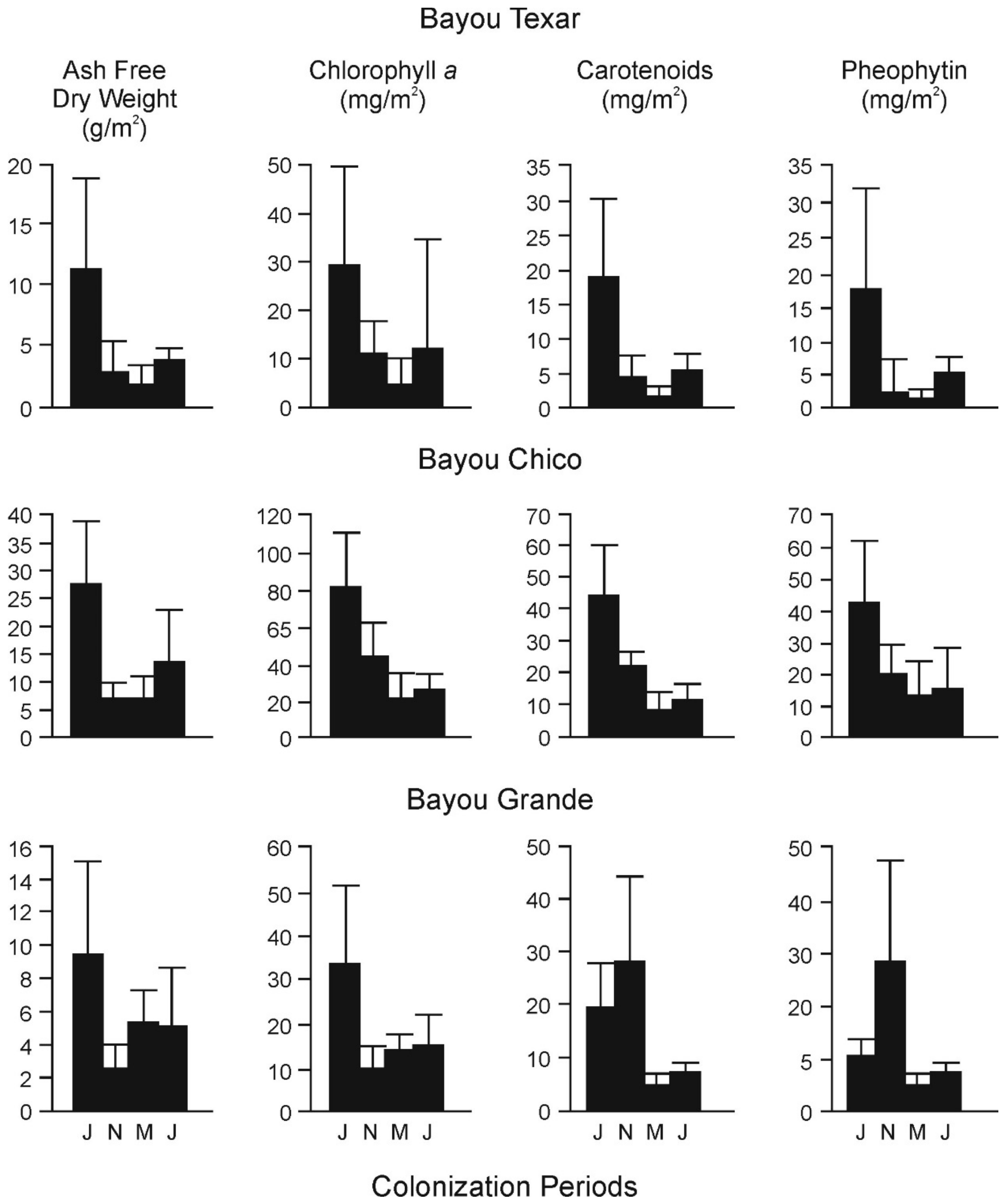


Figure 14.2 Temporal and spatial variation for structural characteristics of periphyton colonized 21 days during June (1993), November (1993), March (1994) and June (1994) at 14 sites in Bayous Texar, Chico and Grande. Values represent means (±1 SD). Unpublished results (USEPA, Gulf Breeze, FL).

Autotrophic index (AI) values are high for PBS algal-periphyton. The AI, the ratio of algal biomass and chlorophyll *a*, is an indicator of nutrient enrichment and relative input of allochthonous material to a waterbody (Weitzel 1979). Although somewhat controversial, values greater than 100 are thought to indicate heterotrophic polluted conditions while values less than 100 indicate autotrophic clean conditions. AI values averaged 124 (Pensacola Bay), 244 (Bayou Grande), 260 (Escambia Bay), 283 (Bayou Texar), 442 (Bayou Chico), and 689 (Santa Rosa Sound, near golf course). Maximum AI values were 911, 1,158, and 487 for Bayous Texar, Chico, and Grande, respectively.

15 Submerged Aquatic Vegetation

The coverage of freshwater and saltwater submerged plants (SAV) in the PBS approximates 6,600 acres (Reynolds, Smith and Hill Inc. 2014). Current SAV coverage is about 3% of bay bottom (Yarbro and Carlson 2013) relative to 8% 60 years ago (Handley et al. 2007). *Vallisneria americana* (Eel grass, Water celery) and six species of seagrass comprise the bulk of the SAV. Attached macroalgae are typically absent. Most scientific and public attention has centered on the “iconic” seagrass which have dramatically declined in the PBS and elsewhere along the northern Gulf of Mexico coast (U.S. Geological Survey and Gulf of Mexico Program 2004). Seagrass are considered biological sentinels of coastal ecosystems due to their role in supporting biodiversity and their sensitivity to changes in water and sediment quality. Seagrass meadows support grazing and detrital food webs, stabilize sediment, and are important in carbon sequestration and storage. One acre of Florida seagrass produces 10 tons of leaves, supports 40,000 fish and 50 million invertebrates according to the Florida Department of Environmental Protection. McAfee (1986) reported that grass beds were second to oyster beds in biodiversity and productivity in Escambia Bay. It was thought that the destruction of *V. americana* and *Halodule beaudette*i (Shoal grass; formerly *Halodule wrightii*) in Escambia and East Bays could reduce biodiversity 50% and 60%, respectively (Olinger et al. 1975). The decline in scallops and shrimp industry in the 1960s has been attributable to the decline in seagrass coverage (Lewis T 1986).

At least 50 reports have been published since 1965 (Lewis et al. 2008) describing habitat condition, species structural characteristics, and coverage of *Thalassia testudinum* (Turtle grass) (Fig. 3.1), *Syringodium filiforme*, (Mantee grass), *H. wrightii*, *Halophila engelmanni* (Star grass), *Ruppia maritima* (Widgeon grass), and *V. americana*. In PBS history, status and trends of seagrass coverage have been reported locally to various degrees by many (Rogers and Blisterfied 1975; Williams 1981; Lewis 1986; Collard 1991a, b; Heck et al. 1996; Lores and Specht 2001; U.S. Geological Survey and Gulf of Mexico Program 2004; Schwenning et al. 2007; FDEP 2001a; Yarbro and Carlson 2013; Reynolds, Smith and Hills Inc. 2014; Harvey et al. 2015) and at larger geographic scales for the Gulf of Mexico (Handley et al. 2007; U.S. Geological Survey and Gulf of Mexico Program 2004) and Florida (Dawes et al. 2004; Carlson and Madley 2007). In other studies, Winter (1978) and Macauley et al. (1988) reported structural characteristics and life-supporting requirements of the seagrass in Santa Rosa Sound. The effects of epiphytes (Big Lagoon) (Wear et al. 1999; McCall 2005), nutrient enrichment (Escambia Bay, Big Lagoon) (Wear et al. 1999; Lores et al. 2000), and low salinity (Escambia Bay) (Lores and Specht 2001) have also been reported, as well as the ecology, composition of the microbial community, and biogeochemical interactions (Kusel et al. 1999, 2001; Smith et al. 2004; Devereux et al. 2011).

The first reported loss of seagrass for the PBS was in 1955 (Hopkins 1973; FDEP 2007). Coverage was extensive during 1948 but it continually receded between the 1950s and 1970s (Rogers and Blisterfield 1975; Olinger et al. 1975; WFRPC 2005). A 95% decline occurred between 1950 and 1980 (Harvey et al. 2015) and all major beds were gone in Escambia and Pensacola Bays by 1966 or 1976, depending upon the source. Coverage during the past 30 years has generally been between 4,000 and 4,600 acres with little evidence of dramatic drops and increases. Historically, most seagrass coverage was for Santa Rosa Sound and Big Lagoon. Most coverage for 2010 was in Santa Rosa Sound (65% of total). The stability of coverage in Santa Rosa Sound and Big Lagoon is uncertain. Heck et al. (1996) reported that above-ground biomass of *H. wrightii* and *T. testudinum* decreased in Big Lagoon and Santa Rosa Sound during 1993-1995. A decline of 5.6% occurred between 2003 and 2010 for Santa Rosa Sound (Harvey et al. 2015). The decline in seagrass coverage for Big Lagoon, based on a workshop, was attributable to 19 causes (BARC et al. 1998).

The first record of SAV spatial coverage was for 1931 on navigational charts (Collard 1991a). The first aerial surveys for seagrass coverage occurred in 1940 (Collard 1991b). At least 39 sources of seagrass coverage based on navigational charts, drawings, and photographs are available from 1931-2010. Several early time sequence surveys are available (Figs. 15.1, 15.2) for Escambia and East Bays from 1949-1974 (Olinger et al. 1975). About 6,500 acres (2,633 ha) were reported for the PBS based on vegetation maps of 1940 and 1954 (McNulty et al. 1972). McNulty et al. (1972) reported 30, 43 and 1,547 acres of submerged SAV in East, Escambia, and Pensacola Bays, respectively. More recent coverage (acres) for the same areas was 60, 250 and 475 (FDEP 1998). At least four major aerial surveys have been conducted since 1960. Total coverage for 1960, 1980, 1992, and 2003 was estimated as 3,858 (9,533 acres), 1,894 ha (4,680 acres), 1,814 ha (4,480 acres) and 1,654 ha (4,085 acres), respectively (Lewis et al. 2008). The estimated 1,654 ha (4,085 acres) of seagrass for 2003 was distributed as follows: 74% (Santa Rosa Sound), 13% (Big Lagoon), 9% (Pensacola Bay), 3% (Escambia Bay), and <1% (East Bay) (Lewis et al. 2008). The most current mapping surveys for seagrass were conducted during 2010. Harvey et al (2015) reported coverage of 232 ha (574 acres), 79 ha (196 acres), 115 ha (283 acres), 1,172 ha (2894 acres), and 209 ha (515 acres) for Pensacola Bay, Escambia Bay, East Bay, Santa Rosa Sound, and Big Lagoon, respectively. Total coverage of 4,462 acres was an 8.4% increase since 2003. For reference, total seagrass coverage for Florida is approximately 2.7 million acres and 277 acres for nearby Perdido Bay (2002) (Handley et al. 2007). Coverage increases and decreases relative to 2003 for the PBS which appears in Fig. 15.3. All areas experienced increases except for Santa Rosa Sound (-4.8%) and Big Lagoon (-5.6%). Dominant species were site-specific but in general were *Thalassia testudinum>Halodule wrightii>Ruppia maritima>Syringodium filiforme*. Comparison of results across the aerial and non-aerial surveys is impacted by differences for technical quality and level of ground-truthing. The intermittent pattern of aerial surveys in the past has resulted in recommendations for frequent condition monitoring and less frequent aerial surveys with ground-truthing (Collard 1991b; Harvey et al. 2015). Surveys should be conducted preferably during September-October, periods of greatest water clarity (Heck et al. 1996). It was recommended in the latter report that seagrass should be sampled annually to determine biomass, number of shoots, growth rate of shoots, and basic water chemistry. Other possible condition indicators include leaf area, blade width, shoot density, chlorophyll, C:N:P ratios, and epiphyte biomass. See Neckles (1994) for a detailed description of indicator development for Gulf of Mexico seagrass. Harvey et al. (2015) recommended monitoring every two years and high-resolution imagery and mapping every six years.

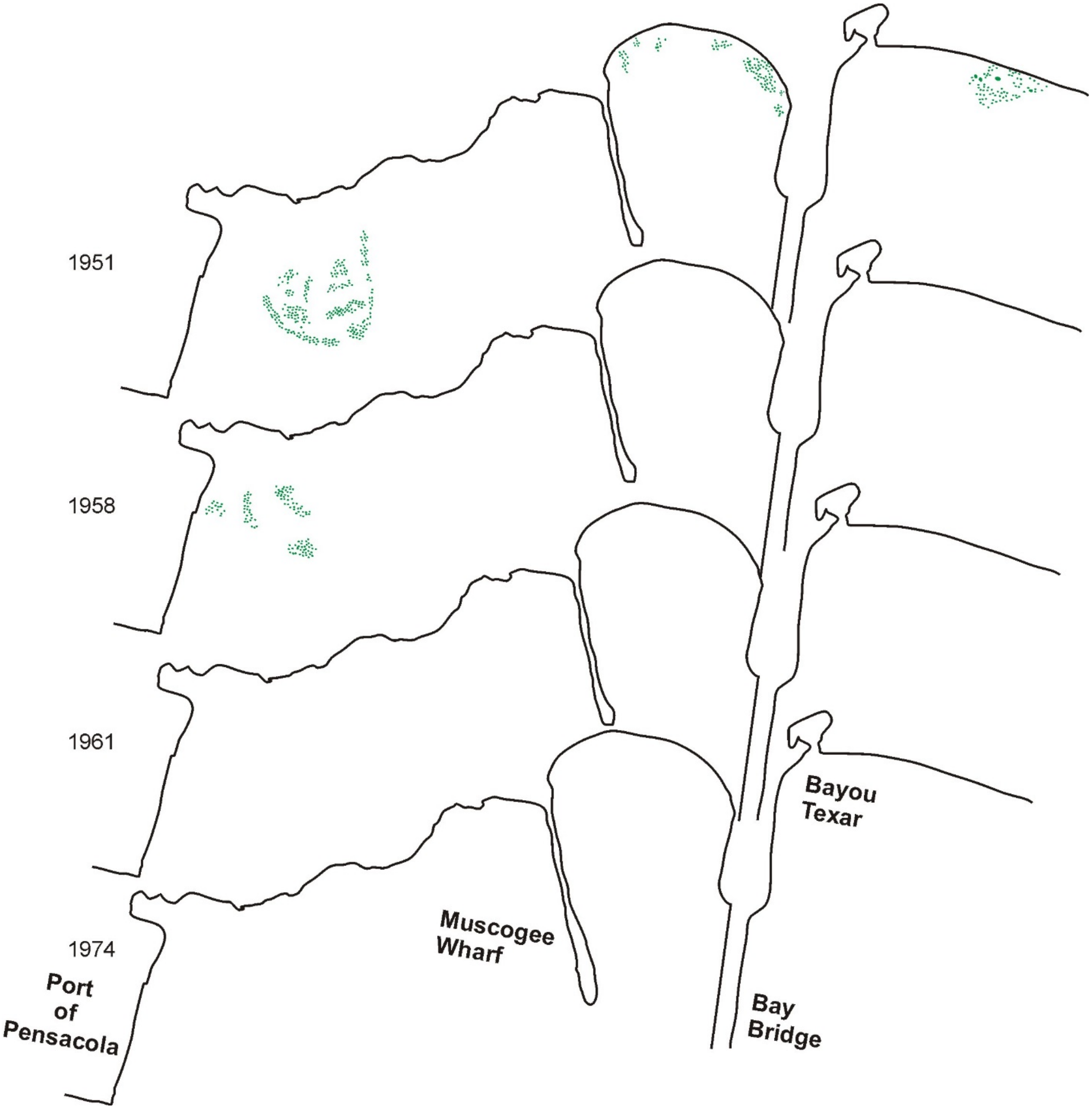


Figure 15.1 Early trend for submerged aquatic vegetation coverage in the Pensacola Bay. From Olinger et al. (1975). Area near Bay Bridge approximates current location of Project GreenShores Phase 1 (FDEP 2001b).

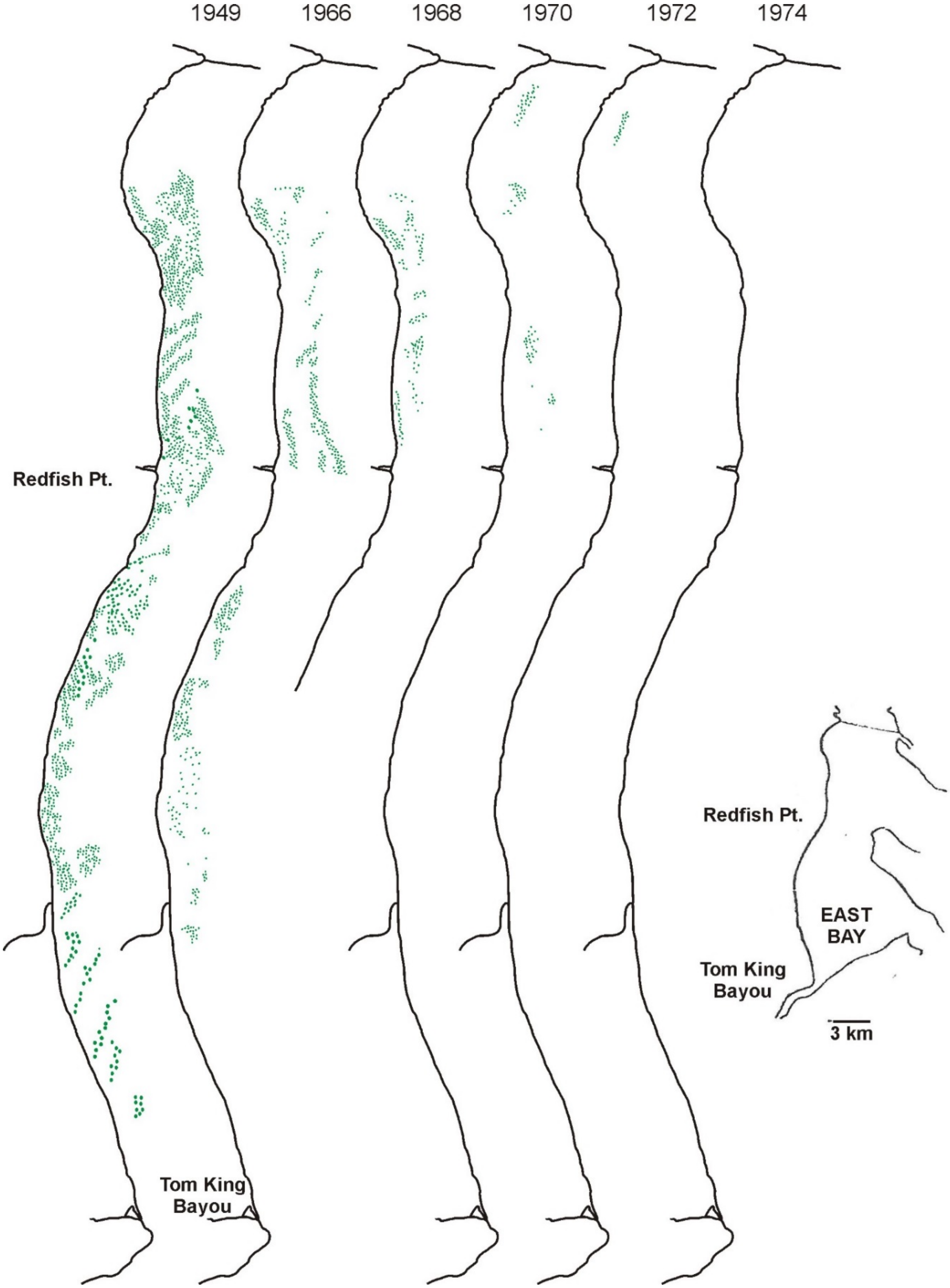


Figure 15.2 Early trend for submerged aquatic vegetation coverage in East Bay. From Olinger et al. (1975).

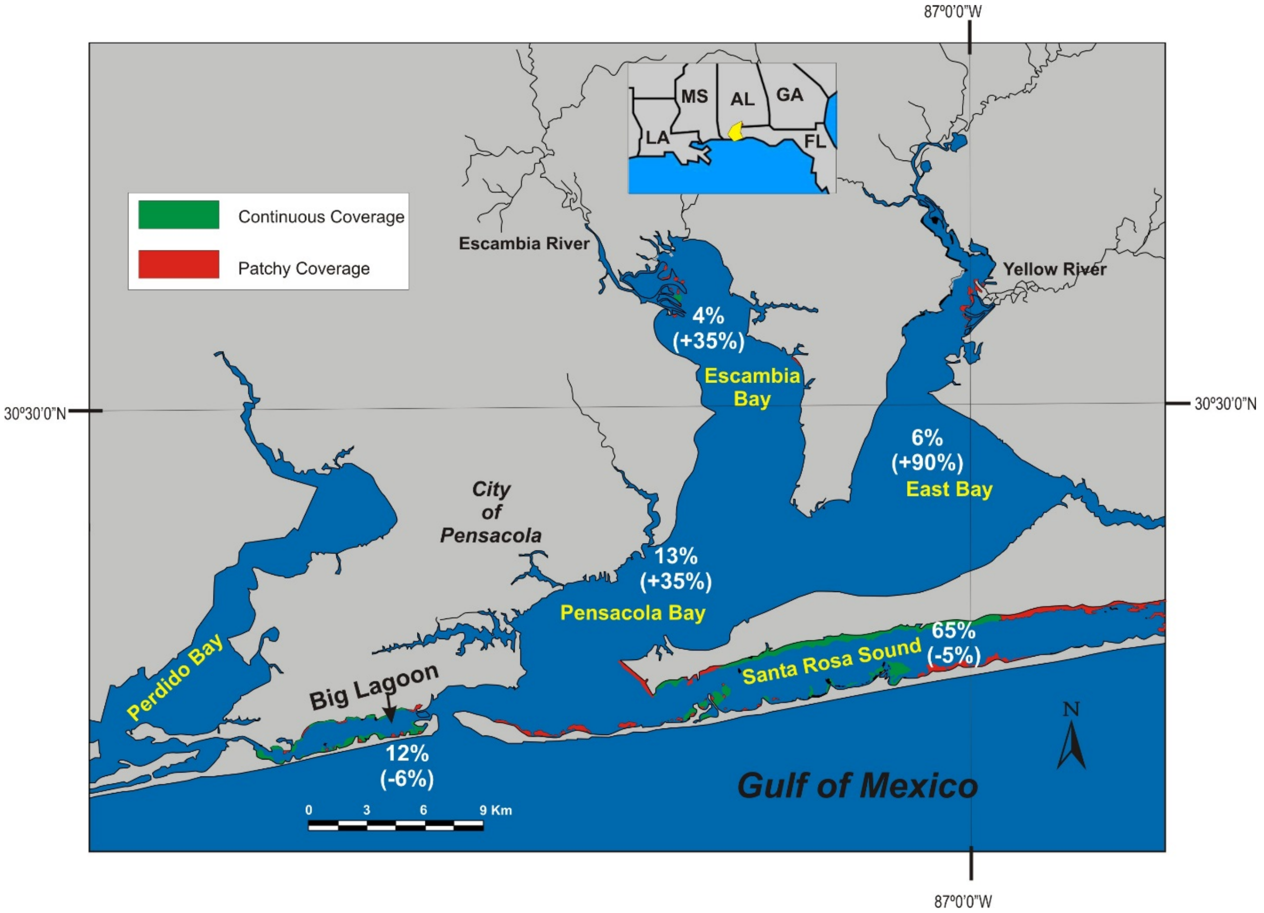


Figure 15.3 Seagrass (%) reported for 2010 and change in coverage (+/- %) relative to 2003. Results from Harvey et al. (2015).

The seagrass meadows destroyed and degraded in the past, despite some recent encouraging evidence (Harvey et al. 2015), have largely not recovered. Numerous restoration attempts and the availability of management and restoration plans for over 40 years (Rogers 1974; Collard 1991b; FDEP 2001a; USDOI 2014) have failed to significantly increase coverage. In general terms, the scarcity of information for local life-supporting characteristic, the impacts of natural and anthropogenic stressors (alone and in combination), and the lack of sensitive indicators of condition have limited successful long-term restorations. Thirteen to 20 reasons are thought responsible for the decline of seagrass in the PBS (Collard 1991a, b; WFRPC 2005). These include hydrological modification, trawling, decreased water clarity, prop scarring, dock shading, coastal landscape practices (armoured shorelines), burial, and dredging. Elevated nutrient concentrations in the PBS were once thought to have a negative influence on seagrass but recent thought suggests that current levels are not an issue, at least from a water clarity point of view (FDEP 2012b). The presence of non-nutrient anthropogenic contaminants has also been considered a possible stressor for seagrass with several possible pathways for adverse effects to occur, including through rooted-sediments (Fig. 15.4). Seagrass settle suspended solids and as a result their sediments can by organically-enriched and chemically-contaminated. However, only one contaminated-related study has been conducted with PBS seagrass. Chemical quality of rooted sediments and tissues of two species were determined for 13 Florida grass beds, including those in the PBS (Lewis et al. 2007). Many contaminants were greater in seagrass-rooted sediments than in nearby non-vegetated sediments, but the magnitude of contamination was not unusual and within the range of concentrations reported for seagrass-rooted sediments worldwide (Lewis and Devereux 2009). Furthermore, only a few

SQAGs were exceeded and bioaccumulation factors were usually less than one (range=1-6). It was concluded that a contaminated sediment effect on seagrass survival and condition was unlikely. In addition, spatial, interspecific, and tissue differences among the different grass beds were usually an order of magnitude or less for the same accumulated analyte.

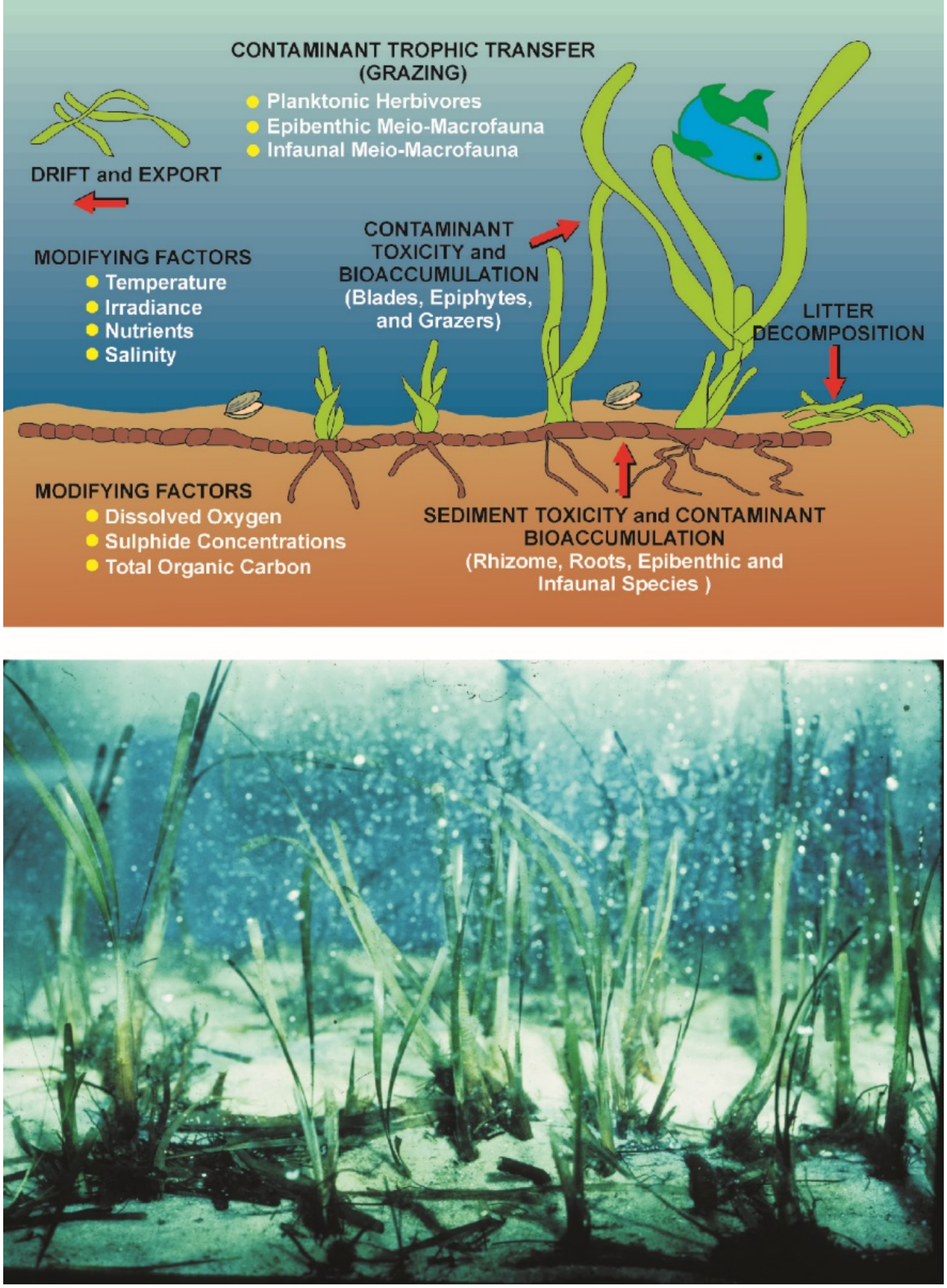


Figure 15.4 Potential impacts of anthropogenic contaminants on submerged aquatic vegetation beds such as those dominated by *Thalassia testudinum* (turtle grass) in Santa Rosa Sound and Big Lagoon. Photo by author.

16 Habitat Restoration/Creation

There has been recognition for at least 40 years of the need to restore, maintain and enhance PBS habitats to reverse historical declines in species diversity and ecosystem services (early examples, Henningson et al. 1975a; Glassen et al. 1977). Most restorations for the PBS have followed a “learn by doing” approach. Success has been limited and the cost-ecosystem benefit ratios are unknown. With the exception of Project GreenShores (FDEP 2001b), there have been no long-term (> 5 years) successful large habitat restorations in the PBS. In contrast, several small-scale restorations attempted since 1994 by the Northwest Florida Department of Environmental Protection (Florida Department of Environmental Protection-Ecosystem Restoration Section; accessed 2016 July 14) have been successful. The contributions singular restoration projects and in aggregate to the environmental quality of the PBS are unknown. Furthermore, it is unknown what percent restoration equates to a full or satisfactory replacement of the original habitat. To some, it is unlikely that habitat substitutes can replace the diverse services of the previous multifunctioning ecosystem (Moberg and Ronnback 2003). For example, 621 wetland restorations failed promised results or matched the performance of natural systems (Ecology Ecosystems; accessed 2016 July 13). In addition, the technical foundation for successful habitat restorations, with the exception for oyster reefs (Kroeger 2012), are not well understood.

Collard (1991a, b) provides an excellent, although dated, historical review of seagrass and oyster bed restorations for the PBS, including a critique of procedures used, reasons for failure, requirements for successful restorations, and research needs. It was concluded that the probability of successfully restoring functional seagrass habitats was low to very low for a variety of still valid reasons. These include incomplete knowledge of the reasons for their destruction and the chemical and biological requirements necessary to maintain their long-term survival and healthy condition. In addition, restoring and maintaining historical conditions, if possible, may not be sufficient to maintain biotic diversity in the future. Therefore, management strategies and risk-based adaptation plans need to include actions to increase the capacity of restorations to absorb stress such as that expected from climate change.

16.1 Seagrass Meadows

Restoration of seagrass meadows is time-consuming and costly based on planning, transplanting and post-restoration monitoring. Re-vegetation is most successful where the loss is recent and the habitat has not been degraded substantially; conditions not usually encountered in the PBS. Seagrass restoration costs are variable and have been estimated from $14,000 to $1,035,000/ha for five coastal areas in the U.S. (Grabowski et al. 2012). The “ins” and “outs” of seagrass restoration for the PBS and requirements and recommendations for success have been presented by Collard (1991b). Collard estimated $25,000 to $75,000 (1991 dollars; estimated $44,000 to $132,000 in 2015 dollars) was needed to restore one acre of seagrass in the PBS. The preferred species was *Halodule wrightii*. He recommended that prior to restoration, 4 one-acre plots be established and monitored for two years. Determination of sediment phytotoxicity has also been suggested as a precursor to seagrass transplantation (Durako et al. 1995). Seagrass restoration and salvage/replantation efforts have been conducted intermittently since the 1970s. These efforts usually included planting individual laboratory-cultured seedlings, seedling mats (sods) or transplanting natural “clumps”. Implantation of synthetic grass was once recommended (Hopkins 1973). Examples of early restoration efforts are those of Rogers (1974) and Olinger et al. (1975). In the Olinger et al. study, *Halodule wrightii* were taken from East Bay and transplanted to Escambia Bay. Success was mixed and no long term success was reported. Seagrass restoration efforts continue; the most noticeable is the 85 m^2 (0.02 acre) of *Ruppia maritima* planted as part of Project Greenshores (2003) which has increased to 10,000 m^2 (about 2.5 acres) as of 2015. This represents about 0.0006% of the 2010 total acreage of 4,462 acres for the PBS. Additional community-based shoreline restorations are planned for 2016 that include seagrass. Despite this success, seagrass restorations should still be considered to be in the trial and error stage until their life supporting requirements are better understood. See Collard (1991a) and WFRPC (2005) for several requirements and strategies needed for seagrass sustainability and recovery. The WFPRC report contains 18 recommendations alone.

16.2 Oyster Reefs

Restoration techniques and life-supporting requirements are better understood for oyster reefs than for seagrass meadows. Regional guidance for establishment and monitoring is available (Baggett et al. 2014). Restoration efforts have generally been historically successful, at least short-term (Collard 1991b). In contrast, the lack of hard substrate coupled with natural variability in salinity, depth and temperature, and the occurrence of predation and disease are factors that have contributed to the unpredictable success of restorations and the slow recovery of oyster populations since their destruction during the 1960s to early 1970s.

Oyster habitat restoration and creation within the PBS have occurred intermittently since 1964 and continues (Little 1973; Olinger et al. 1975; Teehan and Barnett 1989a, b; Hudson 1990; Collard 1991b; FDAC 2005). One of the largest rehabilitations was that reported by Little and Quick (1976) for 1972 when 425 shell piles were used in a 23 acre restoration project. The restoration was short-lived; the oysters were largely absent in 1975 due to low salinity from the flooding Escambia River. Recent efforts continue and include cultch plantings, transplantation of oysters to debilitated beds, and creation of new habitat and reefs. Twenty-eight reefs were installed during 2014 in East Bay, Bayou Texar, and Chico. Approximately 6,800 yd^3 of total clutch material were added during 2008-2012 to East Bay and east Escambia Bay (Florida Department of Agriculture and Consumer Services, Joe Shields III, personal communication, February 2015). Oyster reef breakwaters were a part of the erosion protection of Deadman's Island in Pensacola Bay (Deadman Island; accessed 2016 July 13). This effort was of mixed success and serves as a good example of the difficulty in establishing long-term viable oyster habitat, particularly in areas where oysters did not historically exist. Oyster reef creation, usually in the form of breakwaters, was also included in Project GreenShores and is included in future community-based living shoreline projects. Seven acres were created as part of Project GreenShores Phase I (FDEP 2001b). Other examples for 2016 include a 10 acre commercial oyster farm established in lower Escambia Bay (tstmeyer/PNJ.com; accessed July 2016); addition of 12,000 cubic yards of clutch material to 60 acres in Pensacola Bay as part of the Florida Oyster Clutch Placement Project (Escambia County RESTORE Act; accessed 2016 August 17) and eight miles of oyster habitat restoration planned for the eastern shore of East and Blackwater Bays (abirch@tnc.org; accessed 2016 January).

Costs of oyster reef restorations and creations are variable and location and method-specific. Cost of the Deadman's Island Project approximated $2 million. A proposal to create two miles of oyster reefs along East Bay is for $5 million (Florida Department of Environmental Protection Deepwater Horizon; accessed 2016 July 14). Eight miles of reef are proposed for East and Blackwater Bays for which the projected cost of design, engineering, permitting and monitoring of Phase One approximates $2.2 million (Florida Gulf Environmental Benefit Fund 2015, Proposal 50003, The Nature Conservancy). The $1.5 million cost of construction of one mile of oyster reef breakwater in Mobile Bay is expected to return about $3 million to the local community (NOAA Oyster Economics factsheet; accessed 2016 July 13). Local costs reported by WFRPC et al. (2005) for one acre of restored reef w/shell was $42,000 and $1,650 for one acre w/ gravel. New reef cost estimates elsewhere range from $20,000/acre (Henderson and O'Neil 2003) to $104,000/acre (Grabowski et al. 2012). In the latter report, the reefs recover the median restoration cost in 2-14 y.

16.3 Salt Marsh

Reports for salt marsh restoration along the PBS shoreline are uncommon. Several small-scale efforts have occurred in recent years such as those conducted by the Northwest Florida Department of Environmental Protection (Florida Department of Environmental Protection-Ecosystem Restoration Section; accessed 2016 July 14). Planting of *Spartina* seedlings was included in Project GreenShores and will be included in future living shoreline restorations as well. The outlook is more promising for this habitat type than seagrass and oyster habitats since, in addition to restorations, rising sea levels due to climate change will increase coverage in non-armoured areas (Geselbracht et al. (2013) at the expense of freshwater coastal wetlands and forested areas.

16.4 Community-Based Shoreline Restoration

Shoreline protection and modification have been of increasing interest during the past 10 years (example, NWFWMD 2006) and a homeowner's guide is available (NWFWMD 2001). The most publicized and recent large-scale shoreline restoration is Project Greenshores (FDEP 2001b) which consisted of seagrass and wetland plant restorations and breakwater/oyster reef construction. Thirty acres of oyster, salt marsh, and seagrass habitat were created along 2 miles (3.2 km) of northern urbanized Pensacola Bay for about 6 million dollars (cash plus donated time and supplies). The Project had 87 partners and contributors (Florida Department of Environmental Protection Project Greenshores sponsors; accessed 2016 July 13). About 90,000 *Spartina alterniflora* and 4,000 *Ruppia maritima* seedlings were planted. The success of the Project can be shown by the results for seagrass; seagrass initially covered 0.01 acre (50 m^2) and has increased to 2.5 acres (10,000 m^2). This coverage represents about 0.004% of total seagrass coverage for Pensacola Bay (574 acres) and, as stated earlier, about 0.0006% of total coverage for the PBS (4,462 acres) based on information in Harvey et al. (2015). Similar restorations are planned for additional sites in Pensacola Bay for which 230 acres of emergent marsh and SAV habitat will be created in addition to about 27,000 linear feet of oyster reef breakwater (Restore the Gulf Draft Initial Funded Priorities List; accessed 2016 July 13).

An additional approach to shoreline modification is the establishment of vegetative buffer zones for the terrestrial-aquatic transitional zone. No information on the cost of their construction is available. It has been recommended that these vegetated zones be at least 100 ft (30.5 m) but preferably 1,500 ft (457.2 m) for maximum benefit (WFRPC 2005). Others have proposed an average of 30 ft (9m) and 50 ft (15 m) for optimal protection (NWFWMD 2001). Obviously, the necessary width of buffer zones to ensure the maximum environmental benefit needs additional evaluation. Nineteen shoreline plant species suitable for planting are listed in the NWFWMD report.

17 Spatial Environmental Variation

17.1 PBS Internal

The environmental quality of the PBS is not universal. In general terms, environmental condition improves seaward away from peripheral bayous and entries of rivers and stormwater runoff from adjacent urbanized and industrialized areas. These seaward areas are characterized by greater physical and chemical stability and dilution. The characteristic shallow waters of the PBS are physically, chemically, and biologically unstable relative to short-term, seasonal, and annual changes in salinity, temperature, and water quality. These differences are responsible in part for the spatial differences reported on numerous occasions in this summary between and within PBS subunits for sediment chemical contamination (Figs. 7.3, 7.5, 7.12; Tables 7.2, 7.3), toxicity (Figs. 7.13, 7.14), species numbers/abundance and diversity (Tables 3.1, 3.2; Figs. 3.2, 3.3, 3.4), bioaccumulation (Tables 13.1, 14.1; Figs. 9.3, 17.1), and algal-periphyton structural parameters (Table 14.1; Fig. 14.2).

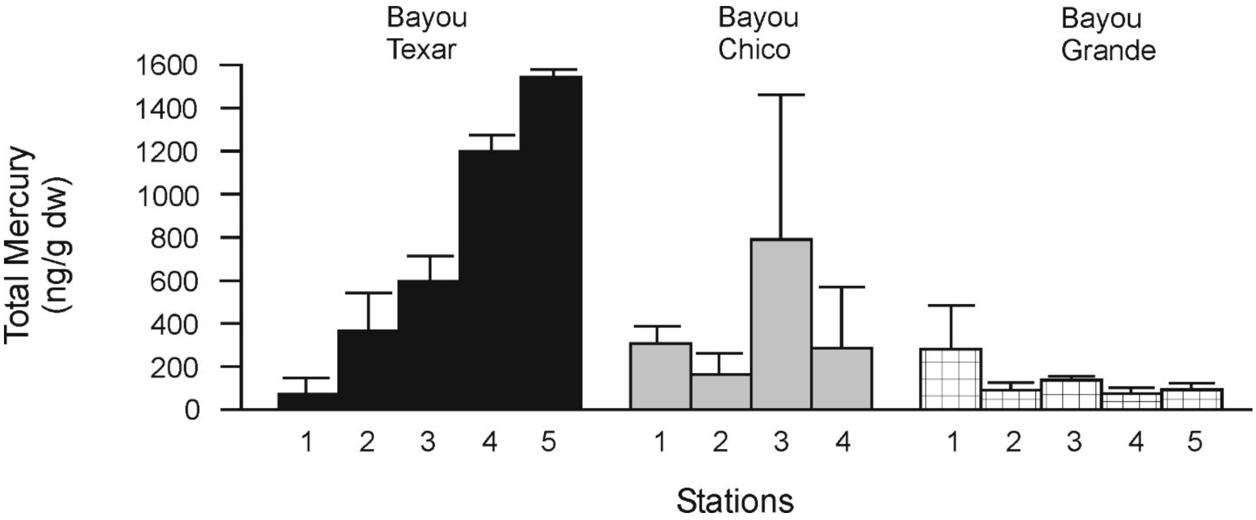


Figure 17.1 Spatial variation for total mercury concentrations (ng/g dry wt.) in algal-periphyton colonized for 21 days at multiple sites in Bayous Texar, Chico and Grande. Values represent means (±1 SD). Unpublished results (USEPA, Gulf Breeze, FL).

17.2 PBS External

The environmental quality of the PBS has been ranked and compared to that for other estuaries for a variety of metrics. The outcomes of most across-estuary comparisons have been directionally mixed and indicate few supportable multimetric differences between the PBS and other northern Gulf of Mexico estuaries. Numerous comparisons are available although scattered in the literature for sediment chemical quality and toxicity, bioaccumulation, oyster reef coverage, productivity/net ecosystem metabolism, biogeochemical aspects, eutrophication potential, and fish community composition (examples, Olinger et al. 1975; USDOI 1989; Long et al. 1996; Hemming et al. 2003; Livingston 2005; Rider and Adams

2000; Kimbrough et al. 2008, 2009; Murrell et al. 2009; Snyder and Karouna-Renier 2009; Lewis et al. 2010; Gesselbracht et al. 2013; Caffery and Murrell 2015). A summary of rankings for several parameters based on results from these and other reports appear in Table 17.1. Many of the across-estuary rankings are based on the often unproven assumptions of similarity for geomorphological characteristics and for results from different experimental techniques (study periods, collection techniques, taxonomic levels, chemical analytical methodologies, statistical analysis, and level of quality assurance). For these reasons, the value of many across-estuary environmental rankings is uncertain. The more supportable generalizations are those for small geographic scales based on results for similar assessment methodologies. See Livingston (2014) for an in-depth comparison of various environmental parameters for five Florida panhandle bay-river systems including Escambia River/Bay and Blackwater River/Bay.

Table 17.1 Comparison of various environmental parameters for Pensacola Bay System subunits (in bold) to other northern Gulf of Mexico estuaries. Apal B – Apalachicola Bay, Bay L – Bay La Launch, BC – Bayou Chico, BG – Bayou Grande, BT – Bayou Texar, Choct B – Choctawhatchee Bay, East B – East Bay, Esc B – Escambia Bay, GL – Grand Lagoon, MS – Mississippi Sound, OR – Old River, PB – Pensacola Bay, SRS – Santa Rosa Sound, St JB – Saint Joe Bay, St And B – Saint Andrew Bay, SR – Suwannee River estuary, WR – Withlacoochee River estuary.

Parameters	Biota	Spatial Difference (high to low)
Sediment Nutrients	Total Organic Phosphorous	**PB**>Choct B>**Esc B**>**East B**
	Total Organic Nitrogen	Choct B>**PB**>**Esc B**=**East B**
Sediment PCBs	Dioxins/Furans	PDB>**PB**>Choct B≥St JB>St And B>Apal B
Sediment Benthos	Benthic Diversity[1]	**BC**>GL=SRS=MS>**BT**>Bay L=OR=WR>SR>**BG**
	Benthic Taxa (Max)	**SRS**>**Esc B**>**PB**>GL>**BT**>WR>MS>**BG**>**BC**>OR>Bay L>SW
Sediment Toxicity	Sea urchin	Apal B>Choct B>**PB**>St And B
	Microbial	Choct B≥ St And B> Apal B >**PB**
	A. abdita [2]	**PB**>Apal B=Choct B=St And B
	A. abdita	**BG**=**BT**>GL=MS=OR=SW=WR=Bay L>WR>**BC**>PDB
	L. plumulosus[3]	MS>OR>Bay L>WR=SW=GL>**BG**>PDB>**BT**
Algal-Periphyton	Mercury	**BT**>**BC**>**BG**>WR>SR>OR>MS>GL=Bay L>OR>GL
	Taxa (Max)	**BC**>**Esc B**>GL>**BT**>**BG**>OR=**Esc R**>Bay L>SR>**SRS**>WL>MS
	Chlorophyll *a*	**BC**>**Esc B**>GL>**BT**>**BG**>OR=**Esc R**>Bay L>SR>**SRS**>WL>MS
	Biomass	BC>BG>SRS>BT>PB=Esc B
	Autotrophic Index[4]	SRS>BC>BT>BG>Esc B>PB
Zooplankton	Diversity	GL>OR>**PB**>**BT**>MS=Bay L>**BC**=**BG**
	Taxa(Max)	**Esc B**>**East B**>GL>**PB**>**BC**>OR>**BG**>**BT**>MS> Bay L
Oyster Bioaccumulation	Copper	**BC**=**BG**>**BT**>GL>MS=Bay L>OR>SRS>**PB=Esc B**
	Zinc	**BC**>**BT**=**BG**>GL>**SRS**>Bay L>OR>BSL=**PB**>MS>**Esc B**

[1] from Shannon and Weaver (1949)

[2] two data sets available for *Ampelisca abdita*

[3] *Leptocheirus plumulosus*

[4] ratio of algal biomass/chlorophyll *a*

18 Temporal Variation

Much of the environmental information generated in the past for the PBS has been based on one or only a few chemical and biological measurements made during a single observation period. It is uncertain if the results for single measurements are sufficient for environmental judgments since it is unknown if they adequately reflect the short and long-term chemical and biological fluctuations that parallel diurnal, tidal, seasonal, and annual biological and chemical cycles. The temporal variability of the composition of the phytoplankton, zooplankton, periphyton, benthic infauna, and fish communities is well understood and, to a lesser extent, the differences for chlorophyll *a*, primary productivity, fish reproduction, dissolved oxygen, and acid volatile sulfides (examples, Livingston 1977; Moshiri et al. 1980; Moshiri and Elewad 1990; Middaugh and Hemmer 1992; Von Appen and Winter 2000; Lores et al. 2002; Murrell and Lores 2004). In contrast, only a few attempts have been made to evaluate the variability of contaminant concentrations in surface water, sediment and biological tissues, and results of toxicity evaluations. One early example is that of Butler (1973). In that report, DDT isomers in oysters collected from East Bay (1965-1971) varied two-fold or less and seven-fold or less for Aroclor 1254.

A series of contaminant-related studies were conducted during the 1990s that included determination of the temporal variability in results as a research objective. As many as 14 identical chemical and biological evaluations were conducted with media collected from the same sites in Bayous Texar, Chico, and Grande during periods up to three years. Variability was assessed for measurements of sediment chemical quality and contaminant uptake in biota (Lewis et al. 2004), fish abundance (Lewis et al. 2010), biotic diversity (Lores et al. 2002; Lewis et al. 2010), whole sediment acute toxicity (Lewis et al. 2001b), and periphytic structural characteristics (Lewis et al. 2002a, b). Some results for these studies are discussed below and the algal-periphyton appear in Figures 14.1 and 14.2. Contaminant concentrations in sediment varied 3-fold or less and a diversity index for zooplankton, 2 to 13-fold during 1-3 years of evaluation. Uptake of six trace metals by oysters varied <1 to 27-fold and mercury uptake by periphyton varied from <1-6–fold (Bayou Texar), 16-26-fold (Bayou Chico) and from <1-6-fold (Bayou Grande). Survival after 10 d exposure to 16 whole sediment samples collected from the same site in Bayou Texar determined during a three year period averaged 63 (SD=9, range=0-83)% for *A. abdita,* and 23 (SD=22, range=0-67)% for 15 tests conducted with *M. bahia*. Survival after exposure to 11-20 sediment samples collected seasonally from the same site in Bayou Grande averaged 86 (SD=28, range=87-100)% for *M. bahia*, 65 (SD=42, range=0-100)% for *A. abdita*, 94 (SD=10, range=70-100)% for *C. variegatus*, and 88 (SD=23, range=23-100)% for *L. plumulosus.* Based on the above results, temporal variability for chemical and biological measurements adds to the complexity of resource management for the PBS. Its impact on environmental conclusions needs increased evaluation. The use of safety or uncertainty factors, a practice commonly used in the past to compensate for the uncertainty of single value measurements (Chapman et al. 1998), may be a worthwhile pursuit.

19 Economic Value of Ecological Services and Goods

Socioeconomics has become an important consideration in environmental science (USDOI 1996b). Within this context, the ecosystem finance approach is an additional tool available to resource managers in making environmental management decisions. The benchmarks of this approach is ecosystem services which are the direct and indirect contributions that ecosystems make to the well-being of humans (USEPA 2009). It has been estimated that coastal systems such as estuaries provide ecological services worldwide in excess of $25 trillion (Barbier et al. 2011). A summary of these ecological services for estuaries and the tropical seascape are available from, among others, Moberg and Ronnback (2003), Pendleton (2009), Barbier et al (2011,) and the Gulf of Mexico Services Viewer (Gulf of Mexico Alliance GecoView; accessed 2016 August 17). They include storm buffering, flood protection, prevention of erosion, seafood production, wildlife support, and carbon uptake which reduces the rate of climate change. In addition, the value of seafood harvests is also included (example, $1.8 million for a single Bluefin tuna). There have been many other efforts to determine the economic value of ecological services (example, Costanza et al. 1997) and of the reduction in water quality (Poor et al. 2007). In the latter report, the cost of a one mg/l increase in dissolved inorganic nitrogen and suspended solids was estimated to reduce home values along the Chesapeake Bay by approximately $18,000 and $1,100, respectively. The PBS has financial value to humans that goes beyond aesthetic appeal and urban shoreline development. It provides the public with many services that are not obvious but nevertheless have monetary value. However, unlike for Tampa and Choctawhatchee Bays (Hass Center 2006; Tampa Bay Estuary Program 2014), the local production of environmental services and their monetary value, with few exceptions (Terrebonne 1973; Stevenson 2007) have not been reported for the PBS. In one of the few studies, the estimated cost of environmental degradation was considerable. Terrebonne (1973) calculated the annual losses (1962-1972) in shrimp, oysters, tourism, recreation, and property in response to increasing water pollution from wastewater treatment facilities in PBS to range from approximately $14 to $141 million.

Three coastal habitats associated with the PBS that are linked to human well-being are seagrass meadows, oyster reefs, and tidal marshes. An analysis follows that provides estimates of their financial value. The analysis is based on current and past coverage of the habitats (Fig. 19.1) and the value of the environmental services provided by one habitat acre. The acre evaluations were based on “local” estimates (seagrass meadows for Florida) and those reported in the scientific literature for oyster and tidal marsh at the time of their reporting. Based on this information, the estimated total value to the public of the three habitats approximates $118 to $126 million annually. This includes about $91.5 million for seagrass, $1 million to $1.7 million for oyster reefs, and between $25.7 million to $33.5 million for salt marsh/tidal wetlands (Fig. 19.2). The evaluations above and others discussed below were inflation adjusted for 2016 (DollarTimes Inflation Calculator; accessed 2016 August 5) using interest rates between 1.2% and 2.3%. Using this approach, the total inflation-adjusted value for the three habitats is between $211 million and $226 million annually. For perspective, the total value exceeds the 2015 property tax revenues for Escambia County of about $112 million and $60 million for Santa Rosa County (Escambia and Santa Rosa Tax Collectors Offices, August 2016); total tourist development tax collection of $9.1 million and total toll collection of $3.9 million for 2015 (Escambia County Public Works Dept. August 2015). The community benefit of trees for removing air pollution, sequestering CO2 and reduction for energy use in Escambia County approximates $0.5 million annually (EDIS Escobedo Report; accessed 2016 August 17).

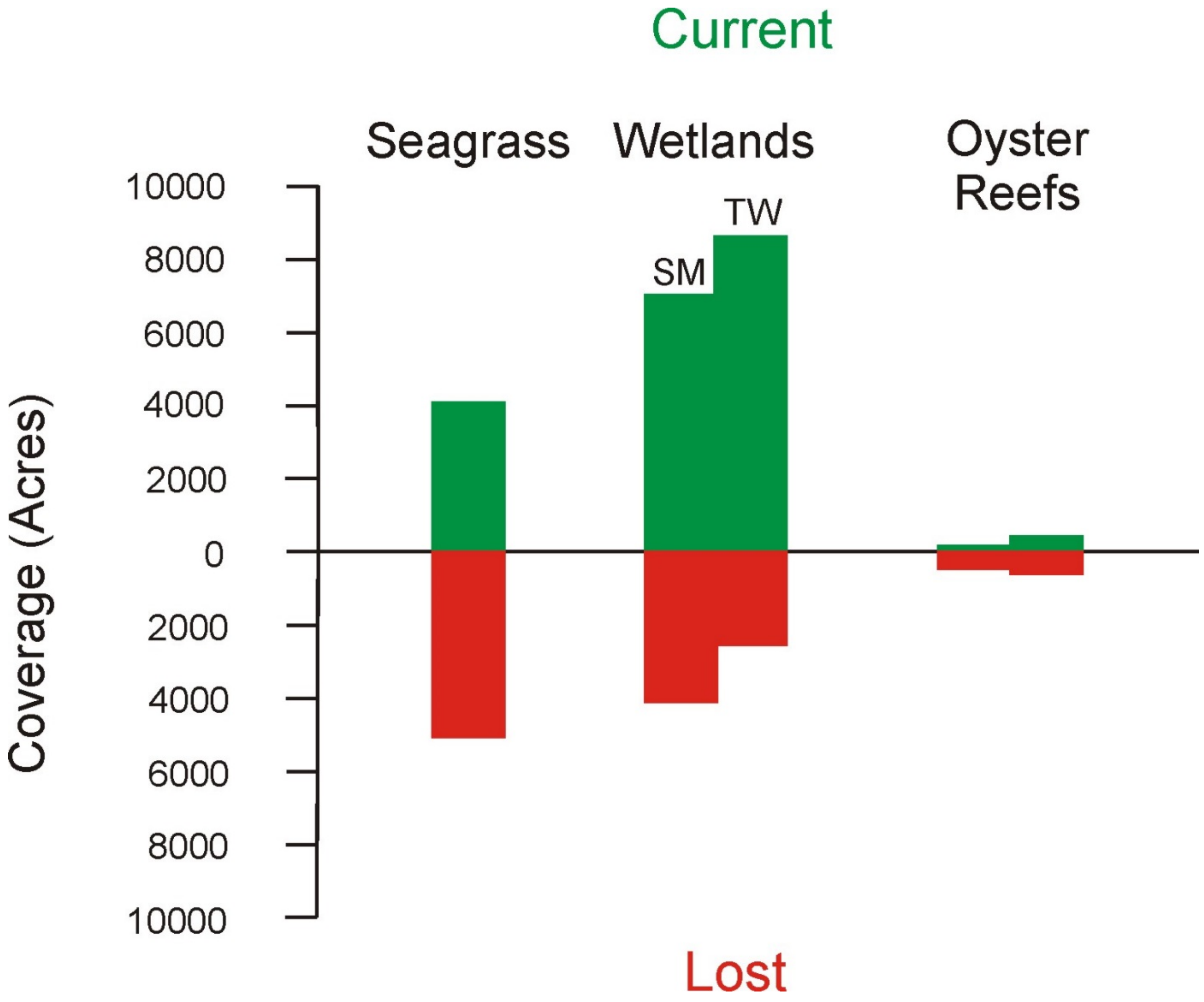


Figure 19.1 Current coverage of submerged aquatic vegetation meadows, salt marsh (SM), tidal wetlands (TW) and oyster reefs relative to that 60 years ago and prior to environmental decline of the Pensacola Bay System. Coverage sources: submerged aquatic vegetation Lewis et al. (2008), oyster reefs-Reynolds et al. (2014) and Florida Department of Agriculture and Consumer Services (personal communication, 2014); wetlands-U.S. Fish and Wildlife Service National Wetland Inventory (2014) and Northwest Florida Water Management District Land Use/Land Cover maps (2010).

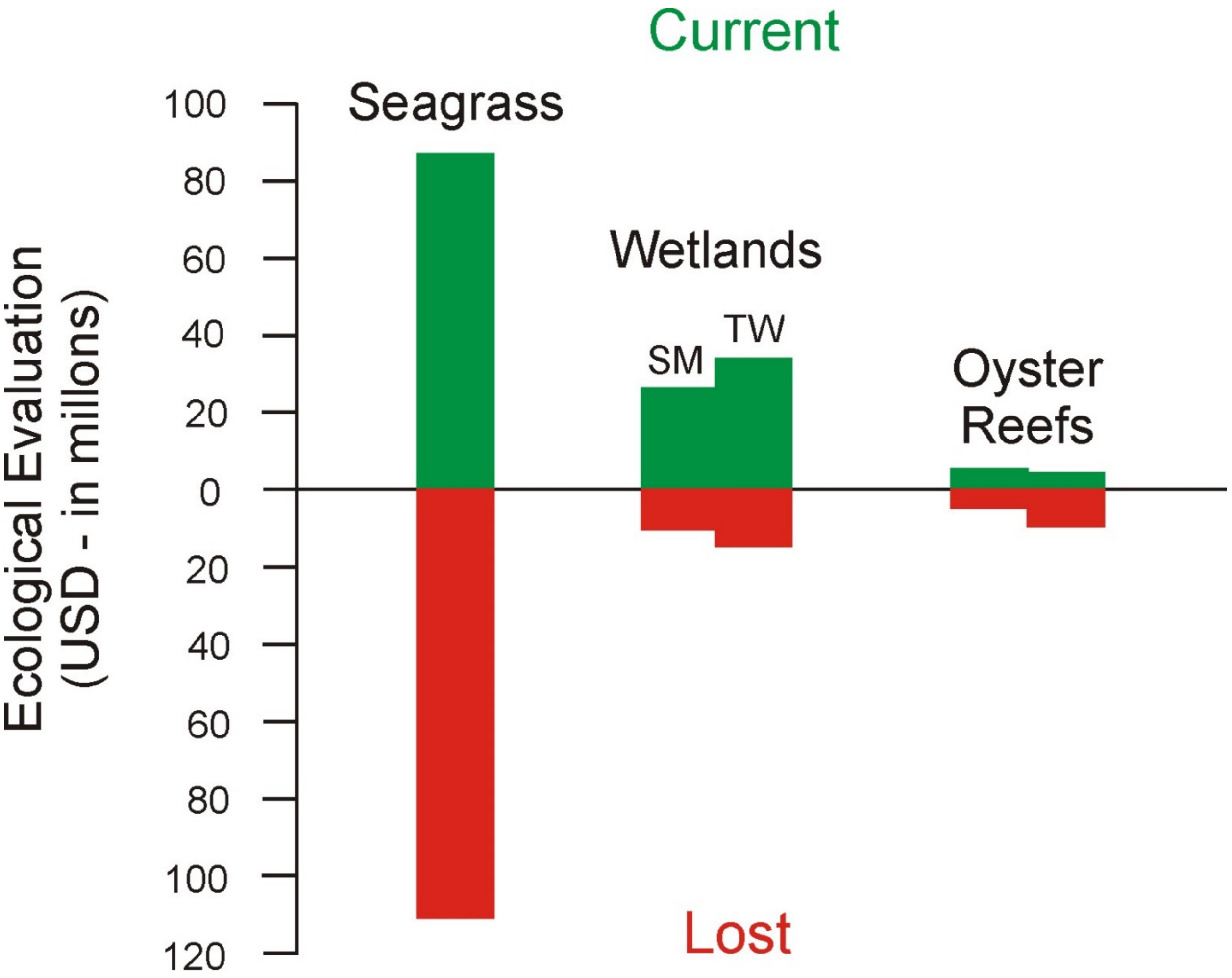


Figure 19.2 Estimated value (USD) of ecological services provided annually by submerged aquatic vegetation meadows, salt marsh (SM), tidal wetlands (TW) and oyster reefs. Value of ecological services lost also shown relative to reduction in coverage as a result of historical habitat degradation. Evaluations per acre used in the calculation are: submerged aquatic vegetation-$20,500 (Handley et al. 2007); oyster reefs-$10,325 (Grabowski et al. (2012); wetlands-$3,900 (Woodward and Wui 2001). Values are not inflation corrected.

The economic cost of not preventing environmental degradation can be severe. It is well known that coverage of the three habitats have historically decreased in the PBS (Fig. 19.1). The value of the lost ecological services associated with their decrease can be estimated by applying the same per acre evaluations used in the above calculations and their reported coverage 50-60 years ago before the declines. The result of this calculation is a total annual loss of about $116 million to $123 million in ecological services ($104 million seagrass, $2 million-$2.6 million oyster reefs, $10 million-$16.3 million tidal/salt marsh) based on a total decrease of about 8,000-10,000 acres combined for the three habitats over time. If inflation-corrected, the total annual loss is between $205-217 million. Therefore, if the degradation and resultant loss of coverage had not occurred, the current estimated total value of these habitats would almost double. A breakdown of the economic analysis by habitat type follows.

19.1 Seagrass

The annual value of one seagrass-vegetated acre in Florida has been estimated as $20,500/acre/year (1991 currency; 2016 currency=$36,240) based in part on storm protection, support of recreational and commercial fisheries, and nutrient cycling (FDEP 2001c; Handley et al. 2007). For reference, the annual value of the ecological services provided by one seagrass-vegetated acre ranges worldwide between $9,000 and $28,000 (Lewis and Devereux 2009). The value of the estimated 4,462 acres in the PBS as of 2010 (Harvey et al. 2015) using $20,500/acre is about 91.5 million dollars/y ($161.7 million inflation corrected). The value of the ecological services lost because of the 5,067 acre decrease from 1960 (coverage=9,529 acres) to 2010 (coverage=4,462 acres) within the PBS, approximates $104 million/y ($183.6 million/y inflation corrected).

19.2 Oysters

Oysters (*C. virginica*) have economic value as seafood, although the production for the PBS is marginal and subject to unpredictable variations. Oyster harvests for 1967-2009 have been between 0-491,000 lbs (Hopkins 1973; Barnett and Gunter 1985; Lewis T 1986; BARC et al. 1998) with an annual value of $0-$87,000. The cost of water pollution on oyster harvests from 1962-1972 was between $1,374 and $858,000 (Terrebonne 1973). The oyster population across years has been impacted by lack of suitable substrate, overharvesting, natural variability in salinity, temperature, dissolved oxygen, water availability, turbidity (sedimentation), predation and infestations of bacterial, and protistan and fungal parasites (WFRPC 2005). The presence of marine biotoxins from toxic dinoflagellates *Karenia brevis* (formerly *Gymnodinium breve)* and *Gonyaulax monilata* also reduces oyster harvesting. A bloom in 1974 (3,000,000 cells/l) resulted in a month long closure of harvesting areas (Barnett and Gunter 1985). Oyster die-offs have historically occurred at least once a decade (Lewis T 1986). Mass mortalities approaching 100% have occurred in 1963, 1967, 1971, 1987, and 1991 (FDEP 1998; Lewis FG 2010). The largest mortality event of 1971 destroyed 95% of the reefs in the PBS, which was the focus of a large restoration event during 1972 (Little and Quick 1976). Abundance, however, can rapidly change. For example, oysters were plentiful in East Bay during 1987 but no oysters were found during 1989 (Collard 1991b). A 3.6 mile reef restoration for nearby Mobile Bay was projected to produce $38,000-$46,000/year from an increase in fish and crab fisheries (Kroeger 2012).

Oyster reefs provide ecological services in addition to harvested meats. These include improving water quality, dissipating wave energy (shoreline protection), stabilizing bottom sediments, and providing substrate for a variety of organisms (see Kilgen and Dugas 1989) important for fish and crabs. Oyster beds in the northern Gulf of Mexico support as many as 170 estuarine species (USDOI 1989). Oyster beds in Escambia Bay had greater density and diversity of macroinvertebrates than seagrass meadows (Olinger et al. 1975).

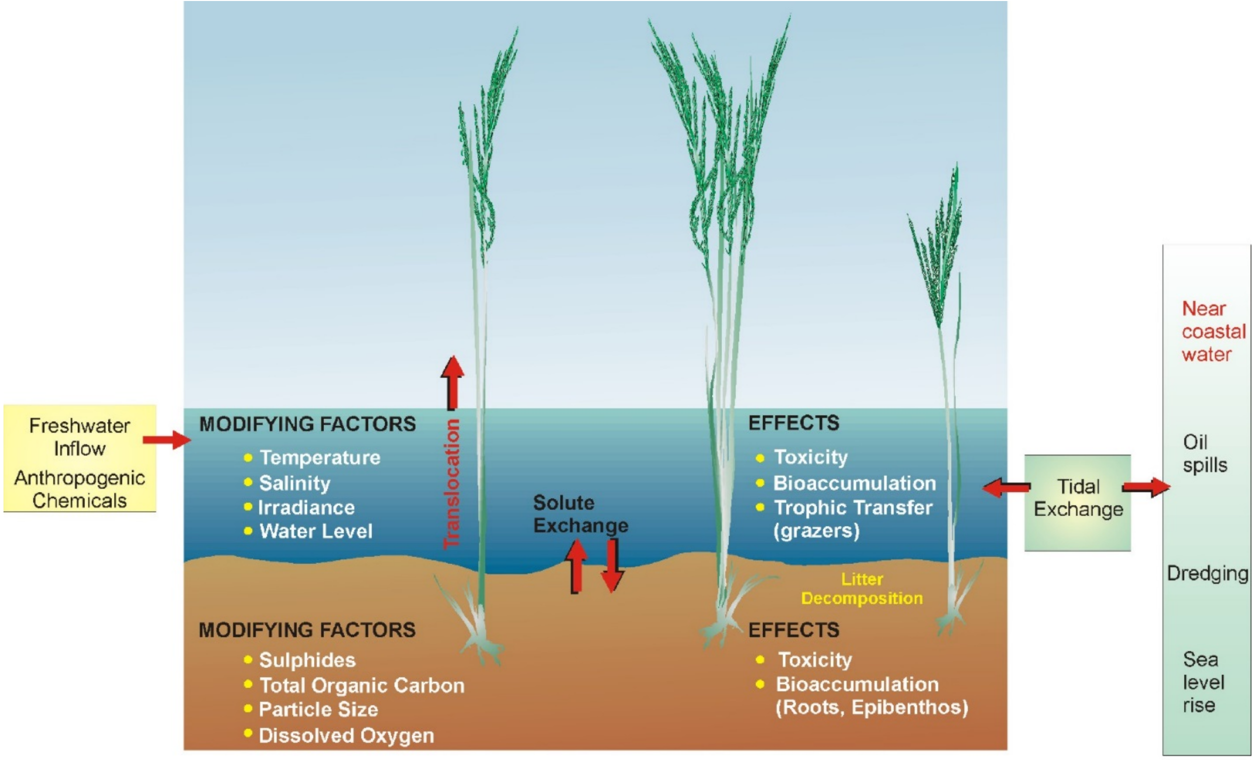
The economic value of harvested oysters is better understood and easier to determine than the value of the ecological services oyster reefs provide. However, the value of oysters as a harvested commodity is considered by some to be an order of magnitude less than the ecological value of oyster reefs (Grabowski et al. 2012). The value of fish species that use oyster reefs may be greater than that of the oysters produced by the same reefs (Beck et al. 2011). There are no reported economic values for the ecological services produced by PBS oyster reefs. The value used for our analysis is $10,325/ha (one hectare=2.54 acres) reported by Grabowski et al. (2012). This is an average value (range=$5,500-$99,000) based on 2011 dollars and water quality services, shoreline protection, and provision of habitat for biota. The estimate is conservative since recreational fishing, carbon burial, oyster harvesting, increased biodiversity and inflation are not included in the Grabowski et al. calculation. The inflation corrected value is $11,142/ha.

The historic trend for oyster reef coverage for the PBS is more difficult to determine than that for seagrass and salt marshes due to a lack of information. This is further confounded by the inconsistent differentiation between public and private reefs and between open and closed reefs. This lack of information is reflected in an evaluation of oyster reef coverage for the Gulf of Mexico by Baggett et al. (2014). The historic oyster reef area and extent remaining could not be determined for Pensacola Bay, unlike for 14 other northern Gulf of Mexico areas. Oyster investigations and reef surveys were first reported for the PBS, depending upon the source, either during 1898 (Brice 1898), 1933 (Prytherch 1933), or 1935 (FDEP 1998). The historical abundance and biological trends for oysters have been summarized by Collard (1991b) based on the results of numerous studies beginning in 1951. Reports for oyster include those of McNulty et al. (1972); Hopkins (1973); Little and Quick (1976); Barnet and Gunter (1985); Teehan and Barnett (1989a, b); Hudson (1990); Hudson and Wiggins (1996); Knight (2003); and FDAC 2004, 2005). McNulty et al. (1972) reported 280 acres of public natural reef, 138 acres of private reefs and about 8,200 acres closed for East and Escambia Bays, for the 1940-1950s. Hopkins (1973) provided a map of shellfish reefs but no values for acreages. Only 10% of oyster reef coverage observed in 1972 (8,388 acres) was observed in 1987-1992 (761 acres) (Florida Department of Environmental Protection Deepwater Horizon Florida; accessed 2016 July 14). Oyster reefs were considered “moderately-sized” in 1998 (FDEP 1998). Recent estimates for oyster reef coverage are 3,144 h (7,768 acres) (Baggett et al. 2014), 400 acres (162 ha) (Reynolds, Smith and Hills Inc. 2014) and 871 acres (353 ha) (1987-1992) (Restore the Gulf Pensacola Bay Watershed restoration; accessed 2016 July 14). The most current assessment available is for 235-245 acres of reefal complex including areas classified as restricted or prohibited and where clutching is warranted (Florida Department of Agriculture and Consumer Services, Joe Shields III, personal communication, February 2015). About 75% of coverage is in East Bay. The estimate by Baggett et al. (2014) was not used in our analysis since it is well above other estimates.

The estimated economic value of current reef coverage estimated for 96 ha (240 acres) and 162 ha (400 acres) is approximately $991 thousand to $1.7 million/y, respectively, based on the average of $10,325/ha reported by Grabowski et al. (2012). If inflation-corrected for 2016 currency, the value is between $1 million and $1.8 million/y. The current reef coverage of either 96 ha or 162 ha when compared to the total coverage (public and private) of 343 ha (871 acres) during 1987-1992 represents an approximate loss of 181 ha or 247 ha, respectively. This equates to an approximate annual loss of $1.9 million to $2.5 million or $2.0 million to $2.8 million (inflation adjusted) in ecological services.

19.3 Tidal Wetlands (Brackish and Salt Marsh)

A summary of the ecological services, goods and stressors impacting tidal wetlands have been summarized (Wright et al. 2006; Engle 2011; Barbier et al. 2011). Multiple pathways for the adverse effects of one stressor, chemical contaminants, appear in Fig. 19.3. Wetlands serve 10 functions (Woodward and Wui 2001; Spalding et al. 2014), including groundwater recharge and discharge, wave attenuation, water quality control (sequesters chemicals and solids), flood control, shoreline and storm protection, and recreation. In addition, tidal wetland vegetation act as carbon sinks (Spalding et al. 2014) and provide habitat and refuge for biota. Young menhaden, spot, croaker, and mullet depend upon PBS wetlands for their survival (Hopkins 1973).



Smooth Cordgrass
(*Spartina alterniflora*)

Figure 19.3 Potential impacts of anthropogenic contaminants on *Spartina*-dominated tidal wetlands common to the Pensacola Bay System.

The economic value of an acre of PBS tidal wetland based on the above services has not been reported. However, many estimates are available for other coastal areas and these differ by as much as two orders of magnitude. Examples are $6,700 (acre of salt marsh) and $10,602(acre of brackish marsh) (Farber and Costanza 1987); an average of $32,149 (median=$2,428, range = $1-$200,994) (Heimlich et al. 1998), a predicted average of $3,900/acre (range=$1,084-$22,856) (Woodward and Wui 2001), and $9,990/ha for tidal marsh/mangroves (Costanza et al. 1997). The mean predicted value of $3,900/acre (1990 currency; 2016 currency=$7,315/acre) by Woodward and Wui (2001) is used for the evaluation below since it is based on a literature review of 39 wetlands and the ten ecological services.

There are multiple reports and sources for tidal wetland coverage for the PBS. Many of the more recent are based on aerial imagery color infrared or true color photography. Comparison of past and present coverage is complicated by the technical differences in assessment techniques and coverage classifications. The differentiation between tidal wetlands, tidal marsh, and salt marsh has not always been made. Salt marsh coverage as a percent of shoreline for 1971 was reported as 20% for the entire PBS and as 14.4% (Escambia County alone) and 31.2% (Santa Rosa County alone) (Hopkins 1973). Salt marsh comprised about 0.05% or 878.3 acres of the Pensacola Basin surface area in 2007 (FDEP 2007). The estimated coverage of PBS tidal marshes (acres) approximated 213 (Pensacola Bay), 309 (Santa Rosa Sound), 3,307 (East Bay), and 5,152 (Escambia Bay) based on vegetation maps of 1940 and 1954 (McNulty et al. 1972). Based on Northwest Florida Water Management District Land Use/ Land Cover estimates for 1995, 2004, and 2010, salt marsh coverage (acres) has decreased during the past 20 years approximately from 149 to 117 in Big Lagoon and 180 to 68 in Santa Rosa Sound. In contrast, coverage increased from 1,400 to 1,794 acres in Blackwater Bay, from 3,750 to 4,519 acres in Escambia Bay and from 59 to 103 acres in Pensacola Bay. Coverage has remained relatively stable for East Bay (96 acres, 100 acres). The 2010 estimated total salt marsh coverage of 6,701 acres is 19% (1,067 acres) more than that for 1995. Using geospatial data from the 2014 U.S. Fish and Wildlife Service National Wetland Inventory (Fish and Wildlife Service National Wetlands Inventory; accessed 2016 July 13), total tidal wetland coverage approximates 8,579 acres consisting of 148, 152, 621, 978, 2,037 and 4,643 acres, respectively, for Big Lagoon, East Bay, Pensacola Bay, Santa Rosa Sound, Blackwater Bay, and Escambia Bay. One point of agreement among the three sources of data covering 1940-2014 (McNulty et al. 1972, National Wetlands Inventory, FLULC System) is the dominance of wetlands and the relative similarity in coverage across years for Escambia Bay (between 3,800 and 5,100 acres) and East Bay (84-100 acres). Finally, as part of the Pensacola Bay Bridge assessment, 8,891 acres of tidal marsh were reported (Reynolds, Smith and Hills Inc. 2014) but no source and date of the estimate was provided. This estimate is almost identical to that reported by McNulty et al. (1972).

The total current value of ecological goods and services produced annually by salt marsh (6,601 acres; 2010 NWFWMD land cover estimates) and tidal wetland (8,579 acres; 2014 National Wetland Inventory) for the PBS approximates $26.1 million and $33.5 million, respectively, based on the mean of $3,900/acre or $48.1 million to $62.8 million if inflation corrected. Based on our evaluation, there appears to be an approximate net loss of approximately 2,600 acres and 4,200 acres of these habitats since the 1940/1950s. The approximate 53% or 71% declines in coverage are based on comparison of the 8,981 acres of tidal marsh combined for Pensacola Bay, Santa Rosa Sound, East Bay, and Escambia Bay, reported by McNulty et al. (1972) to the approximate 6,400 tidal wetland acres from the 2014 National Wetland Inventory and the 4,800 acres of salt marsh from the 2010 Florida Land Use and Land Cover System reported for the same areas. The estimated value of the ecological services lost annually due to the decline in coverage; not accounting for inflation is approximately somewhere between $10 million and $16 million using the mean of $3,900/acre. Loss increases to between $19 million and $31 million based on the inflation corrected $7,315 per acre evaluation. Salt marshes may increase coverage as a result of future sea level rise if not restricted by anthropogenic barriers (roadways, armoured shorelines). This possibility, when combined with the current positive trend indicated by the LULC estimates for 1995-2010, should increase ecological services and the economic value of coastal wetlands.

19.4 Uncertainty

It is important to note that the above calculations are estimates and are specific to our coverage estimates and habitat-specific acre evaluations chosen from on-line and peer-reviewed sources. Local (State of Florida) per acre evaluations are available only for seagrass meadows. The prediction of the value of local oyster reefs and tidal wetlands based on estimates reported for the same type of habitat located elsewhere is uncertain. A more accurate economic evaluation for the PBS would require local determinations of habitat values and confirmation of current coverages. Although the values reported based on our analysis can be debated, it is clear that the intrinsic value of just three estuarine habitats to the public can be argued to be in millions of dollars per year. This type of knowledge certainly justifies the expense of their protection and restoration considering the estimated economic cost of their historical neglect.

20 Climate Change

Climate change is an increasing determinant and threat for the environmental quality of the PBS. Its addition to an already complex human-biophysical system adds uncertainty to maintaining current biodiversity and economic value. The effects of climate change on Florida's coastal resources~~,~~ have been summarized (Florida Oceans and Coastal Council 2009; Livingston 2014). Climate change will cause saltwater encroachment into freshwater habitats and modify the shoreline configuration, similar in part to that reported by Kish and Donoghue (2013) for the effects of storms and Santa Rosa Sound. Sea level rise is occurring in the PBS at about 2.1 mm/y (Zervas 2009) relative to a predicted 0.75 mm and 9.95 mm/y predicted for Gulf coastal states (Thatcher et al. 2013) and a model prediction of a 8-20 inch rise along the Gulf Coast in the next century (Twilley et al. 2001). Increasing sea level will reshuffle habitats within the PBS. Coastal acidification and sea level rise will likely reduce oyster reefs/ harvests due to thinning of shells (more susceptible to predation), decreased size, reduced accretion rates, and submersion. Some, however, think that vertical reef accretion may be able to outpace sea level rise and benefit from the added subaqueous space (Rodriguez et al. 2014). It is expected that tidal wetlands will increase and seagrass beds decrease. The effects of climate change on seagrass have been reviewed (Short and Neckles 1999; Koch et al. 2007). Climate change will also alter the organic carbon cycle, salinity zones, increase water temperature, decrease rainfall and potentiate the biological effects of current stressors. Salinity zones are important to the spatial distribution, condition, and survival of biota such as for seagrass (Shaffer 1995; Koch et al. 2007) and tidal marsh plants (Kurz 1953). The most recent and extensive summary of salinity tolerances are presented in Lewis FG (2010) for plants and animals in Blackwater and East Bays and the lower Yellow River. Salinity effects chemical toxicity (Nimmo and Bahner 1974). Toxicity to aquatic organisms increases with increasing temperature (Kwok et al. 2007). Finally, species tropicalization is occurring in the northern Gulf of Mexico (Fodrie et al. 2013), including the PBS (example, the lion fish, *Pterois volitans*). New species alter species diversity and the influx of grazer species such as herbivorous turtles, manatees, and parrotfish will decrease the condition and nursery functions of seagrass meadows.

Reports for local management strategies to determine the possible effects and specific mitigation strategies of climate change could not be found. However, useful insight is available among others from Twilley et al. (2001); Florida Oceans and Coastal Council (2009); Geselbracht et al. (2013); and Cross (2014). An in-depth analysis of the increase in sea level rise for the PBS and four other estuaries based on use of the Sea Level Affecting Marshes Model (SLAMM, version 6.2, 2012) has been published (Geselbracht et al. 2013). This report describes vulnerable animal and plant species, and predicts changes in various habitat coverages based on sea level increases of 0.7 m, 1.0 m and 2.0 m. Loss of undeveloped dry land is predicted for the PBS with major decreases in coastal forest and inland freshwater marsh and cypress swamp by 2100. In contrast, salt marsh coverage will increase, assuming submergence does not occur and shoreline anthropogenic impediments are absent. The transitioned areas will benefit wading birds and fish. The projected order of net change in coastal wetlands in decreasing order was Tampa Bay>Corpus Christi Bay>Mobile Bay>Pensacola Bay>Big Bend area. Additional information applicable to the PBS is available from the U.S. EPA's Climate Ready Estuaries Program (EPA Climate Ready Estuaries; accessed 2016 July 14), which works with the National Estuaries Program to identify vulnerabilities and develop adaption plans to climate change.

21 Discussion

The environmental condition for PBS is not as well understood as would be expected after 135 years of intermittent analysis and after 40 years of attempted improvement by multiple Federal, state, regional, and local jurisdictional agencies. A “report card” or “dashboard” perspective appears in Figure 21.1 based primarily on the state-of-knowledge found in more recently published reports (Table 21.1). Examples of several unknowns related to resource management and anthropogenic contaminants appear in Table 21.2. Although some environmental recovery has been made since the 1970s, and there has been a steady increase for environmental information, the extent of the recovery is uncharacterized for many biological metrics. Likewise, the specific reasons or causes of the decline in environmental quality of the PBS in other than general terms, are largely unknown and likely the result of the complex interaction of natural and anthropogenic stressors influenced by daily and seasonal factors, the individual effects of which are not well understood. Thus, sensitive response parameters and pressure points for most PBS communities in response to stress are not known and as a result, there is an inability to predict changes in biotic distribution, condition, and productivity in response to current and future environmental perturbations. The lack of this information has resulted in an absence of validated models although the RIOS (Goldstein et al. 2015; Resource Investment Optimization System–Natural Capital Project; accessed 2016 July 13) and the USEPA’s H2O Model (EPA H2O; accessed 2016 July 13) show promise. However, sufficient metadata needed for these models to reliably predict the local effects of stressors on ecological services and goods are largely absent. Therefore, their current and near-future value is primarily conceptual.

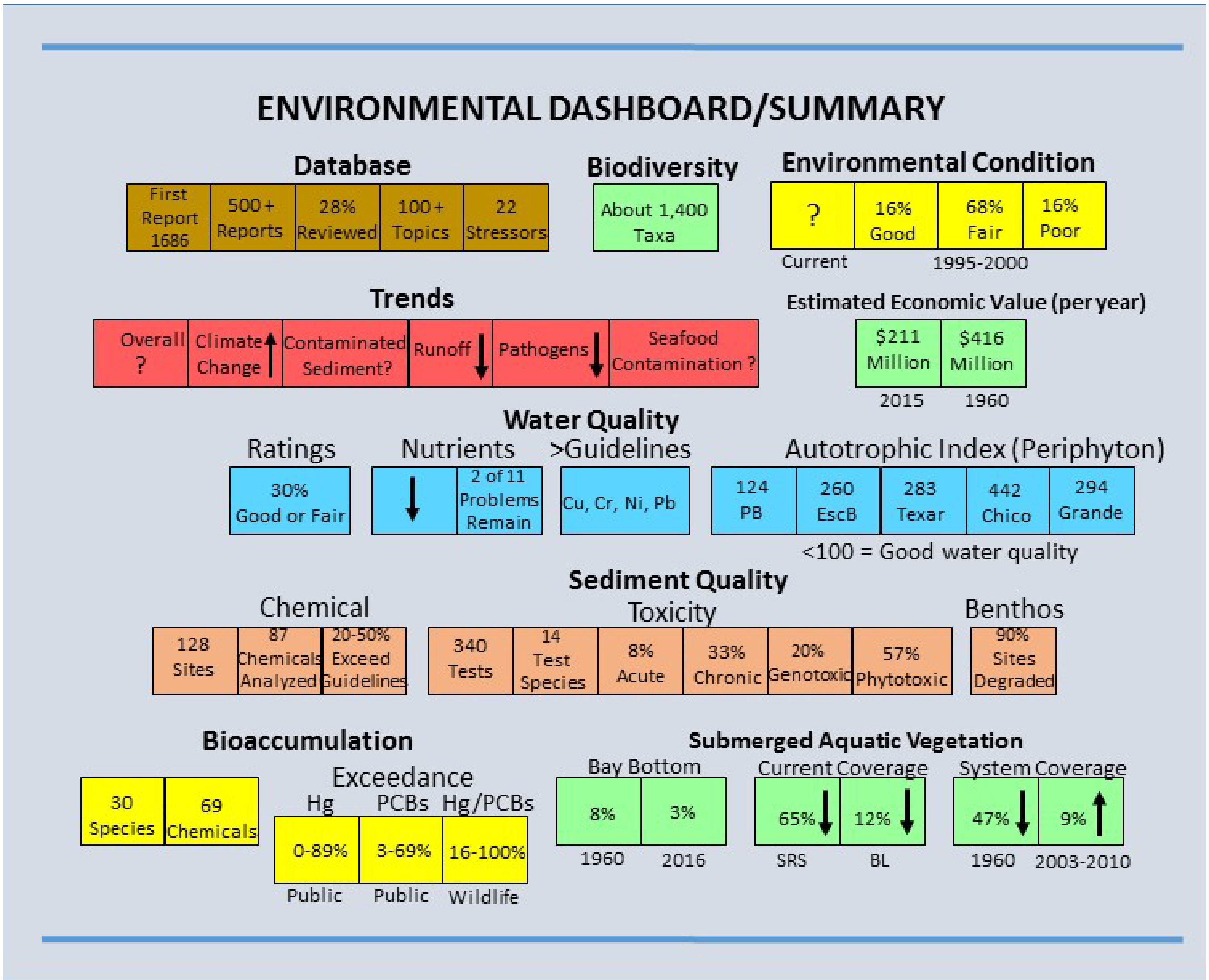


Figure 21.1 An “environmental report card” or “dashboard” perspective of environmental information for the Pensacola Bay System. Economic evaluation for submerged aquatic vegetation, oyster reefs and tidal wetlands. Autotrophic index = biomass/chlorophyll *a*. Sediment toxicity reported as a percent of all toxicity tests. Uncertainties (Table 21.2) related to anthropogenic chemicals, water and sediment quality, and natural resources. Bioaccumulation exceedance (percent of all samples) reported as a range for various numerical guidelines. System coverage for submerged aquatic vegetation, almost all submerged aquatic vegetation, is for the entire Pensacola Bay System. Current submerged aquatic vegetation coverage reported for Santa Rosa Sound (SRS) and Big Lagoon (BL).

Table 21.1 Most recent information for several environmental metrics and the Pensacola Bay System.

Natural Resource Inventory

Olinger et al. 1975

Cooley 1978 (most comprehensive survey)

Ross and Jones 1979 (seven drainage basins)

Moshiri et al. 1980 (Santa Rosa Sound)

Butts and Lewis 2002 (macroinvertebrates)

Lores et al. 2002 (zooplankton)

Murrell and Lores 2004; Murrell et al. 2007 (phytoplankton)

Lewis et al. 2010 (fish)

Lewis 2010 (East and Blackwater Bays)

System Environmental Quality Summaries

Collard 1991a (1950-1990)

Von Appen and Winter 2000 (1990s)

Macauley et al. 2005 (quantitative for 1995-2000)

FDEP 2007, 2012b

Watershed Management Plans

West Florida Regional Planning Council 2005 (19 water quality action plans)

Northwest Florida Water Management District SWIM plan (projected completion-2017)

Nutrients/Eutrophication

FDEP 2012b (overview)

Caffrey and Murrell 2016 (overview)

Toxic Substances

Gulf of Mexico Program 1993 (research needs)

Sediment Quality

Long et al. 1997 (chemical quality/toxicity/ estuarine comparison)

Lewis et al. 2001b (golf course/Santa Rosa Sound)

Lewis et al. 2001d (phytotoxicity)

Debusk et al. 2002 (chemical quality/toxicity overview)

Mohrherr et al. 2005 (Bayou Texar)

Lewis and Daniels 2006 (pore water genotoxicity)

Mohrherr et al. 2006 (Bayou Chico)

Liebens et al. 2007 (Bayou Chico)

Lewis et al. 2007 (seagrass-rooted sediments)

Table 21.1 (contiunued)

Mohrherr et al. 2008 (Bayou Grande)

Mohrherr et al. 2009, 2012 (Escambia Bay)

Dredging

Livingston 1971 (Mulatto Bayou)

Brinson and Keltner 1981 (Bayou Chico with recommendations)

Morgan and Stone 1989 (Bayou Texar)

Moshiri and Elewad 1990 (Bayou Texar)

Lewis et al. 2001a (Bayou Texar)

Bioaccumulation

Karouna-Renier et al. 2007 (PCBs, dioxins, trace metals, PBS, blue crabs, oysters)

Lewis et al. 2007 (above and below substrate seagrass tissues)

Snyder and Rao 2008 (dioxins, PCBs, trace metals, Escambia Bay, fish)

Kimbrough et al. 2008 (Mussel Watch Program summary for 3 PBS stations)

Goff 2009 (PCBs, Pensacola and Escambia Bays, mullet)

Snyder and Karouna-Renier 2009 (PCBs, dioxins, furans, mercury, oysters, blue crabs, fish, PBS)

Seagrass

Collard 1991 (review of value and restoration success for oysters and seagrass)

FDEP 2001 (management plan for Big Lagoon and Santa Rosa Sound)

Handley et al. 2003 (Gulf of Mexico and PBS summary)

Lewis et al. 2007 (chemical bioavailability)

Lewis et al. 2008 (historical coverage review)

Harvey et al. 2015 (current coverage)

Table 21.2 Knowledge-based uncertainties based on contaminant and resource management-related information absent for the Pensacola Bay System that restricts environmental improvement.

1. System-wide analysis for current environmental condition and trend for many metrics

2. Number of FDEP impaired waters based on considerations of chemically-contaminated and toxic sediments; low benthic diversity and PCB-contaminated seafood

3. Sensitive local biocriteria (structural and functional) to judge health (condition) of PBS dominant biota and diversity-building habitats

4. Environmental concentrations, and water column and benthic toxic effects for chemicals of recent concern: pharmaceuticals, anti-microbials, endocrine disruptors, nanomaterials, microplastics, veterinary products, perfluorochemicals (anti-sticking and waterproofing agents) and polybrominated diphenyl ethers (flame retardants)

Table 21.2 (continued)

5. System-wide nutrient budget

6. Long-term biological effects of the continued entry of contaminated groundwater from Superfund sites

7. Specific cause(s) of benthic degradation, and sediment acute and chronic toxicity to benthic flora and fauna

8. Impact of intermittent hydraulic dredging on short- and long-term environmental condition

9. Acute and chronic toxicities of tidal wetland sediments to rooted plants, nutrient-non-nutrient contaminant concentrations to plankton and seagrass, and runoff from indirect wastewater discharges on receiving water biota

10. Verified coverage and health of local biodiversity-building oyster reefs, seagrass meadows and tidal marsh

11. Quantified ecological and economic value of ecological goods and services produced by local naturally occurring biodiversity-building habitats and their restorations/creations

12. Life-supporting requirements for successful long-term habitat restorations and creations

13. Ecological equivalence of natural, restored and created habitats

14. Dimensions of vegetative buffer zones and living shoreline modifications that provide maximum ecological services for stormwater reductions and reduced inputs of chemicals and suspended solids

15. Public health risk for consumption of seafood containing combinations of human-harmful chemicals

16. Wildlife health risk for consuming chemically-contaminated prey from the Pensacola Bay System

17. Effects of tissue-accumulated chemicals, alone and in combination, on the health of dominant estuarine biota

18. Incidence of histopathological disorders in dominant Pensacola Bay System biota

19. Definable limits of chemical and biological variability for the Pensacola Bay System and their impact on conclusions for condition and chemical risk assessments

20. Functional redundancy of Pensacola Bay System biota

21. Validated local models to predict current and future effects of non-nutrient chemical stressors and climate change on the ecological goods and services provided by the Pensacola Bay System

22. Cost-effective mitigation techniques for the chemical, biological and physical effects of climate change (invasive species, upslope migration of tidal wetlands, degradation of seagrass and oyster habitats)

The current environmental trend and rate of improvement are uncertain for the PBS due to a variety of reasons (Fig. 21.2). Over the past few decades, the PBS has been considered stable or on the rebound (Ross and Jones 1979; Thorpe et al. 1997), and water quality has been considered fair and good (Hopkins 1973; WFRPC 2005; Macauley et al. 2005; FDEP 2012a). Collard (1991a) summarized trends for several biota and found no improvement in water quality (1970-1991) and macroinvertebrate community composition (1955-1991). Caffery and Murrell (2015) reported that chlorophyll *a* concentrations have remained steady for the last 40 years. A positive or upward trend for improvement is supported, among other factors, by declines in nutrient concentrations, suspended solid concentrations, septic treatment systems, large-scale fish kills, initiation of a state-wide gill net ban in 1994, the elimination of direct discharges of high-volume wastewaters to Pensacola and Escambia Bays, improved wastewater treatment, and increasing use of living shoreline restorations. The listing of impaired waters and TMDL implementation are also positive developments. As of 2010 (FDEP 2010a), there were 43 impaired water segments in the Yellow, Blackwater and Escambia Rivers, Pensacola, Escambia, Blackwater and East Bays, Santa Rosa Sound, and several bayous (Williams, Indian, Trout, Tom King, Grande, Judges, Jakes, Mulatto). The parameters of concern were largely public health issues for mercury levels in fish, the presence of fecal coliforms, and to a lesser extent, issues for low dissolved oxygen, high nutrients and elevated chlorophyll *a* (Florida Department of Environmental Protection watershed assessment; accessed 2016 July 14). The number of impaired or degraded areas is likely under-estimated if contaminated sediments, PCB-contaminated seafood, and low biodiversity are included in the analysis. However, the degraded areas based on these parameters often overlap many listed impaired waters (Fig. 21.3).

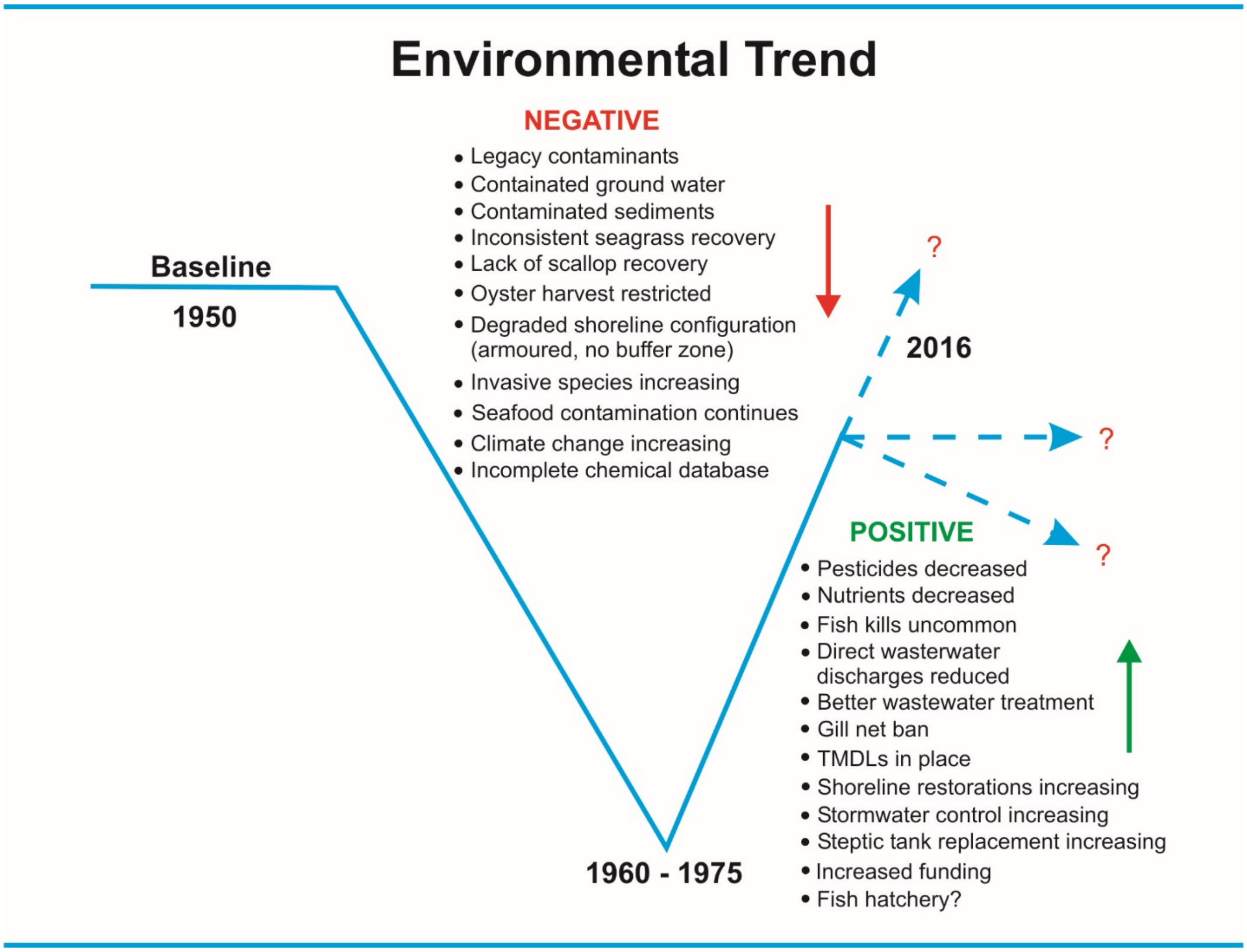


Figure 21.2 Several factors affecting determination of the rate of environmental improvement for the Pensacola Bay System. Blue line=theoretical environmental improvement; 1950 baseline period before major environmental deterioration.

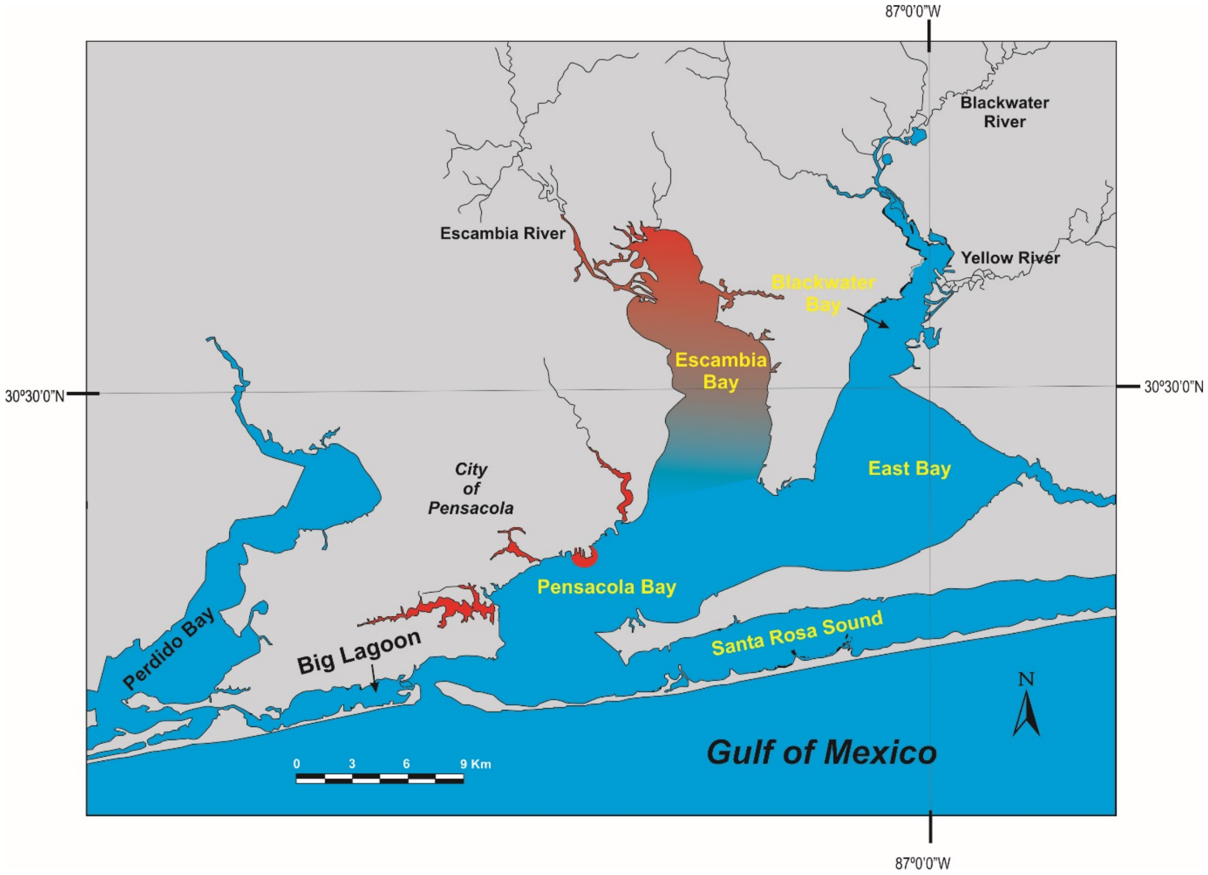


Figure 21.3 The more environmentally-degraded areas in the Pensacola Bay System based on current knowledge for water and sediment quality and contaminant bioaccumulation. Degraded areas generally overlap those for listed impaired waters based on mercury in fish, fecal bacterial contamination and excess nutrients (FDEP 2010a).

In contrast to positive developments, there are few long-term quantitative trajectories for environmental stressors and environmental parameters. Unconstrained entry of untreated stormwater remains a major stressor, although constraints are increasing and the volumes entering the PBS are likely less than those in the past. The total volume of stormwater entering the PBS has not been reported to our knowledge. There is an incomplete chemical database for the effects and concentrations of chemicals of emerging and current concern in the water column and sediment. Turbidity has been a stressor since 1900 (Collard 1991a) and continues to effect environmental quality of several areas. Sediments have become degraded, chemically and biologically, and toxic, and continue to serve as a reservoir for upper trophic level contaminant transfer. The specific cause(s) of toxicity and reduced benthic community quality remain unknown, which restricts rehabilitation by the TMDL process. The oyster industry is limited and temporally and spatially-restricted, shrimp harvests are reduced from historical levels, and the scallop industry (*Argopecten irradians*), which peaked during 1968-1969, is non-existent. Invasive species such as the lion fish, are increasing and likely will continue to do so. Chemically-contaminated seafood represents a public health risk. The estuarine food chain contains anthropogenic contaminants, for which the effects, alone and in combination, on wildlife and organismal health are uncertain. Efforts to repair and replace historically-destroyed habitats have been of mixed success because of often unknown factors. The impact of the few successful restorations on improving the environmental quality of the PBS has been beneficial but the extent is unknown. Armoured shorelines continue to inhibit seagrass coverage.

The current scientific uncertainties for the PBS are largely attributable to a combination of the lack of sufficient economic support for coordinated resource management and conducting consistent state-of-the-art chemical and biological monitoring (examples, Van der Meer 1997; USEPA 2003; FDEP 2013a). Some uncertainty is also because of the limitations of environmental science that include the inability to distinguish effects of most natural and anthropogenic stressors, alone and in combination, on the functional and structural characteristics of aquatic life. There are minimal national, regional, and state numerical criteria available to determine the significance of many environmental measurements made within the PBS. Numerical metrics for judging the condition of an estuary include the national and Florida water quality criteria, *proposed* sediment quality criteria (MacDonald et al. 1996), metrics based on regional frequency distributions (Friedmann and Hand 1989), and the condition criteria used in the past by large monitoring programs conducted in part in the PBS (i.e., EMAP-Estuarine Monitoring and Assessment Program; NCA-National Coastal Assessment). Important numerical benchmarks missing for environmental judgements include tissue-based criteria, biological criteria, and consumption guidelines for wildlife. Furthermore, exceedance frequency of the few tissue-based consumption guidelines, such as for humans and mercury, depend upon which of the guidelines and consumption rates are used (Fig. 21.4), and if the presence of selenium is included in the assessment.

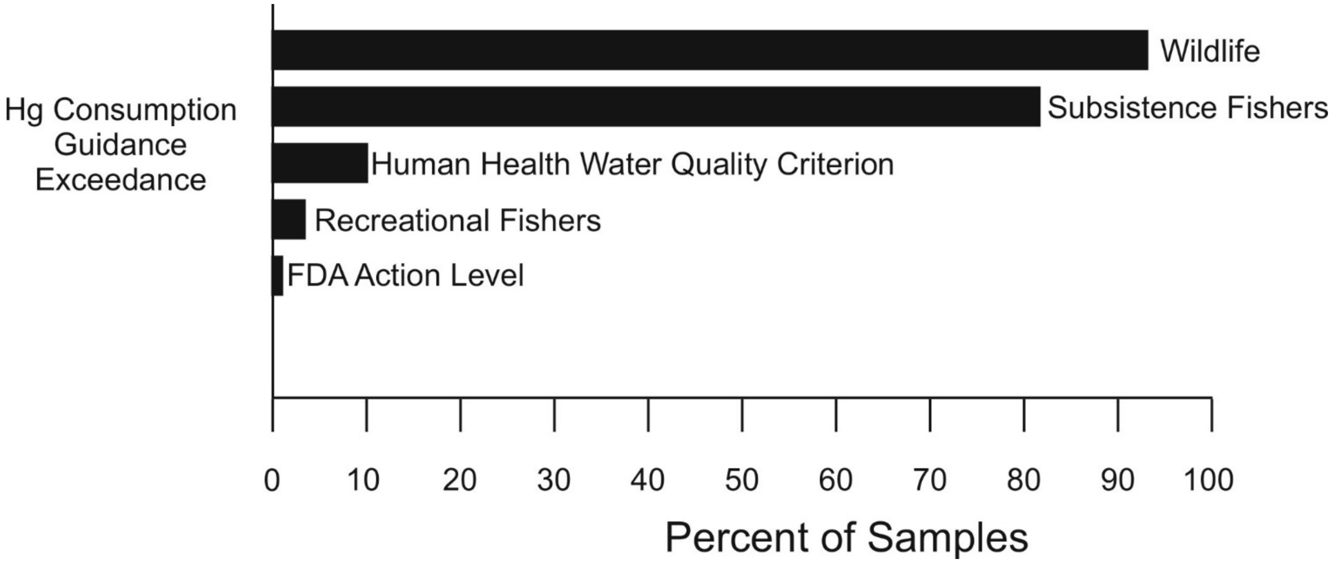


Figure 21.4 Exceedance frequency of different consumption guidelines for mercury based on reported residues in blue crabs, oyster and fish collected from the Pensacola Bay System. Guidelines from USEPA (2000b, 2001); CCME (2001); FDA (2011); FDEP (2013a)

Much of the cause-effect research for the PBS has focused on excessive nutrients that appear to be no longer a major stressor in most areas (FDEP 2012b). In contrast, the fate and effects of non-nutrient contaminants, alone and in combination, are less understood. Concentrations of several historical "problem" chemicals, despite being banned or restricted for use since 1972, persist in PBS surface waters, sediments, and biota. Examples include DDT concentrations in Escambia Bay and adjacent wetlands (Liebens and Mohrherr 2015), the presence of PCBs/furans in some seafood (Karouna-Renier et al. 2007; Snyder and Karouna-Renier 2009), and dioxins and wood treating chemicals entering Bayou Texar from contaminated groundwater (Liebens et al. 2006, 2007; URS 2012). In addition, nothing has been published for the fate and effects of pharmaceuticals, personal care products and the highly bioaccumulated polybrominated diphenyl ethers and perfluorinated compounds (USEPA 2013a, b) which can impact public health. These chemicals have been detected commonly in surface waters, are toxic, and have been of concern since the mid-1990s. Research recommendations and background toxicity data are available for these two compounds (USEPA 2008).

Urban stormwater runoff containing anthropogenic chemicals and suspended solids, contaminated sediments, and the effects of global climate change are major stressors for the ecosystems of PBS. Control and remediation of their effects represent the major challenge for future environmental improvement more so than the research opportunities available to update information and fill data gaps in the historical database. The most practical and cost-effective forward strategy is to determine the current condition of the PBS, which will then serve as the baseline for future comparison using a multiyear, metric-rich, system-wide environmental assessment. This should be followed by a frequently conducted, long-term, state-of-the-art monitoring program that incorporates sensitive local indices of chemical and biological condition. Guidance for this monitoring program is available from the National Water Quality Monitoring Council (National Water Quality Monitoring Council; accessed 2016 July 13), USEPA (2000a, 2003), and Gulf of Mexico Alliance (2013 a, b). Habitat restorations that are resilient to the increasing effects of climate change would supplement this monitoring program to support the goal of incremental improvement. From resource allocation and management perspectives, further chemical and biological data collection for Bayous Texar and Chico, as well as Escambia Bay, should be decreased while areas less studied should be increased (Big Lagoon, East Bay, Blackwater Bay, Bayou Grande). This research "downsizing" also applies to routine determinations of nutrients (chlorophyll *a* concentrations), and the chemical and biological quality of sediments. PBS sediments that are most likely to be contaminated have been effectively characterized for most physical, chemical, and biological metrics. Two sediment-related issues in need of additional information, however, are identification of the specific cause(s) of degradation and assessment of the environmental effects of dredging. Sediment toxicity identification evaluations (USEPA 2007) can be used to determine which contaminants are causing toxicity and lead to their control by the TMDL process, which is currently not possible without a fixed numeric target. Without this information, sediment contamination will continue to restrict environmental improvement in much of the PBS for the foreseeable future, unless extensive dredging occurs or a large scouring event occurs as a result of hurricane activity as reported for Mobile Bay (Isphording et al. 1987). Seven strategies for sediment recovery appear in the WFRPC (2005) report, but most have not been implemented and others have not been effective.

In summary, although considerable advancement for scientific understanding has occurred in recent years, an aggressive watershed and science-based management approach coupled with adaptive and responsive regulation policy is needed if future environmental improvement to be achieved under the influence of climate change. This is necessary since coastal environmental degradation is occurring at a faster rate than the ability of the scientific community to identify sources, specific cause(s), and control procedures. Effective basin management and regulation requires multiple factor risk assessment that considers cascading and scale-related effects that require an ecosystem perspective. This is an idealized approach, however, and all that can or should be done to fully protect the PBS from further degradation is limited by funding and the yet to be understood controlling factors for the structural and functional characteristics of the dominant biota. Consequently, we will never be certain of every technical detail nor have answers to all of the science-based questions necessary to compensate for the historical environmental decline. As a result, professional judgement will continue to be an important factor for conducting focused research and developing the most effective resource management and research strategies.

Surface Water Improvement and Management (S.W.I.M.) Program
Management Options for the Pensacola Bay System: The Potential Value of Seagrass Transplanting and Oyster Bed Refurbishment Programs
Developed under the auspices of Chapter 373.453, Florida Statutes
Northwest Florida Water Management District
July 1991
Water Resources Special Report 91-4

Surface Water Improvement and Management (S.W.I.M.) Program
The Pensacola Bay System
Biological Trends and Current Status
Developed under the auspices of Chapter 373.453, Florida Statutes
Northwest Florida Water Management District
July 1991
Water Resources Special Report 91-3

RESEARCH NEEDS FOR TOXIC SUBSTANCES AND PESTICIDES IN THE GULF OF MEXICO:
A STRATEGY

Northwest Florida Water Management District
Pensacola Bay System
Surface Water Improvement and Management Plan
October 1997
Program Development Series 97-2

PENSACOLA BAY WATERSHED MANAGEMENT GUIDE
AN INTEGRATED
ECOSYSTEM ACTION PLAN
Managing the Nearshore Waters of Northwest Florida

BIOLOGICAL MONITORING IN THE PENSACOLA BAY SYSTEM
1990-2000
Report Submitted to the
Northwest Florida Water Management District
July 2000
Submitted By
LASSANDRA A. VON APPEN
AND
DR. PEGGY A. WINTER

Seagrass Management Plan for Big Lagoon and Santa Rosa Sound
Dec 2001

THE PENSACOLA BAY WATERSHED MANAGEMENT PLAN
AN INTEGRATED ACTION PLAN
2005

Pensacola Bay
Community-Based Watershed Plan
The Nature Conservancy in Florida
DECEMBER 2014
Photo © Ralph Pace
The Nature Conservancy
Protecting nature. Preserving life.

Figure 21.5 Examples of historical sources of largely unfulfilled recommendations for environmental improvement of the Pensacola Bay System.

22 Recommendations

Resource management plans for research, conservation, and restoration and their accompanying recommendations have been numerous during the past 45 years. For examples, see Olinger et al. (1975); Brinson and Keltner (1981); Lewis (1986); Pratt et al. (1990); Jones et al. (1992); Collard (1991a, b); Gulf of Mexico Program (1993); Thorpe et al. (1997); BARC et al. (1998); Von Appen and Winter (2000); DeBusk et al. (2002); Macauley et al. (2005); WFRPC (2005); Gulf of Mexico Alliance (2009); and Caffery and Murrell (2015). The SWIM reports of Pratt et al. (1990) and the updated version by Thorpe et al. (1997) describe as many as 37 projects related to non-point assessment, point sources, habitat preservation, restoration and conservation, administrative planning, and education. The BARC et al. (1998) report and updated version, WFRPC et al. (2005), are comprehensive and detailed. They include as many as 54 action plans for database management, air quality, land management, water quality, and public education. The "to-do-list" or recommendations in the WFRPC document approximate 250. Many of the above plans and their recommendations have been largely planning exercises with their implementation limited by lack of sufficient and long-term economic support. Consequently, many previous recommendations, strategies, and action plans still wait action. Several recommendations that follow encompass those previously made locally (Fig. 21.5), and parallel those made in general for marine waters and the Gulf of Mexico (Gulf of Mexico Program 1993; Boesch et al. 2001; Heinz Center 2008; Gulf Ecosystem Restoration Task Force 2014). Implementation of the following recommendations, either sequentially or in parallel, will require an interactive-phased approach and a long-term resource commitment.

Environmental resource management-Fund an existing local or regional agency to improve coordination and to oversee resource management, environmental monitoring, and research and restoration activities for the PBS. The goal is to reduce repetitive and overlapping environmental studies characteristic of the past.

Environmental information management-Create, fund, and maintain a frequently updated on-line site to consolidate past and present environmental information such as for natural resource coverages, local, regional, federal and state research activities, restoration progress, summaries of chemical and biological monitoring results, updates for TMDL progress, and state regulatory actions. On-line site will increase public awareness and assist policy makers and the regulatory community in making consensus-based and technically-supported environmental management decisions.

Environmental condition and trend analysis-Determine the current environmental condition of the PBS by conducting a one-time, multi-seasonal, multi-metric, and system-wide environmental analysis. Focus this baseline study for locations and metrics historically less studied for which current information is lacking, inadequate or outdated. Follow the comprehensive study with frequently conducted state-of-the-art monitoring to update changes in condition over time and to establish the environmental trend. The long-term periodic monitoring should be adaptable to new found information and include analysis of chemicals of recent concern. Use of a stratified sampling design and targeted monitoring when problems have been detected is recommended. Random site selection is inefficient and not sufficient alone to effectively characterize local conditions.

Spacial priority-Future environmental research, natural resource characterizations, and monitoring activity should decrease for Escambia Bay, Bayous Texar, and Chico unless major restoration activities occur that need confirmation of progress. Redirect effort for areas with less diverse and limited environmental databases such as for Big Lagoon, East and Blackwater Bays, and Bayou Grande.

Temporal variability for environmental metrics-Determine the temporal variability of in-situ single chemical and biological measurements by conducting seasonal evaluations. Determine the impact of the variability on conclusions and recommendations for resource management actions and stressor risk assessments. Determine the value of applying uncertainty or safety factors to single measurements to account for the variability in results.

Anthropogenic chemicals-Standardize analytical methods and quality assurance and control procedures used to determine effects/fate of anthropogenic-source contaminants in the PBS. Differentiate anthropogenic toxicant-caused effects on biota from those caused by natural stressors. Identify a standard toxicity test battery (test species) for common PBS anthropogenic chemicals. Determine the chronic toxic effect and no effect concentrations for common shoreline chemicals (nutrients and non-nutrient contaminants) alone and in combination to phytoplankton, zooplankton, and seagrass. Focus on analyzing the fate and effects of highly phytotoxic atrazine and Irgarol on seagrass meadows. Conduct toxicity tests under natural extreme conditions for salinity and temperature using laboratory tests and in-situ enclosures and mesocosms. Determine effects of runoff from indirect wastewater discharges (spray irrigation, wetland pass-through) on receiving water biota. Develop and validate locally-sensitive models to predict the impacts of current and future common chemical stressors on keystone species and biodiversity-building habitats.

Water quality-Reduce frequency of routine measurements for most physicochemical measurements, nutrients, and chlorophyll *a*. Increase database for environmental concentrations and toxic effects of water column chemicals for which no or inadequate information is available. Conduct monitoring programs for the highly phytotoxic atrazine, a local widely used herbicide, and Irgarol, an anti-fouling chemical commonly found in Florida marina areas. Likewise, determine concentrations for pharmaceuticals, antimicrobials, endocrine disruptors, veterinary products, personal care products, nanomaterials such as microplastics, perfluorochemicals (anti-sticking and waterproofing agents), and polybrominated diphenyl ethers (flame retardants). Validate local nutrient criteria by exposing plankton and submerged vegetation using in-situ and laboratory mesocosms. Expose the biota to combinations of ambient nutrient concentrations and non-nutrient contaminants (i.e., herbicides) under the influence of different conditions of temperature and salinity.

Sediment quality-Develop a management and improvement plan for contaminated sediments. Reduce the frequency of routine chemical and biological measurements for which new information gain will be minimal. These measurements include trace metal concentrations, acute toxicity, and benthic community analysis. Focus attention on identifying the cause(s) of sediment toxicity and benthic degradation using a combination of chronic toxicity tests and sediment toxicity identification evaluations so that the TMDL process can be applied. Determine the acute and chronic phytotoxicities of tidal wetland and seagrass-rooted sediments affected by stormwater runoff. Identify the optimal sediment chemical conditions needed to support sustainable and resilient seagrass meadows. Determine benthic effects and fate of chemicals of more recent concern listed above for water quality.

Dredging-Prevent the entry of contaminants and suspended solids to the waterbody of interest before dredging occurs to prevent repetitive and unnecessary expense. Determine the short-term and long-term ecological effects of local dredging events so that their assumed environmental value can be validated.

Public health-Public health investigations for seafood safety should continue PBS-wide with frequent monitoring for mercury, PCBs, furans, dioxins, and, to a lesser extent, inorganic arsenic. Develop a baseline database for the human-harmful perfluorinated compounds and polybrominated diphenyl ethers for which no local tissue-based published information is available. Evaluate public health risk using a proactive tissue-chemical mixture approach.

Wildlife health-Conduct a risk assessment for wildlife consumers of PBS-dependent prey using information for toxic effects and body burdens of local wildlife species. Evaluate health risk using a proactive tissue-chemical mixture approach.

Organism health-Assess lethal and sublethal impacts of accumulated chemicals, alone and in combination, on health of dominant PBS biota. Routinely determine the incidence of histopathological abnormalities for local recreationally and commercially important shrimp, oysters, blue crabs, and fish.

Biocriteria-Determine locally sensitive indicators of biological condition (biocriteria) for dominant diversity-building habitats (tidal wetlands, oyster reefs, seagrass meadows). Use condition indicators for resource monitoring and judging post-restoration progress.

Habitat restorations/coverage-Identify local life-supporting requirements prior to habitat restorations and creations. Conduct long-term post-restoration monitoring to determine success. Determine the ecological and economic benefits of successful restorations, singular and in aggregate, so their overall value to improving the condition of the PBS can be judged. Determine the ecological equivalency of created and restored habitats to similar naturally occurring habitats. Prior to full scale seagrass restorations, consider use of pilot plots and assessment of sediment phytotoxicity to seedlings. Conduct routine aerial surveys for oyster reef, salt marsh, and seagrass coverage with accompanying ground-truthing and mapping (3-6 years). Monitor condition of these habitats every 1-2 years using locally-developed sensitive biocriteria.

Shoreline modifications-Replace armoured and non-vegetated shorelines with a combination of vegetative buffer zones and/or living shorelines to improve stormwater quality (removal of toxicants and suspended solids). Quantify the near-field and far-field benefits or performance of the modifications and their contribution to the overall ecological condition of the PBS. Determine and validate the dimensions of local shoreline modifications (community-based and buffer vegetated zones) that provide the maximum environmental benefits. Determine the cost/ecological benefit ratios for these modifications needed for effective resource allocations and management.

Climate change-Ensure that the PBS is a climate change-ready estuary by increasing coverage of biodiversity-building habitats (increases resiliency). Adapt to and minimize expected adverse effects by incorporation of expected changes in sea level, shoreline configuration, biodiversity (invasive species), reductions in habitat coverage and condition of seagrass and oyster habitats into resource management and restoration plans.

Environmental economic analysis-Conduct a thorough economic analysis for the environmental services and goods provided by the PBS. Refine the economic analysis presented in this summary for seagrass meadows, oyster reefs, and tidal/salt marshes using validated current coverages and locally-developed economic evaluations for ecological services and goods. This includes reliable economic information for annual seafood harvests.

Predictive models-Develop the metadata needed to support development and validation of locally-sensitive models capable of predicting the current and future effects of different levels of stressors on the ecological services and goods produced the PBS ecosystem. Examples: RIOS and H2O models

Financial commitment-Provide adequate, long-term, consistent, multi-organizational financial commitment for information consolidation/communication, research, modelling, habitat restorations, and resource monitoring.

Environmental education-Increase quality and accessibility of environmental education for students, public and policy makers. “Good scholars are not encouraged as they ought to be. Science is scarcely thought to be a subject worthy of conversation. Swarms of children are running about the streets, improving rapidly in dissipation and vice” (A View of West Florida, J.L. Williams 1827).

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