Sediment Quality Triad Assessment in Kachemak Bay: Characterization of Soft Bottom Benthic Habitats and Contaminant Bioeffects Assessment

S. Ian Hartwell, A. Dennis Apeti, W. Larry Claflin, W. Edward Johnson, and L. Kimani Kimbrough

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List of Acronyms

AAS	Atomic Absorption Spectroscopy
ADEC	Alaska Department of Environmental Conservation
ADF&G	Alaska Department of Fish & Game
Ag	silver
Al	aluminum
AMAP	Arctic Monitoring & Assessment Program
AOOS	Alaska Ocean Observation System
APHA	American Public Health Association
As	arsenic
ASTM	American Society of Testing and Materials
BT	Butyl Tin
Cd	cadmium
CFR	Code of Federal Regulations
CIRCAC	Cook Inlet Regional Citizens Advisory Council
Cr	chromium
Cu	copper
DDT	Dichlorodiphenyltrichloroethane
DO	Dissolved Oxygen
EF	Eastern Flat
EMAP	Environmental Monitoring and Assessment Program
EPA	Environmental Protection Agency
ERL	Effects Range - Low
ERM	Effects Range - Median
ES	Eastern Subtidal
EVOS	Exxon Valdez Oil Spill
Fe	iron
GC/ECD	Gas Chromatography/Electron Capture Detector
GC/MS	Gas Chromatography/Mass Spectroscopy
gm	gram
GOA	Gulf of Alaska
H'	Diversity (Shannon-Weiner)
HCH	Hexachloro-Cyclohexane
Hg	mercury
HH	Homer Harbor
HRGS	Human Reporter Gene
ICP	Inductively Coupled Plasma
KBNERR	Kachemak Bay National Estuarine Research Reserve
km	kilometer
L	liter

m	meter
MDL	Method Detection Limit
mg	milligram
Mn	manganese
MS	Matrix Spike
MSD	Matrix Spike Duplicate
ng	Nanogram
Ni	nickel
NIST	National Institute of Standards and Technology
NPRB	North Pacific Research Board
NOAA	National Oceanic and Atmospheric Administration
NS&T	National Status and Trends
P	Probability
PAH	Polycyclic Aromatic Hydrocarbon
Pb	Lead
PCA	Principal Component Analysis
PCB	Polychlorinated Biphenyl
POP	Persistent Organic Pollutant
POTW	Publically Owned Treatment Plant
ppt	parts per thousand
PWSRCAC	Prince William Sounds Regional Citizens Advisory Council
QA/QC	Quality Assurance/Quality Control
Sb	antimony
Se	selenium
Si	silicon
Sn	tin
SQG	Sediment Quality Guidelines
SQT	Sediment Quality Triad
SRM	Standard Reference Material
TBT	Tributyltin
TIC	Total Inorganic Carbon
TOC	Total Organic Carbon
ug	microgram
WF	Western Flat
WS	Western Subtidal
Zn	zinc

EXECUTIVE SUMMARY

A baseline environmental characterization of the inner Kachemak Bay, Alaska was conducted using the sediment quality triad approach based on sediment chemistry, sediment toxicity, and benthic invertebrate community structure. The study area was subdivided into 5 strata based on geophysical and hydrodynamic patterns in the bay (eastern and western intertidal mud flats, eastern and western subtidal, and Homer Harbor). Three to seven locations were synoptically sampled within each stratum using a stratified random statistical design approach. Three sites near the village of Port Graham and two sites in the footprint of a proposed Homer Harbor expansion were also collected for comparison. Concentrations of over 120 organic and metallic contaminants were analyzed. Ambient toxicity was assessed using two amphipod bioassays. A detailed benthic community condition assessment was performed. Habitat parameters (depth, salinity, temperature, dissolved oxygen, sediment grain size, and organic carbon content) that influence species and contaminant distribution were also measured at each sampling site.

Sediments were mostly mixed silt and sand; characteristic of high energy habitats, with pockets of muddy zones. Organic compounds (PAHs, DDTs, PCBs, cyclodienes, cyclohexanes) were detected throughout the bay but at relatively low concentrations. Tributyltin was elevated in Homer Harbor relative to the other strata. With a few exceptions, metals concentrations were relatively low and probably reflect the input of glacial runoff. Relative to other sites, Homer Harbor sites were shown to have elevated concentrations of metalic and organic contaminants. The Homer Harbor stratum however, is a deep, low energy depositional environment with fine grained sediment. Concentrations of organic contaminants measured were five to ten times higher in the harbor sites than in the open bay sites. Concentration of PAHs is of a particular interest because of the legacy of oil spills in the region. There was no evidence of residual PAHs attributable to oil spills, outside of local input, beyond the confines of the harbor. Concentrations were one to ten times below NOAA sediment quality guidelines. Selected metal concentrations were found to be relatively elevated compared to other data

collected in the region. However, levels are still very low in the scale of NOAA's sediment quality guidelines, and therefore appear to pose little or no ecotoxicity threat to biota.

Infaunal assessment showed a diverse assemblage with more than 240 taxa recorded and abundances greater than 3,000 animals m-2^2 in all but a few locations. Annelid worms, crustaceans, snails, and clams were the dominant taxa accounting for 63 %, 19%, 5%, and 7 % respectively of total individuals. Specific benthic community assemblages were identified that were distributed based on depth and water clarity. Species richness and diversity was lower in the eastern end of the bay in the vicinity of the Fox River input. Abundance was also generally lower in the eastern portion of the study area, and in the intertidal areas near Homer. The eastern portions of the bay are stressed by the sediment load from glacial meltwater. Significant toxicity was virtually absent.

Conditions at the sites immediately outside the existing Homer Harbor facility did not differ significantly from other subtidal locations in the open Kachemak Bay. The benthic fauna at Port Graham contained a significant number of species not found in Kachemak Bay. Contaminant conditions were variable depending on specific location. Selected metal concentrations were elevated at Port Graham and some were lower relative to Kachemak Bay, probably due to local geology. Some organic contaminants were accumulating at a depositional site.

1. INTRODUCTION

1.1 National Status and Trends Bioeffects Studies

This report summarizes the results of the National Oceanic and Atmospheric Administration's (NOAA) sediment toxicity, chemistry, and benthic community studies in Kachemak Bay, Alaska. As part of the National Status and Trends (NS&T) Program, NOAA conducts studies to determine the spatial extent and severity of chemical contamination and associated adverse biological effects in coastal bays and estuaries of the United States. This program encompasses a broad spectrum of research and monitoring studies to evaluate sediment contamination and toxicity in U.S. coastal waters, including the long-term, nationwide monitoring of contaminant concentrations in sediments and bivalves; sediment toxicity assessments in specific coastal areas; the evaluation and application of biomarkers; and the development of ecological indices (Turgeon *et al*. 1998, Hartwell and Claflin 2005). The National Status and Trends Program has conducted sediment toxicity assessment studies in coastal water bodies since 1991. Results from previous sediment bioeffects studies in over 20 coastal water bodies and estuaries have been published (Long *et al*. 1996, Turgeon *et al*. 1998, Long 2000, Hartwell and Hameedi 2006, Hartwell and Hameedi 2007, Pait *et al*. 2006). As a part of the NS&T goal to expand its coastal contamination and benthic community database to include Alaska, sediment chemistry, toxicity, and benthos assessments were conducted in Kachemak Bay. This report presents the results of the study which was funded in part by the North Pacific Research Board (NPRB), the Cook Inlet Regional Citizens Advisory Council (CIRCAC), and NOAA.

Sediment contamination in U.S. coastal area is a major environmental issue because of potential toxic effects on biological resources and often, indirectly, on human health. A large variety of contaminants from industrial, agricultural, urban, and maritime activities are associated with bottom sediments, including synthetic organic chemicals, polycyclic aromatic hydrocarbons (PAHs), and trace elements. In many instances, fish consumption advisories are coincident with severely degraded sediments in coastal water bodies. Contaminants, particularly those that are lipophilic can biomagnify in the coastal food

chain with increasing concentration in predatory wildlife and humans. Thus, characterizing and delineating areas of sediment contamination and toxicity are viewed as important goals of coastal resource management. This is particularly important in Alaska where subsistence food contamination is an emerging health concern, especially in rural areas where large amounts of these foods are consumed as a primary source of protein (Wolfe 1996). With no known industrial point sources of contamination, current sources of pollution to Kachemak Bay may include wastewater discharge, leaking septic tanks, marine activities associated with commercial and recreational fishing, commercial shipping, stormwater runoff, and long-range atmospheric transport. Historically, seafood canning operations and the mining and export of coal and minerals in the region have generated shoreline and watershed contaminant inputs in the region. Additionally, natural sources of pollution, particularly trace elements, may be associated with river runoff. Excessive levels of contaminants in the sediments, whether of natural or anthropogenic origin, can pose ecological and human-health risks. The presence of contaminants in coastal ecosystems can cause habitat degradation and loss of biodiversity through degraded habitats, loss of fauna, biomagnification of contaminants in the coastal ecosystem, and human consumption of contaminated fish and wildlife.

Macrobenthic organisms play an important role in the estuarine environment. Critical habitats and food chains supporting many fish and wildlife species involve the benthic environment. Benthic organisms are secondary consumers in the ecosystem, and represent an important link between primary producers and higher trophic levels for both planktonic and detritus-based food webs. They are composed of diverse taxa with a variety of reproductive modes and life history characteristics. They are a particularly important food source for juvenile fish and crustaceans. Furthermore, most benthic species have limited mobility and cannot physically avoid stressful environmental conditions. Benthic assemblages thus cannot evade, and must respond to, a variety of stressors such as toxic contamination, eutrophication, sediment quality, habitat modification, and seasonal weather changes. Biological systems are able to integrate the complexity of natural habitat stressors and ambient pollutant mixtures, through physical contact with sediments, ingesting sediment, and bioaccumulating contaminants in food webs, and expressing the synergetic effects of exposure to toxic chemicals.

Distributions of benthic organisms are predictable along estuarine gradients and are characterized by similar groups of species over broad latitudinal ranges. Benthic species composition, abundance, and biomass are influenced by habitat conditions including salinity, sediment type, and environmental stressors, both natural and anthropogenic (Slim *et al.* 1997, Nanami *et al.* 2005). Information on changes in benthic population and community parameters due to habitat change can be useful for separating natural variation from changes associated with human activities. For that purpose, benthic community studies have a long history of use in regional estuarine monitoring programs and have been proven to serve as an effective indicator for describing the extent and magnitude of pollution impacts and habitat modification in estuarine ecosystems, as well as for assessing the effectiveness of management actions (Llanso *et al*. 2004, Long *et al.* 1995).

Several examples exist in which marine benthic communities' response to contaminant and physical stressors have been documented. Impacts of organic enrichment on marine benthos have shown that total biomass, relative proportion of deposit feeders, and abundance of species with 'opportunistic' life histories (e.g. high fecundity, short generation time, and rapid dispersal) increase. Some opportunistic taxonomic groups are known to be tolerant of chemical toxicants. Others are capable of thriving in physically disturbed habitats (e.g. high sedimentation, dredging operations, etc) but not necessarily in contaminated areas. In areas impacted by excessive sedimentation from terrestrial runoff, dominant organisms tend toward surface suspension feeding modes and high reproductive potential regardless of taxonomic relationship, whereas away from the sedimentation stress, feeding modes shift to species that are deep deposit feeders and the emergence of filter feeders (Wlodarska-Kowalczuk *et al* 2005, Pearson and Rosenberg 1978). Experimental manipulation of habitats has shown that specific taxonomic lines, with opportunistic life history strategies respond positively to organic enrichment (Lenihan *et al*. 2003). Other taxa respond negatively to both toxicants and excessive organic enrichment. The response of specific species to organic and toxic contamination is mediated by life history and feeding mode characteristics.

National Status and Trends Bioeffects studies also utilize measures of toxicity using bioassays that may evaluate different modes of contaminant exposure (bulk sediment, sediment porewater, and chemical extracts of contaminants from sediment) to a variety of species and different assessment end-points (i.e., mortality, impaired reproduction, physiological stress, and biomarker response). Since the test results are usually not necessarily axiomatic and biological effects of contaminants occur at different levels of biological organization, i.e., from cells to ecosystems, results from a suite of toxicity tests are used in the "weight of evidence" context to infer the incidence and severity of environmental toxicity (Chapman 1996). Typically, the amphipod mortality bioassay, the sea urchin fertilization impairment bioassay, the Microtox test, and, in recent years, a Human Reporter Gene System (HRGS) P450 tests are used in each study area. Other tests, based on promising new techniques, e.g. full life-cycle tests, and genotoxicity, have also been used in some areas for test evaluation or to meet a specific information need.

Taken together, all three assessments, sediment chemistry, sediment benthic assemblage, and sediment toxicity constitute what is referred to as the Sediment Quality Triad (SQT). The SQT is an important ecosystem based management tool widely used by coastal managers for coastal resource management.

Although NS&T has conducted SQT assessments in estuaries and embayments in most coastal regions of contiguous U.S. and portions of the Hawaiian Islands, none have been conducted in the Gulf of Alaska area. Despite its extensive coastline of 33,000 miles, greater than the contiguous US (EPA, 2005), and vast natural marine and coastal resources, Alaska lacks adequate data to provide baseline information necessary to assess future trends. More environmental monitoring and research is needed to assess not only areas of known pollution impact, but also the whole coastal Alaska region. Historically, assessment in the region has been either limited or focused on areas of known impairment. The National Status and Trends Program has analyzed contaminants in sediment and mussels collected from a few selected sites in the Gulf of Alaska (O'Connor 2002). The Prince William Sound Regional Citizens Advisory Council (PWSRCAC) has been assessing PAHs and other petroleum-related compounds in Prince William Sound since the Exxon Valdez Oil Spill in 1989 (EVOS) (Page *et al*. 2001). In

collaboration with the U.S. EPA Environmental Monitoring and Assessment Program (EMAP), the Alaska Department of Environmental Conservation undertook a state-wide coastal ecological condition study that encompasses assessment of contaminants and benthic assemblage in sediment along the Gulf of Alaska and the Aleutian Islands (Saupe *et al.* 2005). The Cook Inlet Regional Citizens Advisory Council (CIRCAC) assesses the impacts of oil and gas operations in Cook Inlet including chemical and benthic community assessment. The Cook Inlet Regional Citizens Advisory Council has also undertaken a comprehensive sediment and water quality survey of Cook Inlet. This NS&T study augments these ongoing efforts to provide detailed data on sediment quality in Kachemak Bay. The goal of the project was to assess habitat conditions that influence biodiversity and distribution of benthic infaunal community using the SQT approach. Specific objectives were to determine spatial patterns or gradients in chemical contamination, benthic macroinvertebrate community characterization, and measures of sediment toxicity to aquatic organisms in soft bottom habitats in Kachemak Bay. The present study provides sediment quality information as baseline data on contaminant concentration and sediment benthic community condition for future development in the area, to help evaluate unforeseen spill events or other disasters (e.g. earthquakes), and to supplement ecosystem based management assessment in Kachemak Bay, Alaska's only National Estuarine Research Reserve

The resulting data of this project are georeferenced and could be integrated into the Alaska Ocean Observation System (AOOS) database. The data will help achieve the long-term goal of conducting research designed to address pressing fishery management or marine ecosystem information needs. The National Status and Trends Program has been developing a relational web-portal database on contaminants, toxicity, and benthic infaunal species distribution in coastal United States. The data portal is an "Internet doorway" to data and information products of NS&T. Data of this study is incorporated into this database and available to local managers as well to concerned citizens nationally. The comprehensive georeferenced data base of this and previous studies are available online in downloadable format through our data portal at http://nsandt.noaa.gov.

1.2 Site Background

Kachemak Bay is a 64 km long glacial fjord on the east side of lower Cook Inlet located in south central Alaska. At the mouth between Anchor Point in the north and Point Pogibshi to the south, Kachemak Bay is nearly 40 km wide but narrows to 10-11 km at Homer spit (Figure 1) which bisects the Bay into inner and outer portions. The inner portion of the Bay behind the spit is approximately 32 km long. The north shore of Kachemak Bay is characterized by extensive tidal flats below sandy bluffs with numerous coal seams. The steep bluffs are vulnerable to landslides. The south shore has numerous smaller fjords and embayments cut into steep terrain that rises to glaciated valleys and mountain peaks on the Kenai Peninsula. Except for the Jakalof Trench running along its southern edge, inner Kachemak Bay has a relatively flat bottom and averages 46 m in depth. The outer Bay has a sill at the opening to Cook Inlet from 20-70 m deep and drops to more than 160 m deep in Jakalof Trench south of Homer Spit. Glaciers have covered and retreated from Kachemak Bay repeatedly over the past 25,000 years. Homer Spit and the Archimandritof Shoals to the west of it may be the result of terminal glacial moraines. An extensive description of the physiography of Kachemak Bay is presented by Alaska Department of Fish and Game, ADF&G (1998).

The relatively flat watershed to the north lies in the Kenai Lowlands of the Cook Inlet Basin. The soils are layered sand, silt, clay, conglomerate, coal seams, and volcanic ash. Glacial till covers the underlying sedimentary rocks and blankets most of the area. In contrast, the south side on the Kenai Peninsula is characterized by steep mountains that rise 1,000-2,000 m, composed of a jumble of volcanic rock and upthrusted marine sedimentary deposits. The Kenai Peninsula is a tectonic rupture zone and is subject to violent earthquakes, including the largest ever recorded in North America in modern times (Good Friday earthquake 1964). This caused a land subsidence of 4 ft in the Kachemak Bay area. This sudden change in elevation has resulted in dynamic changes in local sedimentation and erosional patterns. There are five active volcanoes on the western

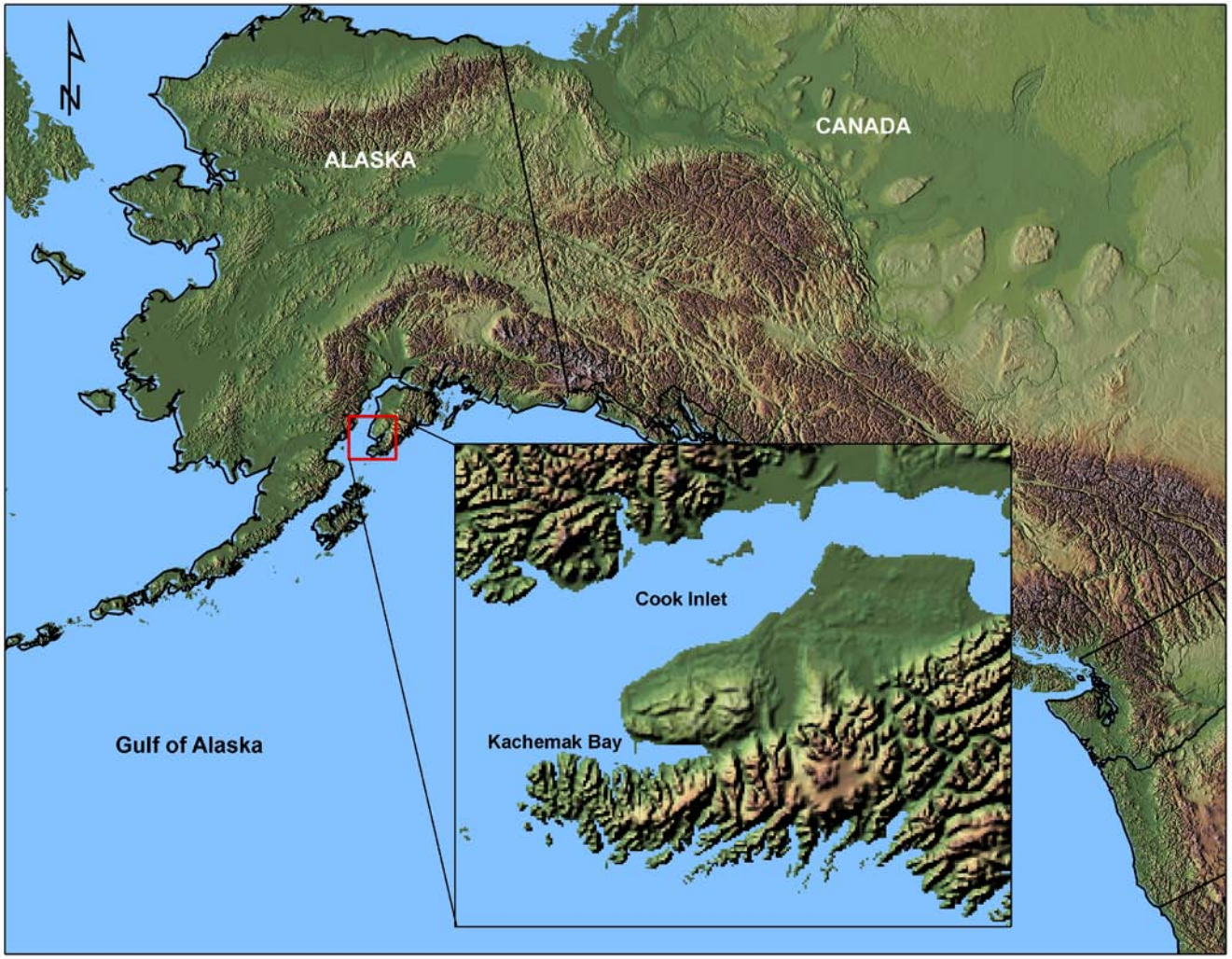


Figure 1. Map of Alaska and (inset) the Kachemak Bay study area.

side of Cook Inlet. These periodically contribute volcanic ash to the region, and have produced tsunamis that impact Kachemak Bay. On the north shore, beyond the bluff's crest, much of the land drains into the Anchor River watershed and not into Kachemak Bay. East of Homer, small canyons cut through the bluff crest, draining the Fritz, McNeil, and Eastland Creeks, as well as numerous other creeks toward the head of the Bay. Runoff from the northern rivers is from spring and fall precipitation and spring snowmelt. On the Kenai Peninsula, there are nine glaciers that contribute meltwater to the bay during the summer months. The volume of flow from glacial rivers can be much higher than from clearwater rivers. The summer glacial meltwater delivers large volumes of freshwater into the Bay. Glacial and clearwater streams are characteristically different with respect to turbidity. Glacial meltwater carries a large sediment load of clay and silt, and this is what gives them their color and opacity. As glaciers melt in the summer, the freshwater drains into the Bay, altering salinity and possibly the circulation patterns. Glaciers can also cause flooding and large mudslides when ice dams that hold back lakes fail and release huge amounts of silt and water downstream. The Fox and Bradley Rivers in the eastern end of the bay deliver large volumes of freshwater and silt to the bay from the Kachemak, Dinglestadt and Chernof Glaciers.

Kachemak Bay has a complex water circulation pattern (Burbank 1977, KBNERR 2001). The inner bay displays the characteristic features of a brackish water estuary resulting from the mixing of freshwater inflow at the head of the bay and saltwater coming from the outer bay. In addition to the main sources of freshwater input in the east, turbid glacial meltwater also enters from ice fields on the south side during the summer. The semi-diurnal tidal range in the inner bay is as high as 6 m. The tide and wind fuel the mixing of masses of fresh and saline waters in the inner bay that creates two counterclockwise tidal gyres that tend to deposit sediment in the northern portion of the bay (Burbank 1977). Seasonal winds and summer glacial melt causes the eastern gyre to periodically elongate and eliminate the western gyre, encompassing the entire inner bay. The net overall inner Bay circulation remains in a counterclockwise direction in spring, summer, and early fall, with inflow along the southern shore and outflow along the northern shore. This circulation pattern coupled with the tidal exchange help create

diverse habitats such as tidal flats, kelp beds in the north, marshes and eelgrass in the east, and relatively deep zone in the middle and south of the bay. In addition to these habitats, the brackish and low current water makes the inner bay an excellent spawning ground and for several marine organisms (KBNERR 2001).

The circulation pattern in the outer bay is characterized by the seawater influx from the Gulf of Alaska (GOA) via lower Cook Inlet, and input of low salinity brackish water from the inner bay. Both lower Cook Inlet and the outer Kachemak Bay are part of the general Gulf of Alaska circulation system (Figure 2). According to Burbank (1977), seawater transported northward by the Alaskan Current from the GOA enters lower Cook Inlet through the Kennedy entrance. The bulk of the seawater bypasses the outer Kachemak Bay. Because of upwelling along the tip of the Kenai Peninsula northwest of the Chugach Islands, the seawater is diverted offshore. The outer bay circulation is dominated by two semi-permanent gyres. The outer clockwise gyre is driven by wind and tidal currents and the predominant northward flowing current along the east side of Cook Inlet. The inner counterclockwise gyre is driven by the outer gyre and the surface outflow from the inner Kachemak Bay. The net exchange of water in and out of each gyre occurs primarily around the gyre perimeters, with water gain from the south and water loss to the north. The outflow of water from the outer bay is carried out along the northeast shoreline of Cook Inlet. (Burbank 1977). The introduction of GOA water and upwelled water delivers a rich supply of nutrients to Kachemak Bay.

This nutrient rich estuarine environment sustains a diverse marine wildlife of important economic value such as shrimp, Dungeness crab, cockles, blue mussels, and clams (KBNERR 2001). Additionally, hundreds of plant and animal species inhabit the bay and its watershed, including thriving populations of sea otters, bald eagles, moose, black bears, salmon, Pacific halibut and large number of other marine organisms. The bay supports significant subsistence and commercial fishery resources and it is considered as one of the most productive bays in the U.S. although stocks have been reported to be declining in recent years (Szarzi *et al*. 2007, ADF&G 1998). Commercial harvests of herring, coonstripe shrimp, and king, Dungeness, and Tanner crabs have been closed due

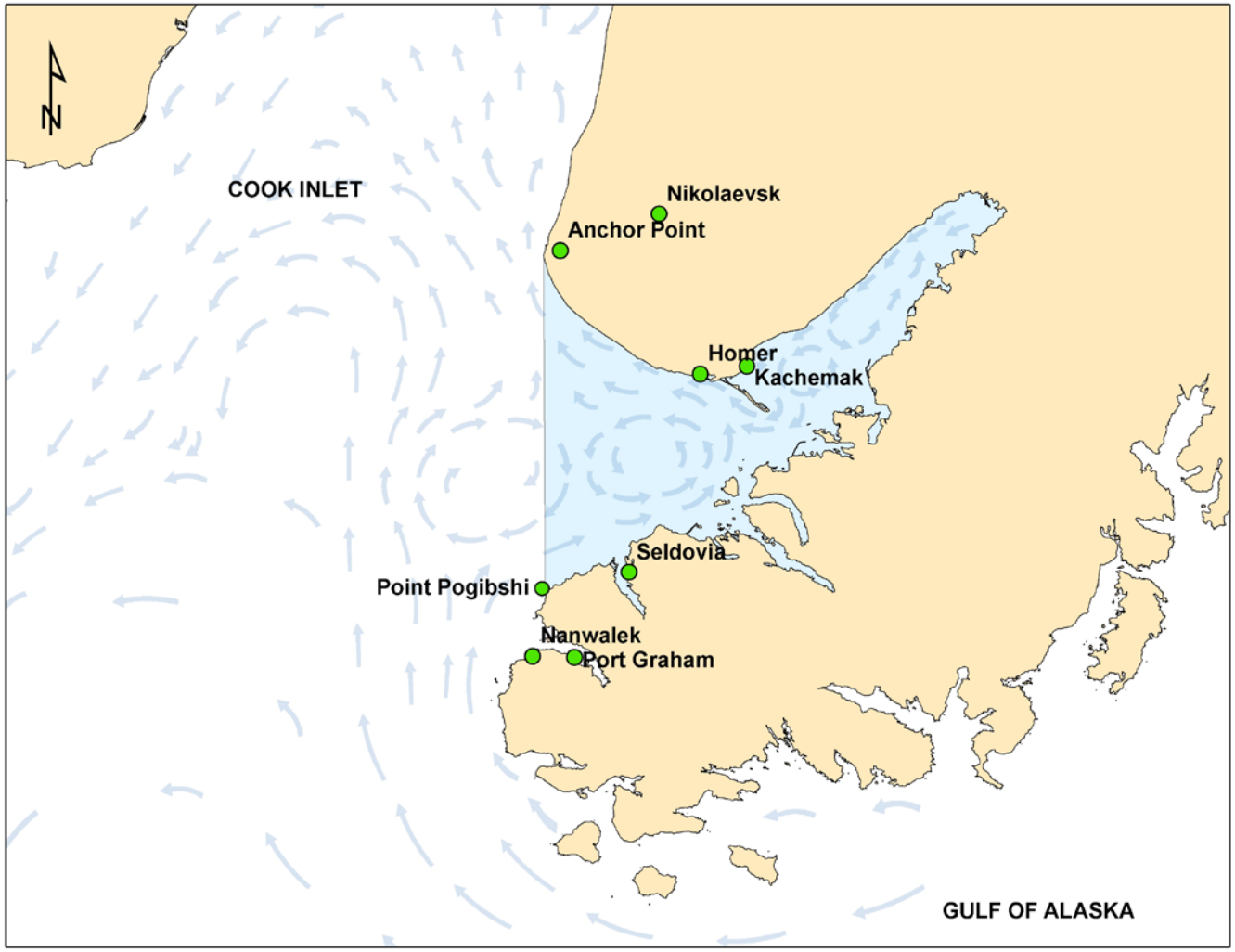


Figure 2. Map detailing Lower Cook Inlet and Kachemak Bay circulation pattern. Circulation in Kachemak Bay is driven by a complex interaction between the Alaskan Current, wind and tidal currents, and surface outflow from the inner bay.

to depressed stock (ADF&G 1998). Other studies point to impacts of natural changes and anthropogenic activities that cause pollution as the overriding causes of the depressed stock (Exxon Valdez Oil Spill Trustee Council 2002).

Since Kachemak Bay lies between Cook Inlet and Prince William Sound oil operations traffic, its deepwater anchorage is being proposed as one of several repair sites and safe refuges for distressed and disabled vessels (ADEC 2006). The shortcomings of using the bay as shelter for vessels would be pollution from oil leaks and release of other hazardous substance that can impact marine resources. The bay was impacted by the Exxon Valdez Oil Spill (EVOS) of 1989. Fourteen days after the spill, the oil slick travelled westward then northward through the Kennedy Entrance to cover part of the lower Cook Inlet and outer Kachemak Bay (www.evostc.state.ak.us/History/PWSmap.cfm). Kachemak Bay, being further removed from the spill epicenter in Prince William Sound suffered relatively minimal ecological damages (Kuletz 1994) which nevertheless injured marine and coastal resources. It is anticipated that results of this study will serve as baseline data for unforeseen events and future reference. In the event of a spill, the water circulation pattern in the inner bay may drive oil northward toward the tidal flats.

1.3 Objectives

The objectives of this project were to:

1) identify natural and anthropogenic stressors that influence habitat quality and affect infaunal community spatial distribution;

2) provide chemical concentrations for a suite of metals and organic contaminants including PAHs and persistent organic pollutants (POPs);

3) produce a comprehensive taxonomic list and distribution patterns of infaunal species in soft bottom substrates.

2. METHODS

The National Status and Trend Program uses a stratified-random design for selection of sampling sites to determine the spatial extent of sediment toxicity in U.S. coastal waters. One of the design principles is to apply the same suite of tests synoptically to all areas so that comparisons can be made without the confounding interference of using different methods in different areas. Thus, comparison of spatial extent of impact between areas is possible even if the areas are not contiguous.

The choice of the study location in the northern half of Kachemak Bay was based on the presence of extensive soft bottomed habitat, the presence of a diverse assemblage of marine organisms including harvestable species, and water circulation patterns which would likely deliver contaminants or spilled oil to a depositional area of the bay. The study site was divided into five strata of relatively uniform habitat: Homer Harbor (HH), intertidal mudflats (WF) and subtidal zones of Coal Bay west of 151^{o} 20' (WS), and intertidal mudflats (EF) and subtidal zones (ES) to the east of Coal Bay to Chugachik Island. Multiple sampling sites were located on a random basis within each stratum. Three sites were located in Homer Harbor; six sites were located in each stratum in Coal Bay; and seven in both of the strata between Coal Bay and Chugachik Island (Figure 3). This approach combines the strengths of a stratified design with the random-probabilistic selection of sampling locations, allowing the data generated within each stratum to be attributed to the dimensions of that stratum with a quantifiable degree of confidence (Heimbuch et al. 1995). Strata boundaries were established in consultation with regional scientists and resource managers, and were based on bathymetric, hydrographic, and regional environmental considerations, and previous studies detailing geochemical reservoirs, sediment grain size distribution, and organic carbon maps. Within each stratum, two randomly selected alternate sites were also selected for each primary sampling site. In instances where the primary site could not be sampled due to non-accessibility or an unsuitable substratum, the next sequential alternate site was sampled.

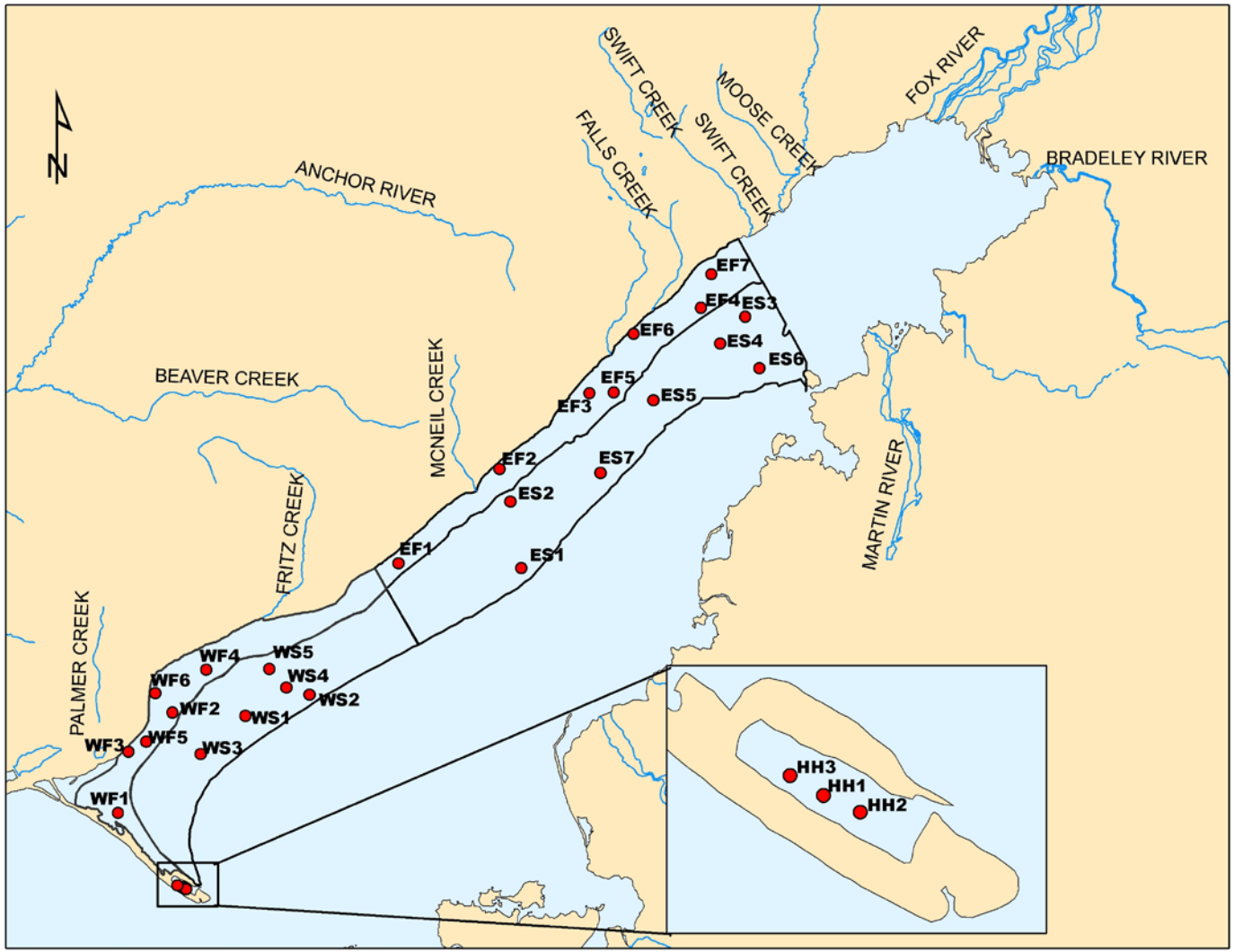


Figure 3. Map of Kachemak Bay showing strata and site locations. Strata from left to right: Western Flat (WF); Western Subtidal (WS); Eastern Flat (EF); Eastern Subtidal (ES). The insert depicts the Homer harbor stratum (HH).

2.1. Sampling procedures

Samples were collected from a locally chartered fishing boat. Two sediment samples were taken at each site in addition to water quality measurements with YSI meter readings at the surface and bottom of the water column. A total of 29 sites were sampled. Samples were collected with a Kynar-coated 0.1 m-2 Young-modified Van Veen grab sampler. The sampler was initially washed, rinsed with acetone and deionized water, followed by an acid wash with 10% HCl and again rinsed with deionized water. At each site, the sampler was rinsed with acetone and deionized water immediately prior to sampling. Only the upper 2-3 cm of the sediment was retained in order to assure collection of recently deposited materials. A sediment sample was discarded if the jaws of the grab were open, the sample was partly washed out, or if the sediment sample in the grab was less than 5 cm deep. Sediments were removed with a Teflon coated stainless steel scoop. Sediment was composited from multiple grabs in a bucket with an acetone rinsed, high-density polyethylene (HDPE) liner. Between each deployment of the sampler, the bucket was covered with an HDPE lid to minimize sample oxidation and exposure to atmospheric contamination. Additional grab samples were taken and the top layer of sediment was collected and composited until sufficient volume (3-4 L) of sediment for all the toxicity bioassays and chemical analyses was collected.

The sediment samples were thoroughly homogenized in the field with an acetone-rinsed, stainless steel mixer attachment on an electric drill. This composite sample was subdivided for distribution to various testing laboratories. Subsamples were collected for grain size characterization. Samples for chemical analyses were stored in pre-cleaned glass jars with Teflon® liners. Samples for toxicity testing were stored in 1 L polyethylene jars with Teflon® coated lids. All subsamples were either stored on ice or frozen, as appropriate, prior to shipment to analytical laboratories. The bucket liners were not reused between sampling sites. A second sample was taken for benthic community analysis with a Kynar-coated 0.04 m-2 PONAR grab sampler. The entire contents of an acceptable sample (at least 5 cm deep) were sieved on site through 0.5 mm mesh. All organisms were retained in Nalgene bottles and preserved in buffered formalin containing Rose Bengal stain.

2.2. Chemical analysis

Chemical analyses followed procedures routinely used in the NOAA NS&T Program (Kimbrough and Lauenstein 2006a, 2006b, American Society for Testing and Materials (ASTM 2003). A broad suite of sediment contaminants were analyzed at each station, including 55 PAHs, 27 chlorinated pesticides including DDT and its metabolites, 37 polychlorinated biphenyls (PCBs), 16 major and trace elements, and three butyl-tins (Tables 1 – 5) . Other parameters included grain size analysis, total organic/inorganic carbon (TOC/TIC), and percent solids. All chemical analyses were performed at TDI-Brooks Inc. a government contracted laboratory.

2.2.1 Metals

Samples were shipped frozen to the laboratory and stored at -20 °C until analysis. Samples were prepared for inductively coupled plasma/mass spectrometry analysis (ICP-MS) for major metals while atomic fluorescence spectrometry was utilized to measure arsenic and selenium and atomic absorption spectrometry was used for mercury analysis. In general, samples were homogenized, freeze dried, weighed and digested in a sequence of heating steps with metal grade HNO_3, HF and, boric acid. For analysis of Hg, sediment samples were digested based on a modified version of EPA method 245.5, using a concentrated H_2SO_4 and HNO_3 digestion, followed by addition of $KMnO_4$, and $K_2S_2O_8$, and the samples were again digested. Before analysis, 5 mL of 10% (w/w) $NH_2OH \cdot HCl$ were added to reduce excess permanganate and the volume brought to 40 mL with distilled water.

Quality control samples were processed in a manner identical to actual samples. A method blank was run with every 20 samples, or with every sample set, whichever was more frequent. If corrected blank concentrations for any component were above three times the method detection limit (MDL), the whole sample set was re-extracted and reanalyzed. If insufficient sample was available for re-extraction, the data was reported and appropriately qualified. Matrix spike/matrix spike duplicate (MS/MSD) samples were run with every 20 samples, or with every sample set, whichever was more frequent. Recalibration standards were also run every 12 samples, and matrix modifiers were used as necessary. The appropriate spiking level was ten times the MDL. Reference materials were extracted with

Table 1. Major and trace elements (metals) measured in the Kachemak Bay sediments. For simplicity the term metal is used without distinction between true metals and metalloids.

Symbol	Element	Symbol	Element	Symbol	Element
Ag	Silver	Fe	Iron	Sb	Antimony
Al	Aluminum	Hg	Mercury	Se	Selenium
As	Arsenic	Mn	Manganese	Sn	Tin
Cd	Cadmium	Ni	Nickel	Si	Silicon
Cr	Chromium	Pb	Lead	Zn	Zinc
Cu	Copper				

Table 2. Butyltins measured in Kachemak Bay sediments.

Compound
Monobutyltin trichloride
Ditbutyltin dichloride
Monobutyltin trichloride

Table 3a. Low molecular weight Polycyclic Aromatic Hydrocarbons (PAHs) measured in Kachemak Bay sediments.

Compound	Parent	Substituted
Acenaphthylene		
Acenaphthene		
Dibenzofuran		
Biphenyl		
Decalin		
Naphthalene	■	
C1-Naphthalenes		●
C2-Naphthalenes		●
C3-Naphthalenes		●
C4-Naphthalenes		●
Benzothiophene	■	
C1-Benzothiophene		●
C2-Benzothiophene		●
C3-Benzothiophene		●
Dibenzofuran	■	
Dibenzothiophene	■	
C1-Dibenzothiophenes		●
C2-Dibenzothiophenes		●
C3-Dibenzothiophenes		●
Anthracene	■	
Phenanthrene	■	
C1-Phenanthrenes_Anthracenes		●
C2-Phenanthrenes_Anthracenes		●
C3-Phenanthrenes_Anthracenes		●
C4-Phenanthrenes_Anthracenes		●
Fluorene	■	
C1-Fluorenes		●
C2-Fluorenes		●
C3-Fluorenes		●
Naphthobenzothiophene	■	
C1-Naphthobenzothiophene		●
C2-Naphthobenzothiophene		●
C3-Naphthobenzothiophene		●

Table 3b. High molecular weight Polycyclic Aromatic Hydrocarbons (PAHs) measured in Kachemak Bay sediments.

Compound	Parent	Substituted
Fluoranthene	■	
Pyrene	■	
C1-Fluoranthenes_Pyrenes		●
C2-Fluoranthenes_Pyrenes		●
C3-Fluoranthenes_Pyrenes		●
Dibenzo[a,h]anthracene	■	
C1-Dibenzo[a,h]anthracene		●
C2-Dibenzo[a,h]anthracene		●
C3-Dibenzo[a,h]anthracene		●
Benz[a]anthracene		
Perylene	■	
Chrysene	■	
C1-Chrysenes		●
C2-Chrysenes		●
C3-Chrysenes		●
C4-Chrysenes		●
Benzo[b]fluoranthene		
Benzo[k]fluoranthene		
Benzo[e]pyrene		
Benzo[a]pyrene		
Indeno[1,2,3-c,d]pyrene		
Benzo[g,h,i]perylene		

Table 4. Chlorinated pesticides measured in Kachemak Bay sediments.

Compound Class	Compound
Hexachlorocyclohexanes	Alpha HCH
	Beta HCH
	Delta HCH
	Gamma HCH (lindane)
Cyclodienes	Heptachlor
	Heptachlor epoxide
	Oxychlordane
	Alphachlordane
	Gamma Cholrdane
	Cis-Nonachlor
	Trans-Nonachlor
	Aldrin
	Dieldrin
	Endrin
Chlorinated Benzenes	Tetrachlorobenzene 1,2,3,4
	Tetrachlorobenzene 1,2,4,5
	Pentachlorobenzene
	Hexachlorobenzene
DDT and breakdown products	2,4' DDD
	2,4' DDE
	2,4' DDT
	4,4' DDD
	4,4' DDE
	4,4' DDT
Others	Mirex
	Endosulfan
	Chlorpyrofos

Table 5. Polychlorinated biphenyls (PCBs) measured in Kachemak Bay sediments.

Compound		Compound
2,4'-Dichlorobiphenyl		3,3',4,4',5-Pentachlorobiphenyl
2,2',5-Trichlorobiphenyl		2,2',3,3',4,4'-Hexachlorobiphenyl
2,4,4'-Trichlorobiphenyl		2,2',3,4,4',5'-Hexachlorobiphenyl
2,4,5-Trichlorobiphenyl		2,2’,3,4’,5,5’-Hexachlorobiphenyl
2,4',5-trichlorobiphenyl		2,2',3,4',5',6-Hexachlorobiphenyl
2,2',3,5'-Tetrachlorobiphenyl		2,2’,3,5,5’,6-Hexachlorobiphenyl
2,2',4,5'-tetrachlorobiphenyl		2,2',4,4',5,5'-Hexachlorobiphenyl
2,2',5,5'-Tetrachlorobiphenyl		2,3,3',4,4',5-Hexachlorobiphenyl
2,3,3',4'-tetrachlorobiphenyl		2,2',3,3',4,4',5-Heptachlorobiphenyl
2,3',4,4'-Tetrachlorobiphenyl		2,2',3,3',4,5,6'-Heptachlorobipenyl
2,3',4',5-Tetrachlorobiphenyl		2,2',3,4,4',5,5'-Heptachlorobiphenyl
2,4,4',5-Tetrachlorobiphenyl		2,2',3,4,4',5',6-Heptachlorobiphenyl
2,2'3,4,5'-Pentachlorobiphenyl		2,2',3,4',5,5',6-Heptachlorobiphenyl
2,2',3,5',6-Pentachlorobiphenyl		2,2',3,3',4,4',5,5'-Octachlorobiphenyl
2,2',4,4',5-Pentachlorobiphenyl		2,2',3,3',4,4',5,6-Octachorobiphenyl
2,2',4,5,5'-Pentachlorobiphenyl		2,2',3,3',4',5,6,6'-Octachlorobiphenyl
2,3,3',4,4'-Pentachlorobiphenyl		2,2',3,3',4,4',5,5',6-Nonachlorobiphenyl
3,3',4,4'-Tetrachlorobiphenyl		2,2',3,3',4,4',5,5',6,6'-Decachlorobiphenyl
2,3',4,4',5-Pentachlorobiphenyl		

each set of sample and were analyzed when available. The MDLs were determined following the procedures outlined in CFR 40, part 136 (1999).

For analysis of Hg, sediment samples were digested using a modified version of EPA method 245.5, using a concentrated H_2SO_4 and HNO_3 digestion, followed by addition of $KMnO_4$, and $K_2S_2O_8$, and the samples were again digested. Before analysis, 5 mL of 10% (w/w) $NH_2OH \cdot HCl$ were added to reduce excess permanganate and the volume brought to 40 mL with distilled water.

2.2.2 Organics (PAHs, PCBs, chlorinated pesticides, aliphatics)

Samples were shipped frozen to the laboratory and stored at -20 °C until analysis. An aliquot of approximately 1 gm of sample was weighed and oven dried at 63 – 56 °C to constant weight to determine wet/dry weight. Homogenized sample aliquots were chemically dried with Hydromatix®. Sample/Hydromatix® mixtures were spiked with surrogates then extracted with 100% dichloromethane using accelerated solvent extraction (ASE) method. The extracts were then concentrated to 3 ml by evaporative solvent reduction. Silica gel/alumina column chromatography was utilized to concentrate and purify the samples before analysis. If sediment or other particulates were present in the sample extract, the extracts were filtered through a funnel containing glass wool and sodium sulfate. Quality control samples were processed with each batch of samples in a manner identical to the samples, including matrix spikes. Extracts were stored in the dark at or below 4°C. A method blank was run with every 20 samples, or with every sample set, whichever was more frequent. If blank levels for any component were above three times the MDL, samples analyzed in that sample set were re-extracted and reanalyzed. If insufficient sample was available for extraction, the data were reported and appropriately qualified. Matrix spike/matrix spike duplicate samples were run with every 20 samples, or with every sample set, whichever was more frequent. Surrogate standards were spiked into every sample and quality control sample.

Quantitation of PAHs and their alkylated homologues was performed by gas chromatography mass spectrometry (GC/MS) in the selected ion monitoring (SIM) mode. Target analytes are

listed in Table 3. The compounds in the surrogate solution were deuterated naphthalene-d_8, acenaphthene-d_{10}, phenanthrene-d_{10}, chrysene-d_{12} and perylene-d_{12}. The internal standards were fluorene-d_{10}, and benzo[a]pyrene-d_{12} at 4 µg mL-1 and were prepared with a certified standard (NIST or equivalent). The GC conditions were set so that the internal standards were resolved, but would elute in close proximity to, the analytes of interest.

A solution containing 2- to 5-ring PAH compounds was used to fortify matrix spike samples. A certified solution (NIST SRM 2260) was diluted to the appropriate working concentration. Dibenzothiophene was not present in the SRM and was added to the solution by weighing neat material to make a concentration of 1.00 µg L-1. The spiking solution was used to fortify samples to a final concentration of approximately ten times the MDL. A laboratory reference oil solution was analyzed as an instrument reference solution with each analytical batch. After every 8 - 10 samples, the mass spectrometer response for each PAH relative to the internal standard was determined using check standards. Daily response factors for each compound were compared to the initial calibration curve and recalibration was repeated when necessary. The standard reference oil was analyzed with all analytical batches.

When available, a standard reference material was extracted and analyzed with each batch of samples. Target concentrations were defined as the range of the certified value plus or minus the 95% confidence intervals found in the SRM certification. The measured concentration was within ±30% of the target concentration on average for all analytes either certified or non-certified with concentrations greater than 10 times the MDL. The actual analytical method detection limit (MDL) was determined following procedures outlined in CFR 40, part 136 (1999).

Quantitation of aliphatic alkanes of C-10 through C-34 plus pristine and phytane was performed by high resolution, capillary gas chromatography with flame ionization detection (GC/FID) on four selected samples, representing intertidal and subtidal strata, Homer Harbor, and Port Graham. Quality control procedures (blanks, duplicates, matrix spikes) were identical to the PAH procedures, except there are no certified SRMs for these materials.

The compounds in the surrogate solution were deuterated n-dodecane-d26, n-eisocane-d42, and n-triacontane-d62. The internal standards were 5α-androstane and n-hexadecane-d34.

Chlorinated hydrocarbons (chlorinated pesticides and PCBs, Tables 4, 5) were quantitatively determined by capillary gas chromatography with an electron capture detector (ECD). If the response for any peak exceeded the highest calibration solution, the extract was diluted, a known amount of surrogate and tetrachloro-m-xylene (TCMX) solution added, and the sample reanalyzed for those analytes that exceeded the calibration range. Analyte concentrations in the samples were based on calculations using the PCB 103 surrogate. The internal standard (TCMX) was used to calculate surrogate recoveries. 4,4'-dibromooctafluorobiphenyl (DBOFB) or PCB 198 was used to calculate selected analytes concentrations, if it was demonstrated that they produced more reliable data (i.e., if matrix interference occurs with PCB 103) based on percent recoveries in spiked blanks, matrix spikes, or reference materials. The calibration solutions that were analyzed as part of the analytical GC/ECD run were preceded by no more than six samples and no more than six samples were run between calibration mixtures.

An acceptable method blank contained no more than two target compounds at concentrations three times greater than the MDL. All samples and quality control samples were spiked with DBOFB, PCB 103 and PCB 198. The surrogate standard solution was spiked into the samples prior to extraction in an attempt to minimize individual sample matrix effects associated with sample preparation and analysis. A matrix spike and a duplicate were analyzed with each sample set or every 20 field samples, whichever was more frequent. The acceptable matrix spike recovery criteria were 50 - 125% recovery for at least 80% of the analytes. Criterion for duplicates was ≤30% relative percent difference (RPD). The method detection limit was determined following the procedures outlined in CFR 40, part 136 (1999). Most target compounds, surrogates and internal standard were resolved from one another and from interfering compounds. When they were not, coelutions were documented. A standard reference material sample was analyzed per batch of samples or every 20 samples whichever was more frequent.

2.2.3 Butyltins

An aliquot of freeze dried sediment was weighed and appropriate amounts of surrogate standards (approximately 10 times the method detection limit, MDL) were added to all samples, matrix spikes, and blanks. Samples were extracted three times by agitation with tropolone in dichloromethane. The sample extract was concentrated in a hot water bath, and the extract was centrifuged and further concentrated. The solvent was exchanged to hexane and concentrated to a final volume of about 10 – 20 mL at which point only hexane remained. Hexylmagnesium bromide (2 M; Grignard reagent) was added to the sample extract under nitrogen and heated to hexylate the sample. After separation from the organic phase, pentane:CH_2Cl_2 (3/1, v/v) was added to the aqueous phase and the sample shaken vigorously. The pentane:CH_2Cl_2 extraction was done twice. The hexylated extract was dried by addition of anhydrous Na_2SO_4 and then concentrated. The extract was purified using silica gel/alumina column chromatography. The eluent was collected and concentrated on a water bath.

The quantitative method was based on high resolution, capillary gas chromatography using flame photometric detection (GC/FPD). This method quantitatively determined tributyltin (TBT), dibutyltin (DBT), and monobutyltin (MBT).

Quality control samples were processed in a manner identical to actual samples. A method blank was run with every 20 samples, or with every sample set, whichever was more frequent. If corrected blank concentrations for any component were above three times MDL, the whole sample set was re-extracted and reanalyzed. If insufficient sample was available for re-extraction, the data was reported and appropriately qualified. Matrix spike/matrix spike duplicate (MS/MSD) samples were run with every 20 samples, or with every sample set, whichever was more frequent. The appropriate spiking level was ten times the MDL. Reference materials were extracted with each set of sample and were analyzed when available. The method detection limit was determined following the procedures outlined in CFR 40, part 136 (1999).

2.3. Benthic community characterization

In the laboratory, samples were inventoried, rinsed gently through a 0.5 mm mesh sieve to remove preservatives and residual sediment, stained with Rose Bengal, and stored in 70% isopropanol solution until processing. Sample material (sediment, detritus, and organisms) were placed in white enamel trays for sorting under Wild M-5A dissecting microscopes. All macroinvertebrates were carefully segregated into major taxonomic groups (e.g. Polychaeta, Mollusca, and Arthropoda). The macroinvertebrates were then identified to the lowest practical identification level (LPIL), which in most cases is to species level unless the specimen is a juvenile, damaged, or otherwise unidentifiable. The number of individuals of each taxon, excluding fragments was recorded. Data were synthesized into a data summary report for each site, which includes a taxonomic species list and benthic community parameters list. At a minimum, 10 percent of all samples were resorted and recounted on a regular basis. Also 10 percent of samples were randomly selected and re-identified. The minimum acceptable sorting and taxonomic efficiency was 95%. A voucher collection composed of representative individuals of each species encountered in the project was accumulated and retained.

Taxa are distributed along environmental gradients, so there are generally no distinct boundaries between communities. However, the relationships between habitats and species assemblages reflect the interactions of physical and biological factors and can indicate major ecological trends. Quantitatively, the benthic communities were characterized as enumeration by abundance, species richness, evenness, and diversity, followed by pattern and classification analysis for delineation of taxa assemblages. Abundance was calculated as the total number of individuals per square meter; taxa richness as the total number of taxa represented at a given site; and taxa diversity was calculated with the Shannon-Weiner Index (Shannon and Weaver, 1949), using the following formula:

Eqn1
$$H' = -\sum_{i=1}^{S} p_i (\ln p_i)$$

where, S = is the number of taxa in the sample,

i is the i_{th} taxa in the sample, and

p_i is the number of individuals of the i_{th} taxa divided by the total number of individuals in the sample.

Evenness of taxa diversity for a given station was calculated as Pielou's Index J' (Pielou 1966);

Eqn 2 $J' = H'/1n\ S$

where $1n\ S$ = H'max,

When all taxa are represented by the same number of individuals, $J' = H'/H'_{max}$

2.4. Sediment toxicity bioassays

Amphipod mortality bioassays using two species of amphipods were carried out on the sediment samples. All methods are based on standard methods promulgated by the EPA, ASTM, and/or APHA. The whole sediment toxicity bioassay test is commonly used in North America for assessing sediment quality, in part because the test integrates the effects of complex contaminant mixtures in relatively unaltered sediment and also because amphipods are fairly common and ecologically important species in coastal waters. The organisms are standard test species with known ranges of sensitivity and their presence or absence in a particular habitat is not relevant because they are tested under standardized conditions.

2.4.1 Amphipod bioassays

Ampelisca abdita is the most commonly used species in NOAA's studies, as well as other agencies. A large data base exists for this species for comparative purposes. This euryhaline species occurs in fine sediments from the intertidal zone to a depth of 60 m, with a distribution range that extends from Newfoundland to south-central Florida, and includes the eastern Gulf of Mexico, and portions of the California coast. *Ampelisca abdita* builds soft, membranous tubes and feeds on surface deposited particles as well as particles in suspension. In previous studies, this species has shown relatively little sensitivity to nuisance factors such as grain size, ammonia, and organic carbon. The amphipod *Eohaustorius estuarius* is found in shallow subtidal water along the Pacific coast. *E. estuarius* is a free burrowing deposit

feeder found in medium-fine sand with some organic content. It is routinely collected in areas where pore-water salinity ranges from 1 to 25‰**.**

The tests were performed in accordance with a standard guide for conducting 10-day static sediment toxicity tests with amphipods (ASTM 2003) and additional guidance developed for testing four different amphipod species (EPA 1994). Briefly, amphipods were exposed to test and control sediments for 10 days under static conditions. The bioassays included 4-5 replicates (depending on sediment sample volume), with 20 animals per replicate. During the test, the animals were exposed to constant light in filtered, aerated seawater at 28 ppt salinity. The test chambers were 1L glass vessels, containing 200 mL of sediment. The vessels were monitored daily for water temperature and condition of test organisms. Measurements for salinity, dissolved oxygen, ammonia, and pH were made at least twice during the course of the bioassay. Hydrogen sulfide in sediment pore water was also measured periodically. All sediment sample locations were tested with *A. abdita.* Due to limited resources, only 18 randomly selected samples were tested using *E. estuarius*.

A positive control, or reference toxicant test, was used to document the sensitivity of each batch of test organisms. A commonly used industrial chemical, sodium dodecyl sulfide (SDS), also known as sodium lauryl sulfide, was used in 96-hour water-only exposure bioassay as a control test. The LC_{50} results were recorded in a control chart, and were expected to be within 2 standard deviations of the mean of the previous 20 positive control tests.

Based on statistical analyses of amphipod survival data, including power analysis, two criteria are used to declare a sample mean LC_{50} to be different from the control mean: first, the t-test must show that the sample survival is statistically lower than in the control, and second, the sample's mean survival must also be equal to less than 20% of that in the control (Thursby *et al*. 1997). These results are described as having statistically lower survival, and demonstrating a toxic response, respectively.

2.4.2 Integrated toxicity response index

A ranking scheme was used to evaluate the toxicological results on a site by site basis (Hartwell 1997). The ranking system quantifies relative toxicological impact, not merely cataloging presence or absence of toxic effects. The simplified version of the ranking scheme is the sum of the products of endpoint severity and percent response divided by $\sqrt{N}$.

Eqn 3 $$\text{Site Score} = \{\Sigma [(\text{Severity})\ (\%\ \text{Response})]\} / \sqrt{N}$$

The sum was divided by the square root of the number of test endpoints (N) for each site, to compensate for bias between different sites where different amounts of data may be present. Severity refers to the degree of effect which the bioassay endpoints measure. Mortality is considered the most severe response, followed by impaired reproduction and exposure. They were arbitrarily set as integers of mortality = 3, reduced fecundity = 2 and elevated exposure = 1.

Degree of response is the measure of the proportion of response in each bioassay regardless of statistical significance (e.g. 5% mortality, 45% reproductive inhibition, etc.). Low level impacts may have significant population level ramifications if present over widespread areas or for long time periods. In this regard, it is as important to know what percentage of the organisms responded as it is to know whether it was `statistically significant'. The response values were adjusted for mean control values in their calculation formulas. Negative values were assigned a value of zero. The following equations were used to calculate degree of response:

Eqn 4 $$\%\ \text{mortality response} = \{(\text{test \# dead} - \text{control \# dead})/\text{initial total \#}\} \times 100$$

The number of endpoints measured at each site refers to the number of bioassays which are monitored. For statistical and experimental reasons, the number of tests run at each site ideally should be the same. However, given the uncertainties of experimental work, this is not always possible. This score is a useful technique for comparing individual sites and for examining spatial trends in sediment or temporal trends in water samples.

2.5. Statistical contrasts

2.5.1. Sediment texture assessment

Sediment textural assessment was conducted based on the relative percentages of sediment grain sizes (silt, clay, sand, and gravel). Sediment samples from all the sites were virtually gravel-free. Thus, the benthic sediments in the study site are suitable for the commonly used ternary diagrams that use percent clay, sand, and silt (Shepard 1954), and sand and mud (silt + clay) (Folk *et al.* 1954) for textural classification. Site-specific results of the later analysis were further subjected to Hierarchical cluster analysis, with Ward's minimum variance method, used to assess the overall distribution of sediment types in the study area. Hierarchical clustering groups sites whose sediment textures are similar.

2.5.2 Contaminants

Box-plot statistics were used to assess concentration variations among strata for metals. The approach uses the range of concentration distribution in each stratum based on quartiles and Chi-square approximation for inter-stratum concentration comparison. The plots show the median, the 25^{th} and 75^{th} percentile (bottom and top of the box) and the whiskers above and below the box represent the 10th and 90^{th} percentiles. Because trace elements and other compounds naturally vary in concentration by several orders of magnitude, normalized values were calculated for the purpose of summarizing contaminant data in consistent units. Data were normalized to the overall mean. This was applied to each element and to the summed organic contaminants (derived as the sum of individual compounds; e.g. total PCBs). Thus, all metals and organics can be contrasted against each other, or metals against organics in consistent units. Spearman rank correlations were calculated to assess the degree of association between fine grained sediment distribution and the concentration of trace metals and organic compounds, respectively.

2.5.3 Sediment quality guidelines

Numerical sediment quality guidelines (SQG) developed by Long and Morgan (1990) and Long *et al*. (1995) known as ERM and ERL (effects range-median, effects range-low) express statistically derived levels of contamination, above which toxic effects would be

expected to be observed with at least a 50% frequency (ERM), and below which effects were rarely (<10 %) expected (ERL). The mean ERM quotient (Long *et al*. 1998) is the average of the ratio of ERM value to sediment concentration for each chemical. The mean quotient of the ERMs and observed contaminant concentrations were calculated on a site by site basis. The calculation included all the individual metals, low weight PAHs, high weight PAHs, total PCBs, and total DDT and its metabolites.

2.5.4 Benthic community analysis

Multivariate cluster analysis was employed to group site and species data. The objective was to produce a coherent pattern of association between sites and species. Cluster analysis is a two-step process including; 1) creation of a resemblance data matrix from the raw data, 2) clustering the resemblance coefficients in the matrix. The input resemblance (similarity or dissimilarity) matrix can be created by a number of methods. Input data may or may not be standardized or transformed depending on the requirements of the method (e.g. Bray Curtis). Based on previous research (Hartwell and Claflin 2005) the Jaccard method (Goodall 1973) was used to generate the similarity matrix.

The Jaccard method is a binary method based only on presence/absence data, and thus ignores abundance values. Cluster analyses were calculated from the matrices using the Unweighted Pair-Group Method Using Arithmetic Averages (UPGMA) procedure which clusters coefficients based on arithmetic mean distance calculations (Sneath and Sokal 1973). To optimize the cluster analysis results, several manipulations of the input data were performed to remove confounding effects and bias.

1- Epiphytic species such as sea anemones and tunicates were eliminated from the data set as they are not truly infauna.

2- Artificial species (resulting from failure to identify some specimens all the way down to species) were identified as a data bias. For example, if specimens of 2-3 species were identified in genus A, and other specimens were identified only to genus A, this tends to artificially increase species richness and diversity of the sample when in fact that diversity is

an artifact of imperfect taxonomic identification. In some instances, specimens were only identifiable to family, order or class. To address this problem, specimens not identified to species level were eliminated, unless they were identified to a taxonomic level below which no other specimens in the collection belonged. That is, even though they were not identified to species, they were the only representative of that taxonomic line and did represent a non-redundant taxon. In other cases where a specimen was identified to genus and there was only one species identified in that genus, they were combined at the genus level.

3- Rare and unique taxa were defined as those species that were found at no more than two stations. Although they do contribute to the overall assessment of biodiversity, they were eliminated from the cluster analysis data set. Because of their limited distribution, by definition, they do not provide information on the impact of contaminant or other stressors gradients in the environment because they do not occur across the entire gradient.

After the data set had been finalized, a nodal analysis routine was applied to the data (Lambert and Williams 1962). This consisted of combining independent cluster analyses in a graphical array. The first analysis clustered sites using species occurrence data. The second calculation clustered species together into groups. The intersection of site clusters on the abscissa and species clusters on the ordinate axis yields a pattern of species associations with site clusters, termed nodes (Figure 4). In practice, this is done on large 3'x4' plots of the cluster analysis output. Reduction to normal text page size sacrifices a significant amount of detail. The site and species clusters were also characterized by physicochemical habitat parameters, contaminant concentrations, and other site-specific data (Figure 5). For each species, the parameters were normalized to their abundance at each site. For example, if 100 specimens of species A were found at a site with a TOC value of 1.5% and 10 were found at a site where TOC was 2%, the abundance normalized TOC preference for species A would be [(100*1.5)+(10*2)]/110=1.55.

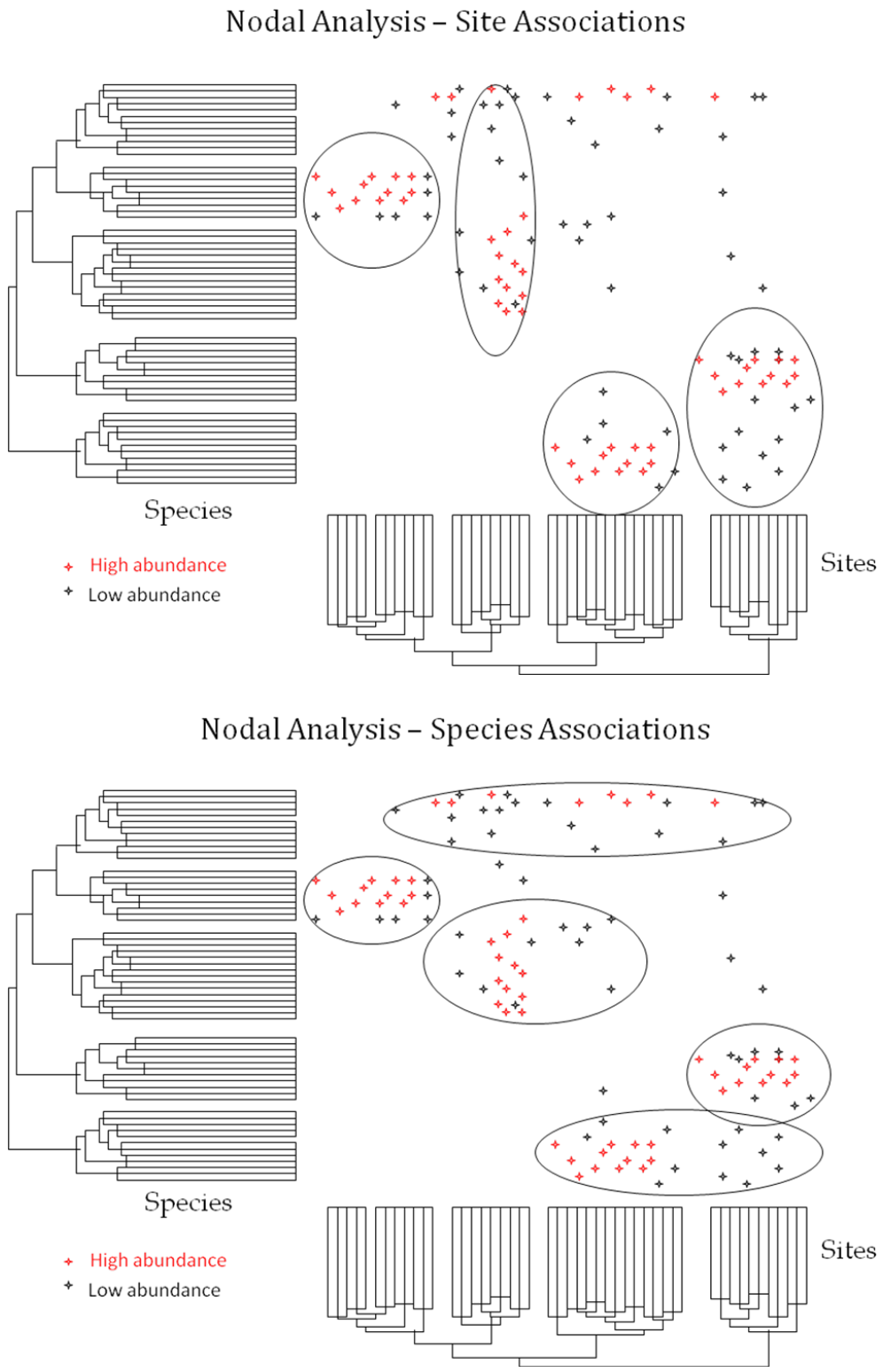
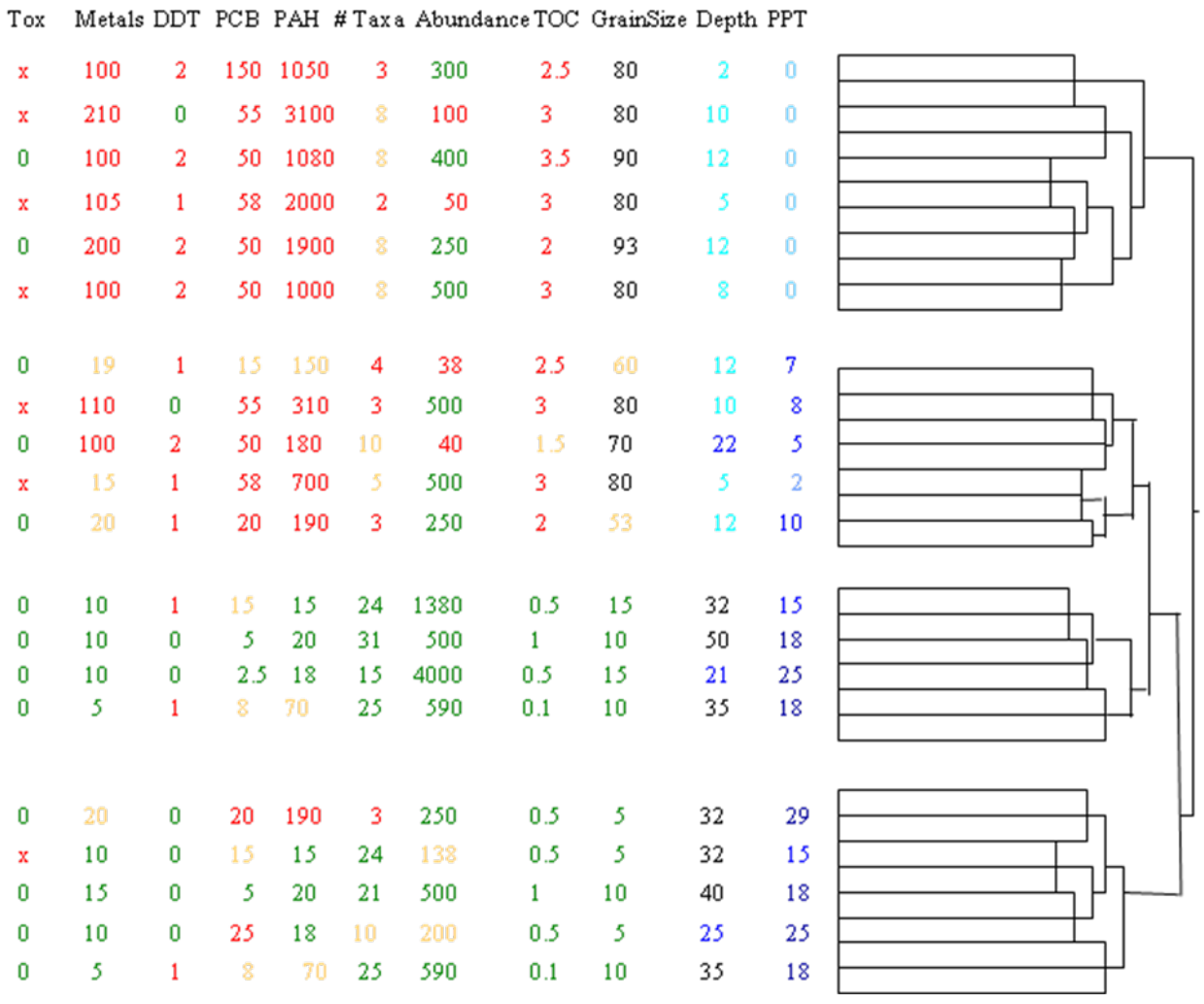


Figure 4. Combined cluster analysis overlays of species clusters and site clusters. The top figure illustrates the dominant species communities found in different site clusters. The lower figure illustrates how different species assemblages distribute themselves between different habitats.

Cluster Characteristics



Tox	Metals	DDT	PCB	PAH	# Taxa	Abundance	TOC	GrainSize	Depth	PPT
x	100	2	150	1050	3	300	2.5	80	2	0
x	210	0	55	3100	8	100	3	80	10	0
0	100	2	50	1080	8	400	3.5	90	12	0
x	105	1	58	2000	2	50	3	80	5	0
0	200	2	50	1900	8	250	2	93	12	0
x	100	2	50	1000	8	500	3	80	8	0
0	19	1	15	150	4	38	2.5	60	12	7
x	110	0	55	310	3	500	3	80	10	8
0	100	2	50	180	10	40	1.5	70	22	5
x	15	1	58	700	5	500	3	80	5	2
0	20	1	20	190	3	250	2	53	12	10
0	10	1	15	15	24	1380	0.5	15	32	15
0	10	0	5	20	31	500	1	10	50	18
0	10	0	2.5	18	15	4000	0.5	15	21	25
0	5	1	8	70	25	590	0.1	10	35	18
0	20	0	20	190	3	250	0.5	5	32	29
x	10	0	15	15	24	138	0.5	5	32	15
0	15	0	5	20	21	500	1	10	40	18
0	10	0	25	18	10	200	0.5	5	25	25
0	5	1	8	70	25	590	0.1	10	35	18

Figure 5. Hypothetical representation of the distribution of physicochemical habitat parameters, contaminant concentrations, and other site-specific data used to characterize site and species clusters.

2.5.5 Principal Components

Principal component analysis (PCA) was calculated for all the sampling sites using habitat characteristics and $\log_{10}$ transformed species abundance data, with and without contaminant data. PCA was also calculated using transformed species abundance data alone.

2.5.6 Sediment Quality Triad

The Sediment Quality Triad (SQT) approach is a tool to assess benthic habitats in terms of their community characteristics, observed toxicity, and chemical contamination loads (Chapman *et al.* 1987). The SQT has traditionally been presented as a weight of evidence matrix of three separate scores. In an attempt to integrate SQT data into a unified score for each site, the three types of data were integrated in a graphical composite to allow comparison between sites and correlation with other parameters.

For contaminants, mean-normalized concentration (site conc./mean conc.) was calculated for each of the trace elements, which were then averaged by site. The mean-normalized value was also calculated for total PAHs, PCBs, TBT, DDT, and cyclodiene pesticides. The overall mean for all these six chemical constituents was then calculated. Because the chemistry data was highly skewed, the log10 of the average was used in the scaling calculation. Data were scaled from 1 to 100 using the formula:

Eqn 5 ((Site Value - minimum Value) / (maximum Value – minimum Value)) x 100

This places all values in the range of 0-100, based on the range of the data. The derived Toxicity index (Hartwell 1997) was scaled in this manner. The inverse of community species richness was used for the third triad leg. Thus high values in each category represented degraded conditions. The three values were plotted on tri-axial graphs and the surface area of each resulting triangle was calculated as a measure of impact. The largest triangle possible in this system would have a surface area of 8,660 (unitless). The angles within the corners of the triangles were also calculated. The standard deviation of the angles represents a measure of the symmetry of the triangles. That is, at sites where there is high contamination, toxicity and low numbers of species,

the triangle tends toward an equilateral shape. A site where one or two metrics are high and the other is low indicates a lack of effective cause and effect linkage between the triad legs (Chapman 1996).

2.5.7 Spatial distribution of habitat and benthic community parameters

To evaluate the spatial distribution of benthic community (e.g. taxa, species abundance), and habitat parameters that influence them (e.g. grain size, salinity and toxicity), a three groups classification scheme was applied using ArcGIS 9.2. In ArcGIS, data classification is based on the Jenks' grouping method, which uses natural break points inherent in the data. ArcGIS identifies break points that best divide the data into the specified number of classes. The resulting classes are made of relatively similar values, while the differences between them are maximized.

2.5.8 Additional Samples

In addition to the 29 sites sampled in the stratified random sampling scheme, five additional sites were sampled with support from NOAA and CIRCAC. Two sites outside of Homer Harbor were taken in the footprint of where the planned harbor expansion will be built. Sediment chemistry and benthos samples were taken, but no bioassays were done. These sites were outside the depth range of the designed study. Three randomized sites were taken in Port Graham Bay to assess conditions in the vicinity of the Native village of Port Graham. The complete sediment quality triad suite of samples was taken there. Additional samples were taken for microbial analysis of *Clostridium perfringens*. The data from these sites were not included in the statistical analyses of the designed study, but do offer informative contrasts to the data set.

3. RESULTS

3.1. Habitat Conditions

The study area is relatively flat with depth varying from 2.6 – 11.2 m at high tide (Figure 6). Since the intertidal areas were always sampled at high tide to allow safe vessel operations, and the subtidal areas were sampled at other times, all depths are presented as the relative depth at mean high tide, calculated from sampling time and tidal stage. The intertidal mud flats vary in width from 150 m near Fritz Creek to greater than 1000 m over much of the area. At the eastern end of the bay, the entire width of the bay is intertidal in the alluvial fan of the Fox River. The subtidal strata are flat, falling in depth by only 1-2 m over a 1500-2500 wide shelf. Beyond this, the bottom falls off more steeply to more than 23 m depth over 1000 m or less beyond the shelf (Figure 6). At the mouth of the Fox River delta, the shelf drops directly into deep water (>30 m).

The water column is fairly well mixed. Only small differences in salinity, temperature and dissolved oxygen (DO) were observed between the surface and bottom. Kachemak Bay is a relatively saline environment with surface and bottom salinity ranging from 15 – 29 and 18-30 ‰ , respectively (Figure 7a). Although small, there was a significant difference (Chi-square = 32.7, $P < 0.05$) between surface and bottom salinity values. Figure 7b illustrates the spatial distribution of bottom salinity in the study area. Subtidal salinity values in the eastern reaches of the study area near the mouth of the Fox River show the lowest values, but this is probably an artifact of sampling the subtidal areas at low tide and the intertidal areas at high tide

Measurements taken in the study area showed no differences (Chi-square = 0.64, $p > 0.05$) between the surface and bottom DO (Figure 8a). Figure 8b illustrates the spatial distribution of bottom DO. There was a slight difference between the eastern and the western strata with values ranging from 8.5 – 9.7 mg L-1 and 9.2 – 10.8 mg L-1 respectively. These DO concentrations indicated that on the shelf of the inner Kachemak Bay, there is no area of oxygen stress in the water column.

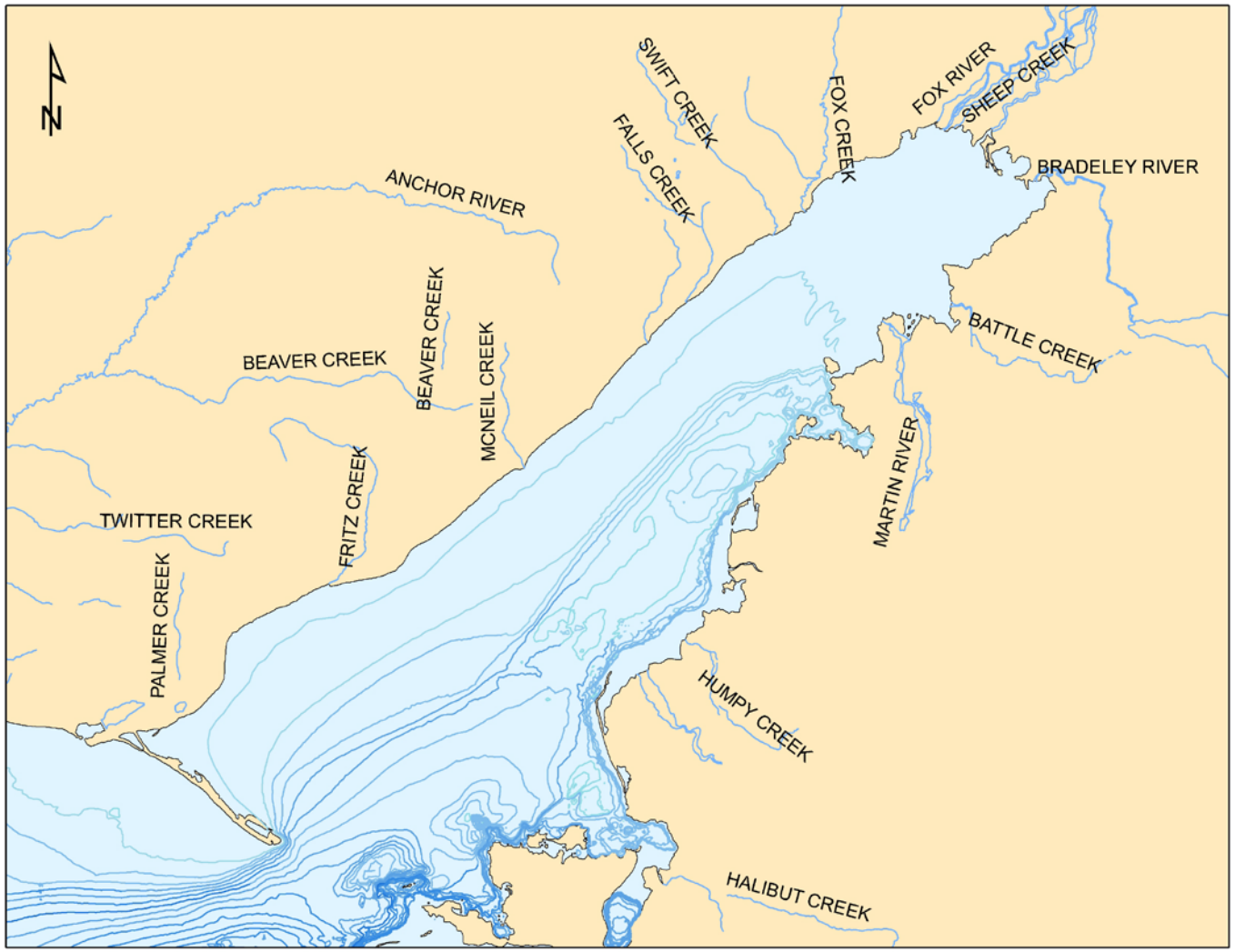


Figure 6. Map of Kachemak Bay bathymetry with 10 meter isobath contours starting at mean low water (KBNERR, 2001). Depths vary from 2.6-11.2 m at high tide in the Bay.

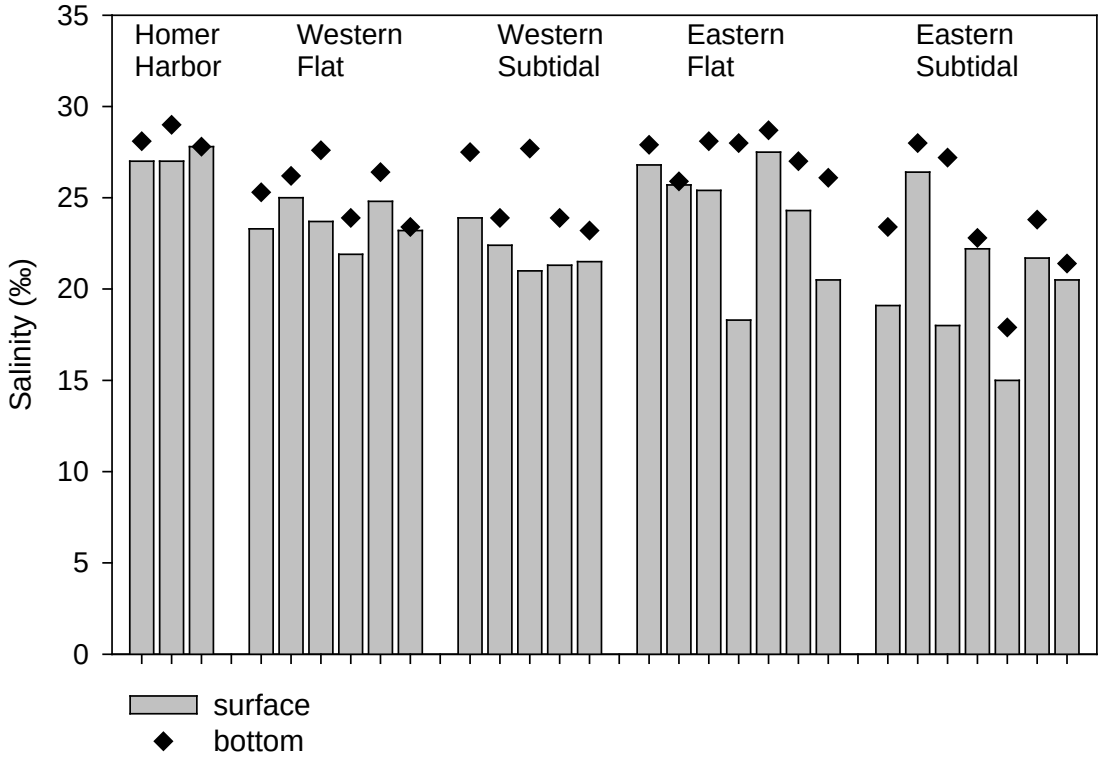


Figure 7a. Contrast between surface and bottom salinity in Kachemak Bay study area. A small difference exist between surface and bottom salinity measurements (Chi-square = 32.7, $P < 0.05$).

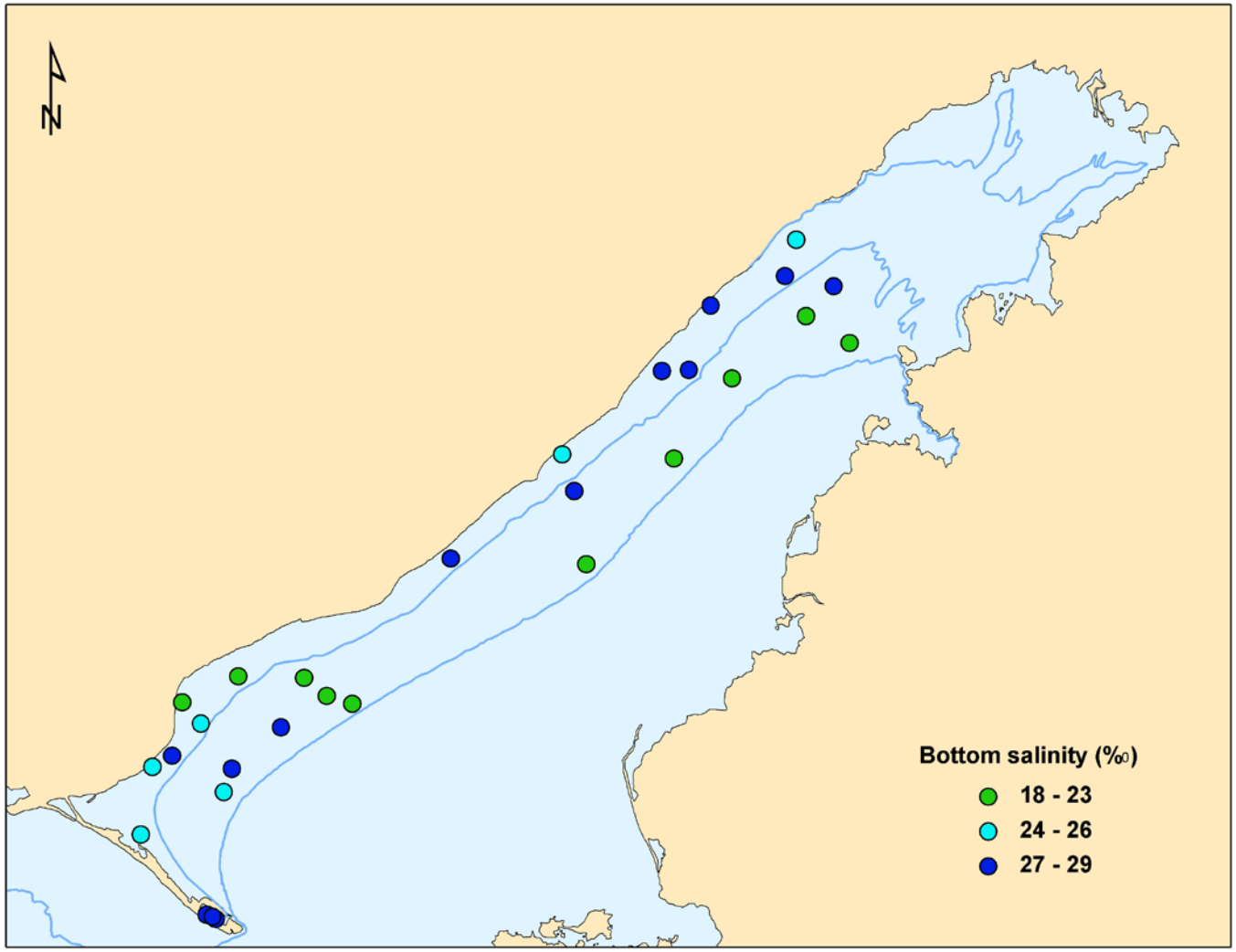


Figure 7b. Distribution of bottom salinity at Kachemak Bay study sites. Variability in salinity measurements may reflect tidal stage as samples were taken at different tidal horizon: intertidal and subtidal at high and low tide respectively. Contour lines show 10 m depth, mean low tide line, and major river channels

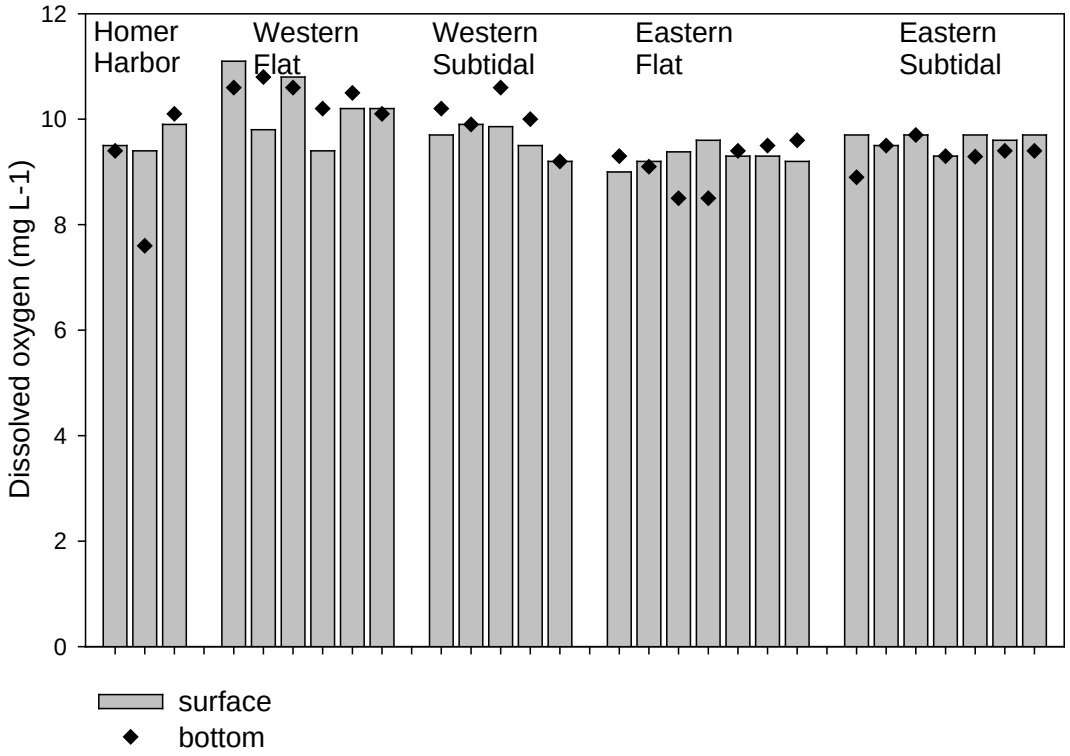


Figure 8a. Contrast
Contrast between surface and bottom dissolved oxygen in the study area. No significant difference was found (Chi-square = 0.64, $p > 0.05$).

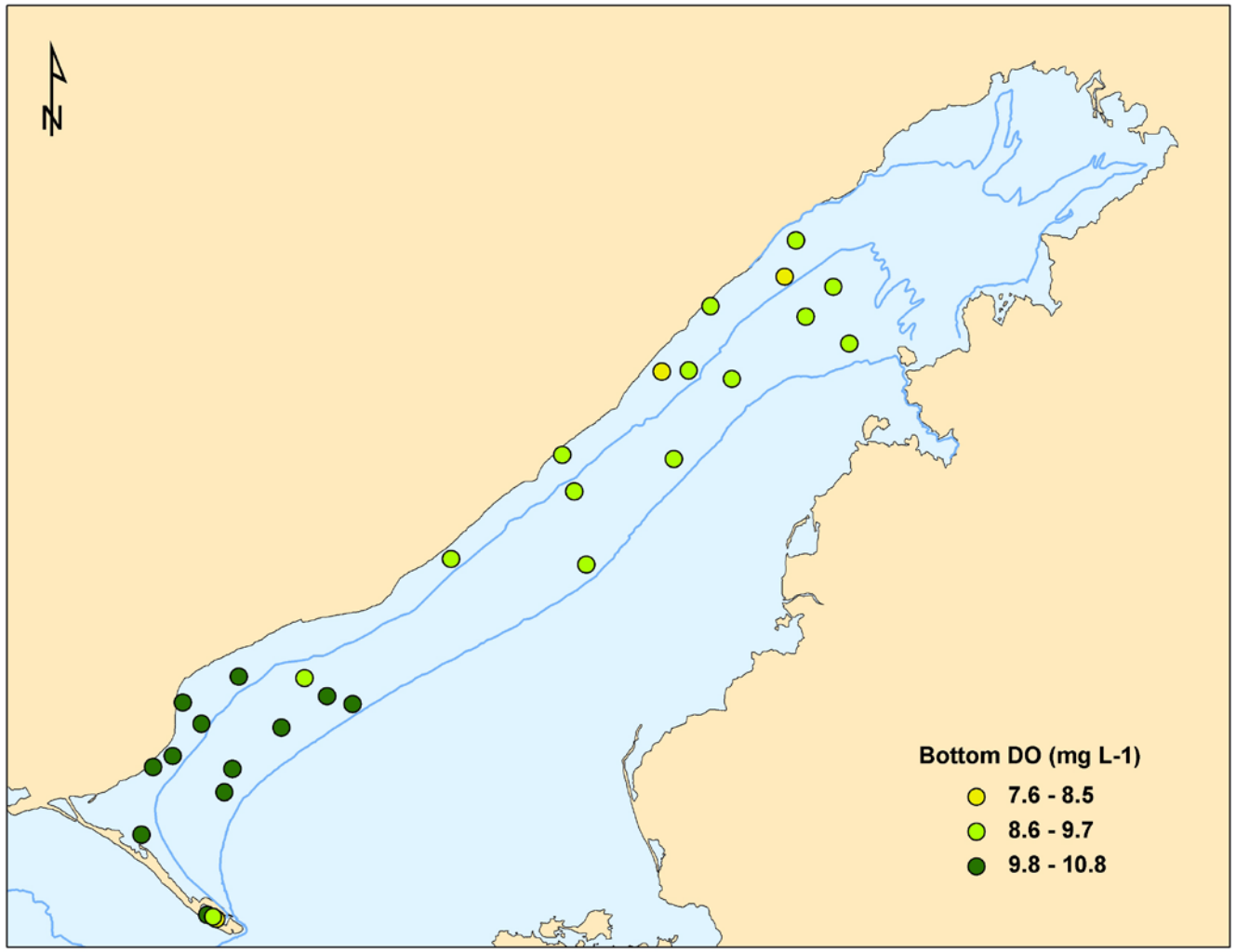


Figure 8b. Distribution of bottom dissolved oxygen (DO) concentration in the study area suggest there is no oxygen stress. Samples were taken at different tidal horizon: intertidal and subtidal at high and low tide respectively.

Average temperatures were roughly 13 and 12°C at the surface and bottom of the water column respectively (Figures 9a and 9b). Using data from all sites in the study area, surface and bottom temperature values were statistically significantly different (Chi-square = 47, $P < 0.05$) but the variation was slight. Again, these values indicate a well mixed water column in the bay.

Water clarity showed a distinct gradient from east to west in the bay, reflecting the turbid inflow of glacial till transported by the Fox and Bradley Rivers (Figure 10). The water column was significantly more turbid in the eastern area than the west (Chi-square =20, $P < 0.05$). Also, in Homer Harbor the water column was more turbid relative to other sites in the western area of the inner bay.

Sediment physical characteristics are one of the overriding environmental parameters that influence the distribution of both contaminants and benthic species. Cluster analysis based on sediment description derived from ternary plots (Figure 11) revealed a fairly uniform sediment texture within each stratum except for Eastern subtidal stratum (Figure 12). Within the Eastern subtidal stratum, sediment texture varied from a coarser sandy type to a finer sandy mud. In the Homer Harbor stratum, the bottom sediment was mainly composed of mud with high contents of clay and silt. Both eastern and western subtidal areas of the inner bay have similar sediment texture of sand to sandy mud as indicated by the cluster analysis. Sediment composition in the intertidal mudflats varied from sandy silt to clayey silt in the eastern flat; and from sandy mud to silty sand in the waster flat.

Sediment type (e.g. mud vs. sand) and associated levels of organic matter content also influences the capacity of the sediment to sequester contaminants, and hence the potential to be toxic to organisms. Sediments tended to have a larger proportion of fine grained material at sites closer to shore (Figure 13). Sediments at all three Homer Harbor sites were composed of more than 80% fine grained material. The high mud (silt and clay) content of sediment in the harbor is an indication of a low energy depositional area. Total organic carbon (TOC) content demonstrated a distinctive gradient between the eastern and western strata of the study area (Figure 14).

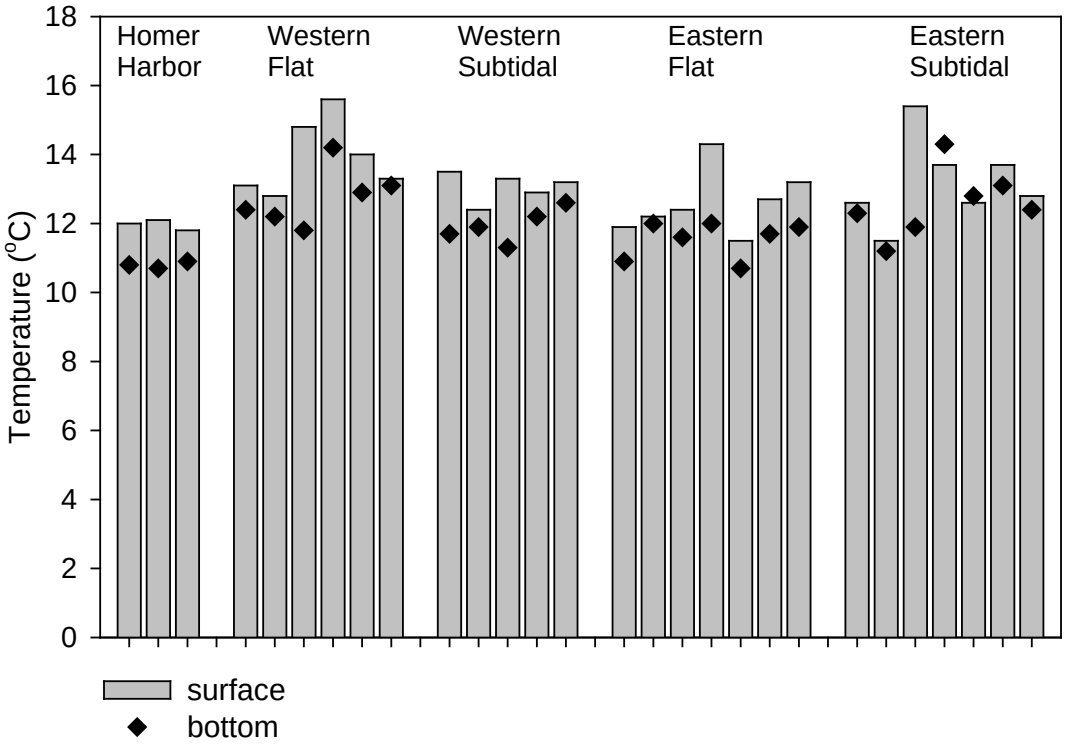


Figure 9a. Measured temperature for surface and bottom water at Kachemak Bay study sites. Surface and bottom temperature measurements were significantly different (Chi-square = 47, $P < 0.05$), the variation was slight, the water column is primarily well mixed.

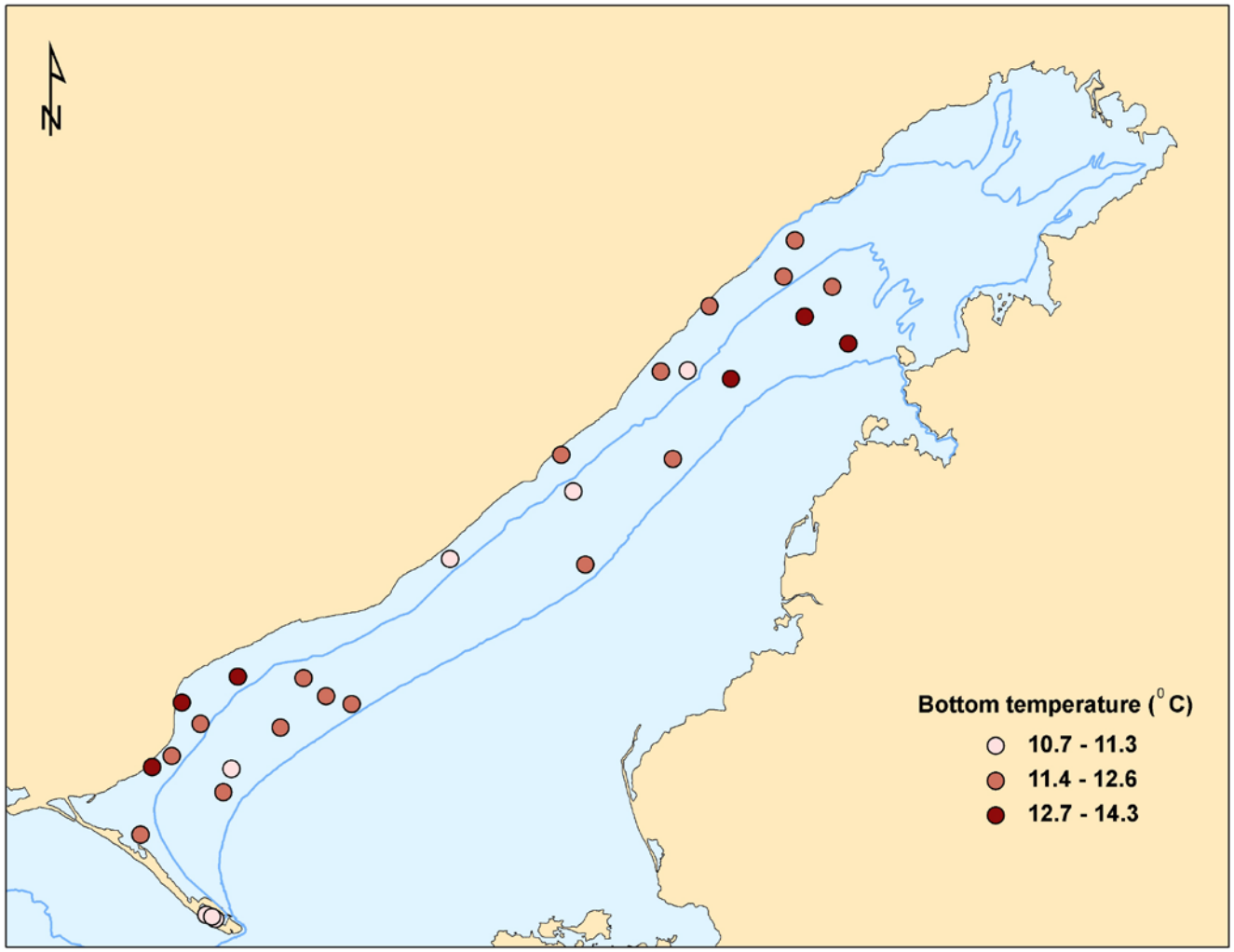


Figure 9b. Map of bottom water temperature measurements at Kachemak Bay study sites. Samples were taken at different tidal horizon: intertidal and subtidal at high and low tide respectively.

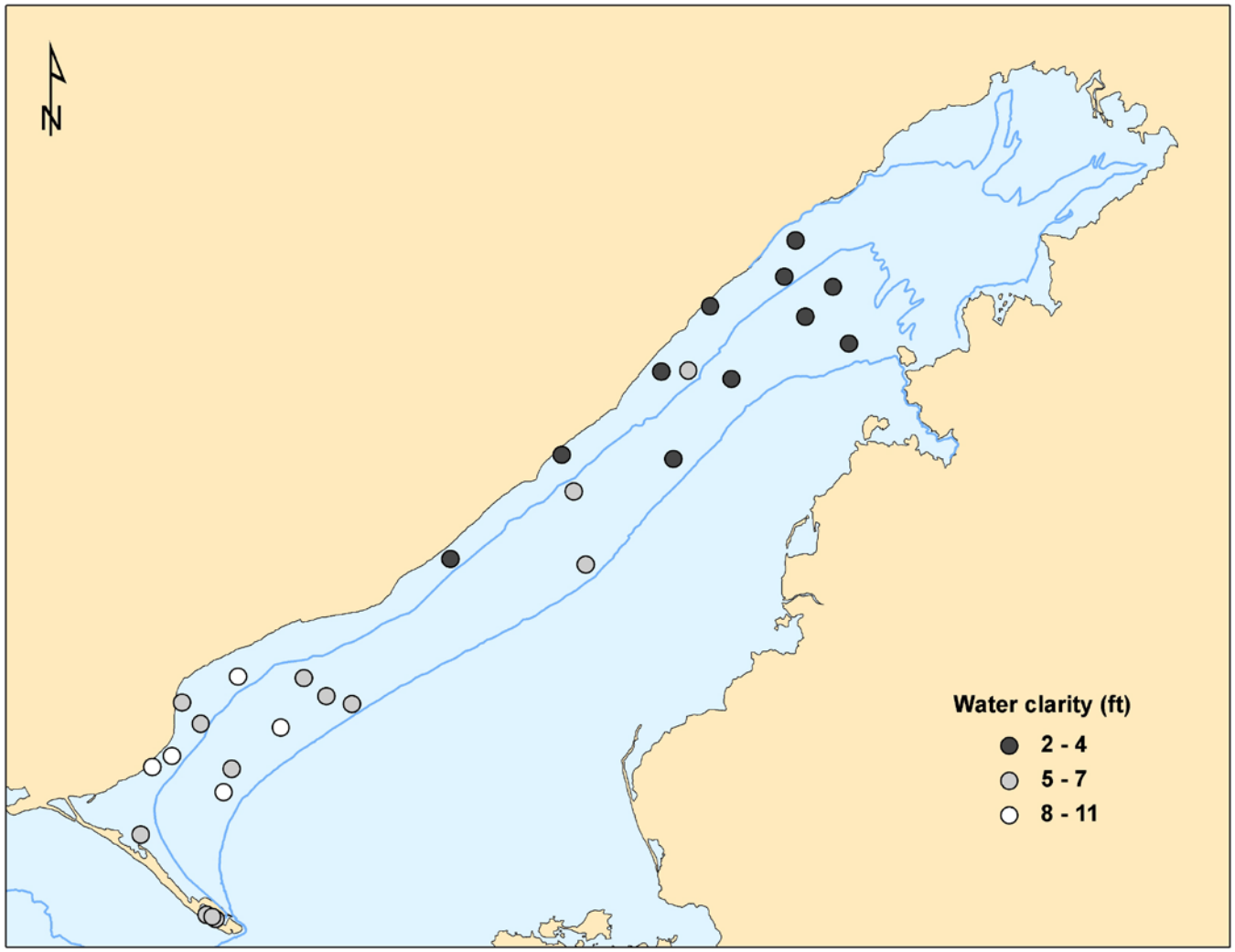


Figure 10. Map of water clarity from Secchi disc measurements in Kachemak Bay. The water column was significantly more turbid in the east than the west (Chi-square =20, $P < 0.05$). Samples were taken at different tidal horizon: intertidal and subtidal at high and low tide respectively.

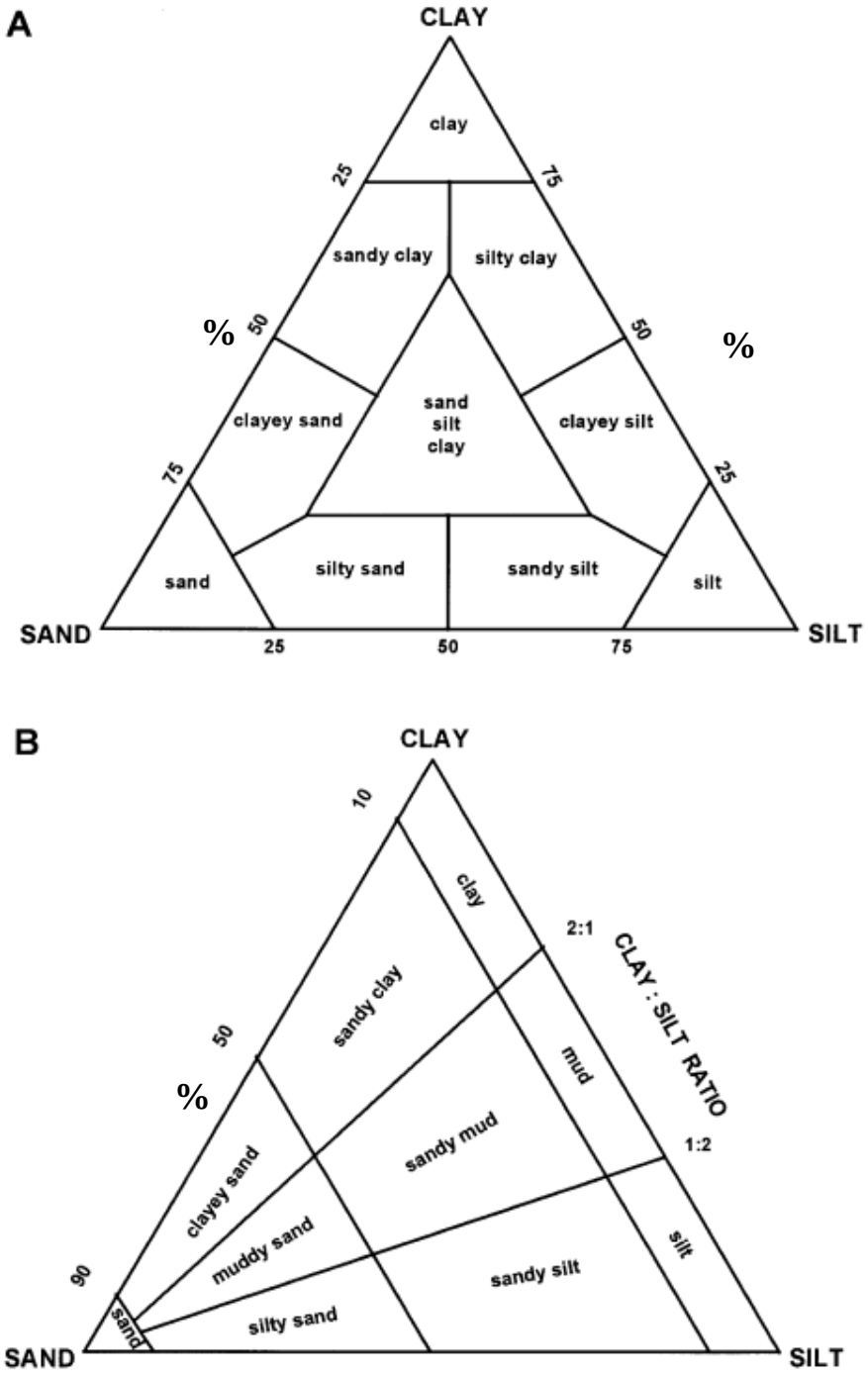


Figure 11. Ternary plots for textural classification of sediment based on: percent silt, clay and sand, diagram A (Shepard 1954); and ratio sand and mud (slit + clay), diagram B (Folk, 1954). This figure is adapted from Flemming (2000).

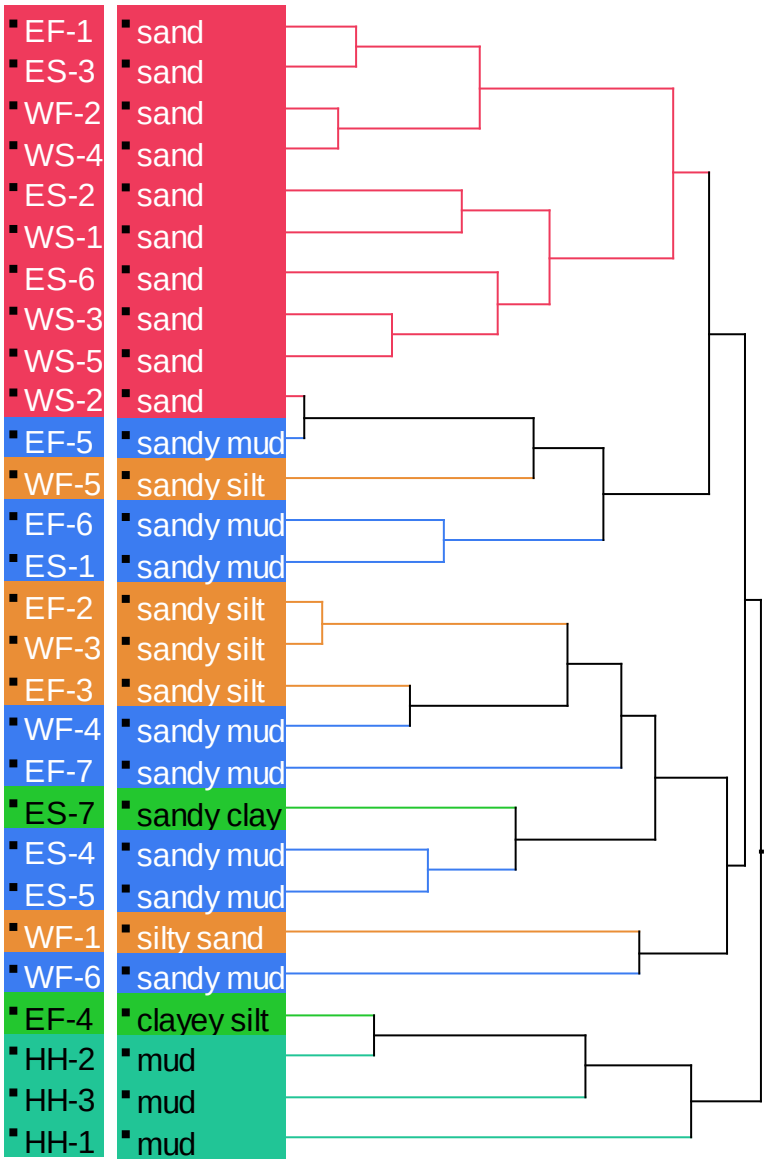


Figure 12. Cluster analysis depicting different types of benthic sediment textures. The muddy sediments of Homer Harbor were distinguished from most other sites.

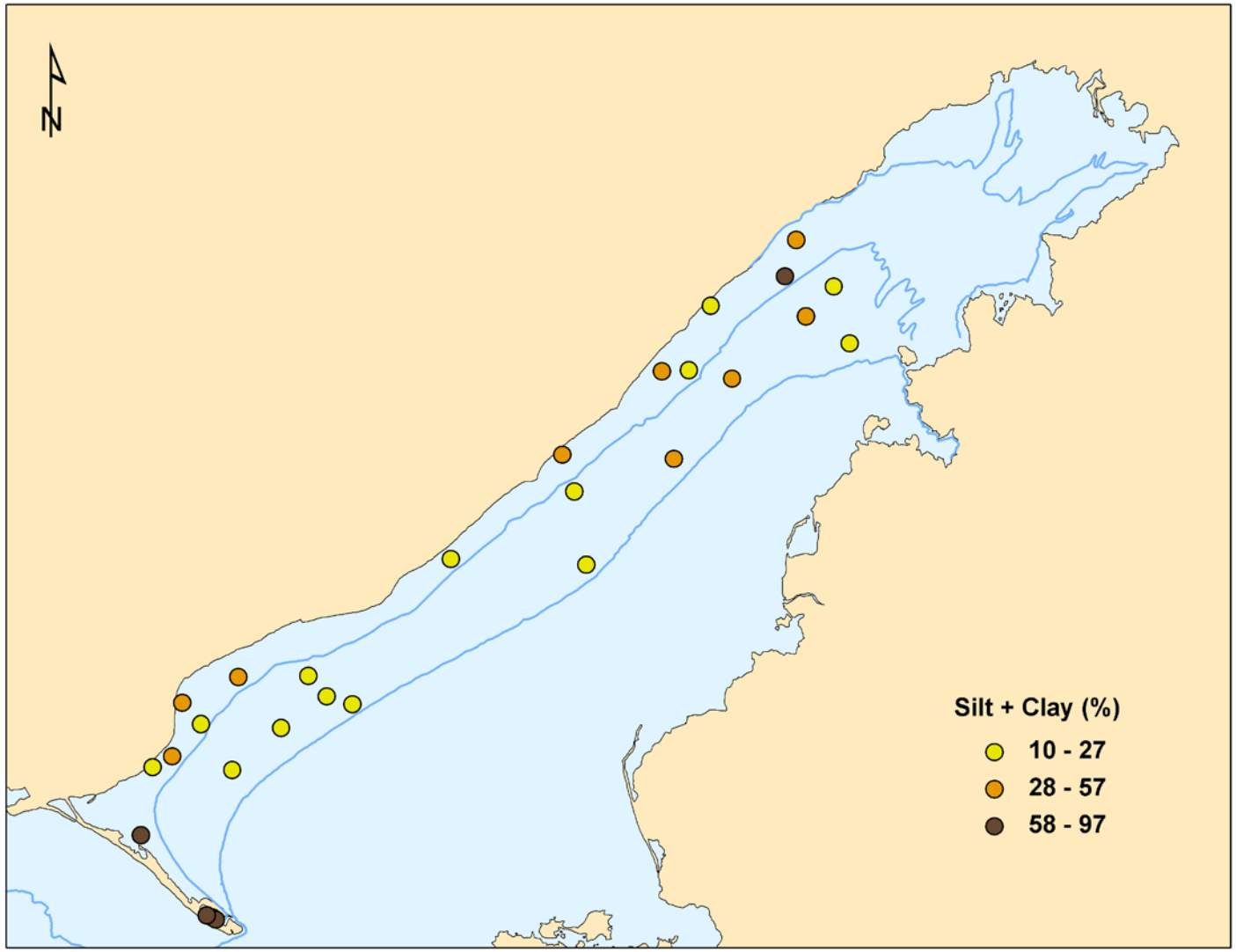


Figure 13. Spatial distribution of fine sediment (percent silt + clay) at Kachemak Bay study sites. .

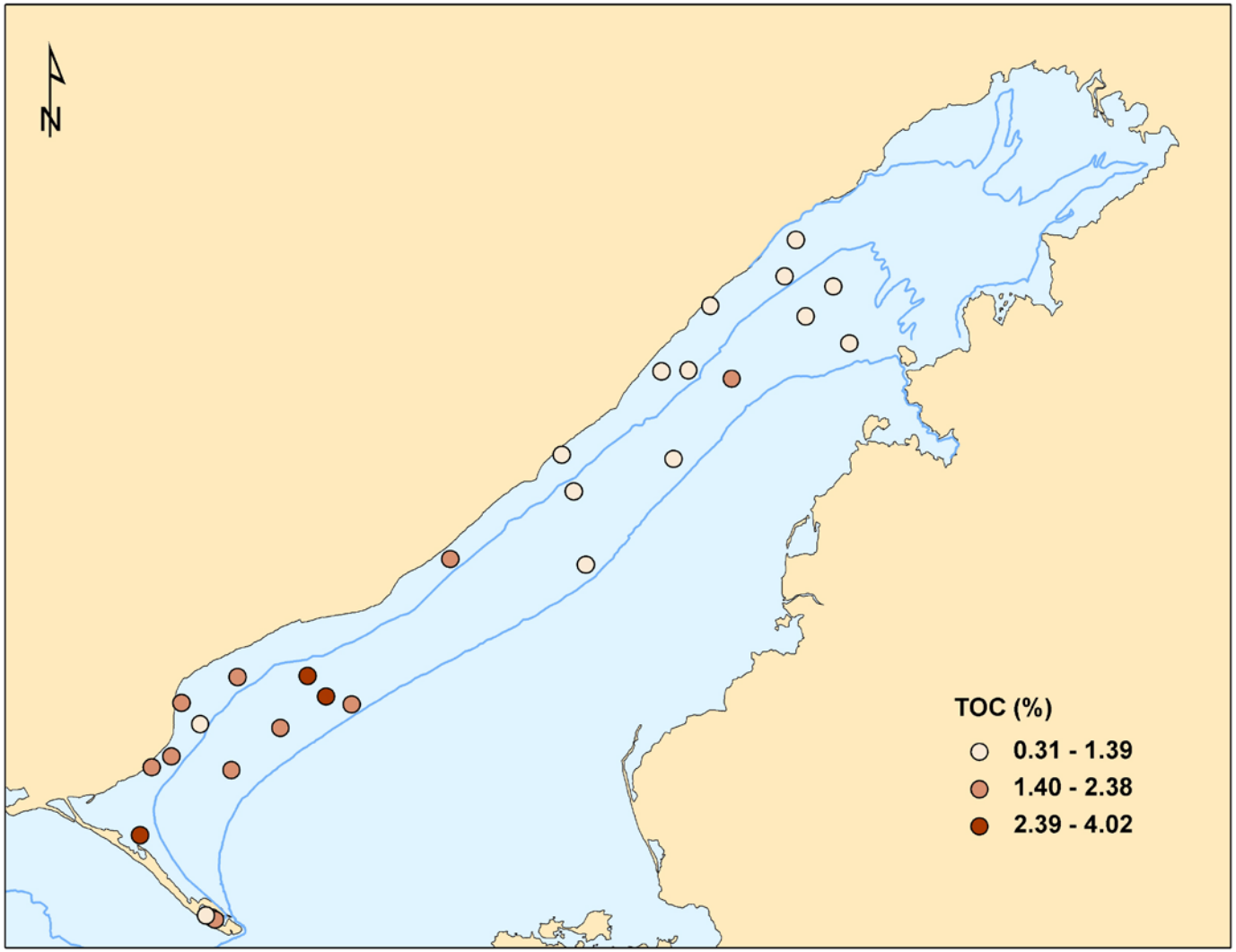


Figure 14. Spatial distribution of total organic carbon in sediment at Kachemak Bay study sites exhibits a distinct east to west gradient.

3.2. Trace metal and organic chemical concentrations

3.2.1 Metals

Summary statistics of concentration ranges and median values for each trace and major element are shown in Table 6. In general, trace element concentrations in Homer Harbor - a depositional area - were slightly elevated relative to other strata. However, sites EF4 and WF6 in eastern and western flats strata showed spikes in the concentration of silver, chromium, copper, nickel, mercury, selenium, antimony and zinc

Box-plot statistics and Chi-square approximation tests indicated significant differences ($P < 0.05$) between strata for nearly all measured metals except antimony and silicon (Figures 15a and b). Metal concentrations were variable across the study area, though most of the elevated concentrations were recorded in the Homer Harbor stratum.
To assess the influence of river discharge at the head of the bay, sediment metal concentrations in the pool of western strata without Homer Harbor were compared to those of the eastern strata. The results revealed some significant differences between the west side and the east. The concentrations of aluminum, chromium, copper, manganese, zinc, antimony, lead, and nickel were found to be significantly elevated in the eastern strata compared to the western strata ($P < 0.05$). Mercury was higher in the western stratum relative to the eastern, while silicon, iron, cadmium, arsenic, and silver were evenly distributed among the eastern and western strata. These results demonstrate the influence of river transport which brings eroded materials to the head of the bay.

To assess relative intra-metal concentrations, trace metal data were normalized by scaling all concentration values to their respective mean for each element (Figure 16). Homer Harbor had elevated concentrations for most elements. Between strata, elemental concentrations were fairly uniform except for a few site spikes. The most noticeable of these spikes was recorded for the site EF4 where virtually all measured elements were relatively elevated.

Table 6. Metal concentration ranges in Kachemak Bay sediments. Values are minimum and maximum with the stratum median in parenthesis (µg gm-1 dry weight).

Element	Homer Harbor	Western Flat	Western Subtidal	Eastern Flat	Eastern Subtidal
Ag	0.115 - 0.15 (0.124)	0.08 – 0.112 (0.099)	0 - 0.074 (0.054)	0.072 - 0.14 (0.09)	0.043 - 0.11 (0.075)
As*	14.1 - 17.9 (14.3)	13.7 - 21.4 (17.85)	18 - 48.6 (30.5)	10.7 – 26 (14.5)	15.2 - 43.4 (19.7)
Cd	0.191 - 0.22 (0.21)	0.103 - 0.171 (0.154)	0 - 0.097 (0.081)	0.11 - 0.171 (0.119)	0 - 0.144 (0.085)
Cr*	94.3 - 96.2 (95.1)	59.3 -73.5 (66.5)	61.8 - 68.1 (63.1)	67.3 – 110 (73.2)	74.7 – 109 (83.2)
Cu*	60.2 - 69.4 (64.7)	20.1 - 40.3 (30.4)	21.8 - 27.9 (26.0)	27.5 - 65.6 (34.2)	23.5 - 39.7 (32.2)
Hg*	0.11 - 0.12 (0.12)	0.09 - 0.12 (0.11)	0.09 - 0.11 (0.10)	0.06 - 0.10 (0.07)	0.05 - 1.07 (0.09)
Mn	650 – 703 (702)	467 – 635 (502)	500 – 1080 (642)	507 – 863 (567)	592 – 989 (656)
Ni*	45.5 - 45.9 (45.7)	32.0 - 37.7 (35.1)	33.4 - 43.7 (34.5)	33.7 - 56.5 (37.7)	33.5 - 43.6 (39.9)
Pb	13.9 - 14.9 (13.9)	8.29 - 11.6 (9.78)	8.33 - 9.82 (8.70)	9.22 - 15.2 (11.2)	8.56 - 13.6 (11.5)
Sn	1.26 - 1.34 (1.29)	0.93 - 1.33 (1.20)	0.93 - 1.79 (1.10)	1.01 - 2.04 (1.09)	0.94 - 1.76 (1.46)
Se	0.30 - 0.33 (0.32)	0.15 - 0.30 (0.20)	0.0 - 0.27 (0.13)	0.11 - 0.26 (0.18)	0.0 - 0.22 (0.11)
Sn	1.82 - 2.02 (2.01)	1.33 - 1.69 (1.45)	1.13 - 1.72 (1.28)	1.35 - 1.98 (1.53)	1.48 - 1.76 (1.55)
Zn	144 – 158 (152)	74.5 - 92.6 (82.2)	74 - 83.4 (81.6)	82.4 – 139 (89.6)	78.4 - 97.3 (91.1)
Al	76800 – 85500 (76900)	62500 – 72100 (64150)	65600 – 71900 (66900)	72600 – 84000 (76200)	65700 – 74800 (70600)
Si	257000 – 288000 (258000)	250000 – 299000 (283000)	275000 – 325000 (305000)	266000 – 311000 (290000)	261000 – 305000 (299000)
Fe	46600 - 49000(48300)	31900 – 39200 (36350)	35700 – 61000 (41200)	33300 – 52500 (37600)	35300 – 43500 (42300)

* denotes metal concentration above the ERL values of sediment quality guideline in, at least one site in the study area.

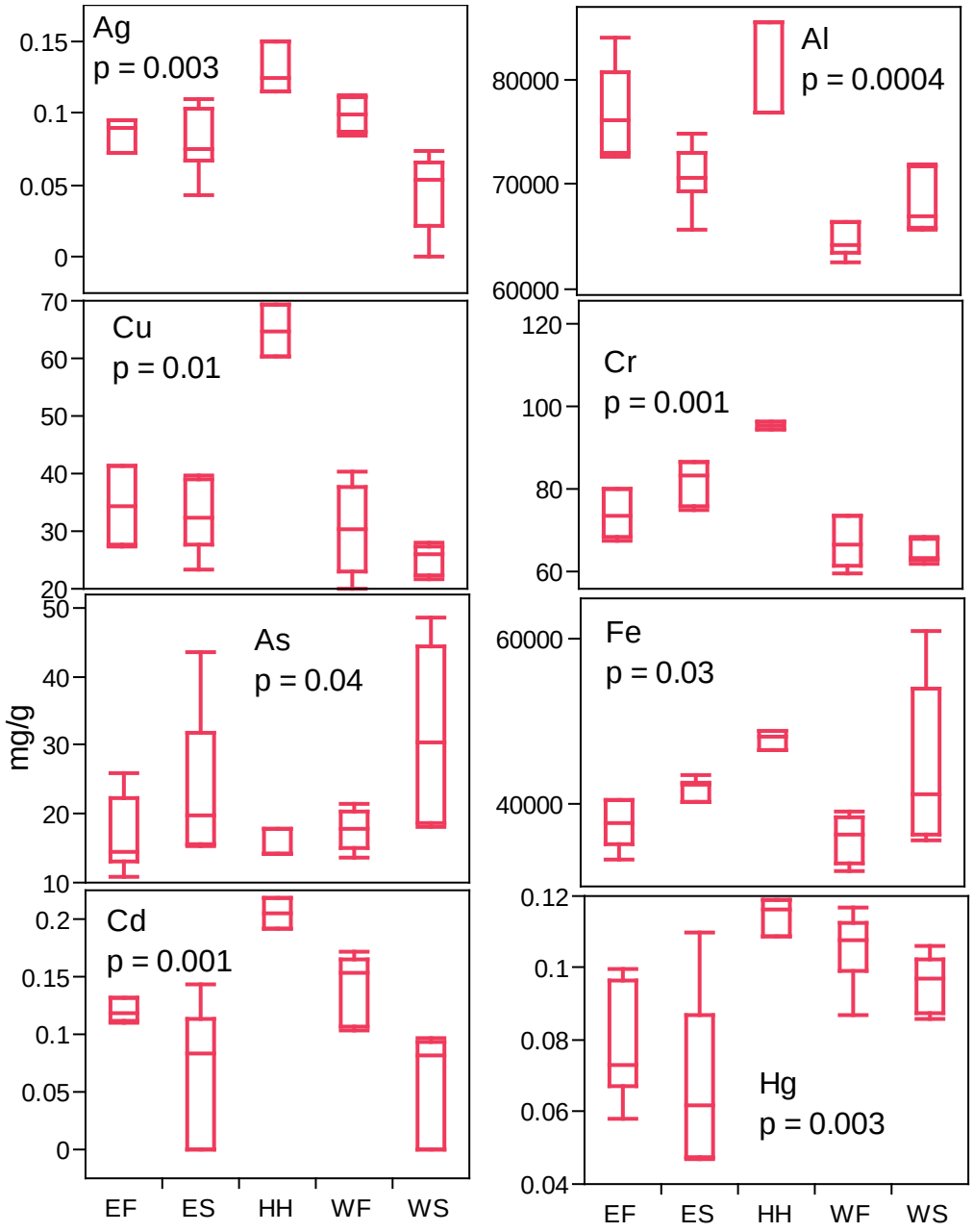


Figure 15a.
Box-plot statistics illustrating metal distribution in each stratum. The p-value indicates the significant of nonparametric inter-stratum comparison based Wilcoxon test. The horizontal lines of the box illustrate the data range in each stratum as the 25th , median, and 75th percentiles, while the top and bottom whiskers of the box represent the 10th and 90th percentiles.

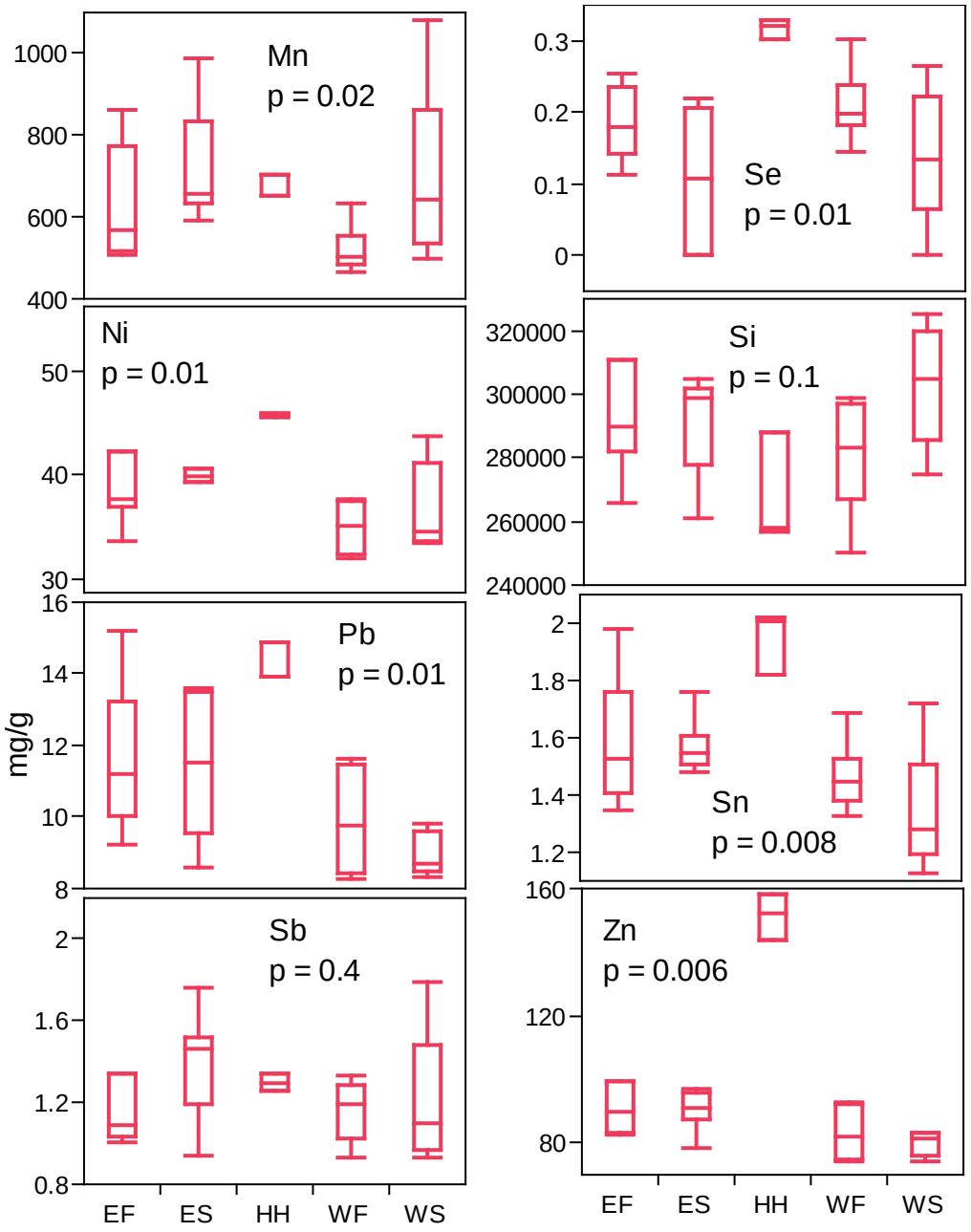


Figure 15b. Box-plot statistics illustrating metal distribution in each stratum. The p-value indicates the significant of nonparametric inter-stratum comparison based Wilcoxon test. The horizontal lines of the box illustrate the data range in each stratum as the 25th, median and 75th percentiles, while the top and bottom whiskers of the box represent the 10th and 90th percentiles.

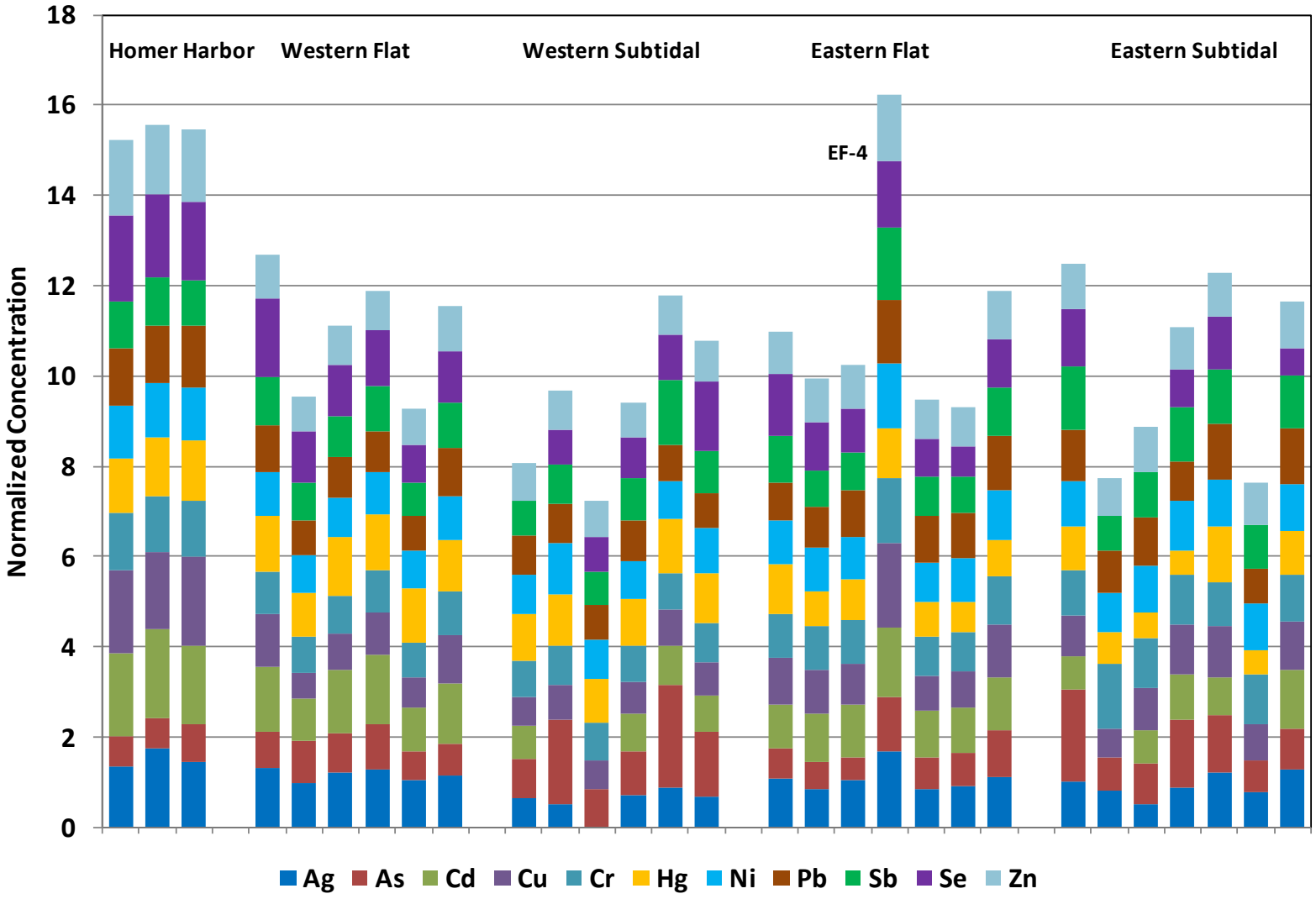


Figure 16. Mean normalized concentrations for trace metals in Kachemak Bay sediments (each site concentration of each metal was divided by the overall mean of the respective metal). EF4 is eastern flat station #4.

Spearman rank correlations among all metals, grain size and TOC are shown in Table 7. The table only depicts results where $P < 0.05$. Spearman Rho values of 0.707 or higher indicate strong correlation, while values below 0.707 indicate weak correlation. Strong associations were found among several groups of metals. For example, significant correlations were found among the group Ag, Cd, and Cu. Zinc was correlated with Cr, Cu, Ni, Pb, and Sn. Nickel correlated with Cr and Cu. EMAP sediment assessment in south central Alaska found similar correlations especially among Cr, Cu, Sn and Zn (Saupe *et al.* 2005). Among the major elements, correlations with Al and the other elements were weak. The correlation between Fe and Mn was much more significant but strong correlations were not seen for the other elements. South central Alaska sediment characterization by EMAP revealed similar results on Al, Fe and Mn (Saupe *et al*. 2005). However, other studies have reported significant correlations between Al, Fe, and Mn in Alaska (Burrell 1979, Robertson and Able 1990) in similar habitats. Silicon was not correlated with Al or Fe, and was negatively correlated with virtually all trace metals.

Grain size (% fine) was found to be strongly correlated with metals. This is consistent with the observation that elemental concentrations are elevated in finer sediment due to adsorption onto particle surfaces. The depositional zone in Homer Harbor had metal concentrations greater than the other strata (Table 6), likely due to grain size and proximity to metal sources. Total organic carbon ranged from 0.3 – 4.3% and was only weakly correlated with metals.

Most of the trace element concentrations were below the ERM values (Appendix A). Several metals however, had concentrations at or above the ERL values. Arsenic, Cr, Cu, and Zn had sediment concentrations that were above the ERL in at least one stratum. Concentrations of Ni were above the ERL value at all sites, but at the EF4 site, nickel's concentration was above the ERM value. Several metals do not have ERL or ERM values, (Sb, Mn, Se and Sn), or State guideline criteria for comparison.

Table 7. Spearman rank correlations between metals, grain size (silt + clay) and TOC, only significant correlations are presented (n = 29).

Variable	Ag	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sb	Se	Si	Sn	Zn	%Fine	%TOC
Ag				**ρ =.873** **p=.000**	ρ =.392 p=.039	**ρ =.780** **p=.000**		ρ=.571 p=.002			ρ =.653 p=.000	ρ =.539 p=.003	**ρ =.717** **p=0.000**	ρ = -.682 p=.000	ρ =.534 p=.003	ρ =.584 p=.001	**ρ =.850** **p=.000**	
Al					ρ =.612 p=0.001	ρ =.596 p=.001	ρ =.411 p=.030		ρ =.404 p=.033	ρ =.616 p=.000	ρ =.615 p=.000				ρ =.587 p=.001	ρ =.700 p=.000	ρ =.420 p=.026	
As							ρ =.432 p=.022		ρ =.378 p=.047			ρ =.473 p=.011						
Cd						**ρ =.740** **p=.000**		ρ =.515 p=.005			ρ =.583 p=.001		ρ =.663 p=.000	ρ = -.643 p=.000	ρ =.460 p=.014	ρ =.550 p=.002	**ρ =.894** **p=.000**	
Cr						ρ =.686 p=.000	ρ =.459 p=.007		ρ =.546 p=.003	**ρ =.757** **p=.000**	ρ =.697 p=.000	ρ =.492 p=.008			ρ =.683 p=.000	**ρ =.771** **p=.000**	ρ =.426 p=.024	ρ =-.572 p=.001
Cu							ρ =.496 p=.007	ρ =.437 p=.020		**ρ =.705** **p=.000**	ρ =.785 p=.000	**ρ =.720** **p=.000**	ρ =.594 p=.001	ρ = -.656 p=.000	ρ =.684 p=.000	**ρ =.865** **p=.000**	**ρ =.839** **p=.000**	
Fe									**ρ =.820** **p=.000**	ρ =.684 p=.000		ρ =.695 p=.000	ρ =.381 p=.046		ρ =.542 p=.003	ρ =.602 p=.001		
Hg												ρ =.396 p=.037	ρ =.634 p=.000	ρ = -.597 p=.001			ρ =.477 p=.010	ρ =.559 p=.002
Mn										ρ =.610 p=.001		ρ =.279 p=.003			ρ =.627 p=.000	ρ =.486 p=.009		ρ =-.459 p=.014
Ni											ρ =.656 p=.000	ρ =.553 p=.002			ρ =.555 p=.002	**ρ =.827** **p=.000**	ρ =.464 p=.013	
Pb												ρ =.532 p=.004		ρ = -.554 p=.002	**ρ =.717** **p=.000**	**ρ =.833** **p=.000**	**ρ =.768** **p=.000**	
Sb													ρ =.458 p=.014	ρ = -.633 p=.000	ρ =.542 p=.003	ρ =.623 p=.000	ρ =.428 p=.023	
Se														ρ = -.518 p=.005		ρ =.446 p=.017	ρ =.626 p=.000	ρ =.427 p=.024
Si															ρ =-.509 p=.006	ρ =-.469 p=.012	ρ =-.724 p=.000	
Sn																**ρ =.743** **p=.000**	ρ =.551 p=.002	ρ =-.445 p=.018
Zn																	ρ =.692 p=.000	

3.2.2 Organic contaminants

Organic contaminants were found throughout the study area. Concentration ranges of the organic contaminants in each stratum are presented in Table 8. Figure 17 illustrates the relative concentration (normalized to their respective means) of all groups of organic compounds measured. This illustration shows that the concentrations of most of organic compounds are nearly an order of magnitude higher in Homer Harbor relative to other strata. However, the hexachlorocyclohexane (HCHs), which were present in subtidal and mudflat strata, were not detected in the Harbor. To assess the influence of sediment characteristics on the overall distribution of organic contaminants present in the study area, Spearman Rank correlations were calculated for the organic contaminants and TOC and % fine grained sediment (Table 9). Only PCBs and HCHs did not correlate strongly with the % fine grained sediment. Conversely, only DDT and PAHs were strongly correlated with TOC.

Total PAHs concentrations in the study area were quite low. Outside of Homer Harbor, only one location exceeded a concentration of 400 ng gm-1 (Figure 18). In most cases, the dominant PAH was perylene, usually accounting for 40-60% of the total PAHs. Figure 19 shows the distribution of individual PAH compounds measured for the western subtidal stations, which were typical of all the locations outside of Homer Harbor. There is a small amount of pyrene (possibly indicative of pyrogenic sources), but the dominant PAH in all cases is perylene. This indicates a terrestrial diagenic input, as opposed to petroleum, coal, or pyrogenic pollution sources. In the harbor, total PAHs concentration varied from 1,600 to over 2,800 ng gm-1. The distribution of individual PAH concentrations in the harbor are distinctly different than those in the bay (Figure 20). The elevated concentrations of pyrene and other unsubstituted high molecular weight compounds, with lower concentrations of alkylated compounds are indicative of pyrogenic sources (burned fuel). In addition, the concentrations of substituted naphthalenes in the harbor are elevated relative to the bay, indicating the contribution of spilled fuel and oil. While considerably elevated above concentrations in the open bay, even these concentrations are below the ERL for total PAHs. The concentrated vessel activity in the harbor is the source of PAHs in the sediment, but the overall contaminant levels are relatively benign.

Table 8. Concentration ranges for classes of organic contaminants measured in Kachemak Bay sediments. Values are minimum and maximum with the stratum median in parenthesis (ng gm-1 dry weight).

Label	Homer Harbor	Western Flat	Western Subtidal	Eastern Flat	Eastern Subtidal
Total BT	7.23 - 11.36 (9.62)	0.13 _ 0.78 (0.55)	0 - 0 (0)	0.31 - 0.6 (0.47)	0 - 0.14 (0.00)
Total Cyclodienes	0.08 - 0.71 (0.46)	0.01 - 0.21 (0.09)	0 - 0.06 (0.01)	0.04 - 0.20 (0.11)	0 - 0.17 (0.05)
Total DDT	0.46 - 0.73 (0.53)	0.15 - 0.27 (0.20)	0.15 - 0.27 (0.23)	0.01 - 0.17 (0.14)	0.01 - 0.15 (0.08)
Total HCH	0 - 0.00 (0)	0.01 - 0.07 (0.04)	0 - 0.01 (0)	0 - 0.04 (0.03)	0 - 0.05 (0.00)
Total PAH	1088 - 1872 (1226)	169 - 271 (250)	107 - 135 (127)	51.3 - 212.6 (186.5)	10.7 - 126.3 (53.00)
Total PCB	2.11 - 3.86 (2.70)	0 - 2.82 (0.36)	0.39 - 0.73 (0.44)	0.08 - 0.5 (0.20)	0.11 - 0.82 (0.59)

Table 9. Spearman rank correlations between organic contaminant distributions and the distribution of fine grained sediment (silt+clay) and TOC content in the sediment (n = 29)

Analyte	% Fine		% TOC	
	Spearman ρ	p	Spearman ρ	p
Total BT	0.6914	0.0001	0.2043	0.2542
Total HCH	0.2022	0.2592	0.0104	0.9540
Total DDT	0.3152	0.0740	0.6197	0.0001
Total PCBs	0.1372	0.4464	0.2288	0.2003
Total PAHs	0.5692	0.0005	0.4715	0.0056
Total Cyclodienes	0.5622	0.0007	-0.0889	0.6229

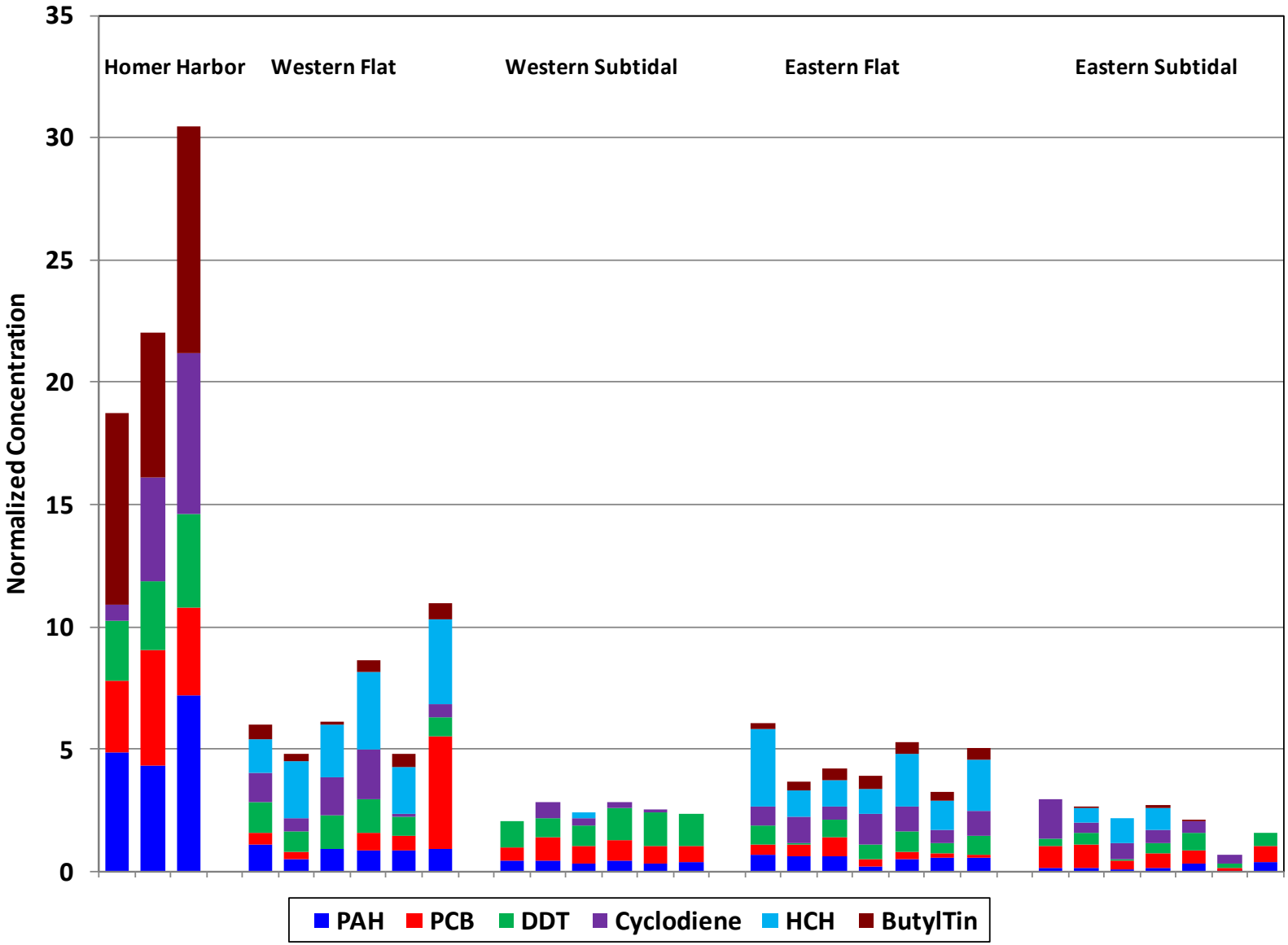


Figure 17. Mean normalized concentrations for six classes of organic contaminants in Kachemak Bay sediments. (site concentration of organic class divided by the overall mean of each respective organic class)

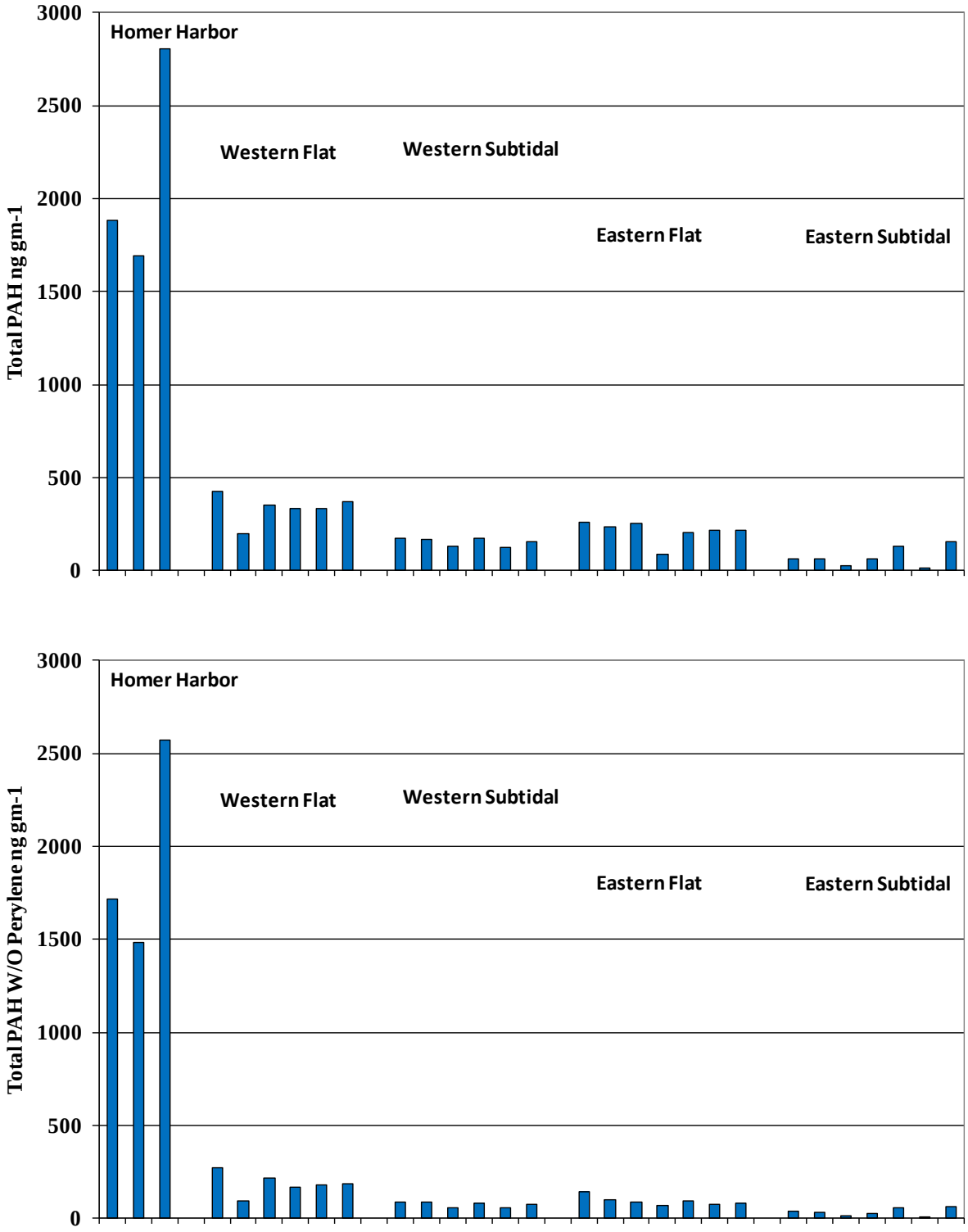


Figure 18. Distribution of total PAHs (sum of low and high molecular weight PAHs) in Kachemak Bay. Totals with and without perylene (naturally derived PAH) are shown.

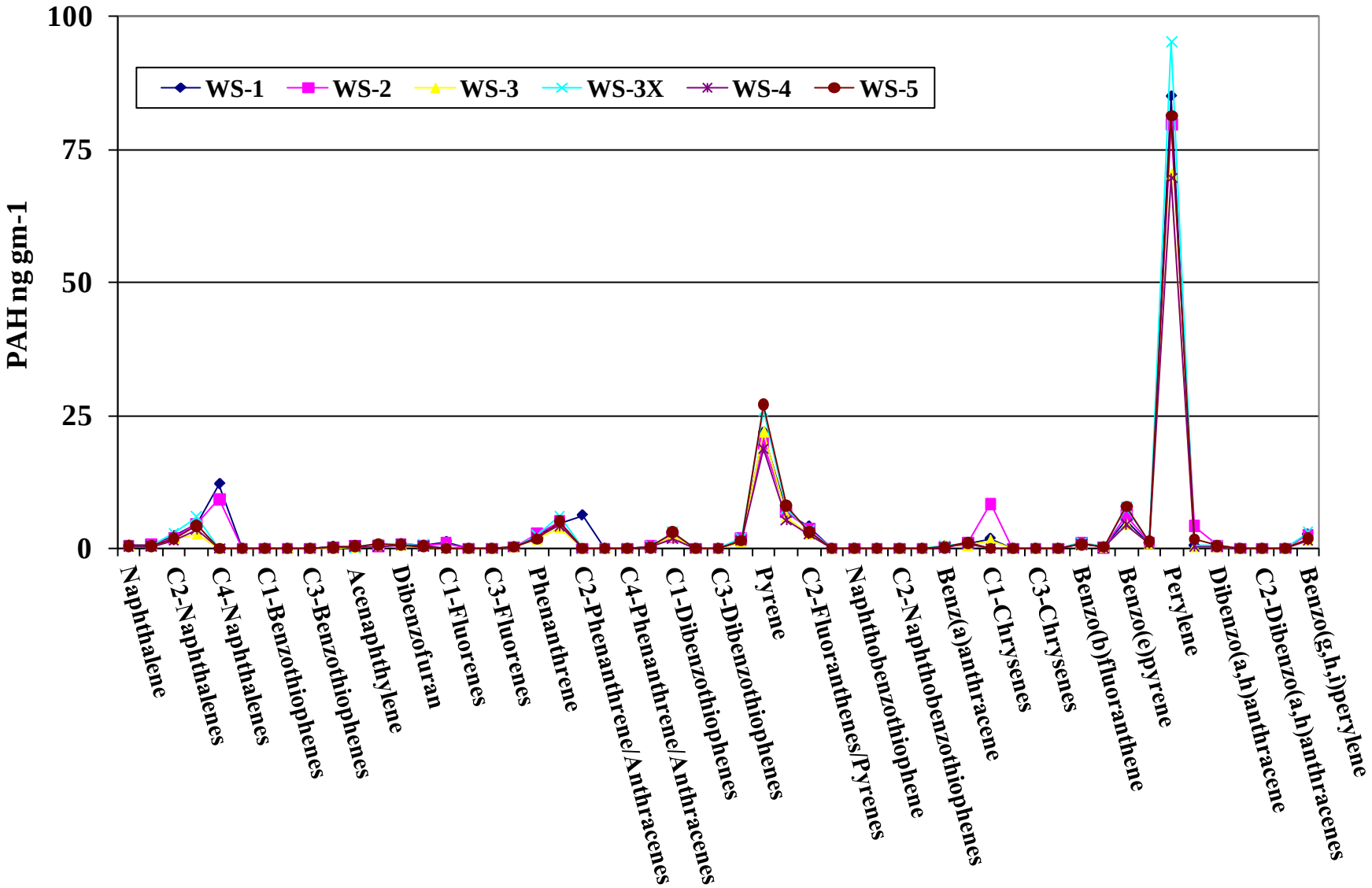


Figure 19. Concentrations of individual PAHs in subtidal station sediments from the western stratum in Kachemak Bay.

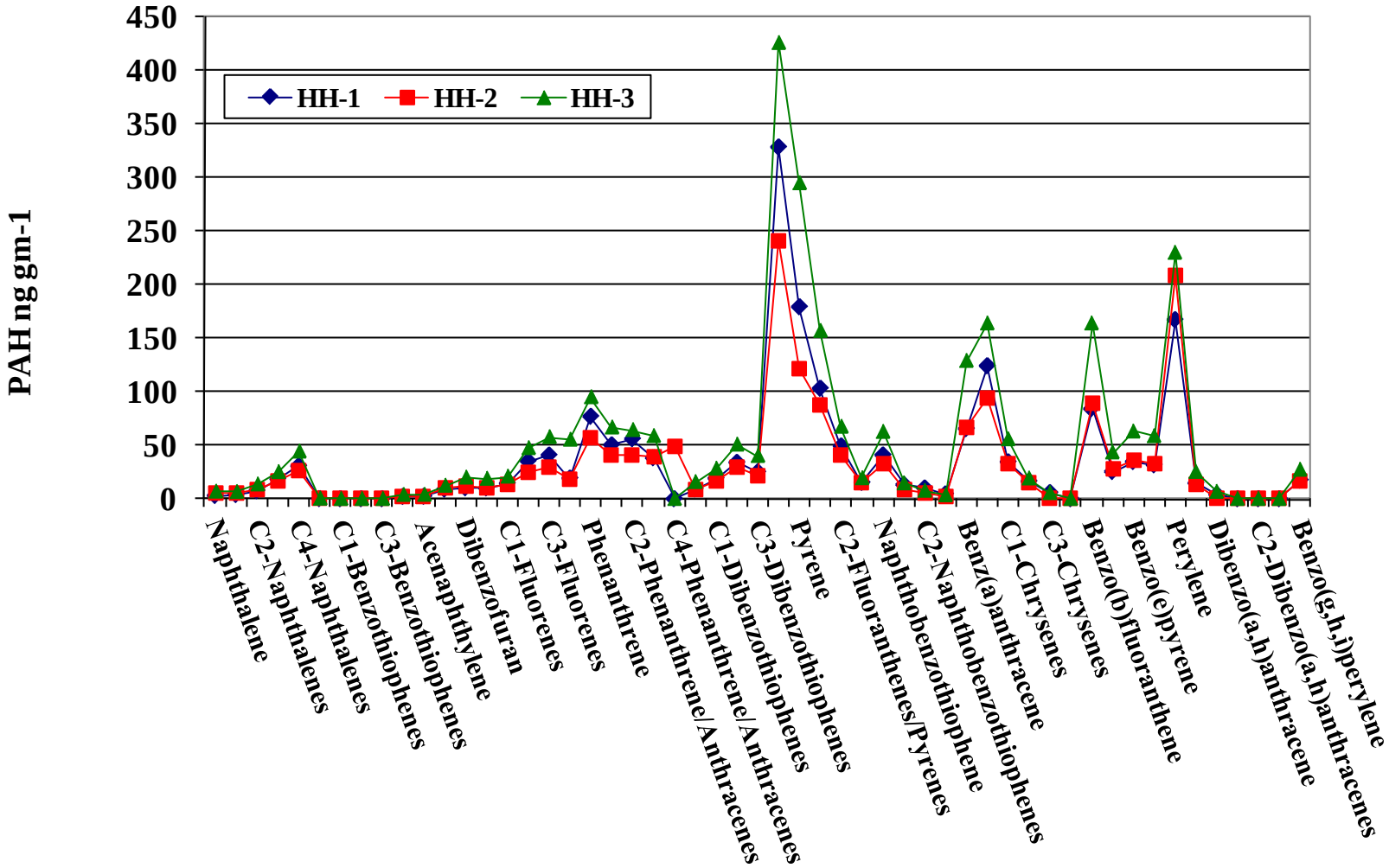


Figure 20. Concentration of individual PAHs in sediment from Homer Harbor stations.

Aliphatic hydrocarbon concentrations are shown in Table 10 for the subset of locations that the analyses were done. Results were varied between sites, but concentrations were not abnormally high. The highest alkane concentration was n-C_{29} in all cases. Compounds with an odd number of carbons predominated over even numbered compounds. Higher molecular weight compounds were predominant over low weight compounds. The carbon preference index (CPI) (Boehm et al. 1984) is given by the ratio;

Eqn 6. $$2(C_{27} + C_{29})/(C_{26} + 2C_{28} + C_{30})$$

Petrogenic hydrocarbons generally have CPI ratios of approximately one while uncontaminated sediments and terrestrial plant residues will have higher values. The ratio of pristine to phytane was greater than one in all cases, but was not over two in any location.

Distribution of measured PCBs in the study area is illustrated in Figure 21. PCBs were detected throughout the study area and their spatial distributions were similar to those of PAHs. Relative to other sites, Homer Harbor had elevated PCB concentrations (up to 4 µg kg-1) while most stations were below 1.0 µg kg-1. Elevated (relative to other sites) PCBs (2.2 ng gm-1) were detected in the western intertidal stratum near Miller's Landing. Because of the site-specific distribution of PCB concentrations across the study area, concentrations were not significantly correlated with the sediment physical parameters of % fine grained sediment and TOC content (Table 9). Overall, PCB concentrations in the study area are very low, and even in Homer Harbor they are well below the ERM and ERL sediment quality guidelines.

Butyltins were above detection limits only in the harbor (Figure 22). Some sites in the intertidal strata had low level detections, but these were below minimal reporting limits. In the harbor, concentrations of butyltins (expressed as Sn) were at levels that ranged from 7.2 to over 11 ng gm-1. Based on data from all the sites, Spearman Rank correlation coefficients indicated that butyltin concentrations in sediment were strongly correlated ($P < 0.05$) with sediment grain size (Table 9). This result is not particularly meaningful however, because the only sites with detectable butyltin concentrations were all in the harbor.

Table 10. Concentrations of aliphatic alkane compounds (straight chain hydrocarbons) in selected sampling locations in the Kachemak Bay system and five diagnostic ratios.

	Sample Station			
Compound	**HH 3**	**WS 1**	**WF 6**	**PG 3C**
n-C_{10}	0.01	0.01	0.01	0.03
n-C_{11}	0.01	0.01	0.01	0.04
n-C_{12}	0.02	0.02	0.02	0.04
n-C_{13}	0.03	0.02	0.02	0.04
n-C_{14}	0.14	0.06	0.07	0.05
n-C_{15}	0.37	0.08	0.12	0.11
n-C_{16}	0.32	0.08	0.10	0.11
n-C_{17}	0.29	0.06	0.11	0.09
n-C_{18}	0.40	0.10	0.16	0.16
n-C_{19}	0.30	0.14	0.28	0.11
n-C_{20}	0.11	0.10	0.13	0.04
n-C_{21}	0.30	0.47	0.93	0.09
n-C_{22}	0.18	0.19	0.23	0.05
n-C_{23}	0.49	0.77	0.91	0.16
n-C_{24}	0.27	0.29	0.43	0.06
n-C_{25}	0.71	0.97	1.13	0.43
n-C_{26}	0.22	0.30	0.30	0.05
n-C_{27}	1.80	2.09	2.72	0.49
n-C_{28}	0.32	0.36	0.33	0.14
n-C_{29}	1.97	3.09	3.30	0.72
n-C_{30}	0.18	0.28	0.27	0.09
n-C_{31}	1.48	2.86	2.40	0.47
n-C_{32}	0.15	0.24	0.30	0.11
n-C_{33}	0.55	0.67	1.06	0.41
n-C_{34}	0.06	0.13	0.11	0.03
Pristane	0.32	0.03	0.04	0.03
Phytane	0.18	0.02	0.02	0.02
Total Alkanes ug/gm	11.2	13.5	15.5	4.2
Total Petroleum Hydrocarbons	213	111	141	68
Total Resolved Hydrocarbons	72	96	111	65
Unresolved Complex Mixture	141	14.3	30	2
Odd:Even	3.5	5.2	5.3	3.3
Σ Alkanes/n-C_{16}	33.1	161.0	161.2	38.7
CPI	7.2	7.9	9.8	5.8
Σ n-C10-20:Σ n-C21-34	0.23	0.05	0.07	0.25
Pristane:Phytane	1.8	1.5	2.0	1.5

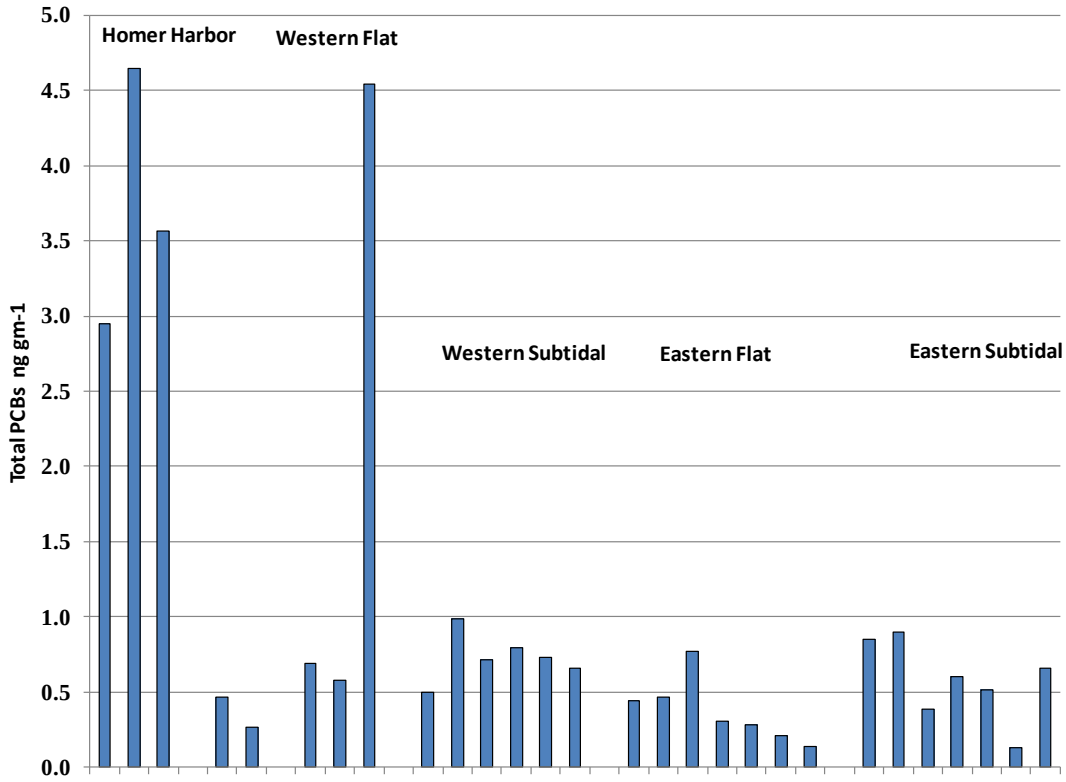


Figure 21. Total PCB concentrations in sediment from Kachemak Bay study sites.

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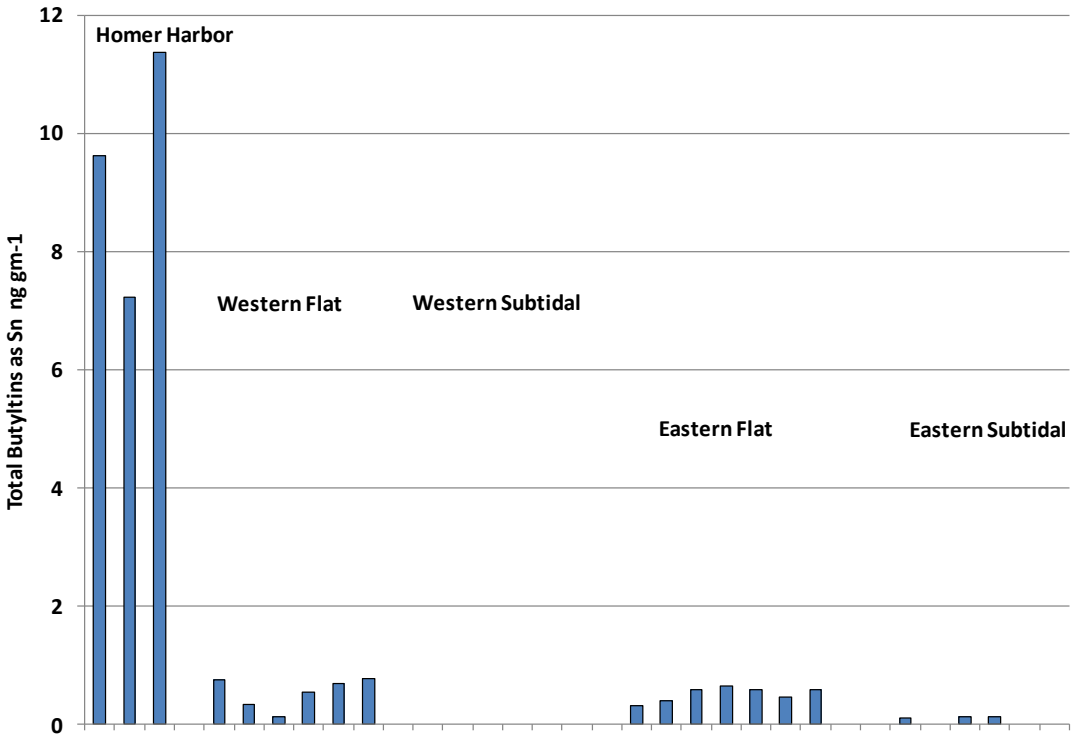


Figure 22. Total butyltin concentrations in sediment from Kachemak Bay study sites.

Low levels of DDTs, cyclodienes and hexachlorocyclohexanes (HCHs) were detected throughout the study area. The spatial distribution these compopunds varied between the types of compound. The distribution of total DDTs (Figure 23) was similar to that of the PAHs. Total DDTs concentration was significantly correlated with sediment TOC, but not grain size in the study area (Table 9). Cyclodiene insecticides (chlordanes, heptachlors, nonachlors, aldrin, dieldrin, endrin and endosulfan) were also found at most sites in the study area (Figure 24), but concentrations were very low. Hexachlorocyclohexanes (HCHs) which include the alpha, beta, delta and gamma (lindane) were not detected in the Homer Harbor stratum (Figure 25). HCHs were found at higher concentrations and more frequently in the intertidal mudflat areas. Consequently, their distribution was poorly correlated ($P > 0.05$) with grain size and TOC in the sediment. Overall, the concentrations of pesticides in Kachemak bay were very low. Total DDTs were well below the NOAA's SQG ERL value suggesting that when considered individually, these organic contaminants are unlikely to cause toxic effects in the sediment.

3.3 Sediment Toxicity

A complete list of all toxicity data is provided in Appendix B. There was virtually no significant toxicity observed in any of the strata. *A. abdita* bioassays demonstrated significantly reduced survival at only one station in Coal Bay (Figure 26). While survival was statistically reduced relative to controls, it was above 80% and is therefore considered to be an indicator of only marginal effect. In Homer Harbor, there was no indication of toxic effect. In the more limited data set with *E. estuarius*, one station near the Fox River showed significant toxicity (Figure 27). Station EF4 (eastern intertidal mudflats) demonstrated a statistically significantly reduced survival of only 25%.

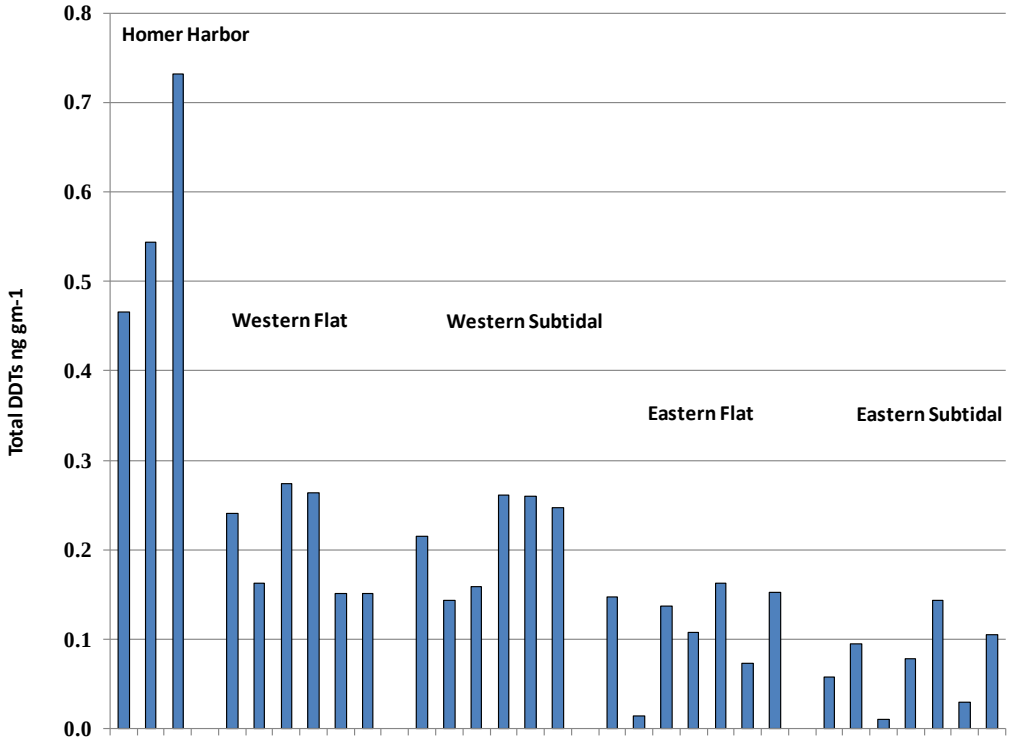


Figure 23. Total DDT concentrations in sediment from Kachemak Bay study sites.

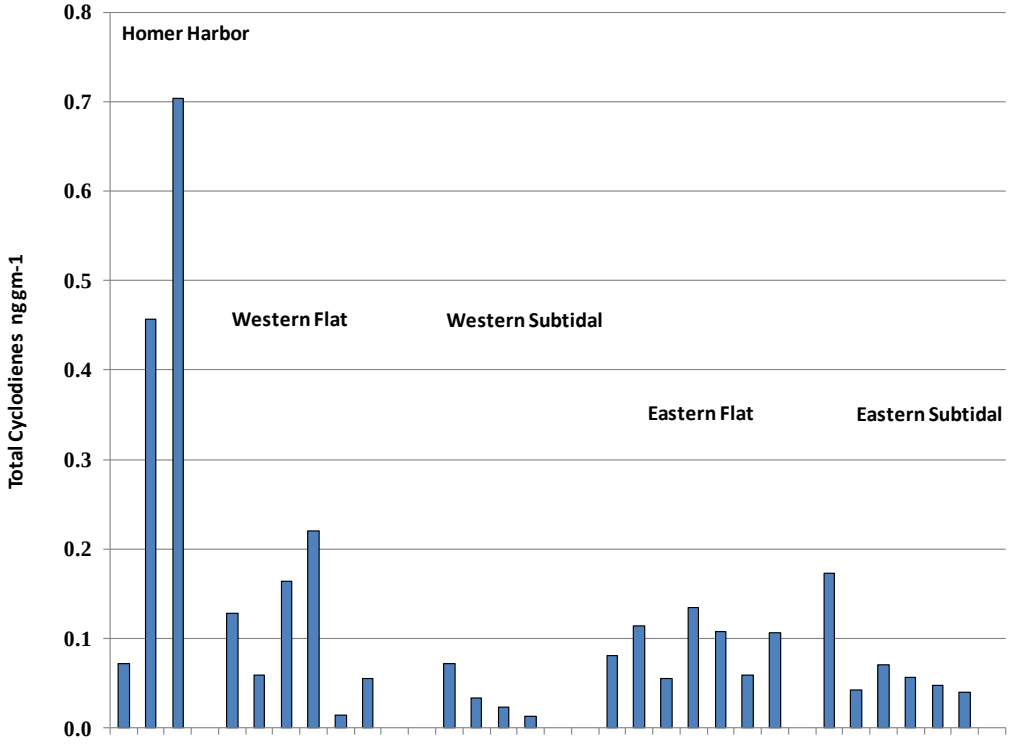


Figure 24. Total cyclodiene concentrations in sediment from Kachemak Bay study sites.

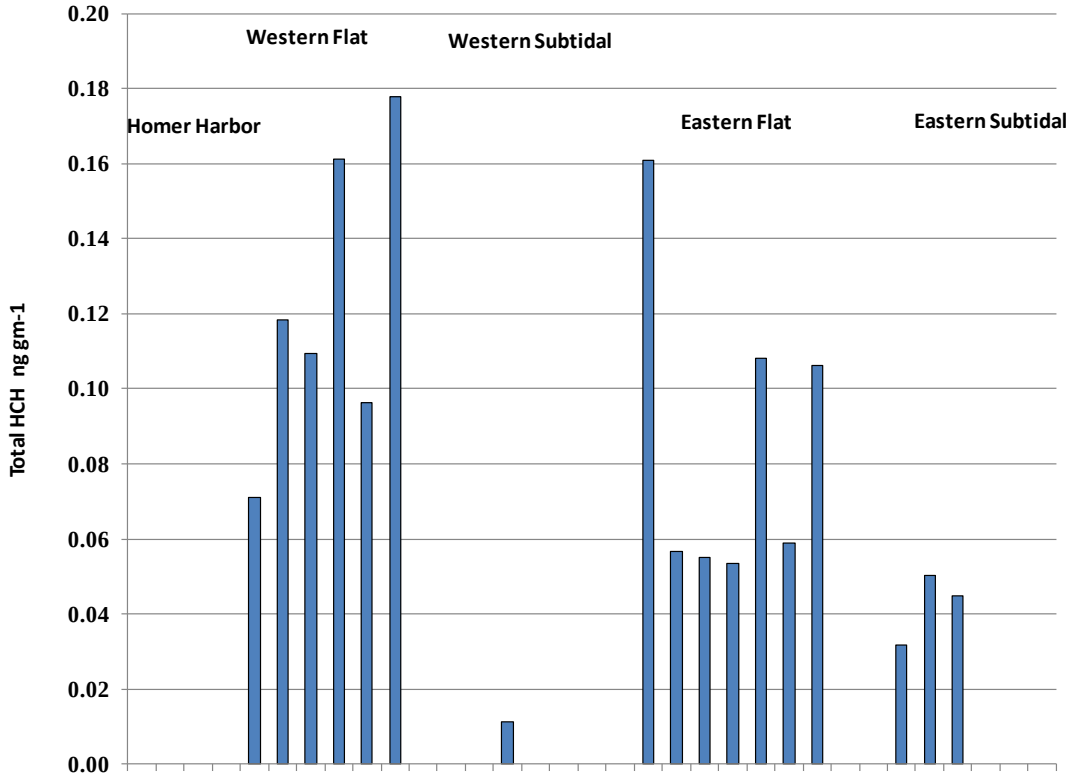


Figure 25. Total hexachlorocyclohexane concentration in sediment from Kachemak Bay study sites.

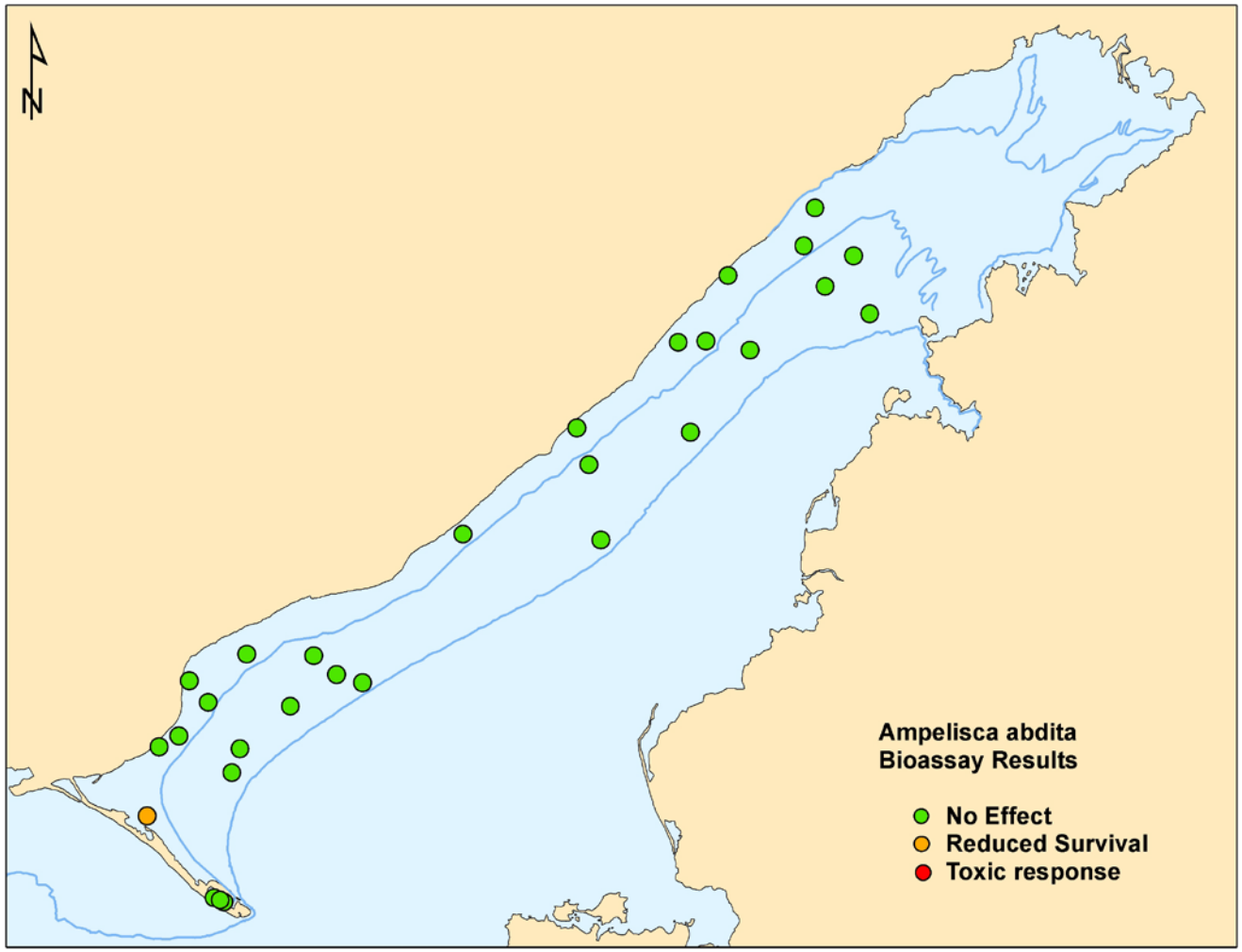


Figure 26. Kachemak Bay sediment toxicity assessment with the amphipod *Ampelisca abdita* bioassay.

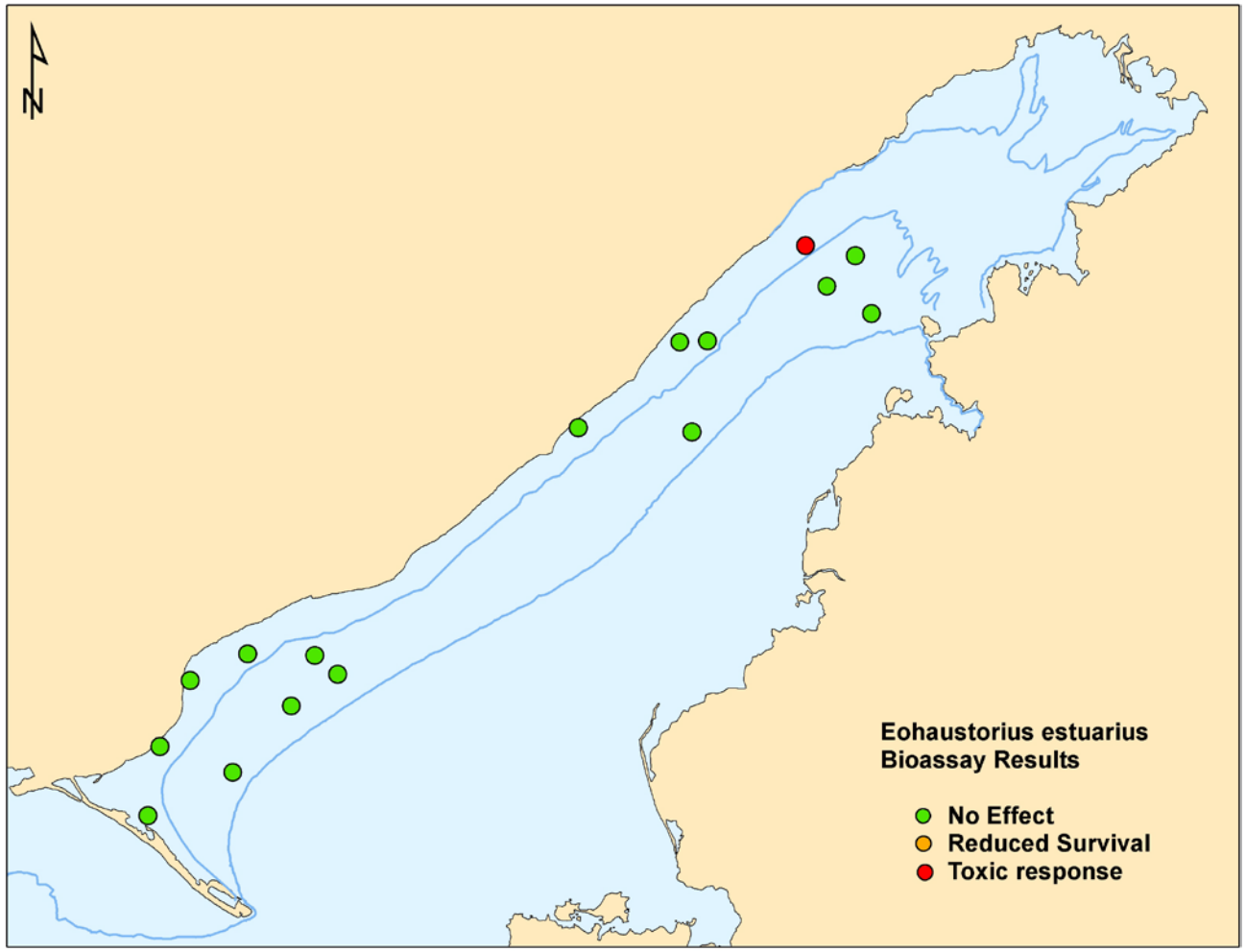


Figure 27. Kachemak Bay sediment toxicity assessment with the amphipod *Eohaustorius estuarius* bioassay. The bioassay was conducted on selected sites in all strata except Homer Harbor.

3.4 Benthic Community Characterization

A complete list of species abundance is provided in Appendix C for all sites. A total of 12,983 organisms, representing 235 taxa were enumerated, excluding epiphytic species. Following elimination of the 'artificial' species (see methods) there were 217 taxa (Appendix C). Polychaete worms had the highest number of taxa at every station, and were the most numerous at all but four stations. Virtually all of the Annelid worms were Polychaetes, with only a few Oligochaetes. Bivalves were the next most abundant taxa. The vast majority of Malacostracans were Amphipods (other taxa included decapod crabs and shrimp, isopods and cumaceans). The dominant taxa are listed in Table 11. At sites where bivalves were numerically among the dominant species they were generally characterized by a large number of animals representing only one of a few species. These cases were restricted to the eastern intertidal stations. Conversely, snails and malacostracans were more numerous and diverse in the western stations.

There was a strong gradient of increasing species abundance and diversity from east to west (Figures 28 and 29). Some stations close to the shoreline also exhibited low abundance and diversity. Station WF6 was a notable exception to the trend of increasing species richness in the west. That station is in the vicinity of Millers Landing where a substantial portion of stormwater runoff from the city of Homer enters the bay.

3.4.1 Spearman rank correlation

Spearman rank correlation results between benthic community and habitat parameters show that higher abundance and diversity were positively correlated with increasing depth (Table 12). High diversity was negatively correlated with increasing proportions of fine grained sediment but positively correlated with TOC and water clarity. Contaminant concentrations did not appear to impact the biota and, in fact, DDT was significantly correlated with abundance and diversity. This is probably a consequence of slightly higher DDT concentrations in the western strata, where average abundance and diversity were also slightly higher.

By assigning dummy variables of one or zero to the strata, correlations for the individual strata were also calculated. Homer Harbor was consistently correlated with elevated

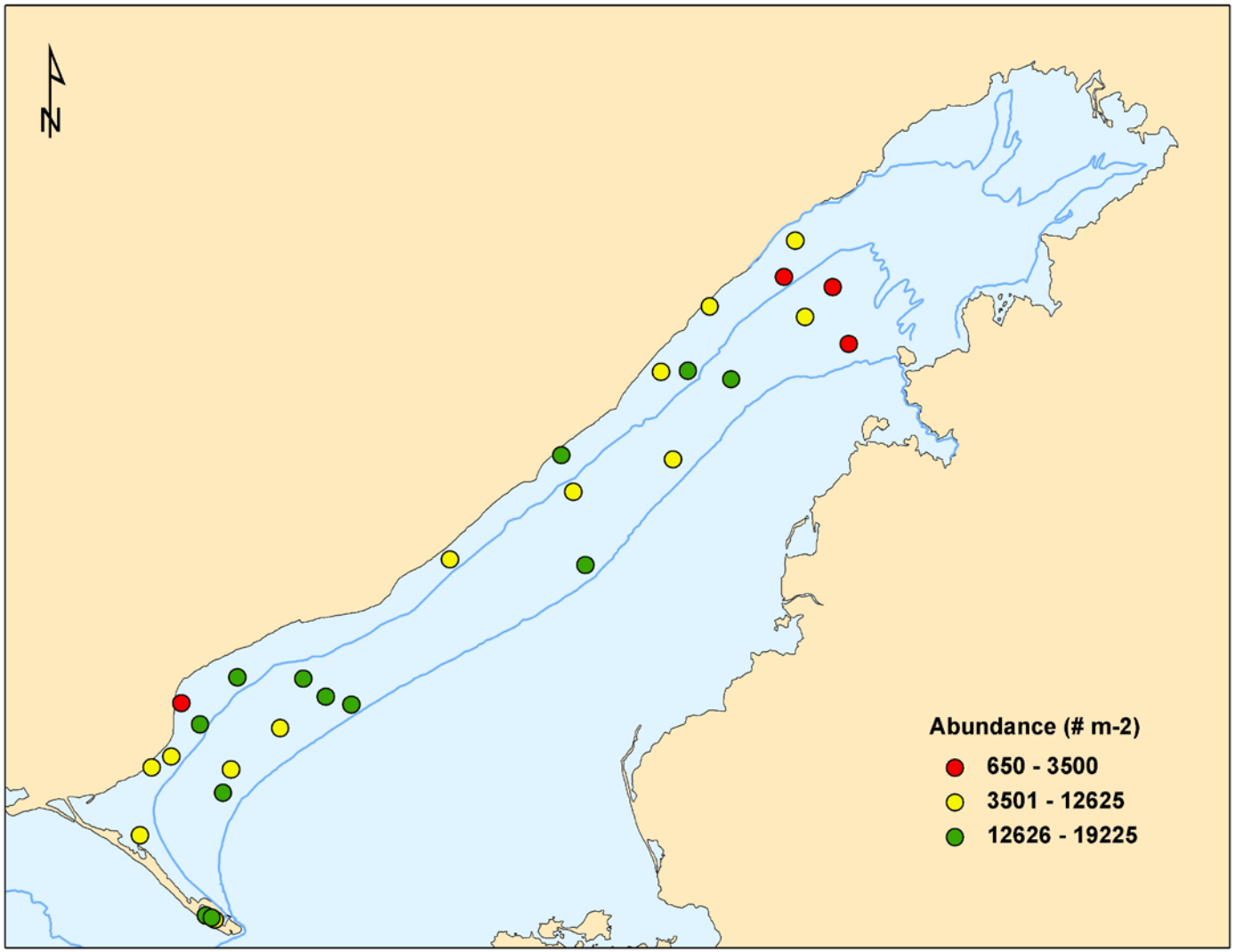


Figure 28. Benthic species abundance distribution in Kachemak Bay. A strong gradient of increasing species abundance was present from east to west.

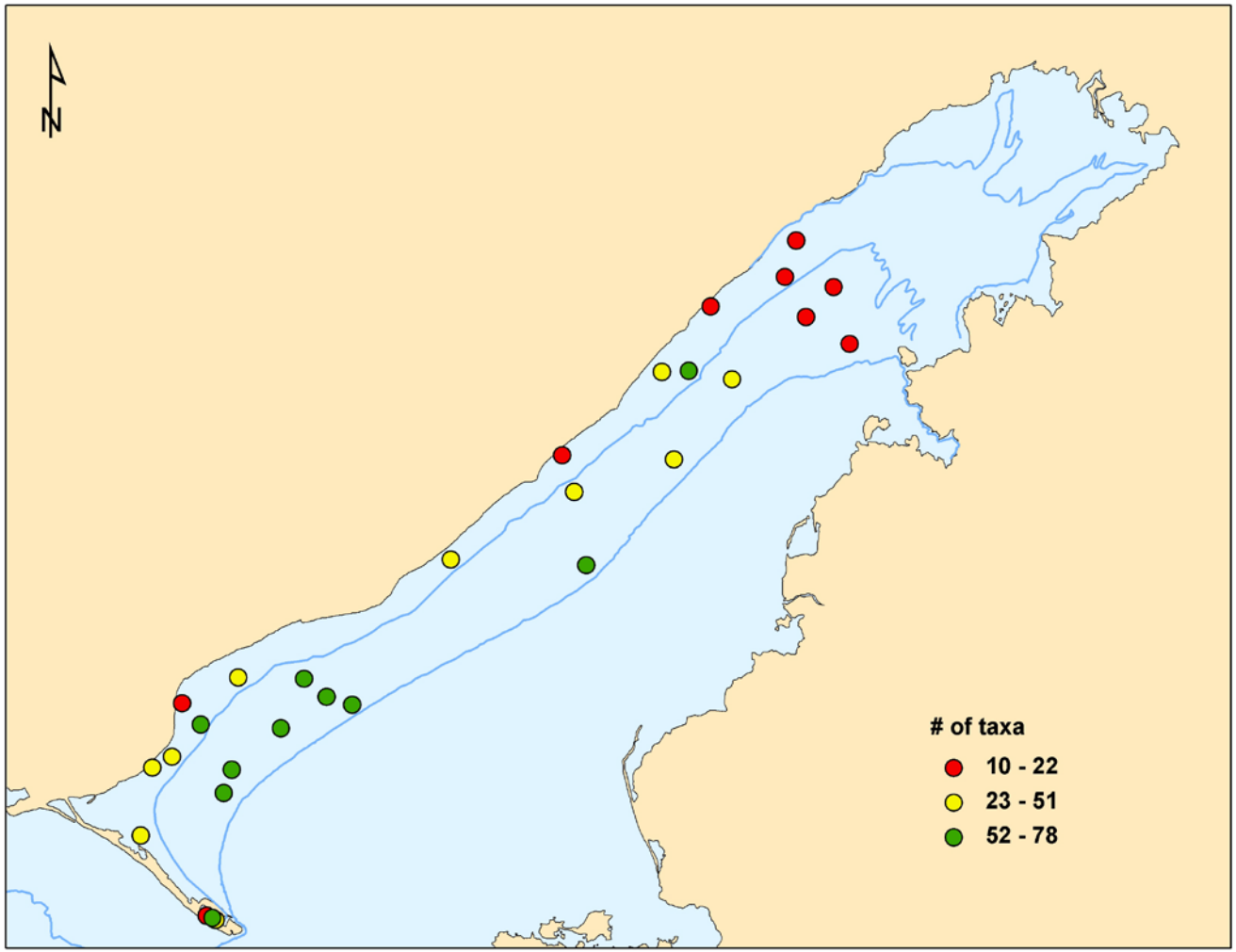


Figure 29. Benthic species diversity distribution in Kachemak Bay. A strong gradient of increasing species diversity was present from east to west.

Table 11. Dominant taxa at each station (numbers are actual counts in the sample, not number per square meter).

	Polychaetes		Malacostraca		Bivalves		Gastropods	
Station	TAXA	ABUND	TAXA	ABUND	TAXA	ABUND	TAXA	ABUND
EF1	21	367	3	10	1	12	2	2
EF2	15	141	3	8	2	529	1	4
EF3	21	326	4	18	3	121	1	10
EF4	8	19	1	1	1	4		
EF5	30	327	6	36	5	30	3	7
EF6	8	28			1	251		
EF7	12	57	1	2	1	303		
ES1	36	455	7	11	9	53	3	35
ES2	26	129	4	81	6	59		
ES3	7	55	1	2	1	1		
ES4	13	282	1	3	1	1		
ES5	31	650	5	25	5	33	1	2
ES6	8	11	2	2	3	3		
ES7	23	337	5	12	9	88	2	3
HH1	34	412	4	41	9	111	7	33
HH2	25	341	3	4	9	65	3	9
HH3	12	565	1	2	1	4		
WF1	31	202	5	31	5	21	2	18
WF2	32	533	8	28	10	95	4	40
WF3	22	274	3	13	4	28	3	36
WF4	29	394	2	4	8	75	4	27
WF5	24	207	4	6	3	62	2	23
WF6	12	50	4	11	2	69	2	10
WS1	28	342	13	59	11	73	4	12
WS2	41	418	12	40	11	73	7	20
WS3	27	153	12	157	8	58	4	46
WS3X	28	431	14	109	7	83	6	55
WS4	31	384	12	61	7	73	5	35
WS5	28	316	14	57	8	101	3	193
Mean	22.9	283.0	5.5	29.8	5.2	85.5	3.3	29.5

Table 12. Spearman rank correlations between benthic community and habitat parameters from Kachemak Bay sediment. Bolded lettering represents the Rho value (ρ) and and standard script represents significance (p).

Variable	Depth m	% Fines	% TOC	TotPAH	TotPCB	TotDDT	MtERMq	Abund.	Diversity	Toxicity Response	# Rare & Unique	Secchi ft
% Fines	**-0.220** 0.2511											
% TOC	**0.071** 0.7127	**-0.044** 0.8213										
TotPAH	**-0.243** 0.2043	**0.611** 0.0004	**0.454** 0.0134									
TotPCB	**0.615** 0.0004	**0.173** 0.3696	**0.188** 0.3300	**0.168** 0.3836								
TotDDT	**0.354** 0.0597	**0.178** 0.3551	**0.677** 0.0001	**0.588** 0.0008	**0.325** 0.0849							
MtERMq	**0.414** 0.0255	**0.488** 0.0072	**0.034** 0.8591	**-0.018** 0.9272	**0.497** 0.0060	**0.227** 0.2368						
Abund.	**0.426** 0.0211	**-0.108** 0.5774	**0.328** 0.0827	**0.141** 0.4651	**0.249** 0.1931	**0.455** 0.0132	**0.171** 0.3738					
Diversity	**0.426** 0.0213	**-0.475** 0.0092	**0.434** 0.0187	**-0.088** 0.6492	**0.217** 0.2580	**0.436** 0.0181	**-0.149** 0.4397	**0.329** 0.0815				
Toxicity Response	**-0.312** 0.0993	**0.290** 0.1265	**0.018** 0.9271	**0.078** 0.6894	**-0.266** 0.1635	**-0.105** 0.5882	**0.043** 0.8229	**-0.334** 0.0763	**-0.317** 0.0933			
# Rare & Unique	**0.642** 0.0002	**-0.183** 0.3416	**0.273** 0.1517	**-0.045** 0.8183	**0.354** 0.0595	**0.407** 0.0286	**0.167** 0.3874	**0.560** 0.0016	**0.627** 0.0003	**-0.389** 0.0369		
Secchi ft	**0.198** 0.3043	**-0.114** 0.5561	**0.621** 0.0003	**0.322** 0.0883	**0.264** 0.1665	**0.585** 0.0009	**-0.161** 0.4034	**0.227** 0.2359	**0.642** 0.0002	**-0.304** 0.1086	**0.377** 0.0438	
EF	**-0.588** 0.0008	**0.222** 0.2481	**-0.250** 0.1901	**0.116** 0.5505	**-0.602** 0.0005	**-0.357** 0.0573	**-0.222** 0.2481	**-0.183** 0.3419	**-0.433** 0.0188	**0.401** 0.0313	**-0.312** 0.0996	**-0.511** 0.0046
ES	**0.241** 0.2083	**-0.231** 0.2276	**-0.626** 0.0003	**-0.693** 3.04E-05	**0.125** 0.5174	**-0.584** 0.0009	**0.125** 0.5175	**-0.212** 0.2697	**-0.173** 0.3685	**-0.174** 0.3673	**-0.039** 0.8409	**-0.448** 0.0149
HH	**0.447** 0.0152	**0.501** 0.0057	**0.000** 1.0000	**0.528** 0.0033	**0.528** 0.0032	**0.529** 0.0032	**0.433** 0.0189	**0.183** 0.3427	**-0.108** 0.5761	**-0.095** 0.6242	**0.151** 0.4354	**0.007** 0.9719
WF	**-0.427** 0.0208	**0.214** 0.2657	**0.397** 0.0331	**0.458** 0.0125	**-0.097** 0.6178	**0.255** 0.1822	**-0.214** 0.2657	**-0.112** 0.5632	**0.132** 0.4940	**-0.082** 0.6739	**-0.165** 0.3932	**0.586** 0.0008
WS	**0.458** 0.0125	**-0.580** 0.0010	**0.529** 0.0032	**-0.244** 0.2018	**0.204** 0.2895	**0.341** 0.0698	**-0.010** 0.9582	**0.392** 0.0355	**0.590** 0.0008	**-0.087** 0.6548	**0.422** 0.0226	**0.421** 0.0228

contaminant concentrations (Table 12). The instances where contaminants were significantly correlated with the eastern strata were negative. Only the western intertidal stratum had a positive correlation to total PAHs. Secchi depth was negatively correlated with the eastern strata and positively correlated with the western strata, but not with the Homer Harbor stratum.

3.4.2 Benthic Community Nodal Analysis

The cluster analysis identified four major site groups shown on the X axis in Figure 30. Not surprisingly, the majority of sites were divided into intertidal and subtidal areas. The two additional site clusters were stressed sites, and were characterized by relatively low abundance and species richness. The average abundance and number of taxa at the subtidal and intertidal sites were at least twice those of the stressed sites (Table 13). One cluster of stressed sites was made up of four sites located in the mixing zone of glacial runoff from the Fox and Bradley Rivers, plus the interior-most site of the Homer Harbor stations (Figure 3). That harbor site was dominated by a polychaete worm (*Chaetozone*) which comprised approximately 90% of total abundance at that site. Without the harbor site contribution of a single dominant species, the mean abundance of the stressed sites would be even lower. The other group of stressed sites included three near-shore stations. These sites are considered stressed in the sense that they are exposed for many more hours per day than they are submerged, and many species cannot tolerate those conditions. These sites were also characterized by reduced species abundance and richness, but were occupied by cosmopolitan species in addition to species found in other intertidal locations.

The species clusters on the Y axis of Figure 30 resolved into three primary groups, with subgroups in the largest cluster. The largest group was comprised of species which were cosmopolitan in distribution. That is, they were found at most sites, regardless of site grouping. However, about half were missing from the stressed sites, but statistically they cluster together due to the large number of sites shared in common. Only if the groups are split at a 60% level of similarity on the dendogram do the species separate between those that are found in all habitats and those that are only found outside of the stressed sites.

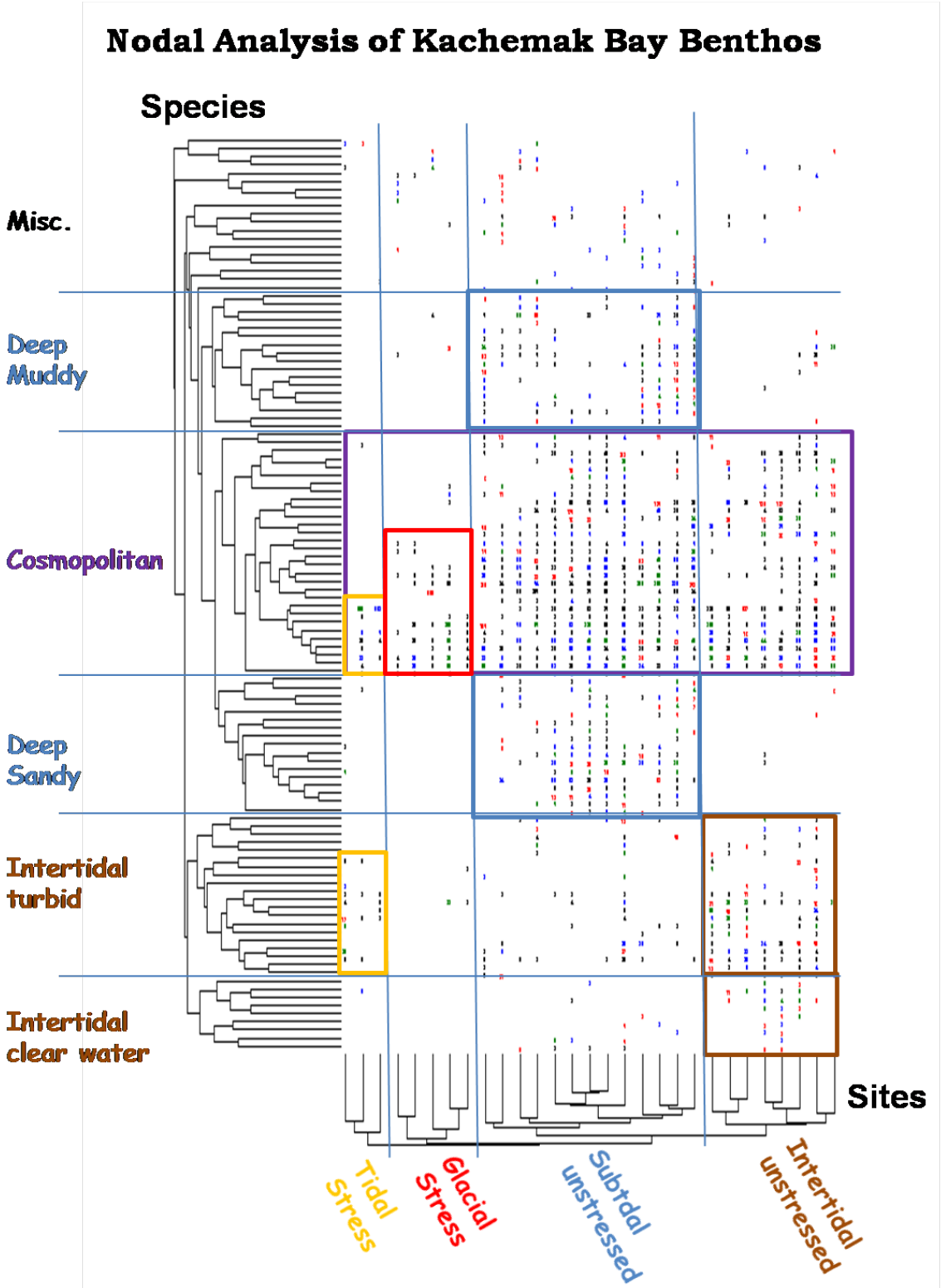


Figure 30. Nodal plot of site vs. species clusters showing the distribution of species among sites. Dots indicate that a species on the Y axis was present at the corresponding site on the X axis. Stressed sites have reduced diversity. Intertidal and subtidal sites overlap, but have a different species mix

Table 13. Total number of taxa and abundance m-2 for stations in Kachemak Bay nodes.

Node	Station	# Taxa	Abundance # m-2	Mean Taxa	Mean Abundance
Subtidal	ES1	58	14,025		
	ES2	46	8,450		
	ES5	48	18,625		
	ES7	48	11,875		
	HH1	59	15,225		
	HH2	43	10,825		
	WF2	61	19,225	56.8	14,267.3
	WS1	62	12,625		
	WS2	78	14,475		
	WS3	59	11,225		
	WS3X	58	17,275		
	WS4	61	14,350		
	WS5	58	17,275		
Intertidal	EF1	32	10,175		
	EF2	22	17,200		
	EF3	33	12,350		
	EF5	52	13,425		
	WF1	51	8,500	39.1	11,681.3
	WF3	39	10,475		
	WF4	50	13,475		
	WF5	34	7,850		
Tidal Stress	EF6	10	7,000		
	EF7	16	9,175	15.3	6,558.3
	WF6	20	3,500		
Glacial Stress	EF4	11	650		
	ES3	11	2,000		
	ES4	18	8,150	14.4	5,200.0
	ES6	17	850		
	HH3	15	14,350		

Within the larger cosmopolitan species cluster, there are two groups of deeper water species. Based on the species' abundance normalized preferences, one subset of species are found primarily in muddier sites, and one comprising species that are found in sandy sites with greater water clarity. This is reflected in the differential lateral distribution of species between the muddy eastern strata and Homer Harbor, and the western strata. These deep water species are virtually absent from the intertidal sites and the stressed sites. The last two species clusters are concentrated primarily in intertidal sites, although they have more scattered distributions than the subtidal species. Like the subtidal species, the intertidal species also separate into two subgroups. Based on the species' abundance normalized preferences, the intertidal species separate not on sediment grain size, but only on water clarity as measured by Secchi depth. As with the subtidal species, this reflects a lateral difference between the eastern and western strata and the influence of glacial meltwater in the east. There is one site in the subtidal site cluster that contains almost all of the intertidal species as well as deep sandy species cluster. That is site WF2, which was situated essentially at the low tide line. The remaining miscellaneous species are comprised of species that are either widespread, but not frequently found, or species which comprise very small clusters that are associated primarily with one or a few sites. Some patterns were obvious with regard to differences in faunal make-up in different areas. There was a greater variety of taxa in the deeper areas and in the western strata. Mollusks (both clams and snails) and Crustaceans were largely absent from the stressed sites. Polychaete and Nermertine worms were the dominant residents of the stressed sites.

All sites were characterized by the presence of a small number of dominant species, and a much larger number of less numerous taxa. The dominant species were comprised of 13 taxa. They were not all present at all sites, but a subset of them were the dominant species, in some combination, at all 29 sites. Figure 31 illustrates the total abundance of each species summed over all sites showing that most species were found at relatively low abundance.

Feeding strategy of the dominant organisms differed from habitat to habitat (Figure 32).

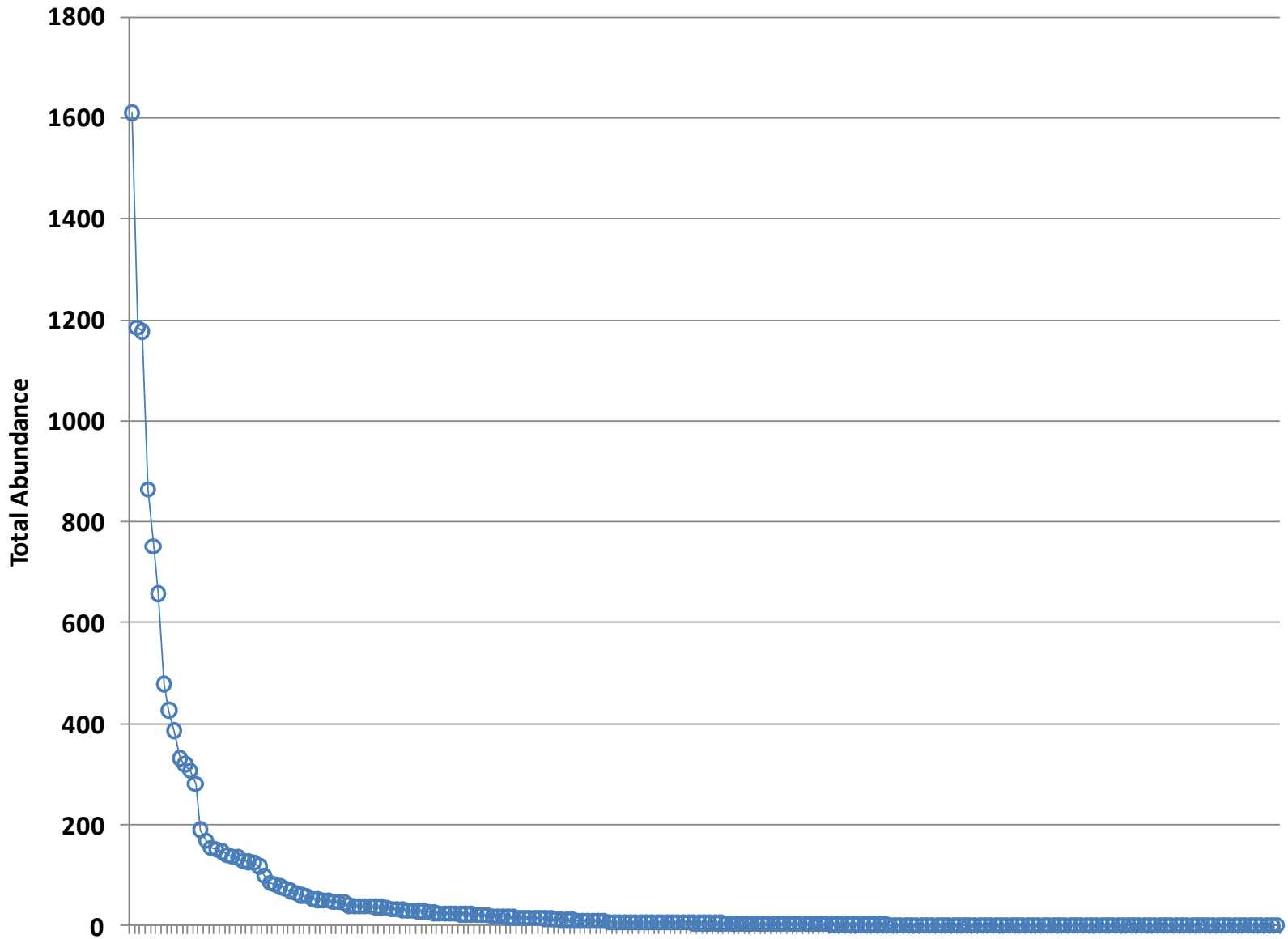


Figure 31. Total abundance of each species collected. Species are arranged on the X axis by abundance. Each dot represents the total number of individuals of a species collected at all sites in Kachemak Bay. The abundance of all species is dominated by a small group of cosmopolitan species.

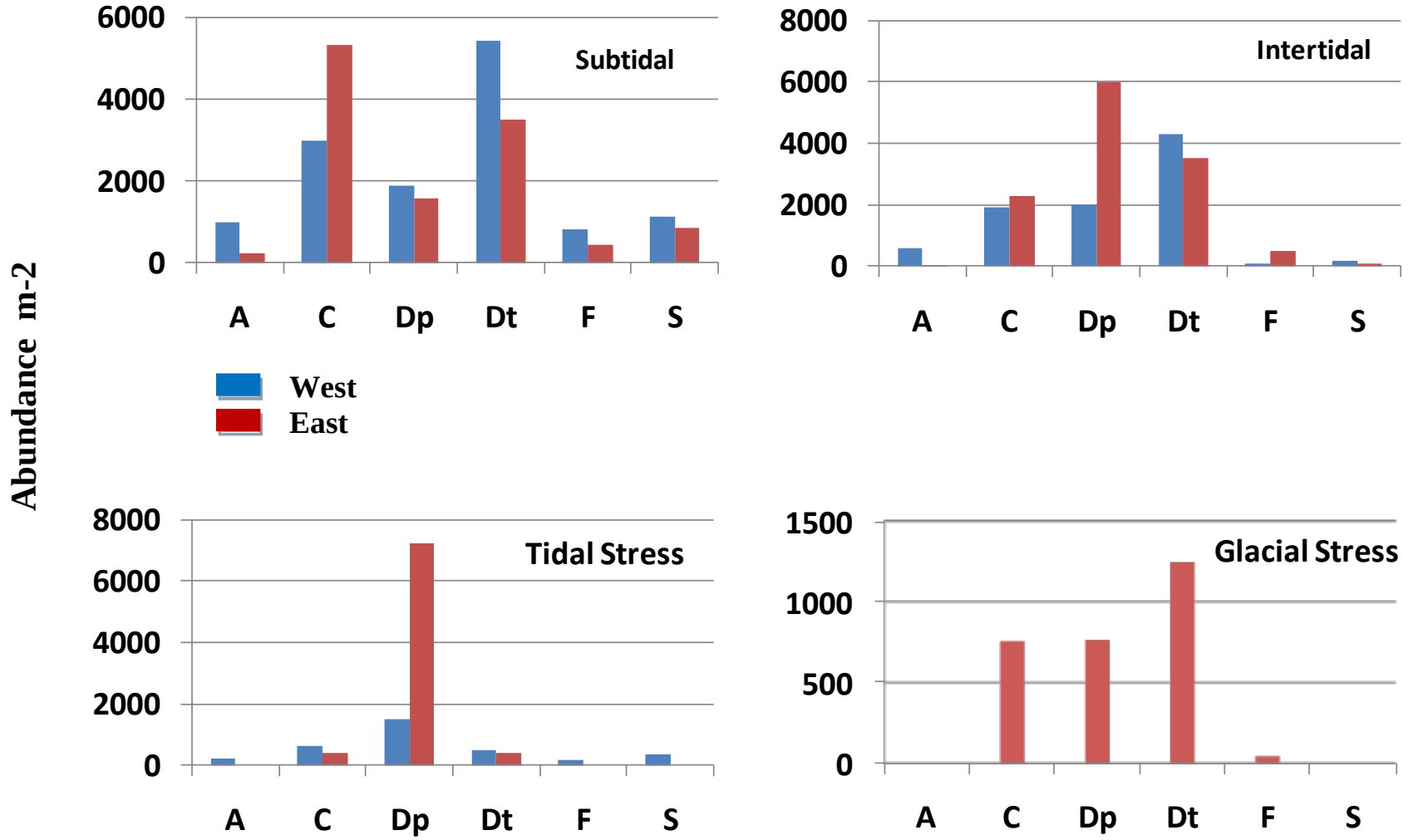


Figure 32. Average density of organisms with different feeding modes in varying habitats in Kachemak Bay. A- Algae; C- Carnivore; Dp – Deposit feeder; Dt – Detritivore; F – Filter feeder; S – Suspension feeder.

In the glacially stressed areas, detritivores were predominant over deposit feeders and carnivores. The shore line stations were occupied almost exclusively by deposit feeders. The intertidal stations were evenly split between deposit feeders and detritivores, but deposit feeders were more prevalent in the eastern stratum sites than in the western stratum. In the subtidal stations detritivores and carnivores were the dominant feeding guilds. Again, there were differences between the east and west strata. Filter and suspension feeders were virtually absent from all areas except the subtidal stations. Algae eaters were all gastropods that feed on algal films on hard surfaces and/or kelp fronds. Because the sampling design targeted soft sediment areas, only a few organisms in this feeding guild would be expected.

While the prevalence of different feeding guilds did vary between nodes, the feeding guild distributions were family-specific. For example, among the carnivorous polychaetes, Goniadid worms were one of the few truly cosmopolitan taxa, being found in all strata, although relatively rare in the stressed sites (Figure 33). Nereids were found in both east and west strata, but were exclusively found in deep water. Polynoids were found in both east and west strata, in both deep and intertidal habitats, but were never found in the near-shore or stressed locations. Capetellids are deposit feeders and are widely recognized as being tolerant of polluted conditions. They were found in all nodes in the study area (Figure 34). With one exception, their numbers were relatively low in the stressed sites. Apistobranchids were found almost exclusively in subtidal habitats but not in the stressed sites. Detritivores were also distributed in a variety of patterns (Figure 33). Orbiniids were truly cosmopolitan in distribution, being found in large numbers in all strata, including the stressed areas. Arenicola are well known intertidal specialists and were found in the east and west intertidal strata, but not in the stressed sites. Cirratulids were frequently very numerous where they were found, especially in the stressed site in Homer Harbor, but were not see at the eastern stressed sites. Clams likewise showed specific distributions (Figure 36). Suspension feeding Hiatellid clams (nut clams) were only found in subtidal sites in the western stratum. Mya (softshell clams) are also suspension feeders but are primarily intertidal in distribution. The two ‘deep’ stations

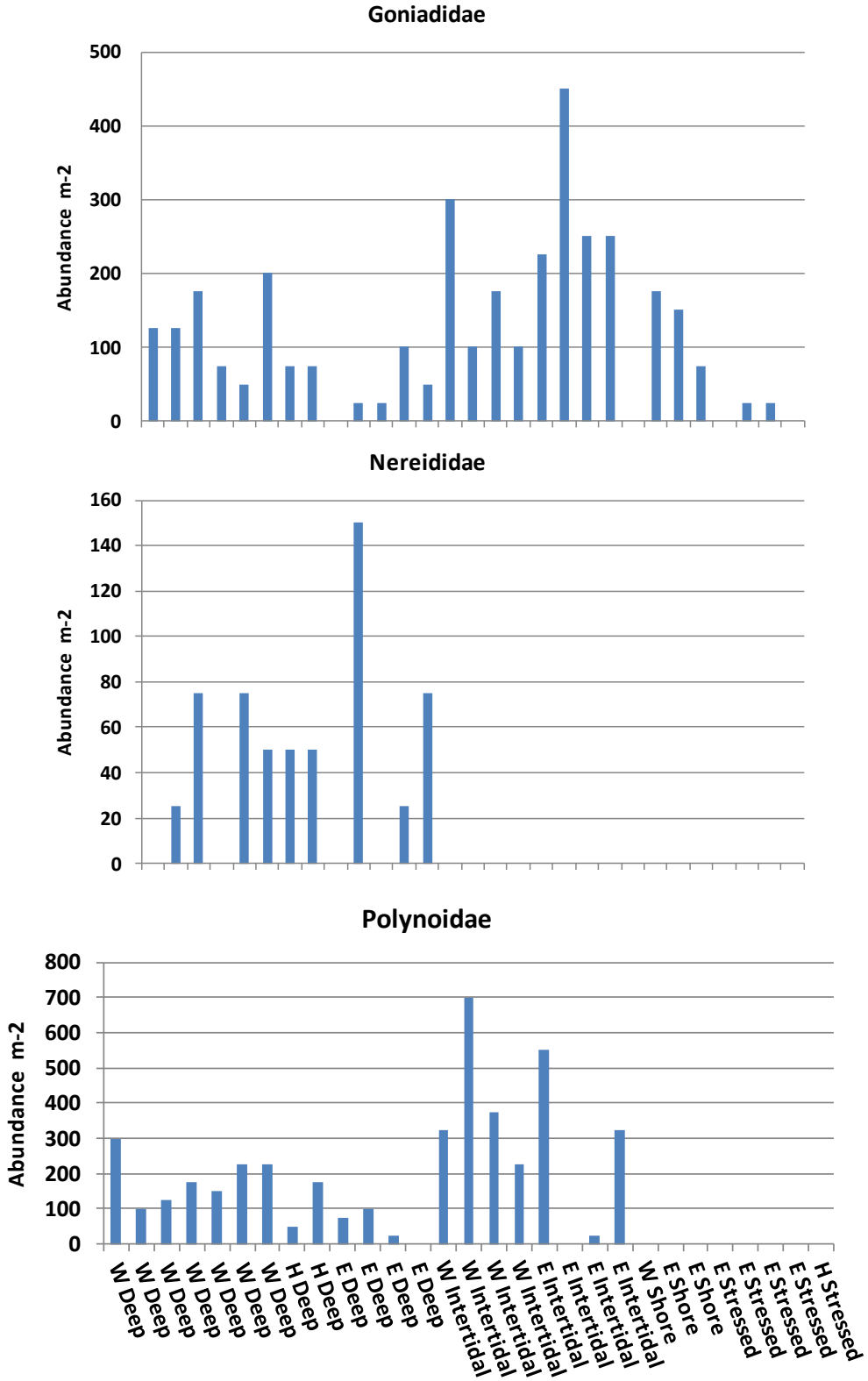


Figure 33. Distribution of dominant carniverous polychaete worms in Kachemak Bay in relation to nodal habitat classifications. (W=west, E=east, H=Homer Harbor)

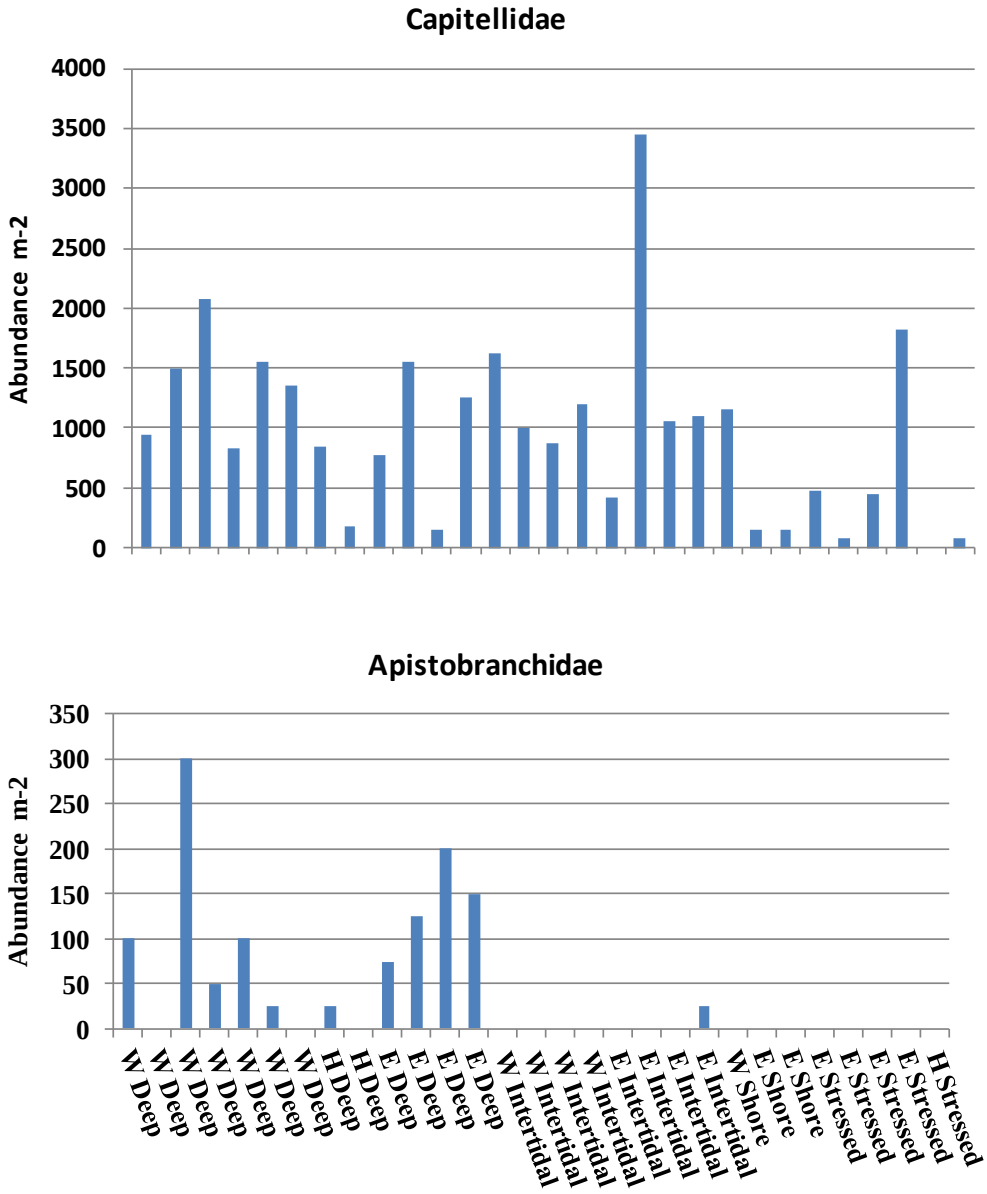


Figure 34. Distribution of dominant deposit feeding polychaete worms in Kachemak Bay in relation to nodal habitat classifications. (W=west, E=east, H=Homer Harbor)

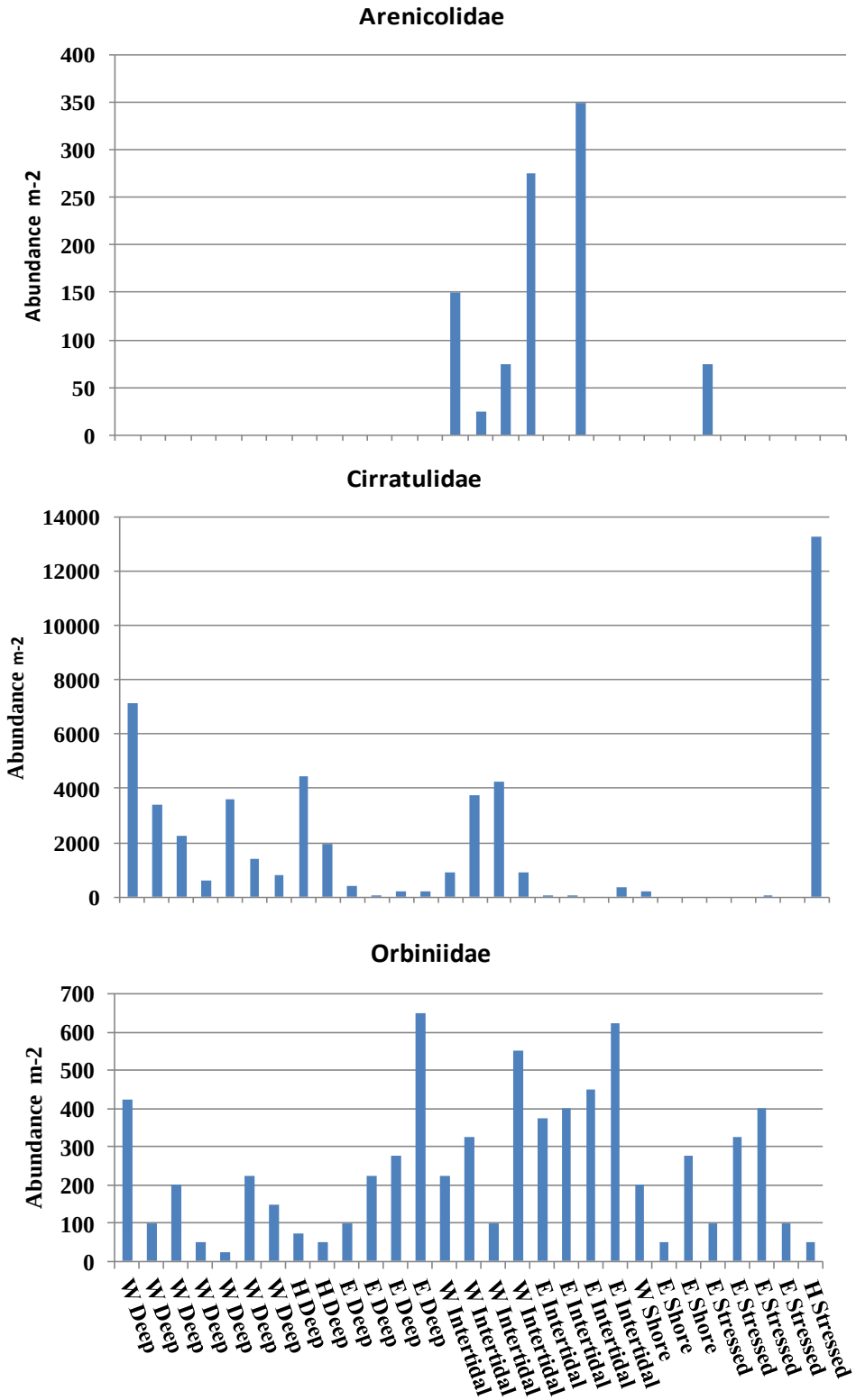


Figure 35. Distribution of dominant detritus feeding polychaete worms in Kachemak Bay in relation to nodal habitat classifications. (W=west, E=east, H=Homer Harbor)

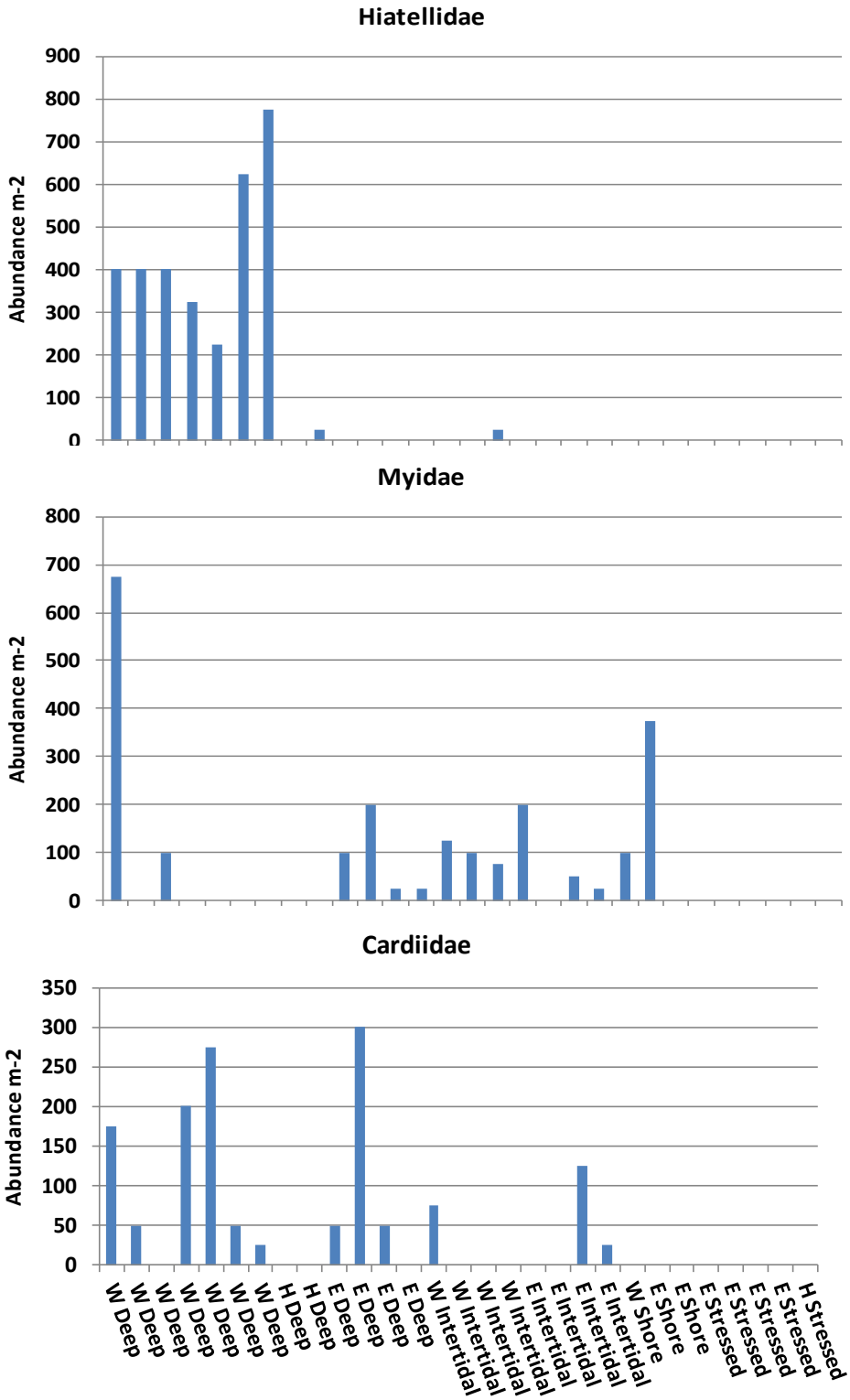


Figure 36. Distribution of suspension feeding clams in Kachemak Bay in relation to nodal habitat classifications. (W=west, E=east, H=Homer Harbor)

they were found at were at or near the low tide line. Cardiids (cockles) were more widely distributed, being found in deep and intertidal habitats.

3.4.3 Principal component analysis

Principal component analysis results were generated on data subsets for habitat characteristics with and without contaminant data, and $\log_{10}$ transformed species abundance data. Using only the biological and physical variables, PCA divides the sites neatly into four quadrants (Figure 37). Component one loadings were highest for TOC and Secchi depth, separating the sites between east and west strata. Component two loadings were highest for depth, separating the sites between intertidal and subtidal. The Homer Harbor sites cluster with the subtidal sites, but were intermediate with respect to TOC and Secchi depth. The third component separates the sites by percent fines in the sediment. Homer Harbor sites along with a subset of the fine grained sites in the eastern intertidal flats in the vicinity of the Fox River discharge are clearly distinct from the other sites (Figure 38). Inclusion of contaminant data in the PCA clearly separates the Homer Harbor sites from all other sites, with factor loadings highest for PAHs, PCBs, DDT, and percent fine grained sediment on component one (Figure 39). Component two loadings were evenly weighted between depth, diversity and number of species which generates a spread of subtidal and intertidal sites respectively above and below the axis. Results using species abundance alone were consistent with the physicochemical calculations. Sites segregated primarily by depth on component one and between east and west strata on component two with the stressed and beach sites all in the lower left hand quadrant (Figure 40).

3.4.4 The Sediment Quality Triad approach

The sediment quality triad triangle assessment approach only identified two stations with triangular areas significantly above other stations (Figure 41). Station EF4 contained very fine grained sediment. Metals accumulated at that site to higher concentrations than other stations, and that was the only station with significant toxicity. Station HH-3 had the overall highest chemical contaminant score due to organic contaminants, and one of the lowest species values. There was no apparent pattern between stations with regard to stratum or other variables.

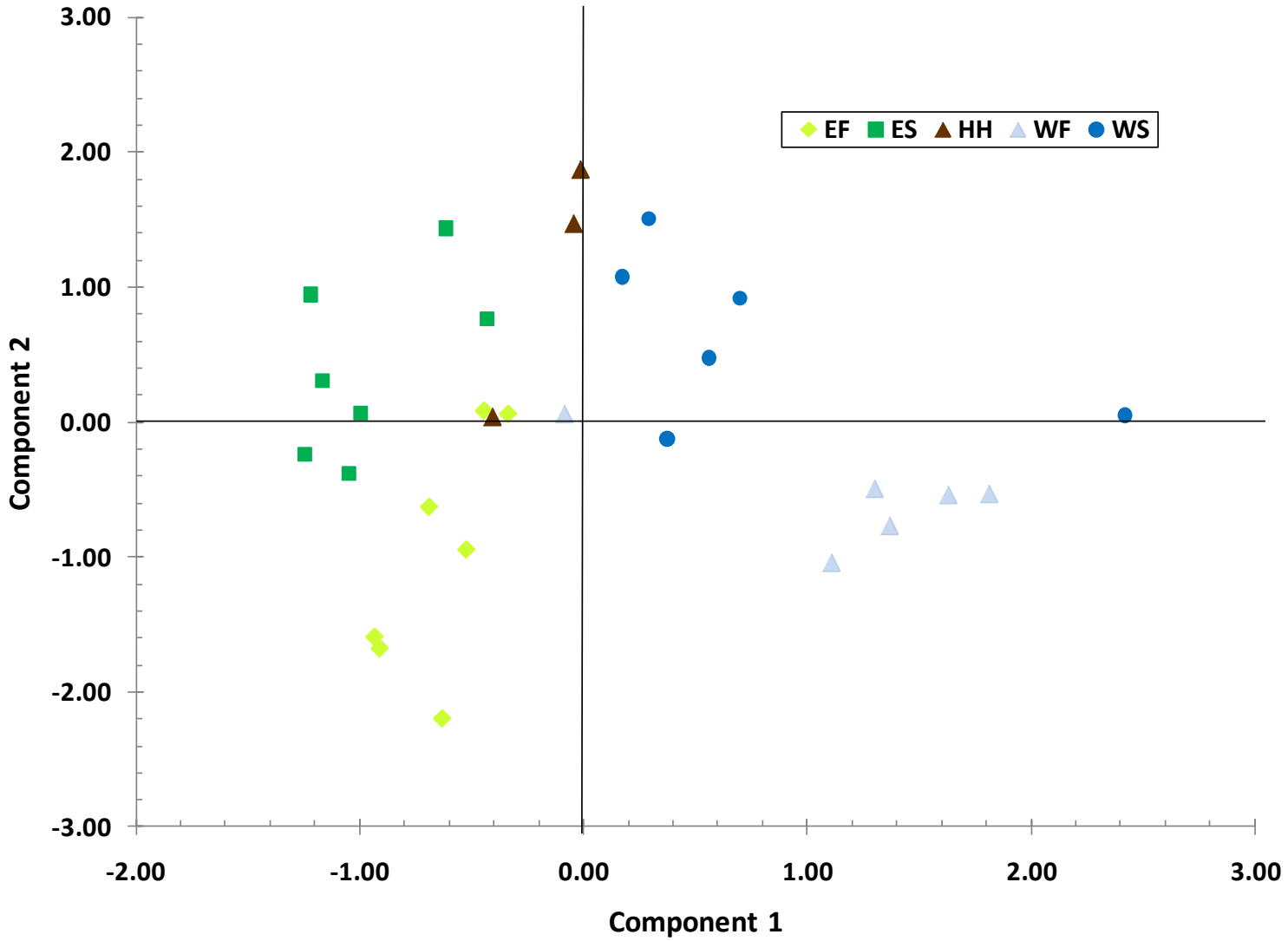


Figure 37. Principal component analysis of species abundance and physical habitat variables, without contaminants. (EF- Eastern intertidal flats, ES- Eastern subtidal, HH- Homer Harbor, WF- Western intertidal flats, WS- Western subtidal).

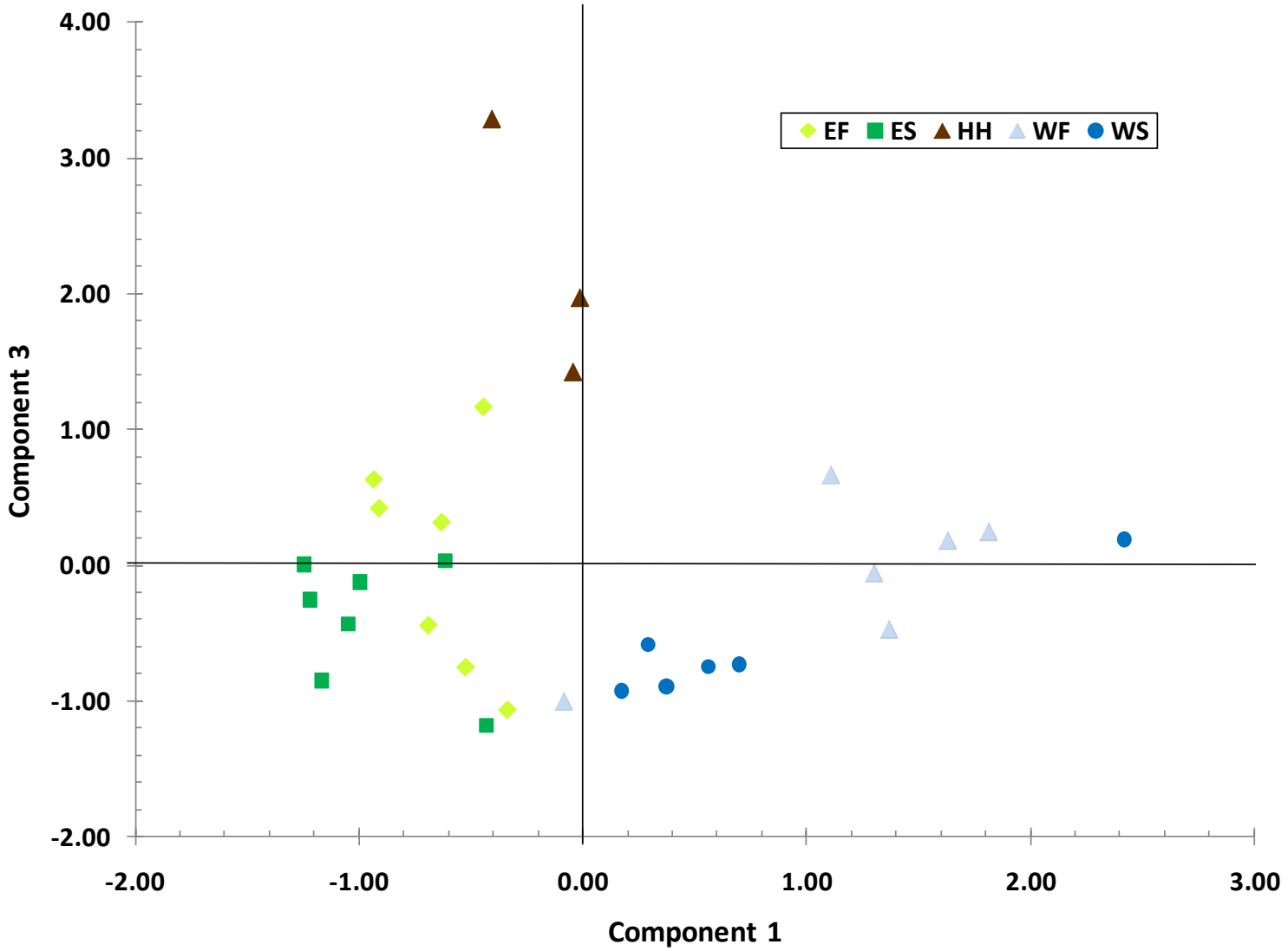


Figure 38 . Principal component analysis of species abundance and physical habitat variables, without contaminants. (EF- Eastern intertidal flats, ES- Eastern subtidal, HH- Homer Harbor, WF- Western intertidal flats, WS- Western subtidal).

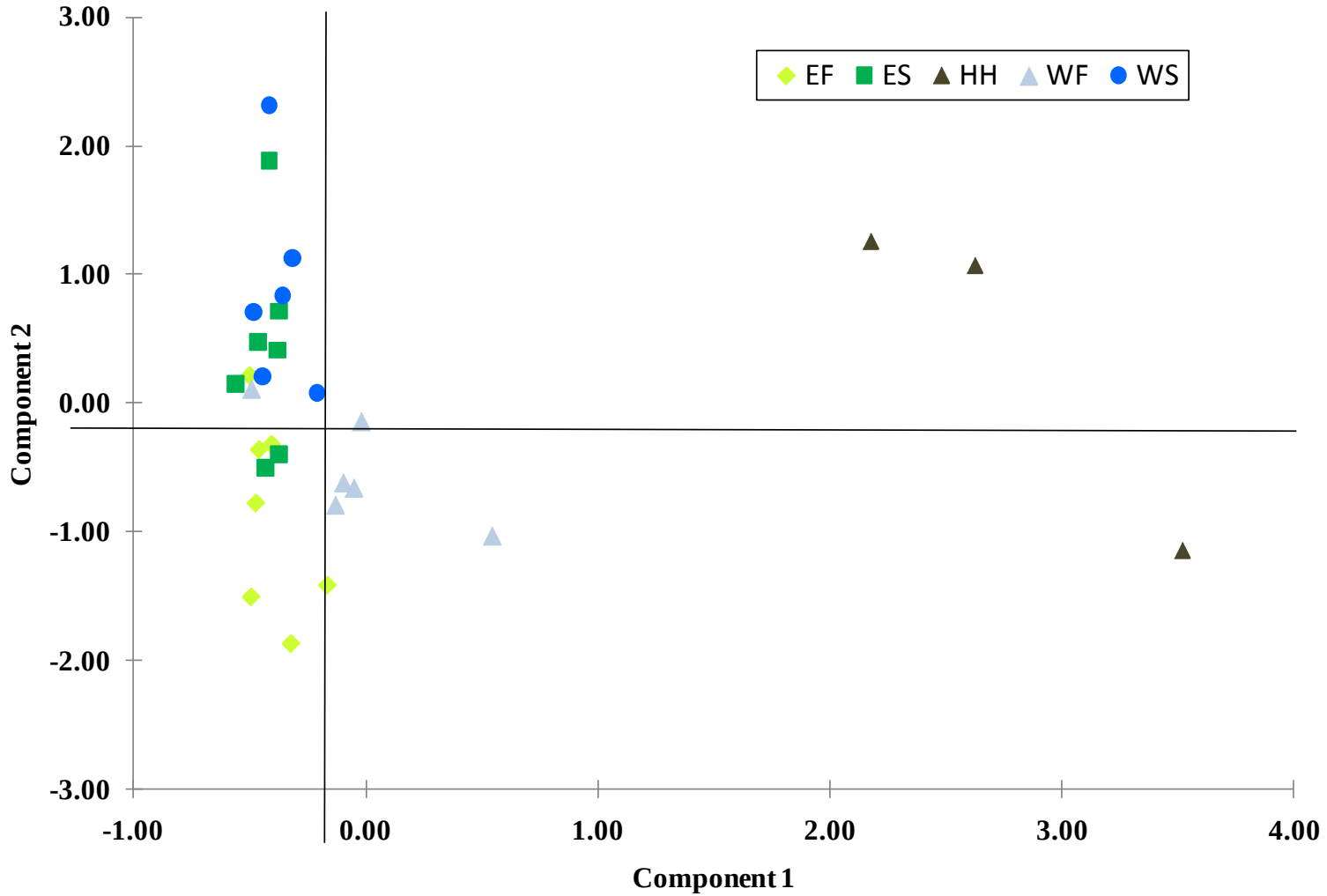


Figure 39. Principal component analysis of species abundance, physical habitat variables, and contaminants. (EF- Eastern intertidal flats, ES- Eastern subtidal, HH- Homer Harbor, WF- Western intertidal flats, WS- Western subtidal).

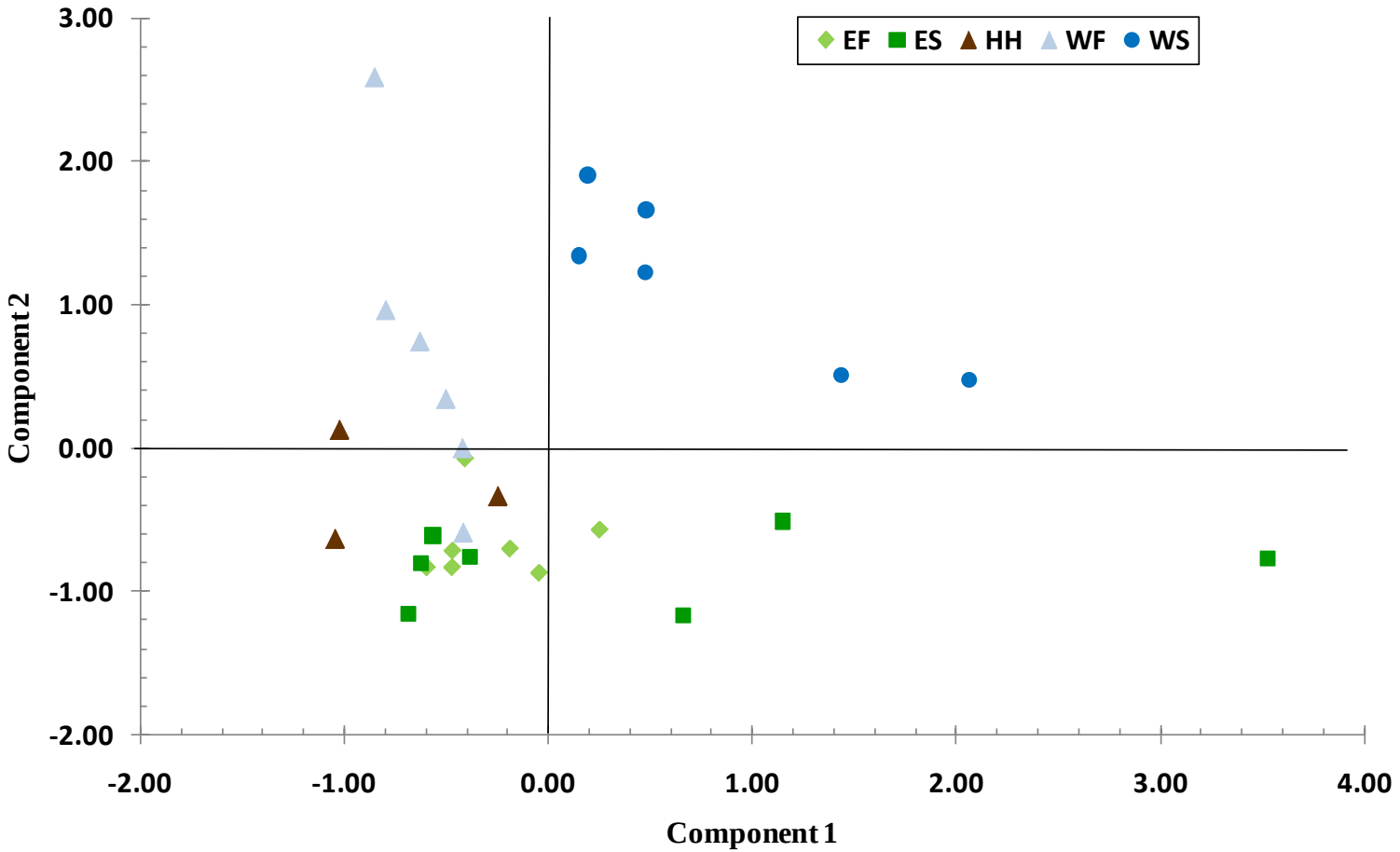


Figure 40. Principal component analysis of species abundance only. (EF- Eastern intertidal flats, ES- Eastern subtidal, HH- Homer Harbor, WF- Western intertidal flats, WS- Western subtidal).

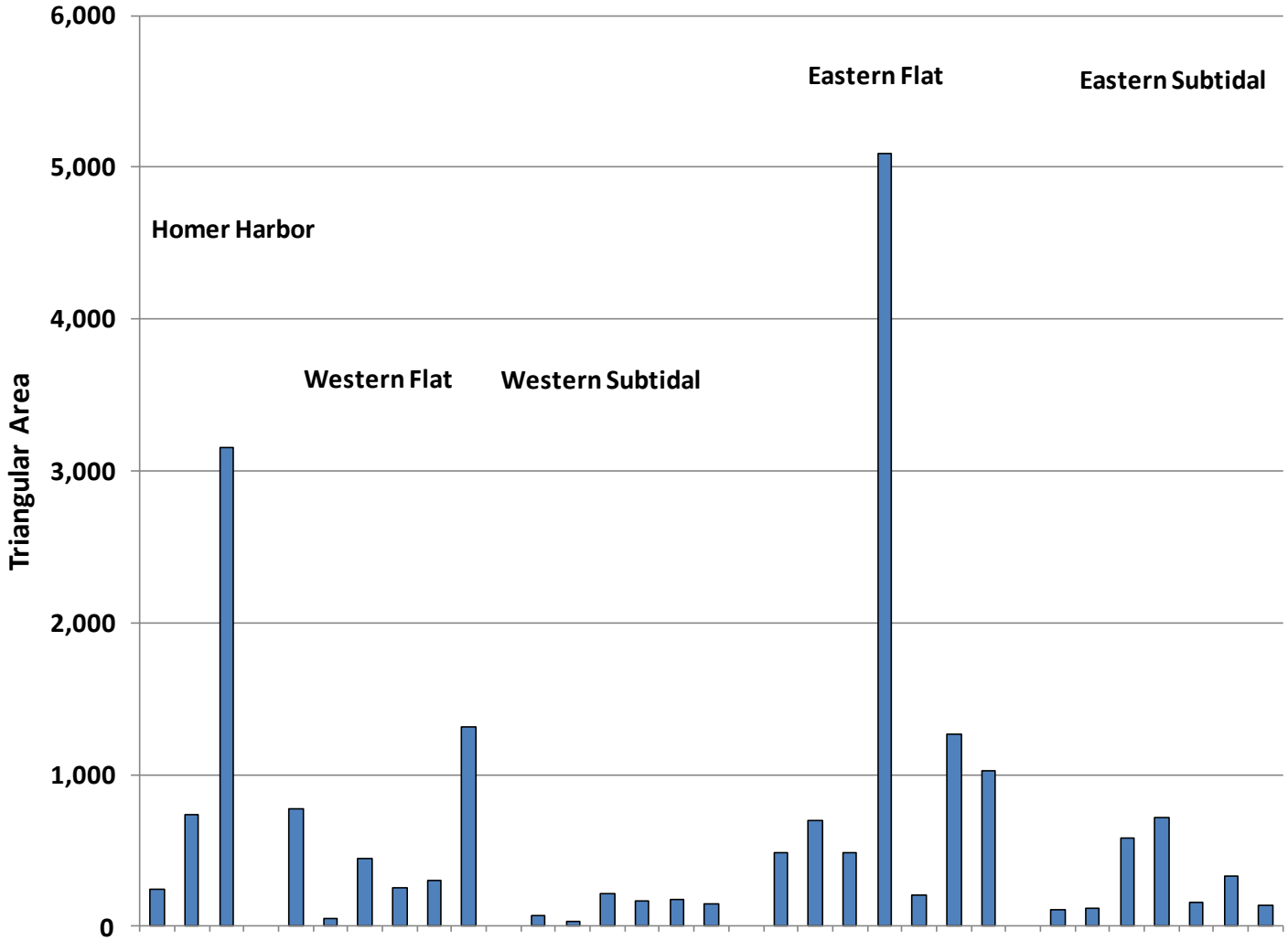


Figure 41. Calculated triangular areas from Sediment Quality Triad assessment of levels of contamination, toxicity and species richness (dimensionless). The sediment quality triad triangle assessment approach only identified two stations with triangular areas significantly above other stations.

3.5 Supplemental Samples

3.5.1 Chemistry summary

Concentrations of PAHs in the outer harbor area (outside the current configuration) were similar to the adjacent western intertidal and subtidal strata, all of which were significantly lower than those in the harbor (Figure 42). One station in Port Graham (Figure 2) was considerably elevated above the others. The distribution of PAH compounds at that station mimic the distribution found in Homer Harbor, with indications of contributions from fuel and combustion by-products (Figures 20 and 43). Like PAHs, the concentration of PCBs outside the harbor mouth are not elevated above levels in the subtidal and intertidal strata (Figure 44). The single station in Port Graham where PAHs were elevated, also had elevated PCBs relative to the other stations, but was below the levels in Homer Harbor. While the concentration distributions are instructive relative to fate and transport processes, none of the levels at any location indicate the potential for concern. PCBs do bioaccumulate in the food chain however, so source reduction should be a management objective. Concentrations of DDT showed a slightly different pattern, in which the outer harbor concentrations are elevated above the Kachemak strata values, and the highest concentration was seen at Port Graham (Figure 44). The second highest concentration in Port Graham was comparable to those in Homer Harbor. That station, station PG-4b, was located at the upper reaches of the bay, upstream from the village. In contrast, the value at the station directly across from the village was below the detection limit. As with the PCBs, none of the levels at any location indicate the potential for immediate concern, beyond bioaccumulation. The ratios of DDD, DDE, and DDT (not shown) do not indicate the input of fresh DDT anywhere. As in the rest of Kachemak Bay, the remaining pesticides and related compounds were generally found at or below detection limits.

Metals concentrations at the two sites outside of Homer Harbor were within the range of concentrations seen in the eastern and western strata. Metals concentrations in greater

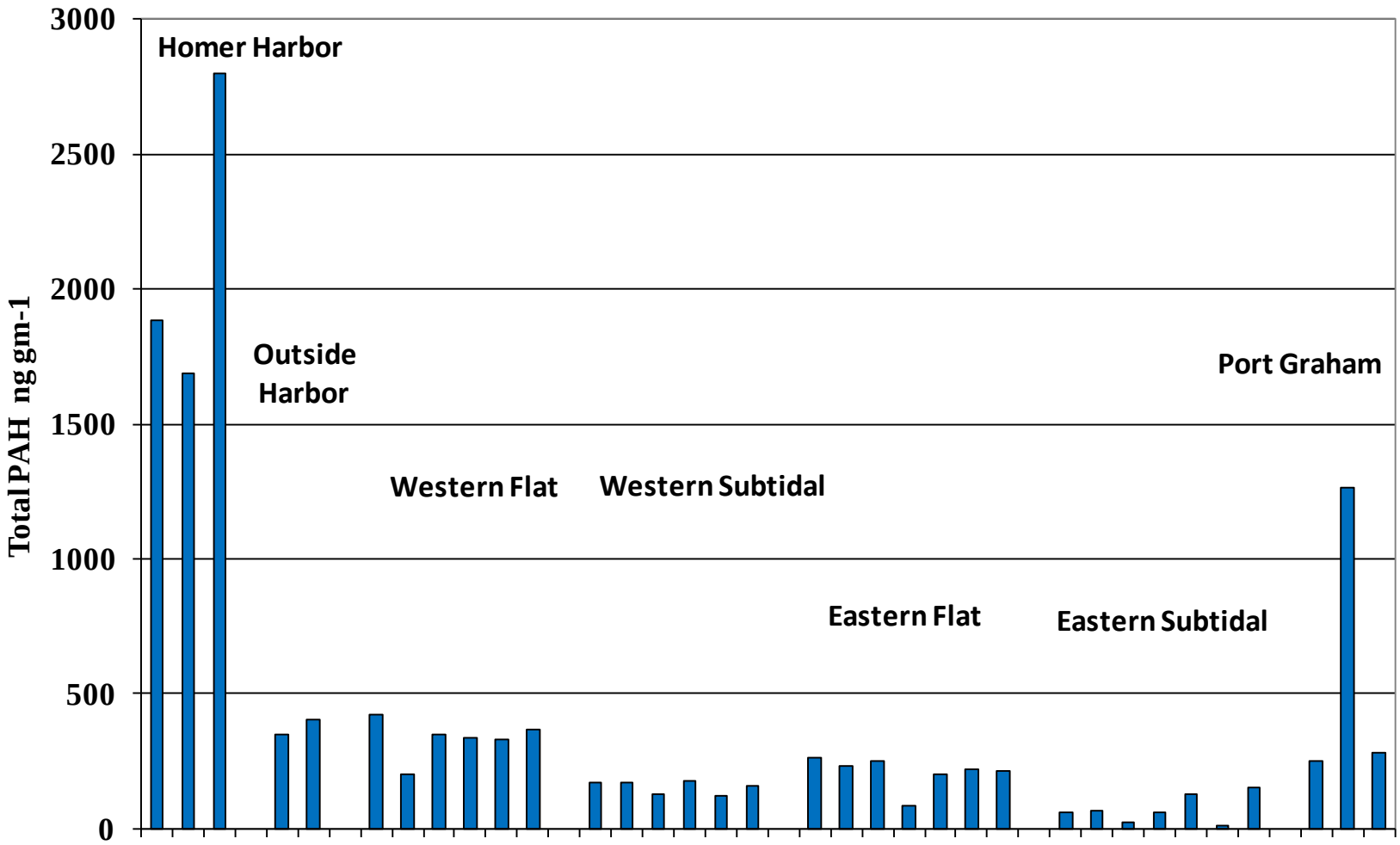


Figure 42. Distribution of total PAHs in Kachemak Bay sampling strata and extra sampling stations outside Homer Harbor and at Port Graham. Only one site in Port Graham exhibited elevated total PAH concentrations.

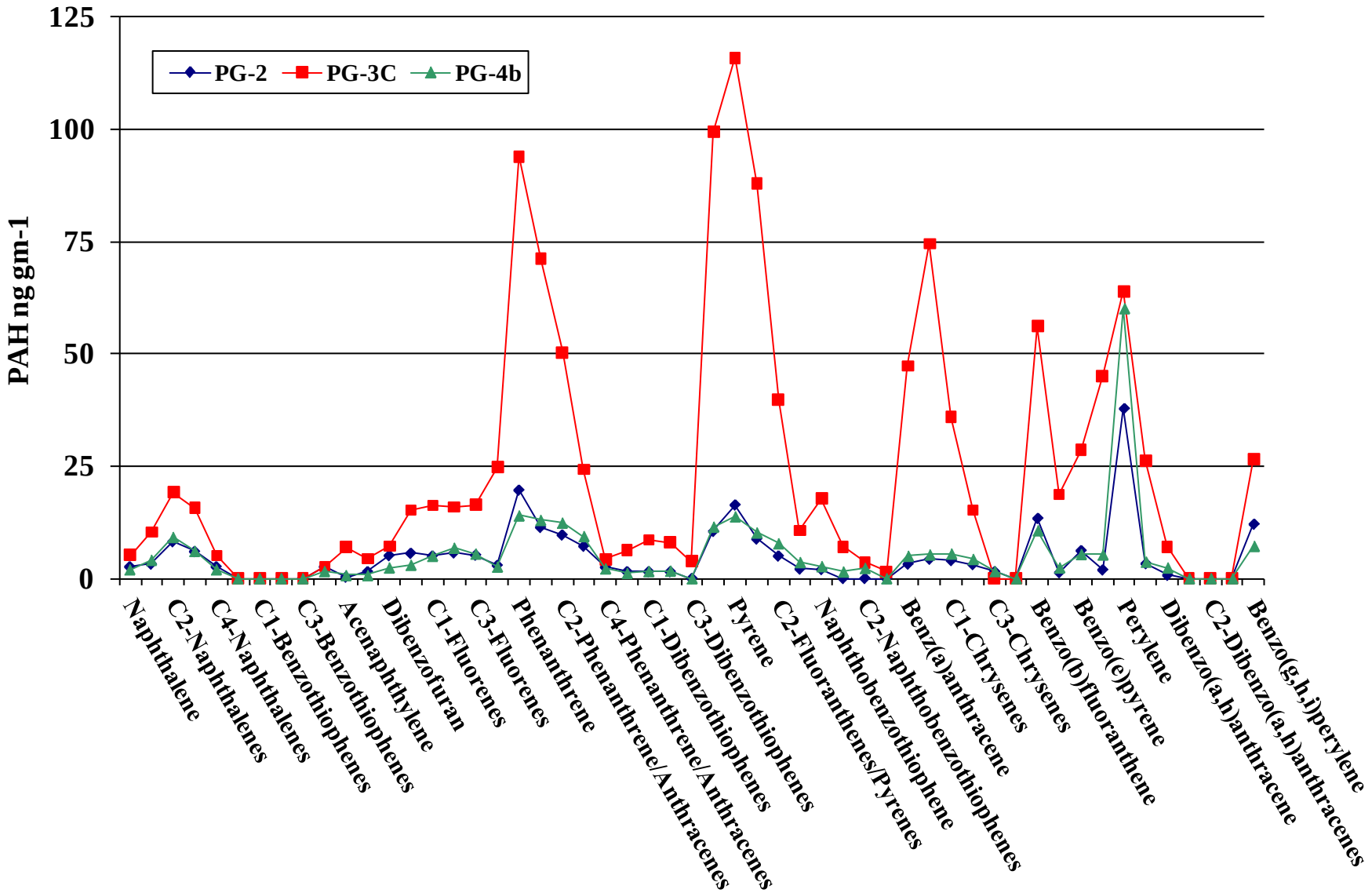


Figure 43 . Concentrations of individual PAH compounds found at three Port Graham stations. The PAH signature for Port Graham appears slightly different from other Kachemak Bay study sites, indicative of source differences. Site PG3c resembles Homer Harbor.

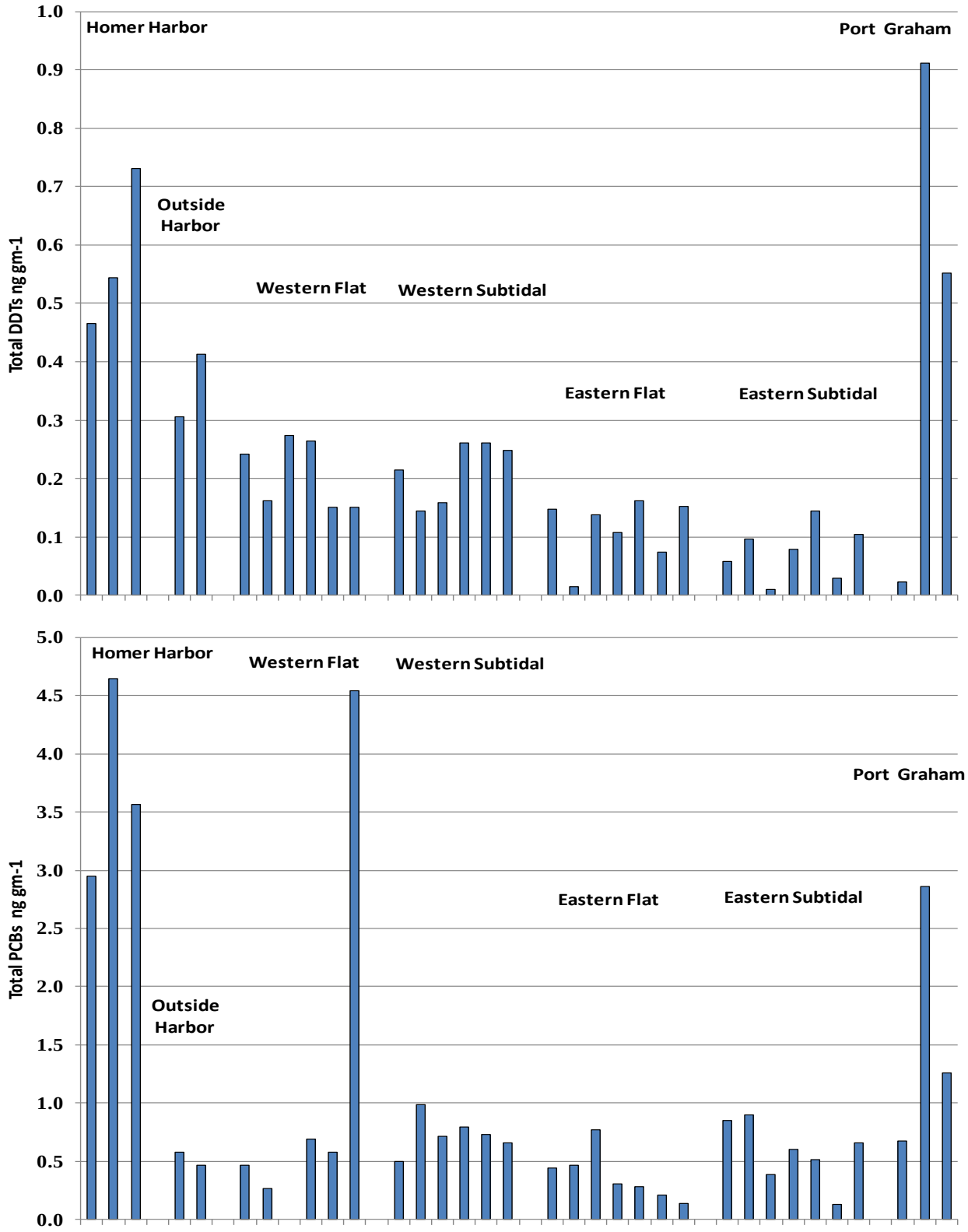


Figure 44. Distribution of total PCBs and total DDTs in Kachemak Bay sampling strata and extra sampling stations outside Homer Harbor and at Port Graham.

Kachemak Bay and Port Graham Bay sediments were quite different however. Cadmium, mercury, and selenium were elevated 4-6 times above the average levels at station PG-3c (Figure 45). Chromium, selenium, and cadmium were elevated at station PG-4b, located toward the head of the bay. Conversely, arsenic, antimony, and lead at all three Port Graham sites were approximately half the concentrations seen in the larger system. Concentrations at station PG-2, located directly across the bay from the village were otherwise unremarkable.

3.5.2 Toxicity

Sediment toxicity tests at Port Graham showed significant toxicity results only with *A. abdita* at station PG3c. Survival was reduced to 68.8%. All the other tests resulted in survival rates of 90% or more. Significant reduction in survival was not observed in the *E. estuarius* bioassays.

3.5.3 *Clostridium perfringens*

Samples were also taken at Port Graham to assess the presence of *Clostridium perfringens* in the sediment as an indicator of possible sewage contamination. *C. perfringens* counts were elevated at station PG3c relative to the other stations. Sediment quality guidelines for *C. perfringens* do not currently exist. While the value at station PG3c is well below what might be expected in the proximity of a sewage outfall, it is elevated relative to the other stations, indicating that conditions favor propagation of pathogenic bacteria. The sediments were organically enriched and anoxic. In the NS&T data base, values of 500 or more spores gm-1 are generally (but not always) found in the vicinity of urban areas.

3.5.4 Benthic Community

Inclusion of the Port Graham and outer harbor sites into the nodal analysis identified interesting contrasts between the main bay and this smaller component of the system. Because there were only three stations in Port Graham and two in the outer harbor area, and the presence of a significant number of taxa unique to Port Graham, we did not

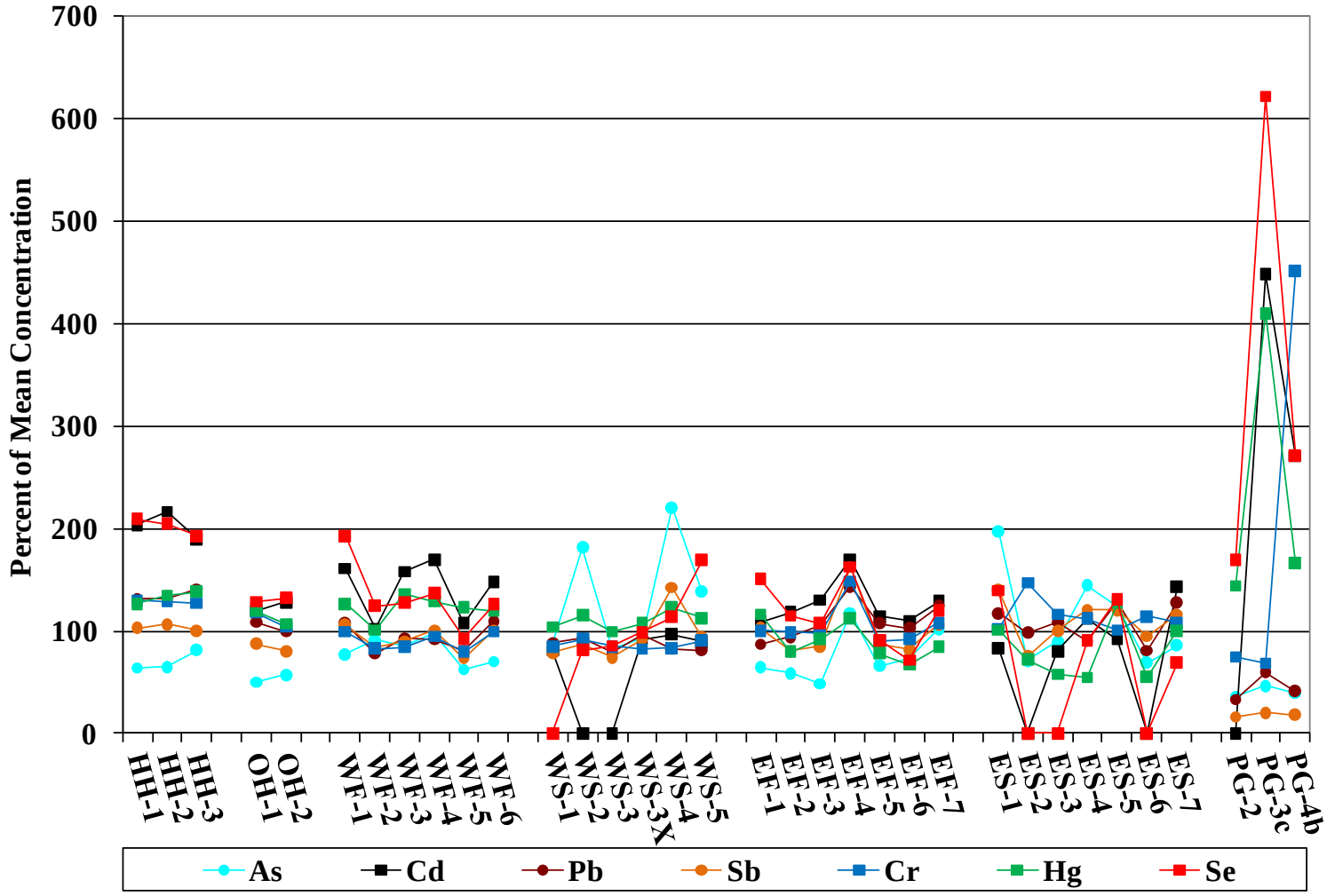


Figure 45. Relative concentrations of seven elements in Kachemak Bay sampling strata and extra sampling stations outside Homer Harbor and at Port Graham. Concentrations are normalized to the overall mean concentration in the Kachemak Bay only (excluding Port Graham) and expressed as a percentage.

exclude the rare and unique taxa from the nodal analysis. Of the 239 total taxa found in Kachemak Bay, 79 were also found in Port Graham. However, 45 taxa were identified in Port Graham that were not seen in the larger bay. None of the Port Graham stations were intertidal, so that portion of the community was largely missing. In addition, the species in deep sandy habitats found in the larger bay were absent in Port Graham. With the additional data, the basic nodal pattern seen in the larger bay remains intact, with the outer harbor and Port Graham sites being tacked on as additional nodes rather than being incorporated into the larger pattern (Figure 46). As before, there is a large cosmopolitan group of species that are found in all site clusters, with some species absent from the stressed sites. Within the cosmopolitan taxa cluster, the taxa in the original subtidal muddy node still cluster together, but are also found in the outer harbor and Homer Harbor nodes. There are still two intertidal nodes (clear and turbid water), a stressed sites node including glacial input sites and the inner-most Homer Harbor site, and a near shore node, this time with only one station. Site ES2 clustered with the Port Graham sites. It is the only site that contained six taxa in common with the unique Port Graham faunal assemblage. Port Graham station PG3c was particularly depauperate in diversity and clustered separately from all other sites. The outer harbor sites contained a small set of taxa rarely seen in the other strata, and did not cluster with the other subtidal sites in the data set, but share the subtidal muddy species assemblage. The remaining two Homer Harbor sites clustered separately from the other deep sites in this version, also due to the presence of a small set of rare and unique taxa not seen at other stations.

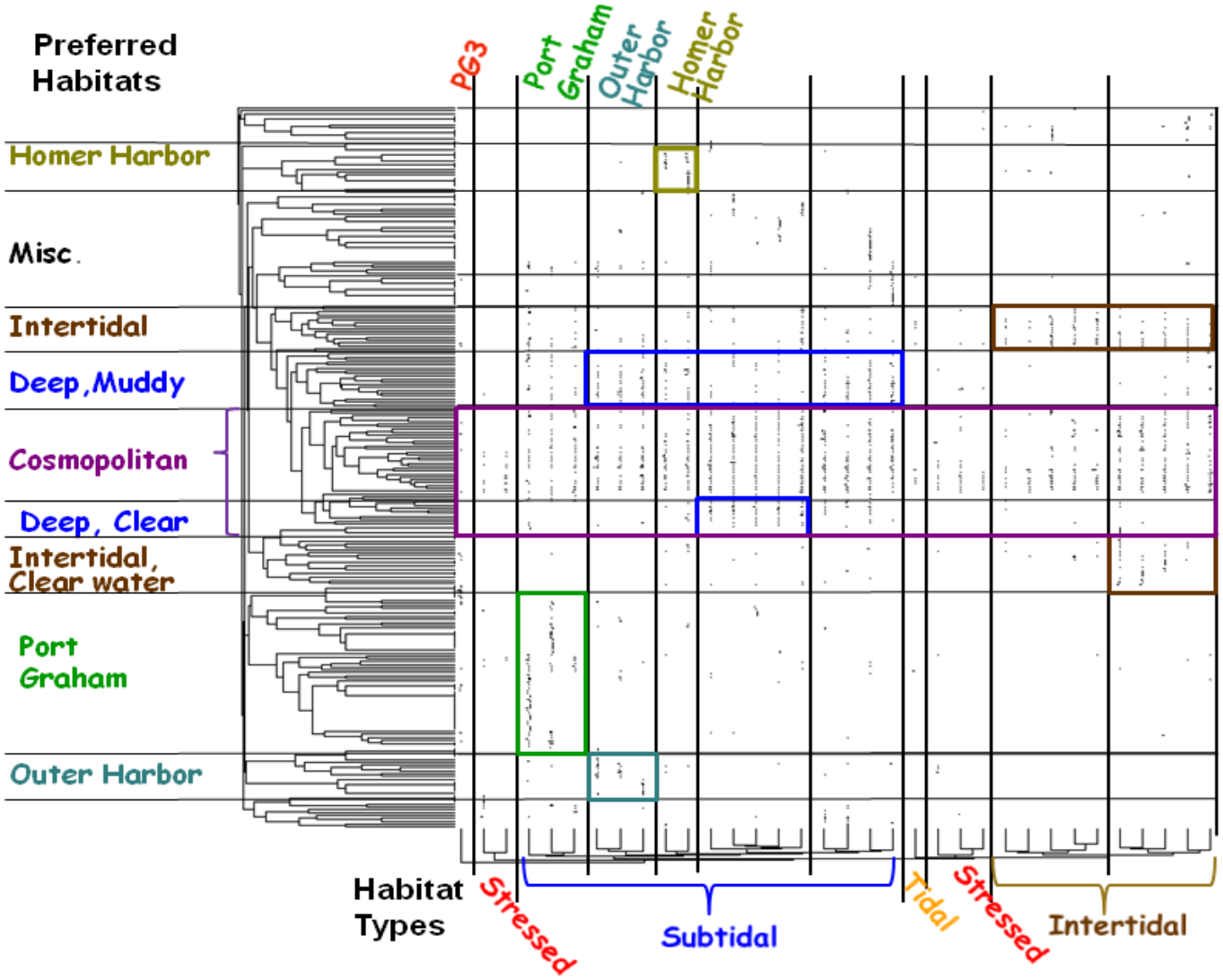


Figure 46. Nodal plot of site vs. species clusters showing the distribution of species among sites, including extra sampling sites and rare and unique species (see text). Dots indicate that a species from the Y axis was present at the corresponding site on the X axis. Stressed sites have reduced diversity. Intertidal and subtidal sites overlap, but have a different mix of species. Port Graham has a unique community.

4. DISCUSSION

4.1 Habitat condition

Inner Kachemak Bay is composed of a shallow shelf in the north and a deeper zone to the south. The bay is relatively flat bottomed with the exception of the Jakalof Trench that runs along the southern edge off the end of Homer Spit (ADFG 1998). Water circulation in the bay is fueled by the intrusion of saline water from the GOA (Burbank 1977) making the inner bay a fairly saline environment. Salinity values as high as 30‰ were measured in the bay as compared to an average salinity value of 35‰ for seawater. Freshwater inputs from rivers, glacial melt water and precipitation maintain a slightly brackish water mass with an overall salinity range of 18 – 30‰. Inner Kachemak Bay has many characteristics of a typical estuary, but did not exhibit a strongly stratified water column during the sampling period.

Water quality measurements (salinity, temperature, and DO) across the study area indicate a well mixed system though some variations were recorded. Slight, but significant vertical variation for salinity (Figure 7a) and a spatial variation for DO (Figure 8b) were detected across the bay. Dissolved oxygen concentrations in strata closer to the Fox River Delta (Figures 8a and b) were lower than other areas, but this may reflect variation due to tidal fluxes. No area appeared to have oxygen stress, including Homer Harbor. Similar conclusions were drawn by the Kachemak Bay National Estuarine Research Reserve (ADFG 1998).

Nine glaciers drain to the bay and deliver large volumes of freshwater and sediment, however, there are no quantitative estimates of seasonal flow available (ADFG 1998). The most significant input is delivered to the eastern end of the bay via the Fox and Bradley Rivers. Water clarity measurements showed an east to west gradient of increasing Secchi depth toward Homer Spit from the river delta (Figure 10). Sediment grain size also tended to be finer in the eastern end of the bay, but grain size characteristics were also affected by proximity to shore. With the exception of pockets of relatively muddy sediment at some near-shore sites, the sediments were found to be

primarily sandy. The semi-diurnal 6m tides and the slow counterclockwise water movement in the bay tend to sort sediments in the open bay. However, sediment characteristics in Homer Harbor were muddy with a high concentration of finer material (67 – 97 % silt + clay). The protected area within Homer Harbor is a significant sediment trap that accumulates fine grained sediment despite the large tidal exchange.

4.2 Concentration and distribution of metals

The concentrations of metals measured in this study were comparable to previously published data by the U.S. Corps of Engineers Alaska District, (CEAD 2007) and EMAP (Saupe *et al*. 2005). The Corps characterized dredged materials from Homer Harbor and found arsenic and chromium at concentrations ranging from 6 - 14.9 µg gm-1 and 16.7 - 56.7 µg gm-1 respectively. These concentrations were in exceedance of the State of ADEC bench standard for soil (ADEC 2008). Relatively higher concentrations were recorded in this study with values of 43.4 µg gm-1 for arsenic and 110 µg gm-1 for chromium. These results agree with the EMAP findings. Data published by Saupe *et al*. (2005) also indicated that concentrations of antimony, arsenic, chromium, copper, mercury and zinc were relatively elevated in the inner Kachemak Bay. The National Status and Trends Mussel Watch Program has monitoring sites in southeast Alaska and the Gulf of Alaska (Kimbrough *et al.* 2008). Compared to the 1995-1997 Mussel Watch sediment data from Prince William Sound, the concentrations of metals in Kachemak Bay had similar ranges with the exception of mercury, which was relatively elevated in Kachemak Bay (Figure 47).

Within Kachemak Bay there were some spatial differences. Relative to the other strata, most of the metals in Homer Harbor were elevated although some spikes were recorded at isolated sites in the mudflats (Table 6). Fine-grained sediment has a high surface to volume ratio. Thus, it has the ability to sequester higher concentrations of particle reactive elements through adsorption. Homer Harbor is a depositional environment with a high percentage of fine grain sediment. It is also a center of concentrated vessel activity

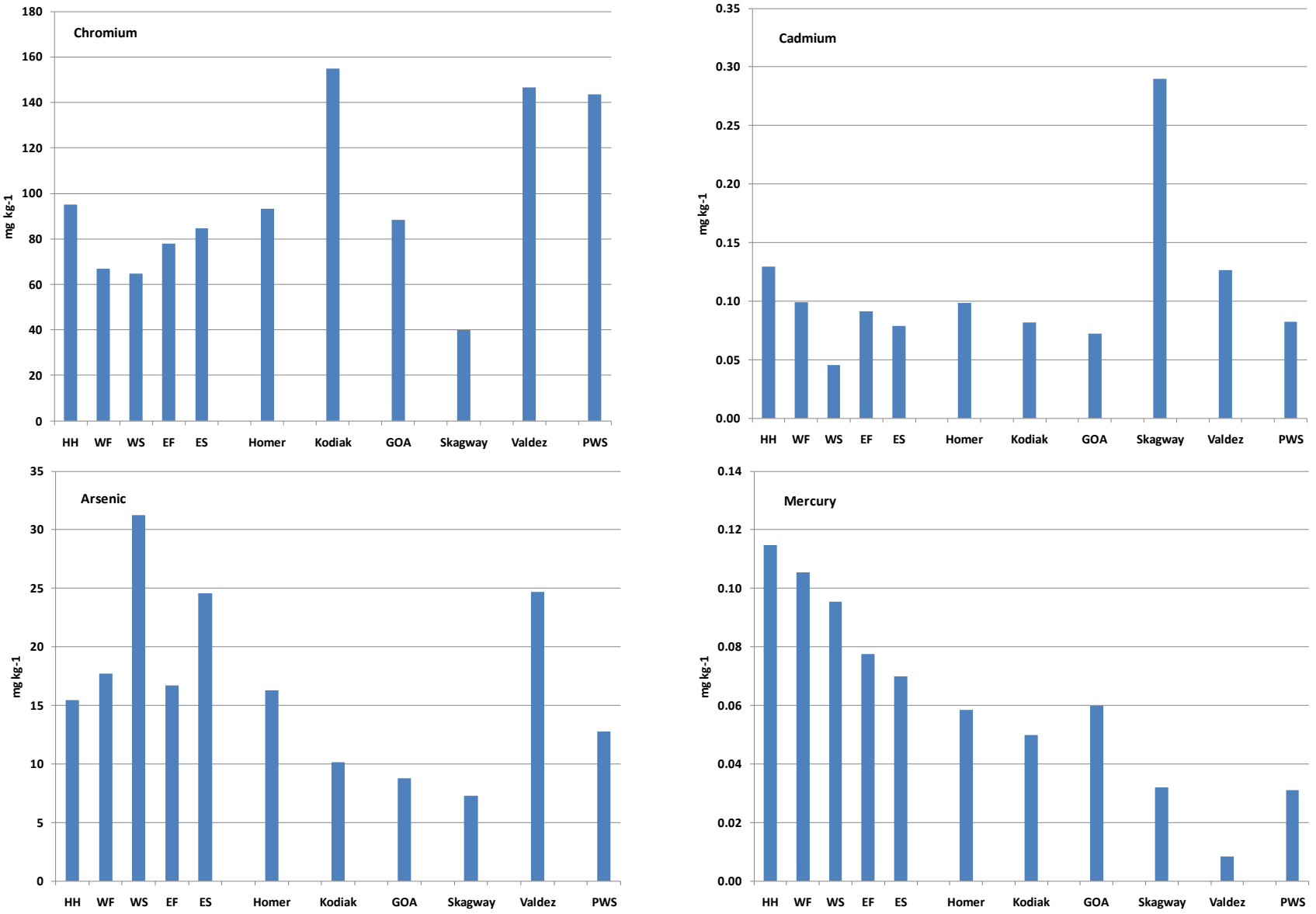


Figure 47. Selected metals sediment concentrations from the present study and averaged Mussel Watch data from southern Alaska. (Homer = Homer spit; GOA = Gulf of Alaska; PWS = average of 5 sites in Prince William Sound)

and maintenance which undoubtedly is a source of metal contamination. The eastern and western segments of the bay revealed that concentrations of most trace metals and some major elements, including aluminum, were relatively higher in the eastern strata than the western strata. Thus, metals distributions in Kachemak Bay are not only influenced by the physiographic characteristics of the sediment, but are also influenced by proximity to river discharge in the bay. Concentrations of aluminum, lead, chromium, copper and mercury were found to be elevated in the eastern area near the head of the bay, while iron, cadmium and silver concentrations were higher in the western area that encompasses Homer Harbor. Metals may be elevated in the system due to the extensive glacial runoff with the concomitant sediment load. Data presented in this study are total metals. The relative concentrations of total vs. bioavailable fractions are not available.

Mercury concentration, and particularly its biomagnification in aquatic food chain, is a concern in Alaska. In Kachemak Bay the source of mercury may be linked to both geological and anthropogenic sources. The Cook Inlet basin that encompasses Kachemak Bay and its watershed lies on top of large coal deposits (Flores *et al.* 2004). Coal has been mined for export and burned for electricity in the Homer region. Coal-fired power plants emit mercury, but its presence in Kachemak Bay sediments may be of atmospheric and/or geological source.

After data normalization to eliminate the wide variation between the major and trace element concentrations, a relatively uniform proportion among all measured elements is seen (Figure 16). A lack of uniformity or erratic concentration distribution of a specific metal may indicate an anthropogenic source of pollution. Plotting trace metals concentrations against major elements such as aluminum to normalize for the relative background input of minerals from the watershed can reveal associations between specific locations and contaminant input. For example, outliers in the relative distribution of cadmium, chromium, and mercury in Chesapeake Bay (Hartwell and Hameedi 2007) have been used to identify anthropogenic contamination in harbors and industrial zones in Baltimore and Norfolk. Some elements (e.g. Se) are less predictable based on elemental ratios because they are subject to more complex fate and transport dynamics due to

particle reactivity, valence states under varying redox conditions, biological uptake, and cycling, etc. Except for Port Graham, cadmium is generally low in Kachemak Bay (Figure 48). Arsenic does not appear to correlate with aluminum in Kachemak Bay. The fact that cadmium, mercury, chromium and selenium are found at much higher concentrations in Port Graham than in Kachemak Bay may be an indication of significant differences in geologic composition of the watershed as much as anthropogenic contamination. Similarly, the relatively low levels of arsenic, antimony, and lead may be the result of local geology. However, given the well documented harmful biological consequences of cadmium, mercury, chromium and selenium, a follow-up study to assess bioavailability and bioaccumulation in local biota may be warranted. Cadmium, while high relative to the rest of the system, is nevertheless well below the ERM and ERL. Mercury exceeds the ERL, but the high concentration is half of the ERM. Chromium is nearly at the ERM level.

Another aspect of the Kachemak Bay sediment system is revealed by plotting the concentration of the major elements of iron, silicon, and aluminum versus grain size. The ratios of these elements are indicative of the possible origin and transport dynamics present in the system.

There are few depositional areas in the shallow portions of Kachemak Bay or Port Graham as evidenced by the lack of deposits of very fine grained sediments (Figure 49). Consequently, the presence of organically enriched sediments available to accumulate hydrophobic organic contaminants in the system is limited. There were only four stations that had greater than 80% fine grained sediment, and three of these were in Homer Harbor. The fourth was station EF4, located in the glacial outflow stressed area. This was the same station that exhibited significant toxicity and elevated metals. The deeper areas of Kachemak Bay may contain more fine grained material than the shallows. (Samples from the deeper areas collected in 2008 in collaboration with CIRCAC will resolve this question.) At the other extreme, Kachemak Bay does not have coarse grained deposits composed of silicate sands despite the continuous input of grit contained in the glacial till. Inner Kachemak Bay is not receiving coarse, well mixed sands from Cook Inlet

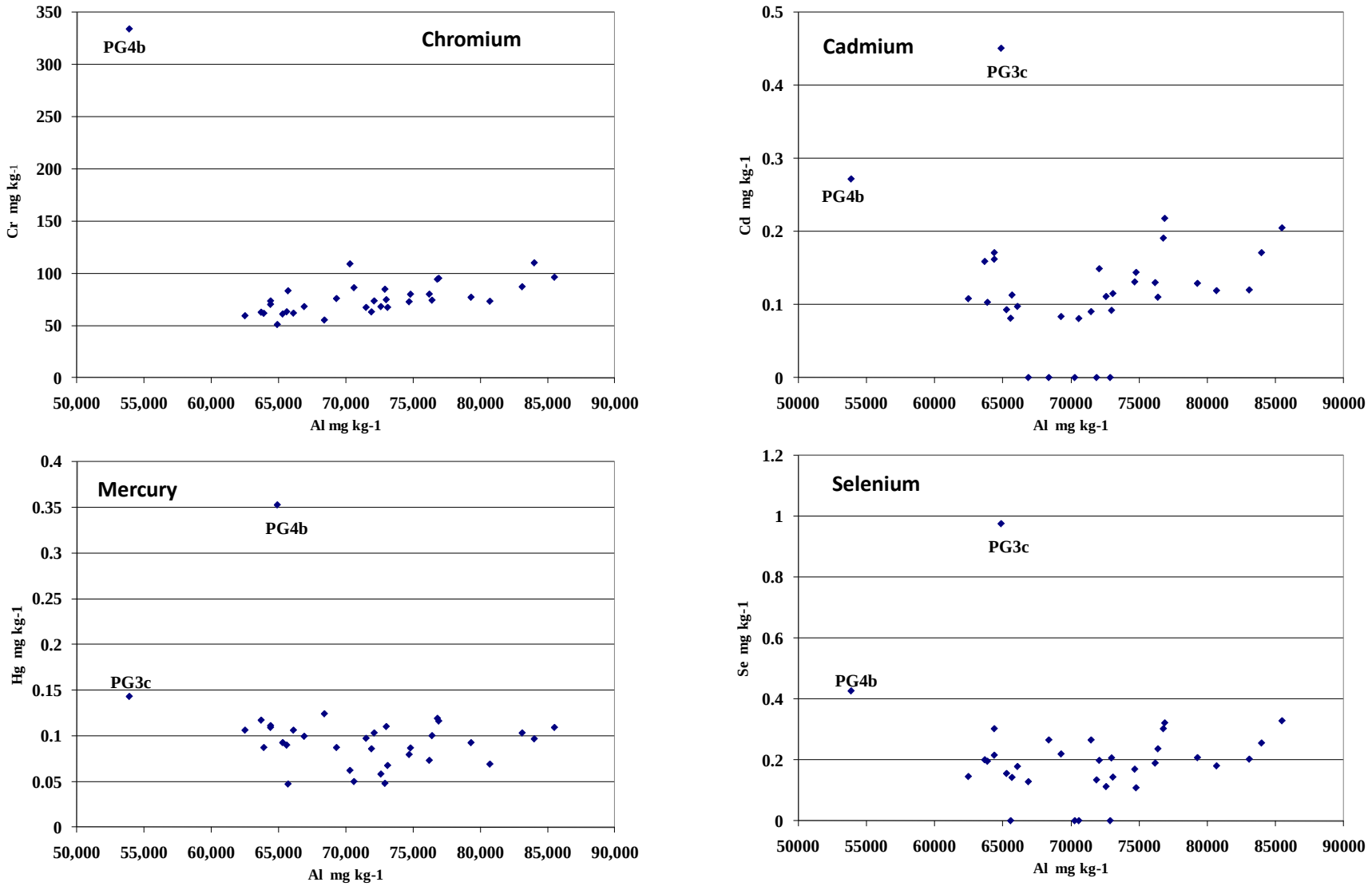
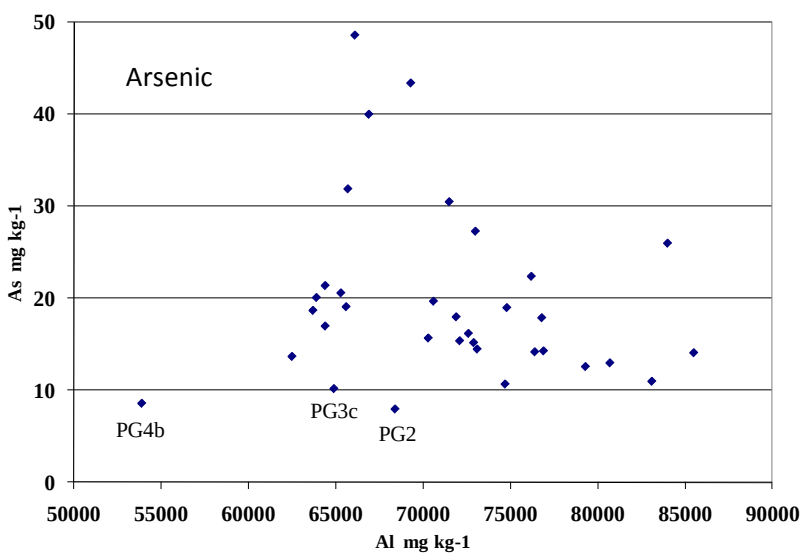
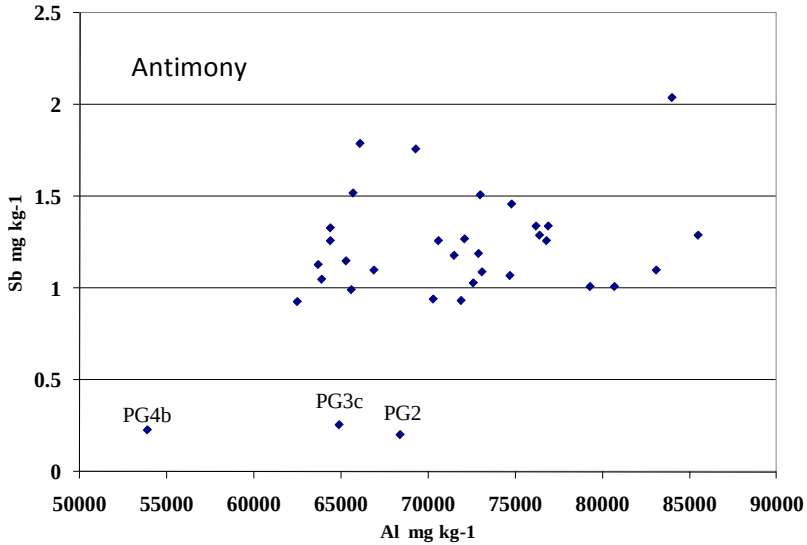


Figure 48. Plots of chromium, cadmium, mercury, and selenium (mg kg-1) as a function of aluminum concentration in Kachemak Bay sediments. Selected stations in Port Graham are denoted with station numbers. Cadmium, mercury, chromium and selenium are found at much higher concentrations in Port Graham relative to Kachemak Bay.





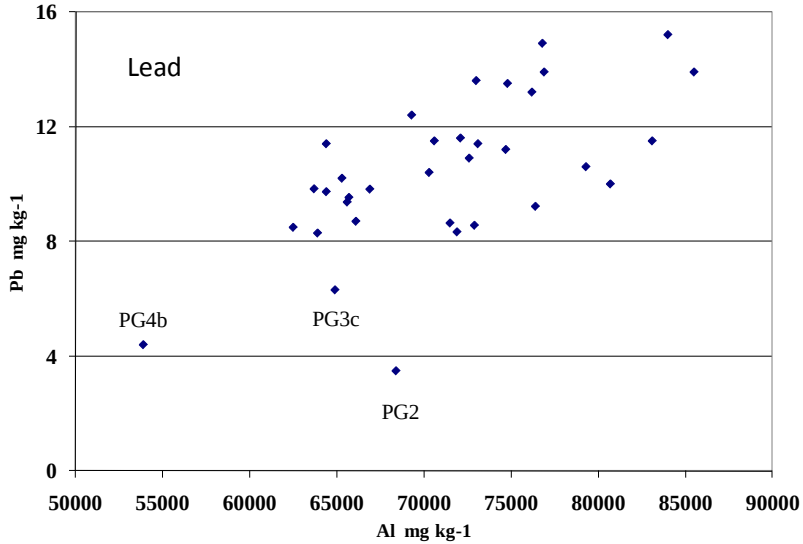


Figure 48(cont). Concentration (mg/kg) of lead, arsenic, and antimony, vs. aluminum (X axis) in Kachemak Bay and Port Graham Bay, Alaska. Port Graham stations are denoted with station numbers. Port Graham stations have lower concentrations.

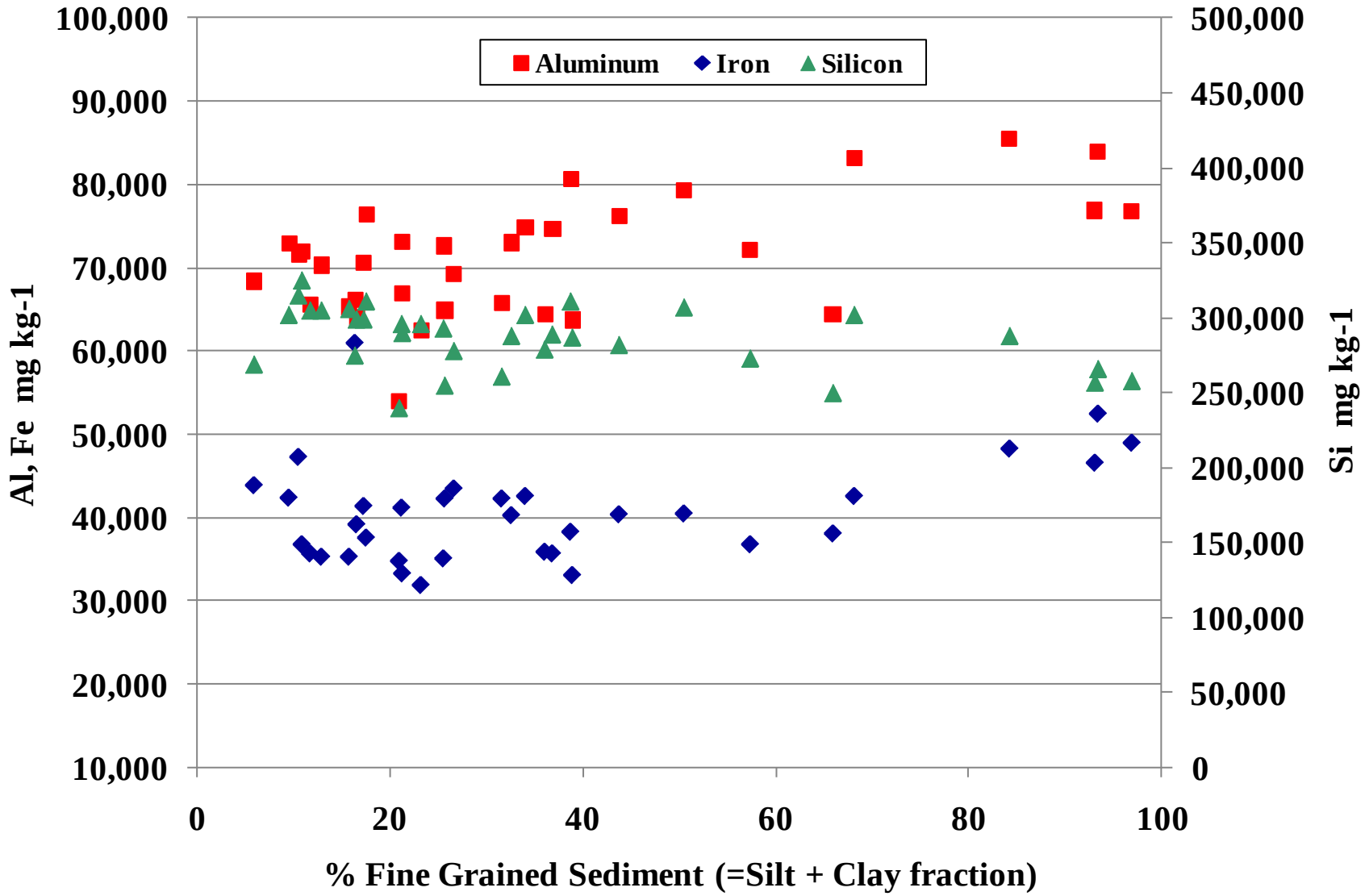


Figure 49. Plots of mg kg-1 aluminum, iron, and silicon vs. % fine grained sediment in Kachemak Bay (including Port Graham stations).

possibly due to the circulation pattern in the outer bay and/or the sill at the open mouth of the outer bay between Anchor Point and Point Pogibshi (Figure 2).

Further assessment of the sources of metal in the sediment of the bay was examined based on results of the correlation analysis among metals, and between metals and sediment parameters (grains size and %TOC). In addition to the grain size correlation, inter-metal positive correlations including those between aluminum and several elements (Table 7) were clear indication of natural sources. In Alaska, strong positive correlations between metals and the fine fraction of sediments are usually linked to materials transported by glacial melt (Saupe *et al.* 2005).

Thus, likely sources of metals in Kachemak Bay are natural bedrock weathering and material transported from mountains by rivers and streams of glacial melt water. Outside of the harbor, anthropogenic inputs are negligible as human population density is low and no large scale industrial activities exist in the region. However long range atmospheric transport is generally considered as a nonpoint source of air-born contaminants in the arctic environment (Arctic Monitoring and Assessment Program , AMAP, 2005). Thus transboundary air pollution may contribute to the overall metals concentration in the region to some extent.

Relative to regional sediment assessment data from EMAP (Saupe *et al.* 2005) and Mussel Watch (1995-1997), concentrations of metals in Kachemak Bay were within the regional averages. Mercury appeared to be elevated compared to the Mussel Watch 1995-1997 data from Prince William Sound, but levels are very low in the scale of NOAA Sediment Quality Guidelines (Appendix A). There are no Alaska State criteria for sediment quality. While some concentrations of metals were at or above the ERL values, overall sediment quality in Kachemak Bay could be qualified as good because virtually all metals were well below the ERM values (Appendix A). This demonstrates that Kachemak Bay is a fairly pristine environment with low levels of anthropogenic metal contamination.

4.3 Concentration and distribution of organics

Low level residues of PAHs, PCBs, butyltins, and pesticides were detected throughout the study area. In general, concentrations of organic compounds in the bay displayed similar spatial distribution patterns. Concentrations in Homer Harbor were elevated relative to the rest of strata (Figure 17). In most cases, the concentrations of organic compounds were strongly influenced by the sediment grain size and TOC. Positive correlations were recorded between sediment grain size and virtually all organic contaminants except PCBs and HCH (Table 9).

There are no reliable records of pesticide use in the Kachemak Bay area and it is unknown if DDT and the other pesticides detected there were of local origin or not. The presence of these chemicals at concentrations above detection limits in a relatively remote and sparsely populated area like Kachemak Bay highlight their environmental persistence and the possible contribution of long range atmospheric transports (AMAP 2005). Chlordane and the related cyclodienes, and DDT have accumulated in the fine grained, organically enriched sediments in Homer Harbor. Their concentrations in the open bay are very low. The HCH concentrations do not follow that pattern, but tend to accumulate in the intertidal sediments as opposed to the harbor or other subtidal areas. PCBs may be linked to long range atmospheric transport as well, but the elevated concentration off Millers Landing area indicates a local source(s).

The presence of butyltins in the harbor is likely linked to the use of antifouling paint applied to boat hulls. Cleaning boat hulls, the sloughing paint chips from hulls, and the slow release from the paint into the water increases ambient environmental levels. Though the U.S. severely restricted the use of tributyltin in 1988 for use on boats less than 25 m in length, the chemical persists in the environment. The presence of butyltins in Kachemak Bay, especially in the harbor area, is the result of past and present anthropogenic application of tributyltin-based paint on recreational and commercial boats, and uncontrolled runoff from power washing hulls that falls directly into the harbor (Figure 50).

Figure 50. Grids used for boat hull cleaning and maintenance operations in Homer Harbor.

Of greater interest in the region is the level and distribution of PAHs. In south central Alaska, the presence of PAHs in coastal and estuarine environment is often linked to the Exxon Valdez oil spill. Sources of PAHs are both petrogenic and pyrogenic. Petrogenic PAHs originate from natural releases from petroleum and coal deposits, or spills. Pyrogenic PAHs are formed as a result of combustion of organic materials such as fuel, trash, or wood.

The relative proportion of low and high molecular weight PAHs and the distribution of parent PAHs versus their alkyl homologues have been used as indicators to discern among sources of PAH contamination (Zeng and Vista 1997, and Baumard *et al*. 1998).

Usually, high proportions of low molecular weight PAHs are associated with oil and petroleum releases (petrogenic source). A high proportion of high weight PAHs is often linked to combustion by-products and/or long-term weathering. However, outside the harbor, by far the largest component of PAHs was perylene. This is a natural by-product of the breakdown of terrestrial plant material (NRC 1985). So, the contribution of anthropogenic PAHs in the bay is extremely limited. There was a small amount of pyrene detected at most locations, probably indicating atmospheric drift of exhaust fumes from diffuse sources. Inside Homer Harbor, and to some extent at Port Graham, the sediment has a typical signature of oil and fuel spills, and exhaust from boat engines. Even in the harbor, the total concentrations are relatively low however, being below the ERL guideline. This suggests that concentration of PAHs alone is unlikely to cause sediment toxicity across the study area.

The aliphatic signature is also consistent with this interpretation. The alkanes are dominated by odd numbered, high molecular weight compounds, indicative of terrestrial plant material input (NRC 1985; Colombo et al. 1989). In Homer Harbor and Port Graham, the odd:even ratio, total alkanes:n-C_{16}, and low weight:high weight ratios all indicate contribution of spilled oil and fuel to the systems relative to the Kachemak Bay sites. The highest CPI value (indicative of hydrocarbons derived from vascular plants) was at station WF6 which is in the vicinity of terrestrial stormwater discharge from the

Homer area. The unresolved complex mixture was much higher in Homer Harbor than all other locations. This is a characteristic of 'weathered' petroleum (NRC 1985) and may be another indication that Homer Harbor is a sink for organic contaminants due to the fine grained nature of the sediments and relatively low flushing due to the restricted entrance.

Relative to regional sediment data from the 1995-1997 Mussel Watch stations, concentrations of PAHs in Kachemak Bay were relatively higher than the others with the exception of the station near Skagway in the eastern panhandle (Figure 51). Excluding perylene from the summed concentrations does not alter this relationship. However, it is important to recognize that the Homer stations are the only locations in the data set that are specifically located in an active harbor. All the other sites are away from harbor activity and reflect ambient background conditions. Outside Homer Harbor, Kachemak Bay organic contaminant concentrations in the sediments are comparable to other locations in the Gulf of Alaska. The harbor was the only place where TBT was detectable. The explanation for PAH concentrations in the fjord where Skagway is located is not as straight forward. It is at the head of a highly constricted system where flushing may not be efficient. The DDT concentrations may also be an example of the consequence of this lack of flushing, as it is assumed there are no sources of DDT in the watershed beyond atmospheric deposition.

A better comparison of data sets is a contrast with other Bioeffects Project's sediment data. Calculating the ERM quotient for all chemicals from a variety of locations and plotting them on a scale of 1-100 reveals the relative contamination levels of the locations. Figure 52 shows the relative position of Kachemak Bay, Port Graham, and Homer Harbor in relation to several other systems (Hartwell et al. 2001; Hartwell and Hameedi, 2007; Hartwell et al. 2007; Lauenstein and Kimbrough 2007; Long et al. 1995). ERM quotients for Delaware, Chesapeake, and Massachusetts Bays are derived from open water sites away from harbors and tributaries, and are thus comparable to Kachemak Bay and Port Graham sites. The harbor site's ERM quotients are derived from sampling in strata specifically within commercial harbor areas and are thus comparable to Homer Harbor. While the Homer Harbor ERM quotient is far below the

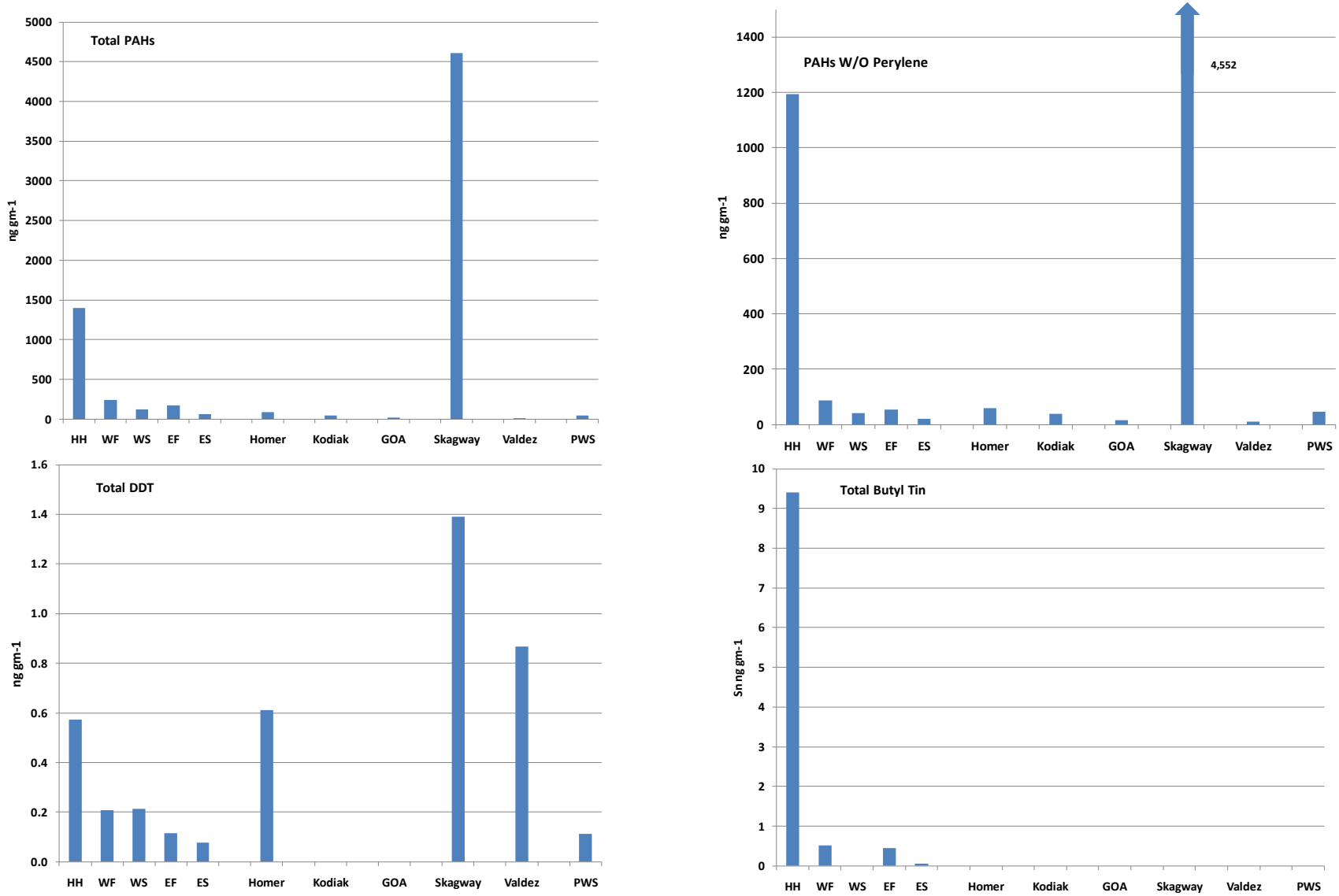


Figure 51. Selected organic compound sediment concentrations from the present study and averaged Mussel Watch data from southern Alaska. Butyl tins are expressed as ng gm-1 Sn. (Homer = Homer spit; GOA = Gulf of Alaska; PWS = average of 5 sites in Prince William Sound).

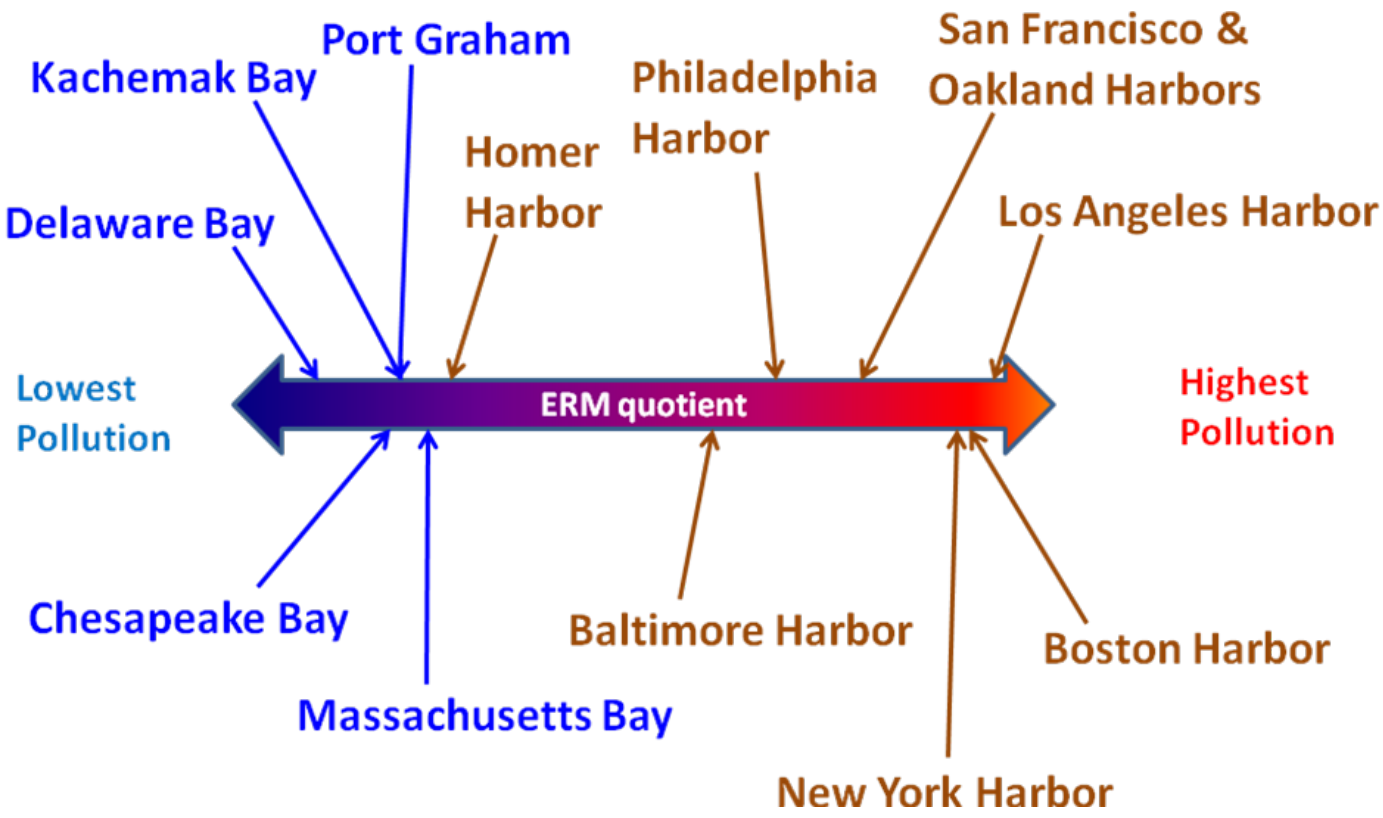


Figure 52. Distribution of ERM quotients in Kachemak Bay, Port Graham, and Homer Harbor relative to open water reaches of other bays, and large ports around the United States.

other harbors, the other harbors are in large metropolitan areas with heavy industry and commercial shipping facilities.

4.4 Benthic Community Assessment

Benthic community analysis indicates the primary influences on community distributions are depth and proximity to the outflow from the Fox and Bradley Rivers. On top of cosmopolitan species that are widespread throughout the bay, there are distinct biological communities found in different portions of the bay. The intertidal habitats contain species assemblages that are dissimilar to those found in the subtidal habitats. Both the intertidal and subtidal habitats each contain distinct species assemblages that segregate themselves into turbid and clear water habitats. Thus, the benthic communities are distributed in a matrix of depth and proximity to the Fox River discharge. The eastern-most region of the Bay in the vicinity of the Fox River mouth is stressed by glacial discharge and the associated high sediment load regardless of depth. This region is characterized by only a small subset of tolerant cosmopolitan species. One site in Homer Harbor also appears to be stressed, based on the paucity of species found there. This was the inner-most location sampled in the harbor.

These results are consistent with species distribution patterns seen in other systems. The Kongsfjord and Hornsund fjords on Spitsbergen Island above Norway have been studied extensively by European researchers as reference areas for climate change impact studies. In Kongsfjord, several researchers have seen gradients of increasing species diversity and abundance away from glacial fronts (Kendall-Widdicombe and Weslawski 2003; Wlodarska-Kowalczuk and Pearson 2004, Holte *et al* 2004). Gradients of increasing diversity with increasing depth have also been observed (Holte *et al.* 2004, Laudien *et al*. 2007). Changes in dominant feeding mode are coincident with depth gradients and distance from glacial input (Holte *et al.* 2004; Wlodarska-Kowalczuk and Pearson 2004, Bick and Arlt 2005, and Laudien *et al.* 2007). Food availability would be expected to be reduced near glacial input due to reduced primary production and burial of organic matter by high sedimentation rates. The combined stresses of physical disturbance from ice scour and excessive sedimentation with the concomitant limitation in food availability

offer habitat to a limited number of tolerant species. They tend toward surface suspension feeding modes and high reproductive potential (r-strategy reproductive mode). Near glacial input, the dominant species also have a high tolerance to physical disturbance. Wlodarska-Kowalczuk and Pearson (2004) reported that Polychaete species such as *Chaetozone setosa* and other Cirratulids which are tolerant to physical disturbance are present near the glaciers, whereas species such as *Heteromastis filiformis* which are tolerant to chemical stress but not necessarily tolerant of physical stress are not. They also hypothesized that sediment stability had as much to do with species distributions as feeding mode. Ice scour will directly destroy benthos, change seafloor topography and bottom currents, and resuspension potential of the re-worked sediments. Bick and Arlt (2005) also observed a higher proportion of juveniles in intertidal areas compared to subtidal habitats, indicating the deeper areas were a source of juvenile recruits. Laudien *et al*. 2007 also reported depth gradients in species composition and the shallower communities tended toward pioneer species. Blanchard *et al*. (2002) reported that benthic communities destroyed by dredge spoil disposal in Port Valdez required more than 2.5 years to recover to a pre-disposal community.

Kachemak Bay does not have glacial fronts directly in the bay. However, due to the extreme tidal range, the extensive tidal flats are subject to annual ice scour during the winter (Gatto 1982). The discharge of sediment laden water into the eastern part of the bay is also seasonally stressful. A predicted consequence of global warming trends is an increase in sediment input to Arctic bays as glacial melting accelerates and a decline of benthic biodiversity due to an increase in mineral sedimentation from meltwaters (Wlodarska-Kowalczuk and Weslawski 2001). The same impacts of physical stress and food availability seen in Kongsfjord are present in Kachemak Bay. The abundance, diversity, and feeding mode gradients in Kachemak Bay are driven by the same physical characteristics, mediated by depth and flow.

The intertidal areas in Kachemak had unexpectedly low TOC. The bluffs along the shore have multiple layers of coal seams (Figure 53). Coal mining in the region was a substantial industry in the past and today, gathering coal for fuel along the beach is not uncommon. The organic matter contributed to the system from exposed coal deposits is

either being diluted or buried by glacial runoff, or flushed away by tidal currents. Shaw and Wiggs (1980) examined hydrocarbon sources in tissues of animals on Homer Spit with differing feeding modes. They concluded that herbivorous limpets are exposed to petroleum hydrocarbons via ingestion of spilled fuel oil on the surface coating of the substrate. Filter feeding mussels were exposed to petroleum hydrocarbons from the water column, whereas deposit feeding clams were exposed to coal-derived hydrocarbons. Significantly, samples from Kasitsna Bay, on the south side of Kachemak Bay, did not exhibit exposure to either petroleum or coal hydrocarbons, regardless of feeding mode.

This study did not assess deeper areas of Kachemak Bay. Beyond the 10 fathom isobaths the bottom drops off more steeply than the shelf to a deeper basin. Samples taken in 2008 may illustrate a more diverse community than the shelf. Monitoring in Port Valdez in neighboring Prince William Sound reveals a very similar species distribution on shelf stations and greater diversity at depth (Blanchard *et al.* 2002).

There were some significant differences between species distributions in Kachemak Bay and Kongsfjord. Kendall *et al.* (2003) found Cirratulid polychaetes to be numerically dominant at locations close to Kongsbreen glacier where the habitat was disturbed by high sedimentation. In Kachemak Bay Cirratulids were notably absent from the glacial runoff stressed area. In fact, they were seldom found in the eastern strata at all. A Cirratulid (genus *Chaetozone*) was the dominant organism at Homer Harbor station #3, which is considered as a stressed site based on the paucity of species. This site would have had very low abundance as well were it not for a density of 12,625 Cirratulid worms per meter^2 at this location. This was the highest observed density at any location in the entire study area. Clearly the parameters that render the harbor and eastern end of the bay stressful are different.

Figure 53. Photograph showing multiple layers of coal seams along the northern shoreline of inner Kachemak Bay.

The various benthic community analysis methods (correlation, nodal analysis, PCA) yield consistent results. Spearman rank correlation results between benthic community and habitat parameters show a pattern that is driven by depth and proximity to glacial outflow as manifested by Secchi depth. Principal component analysis also divides the sampling stations into quadrants based on depth and water clarity. The latter is a proxy for proximity to the Fox River input. Grain size was also a significant factor, which was also related to Fox River input. The nodal analysis identifies distinct communities inhabiting different depth and water clarity habitats, as well as specific locations stressed by high turbidity and the extreme upper intertidal habitats. Principal component analysis plotted as nodal rather than stratum designation reveals a slightly different pattern (Figure 54). Subtidal sites are largely grouped on the upper right side, whereas the intertidal sites, stressed sites, and near-shore sites are in the lower left quadrant including some of the eastern subtidal sites. This implies that the central and western subtidal areas of the bay are areas with minimal forms of stress, either from glacial inflow or intertidal exposure. This may have implications relative to potential source areas for larvae and juveniles of benthic populations within the bay (Bick and Arlt 2005), and prime feeding grounds of higher predatory species. Normal territorial ranges of mobile or migratory resident species are more difficult to establish than for benthos. However, presumably the same stressor dynamics impacting the benthos would apply to species higher up the food chain, including managed species. Management actions should be tailored to knowledge where prime habitats are located within a system. Subsequent sampling in 2008 in the deeper portions of the bay in collaborations with CIRCAC may further refine the distribution of stressed and unstressed habitats. The Sediment Quality Triad triangular plot approach was not particularly revealing in this system. This is primarily because there were so few locations with significant contamination present, and consequently no contamination gradients to identify.

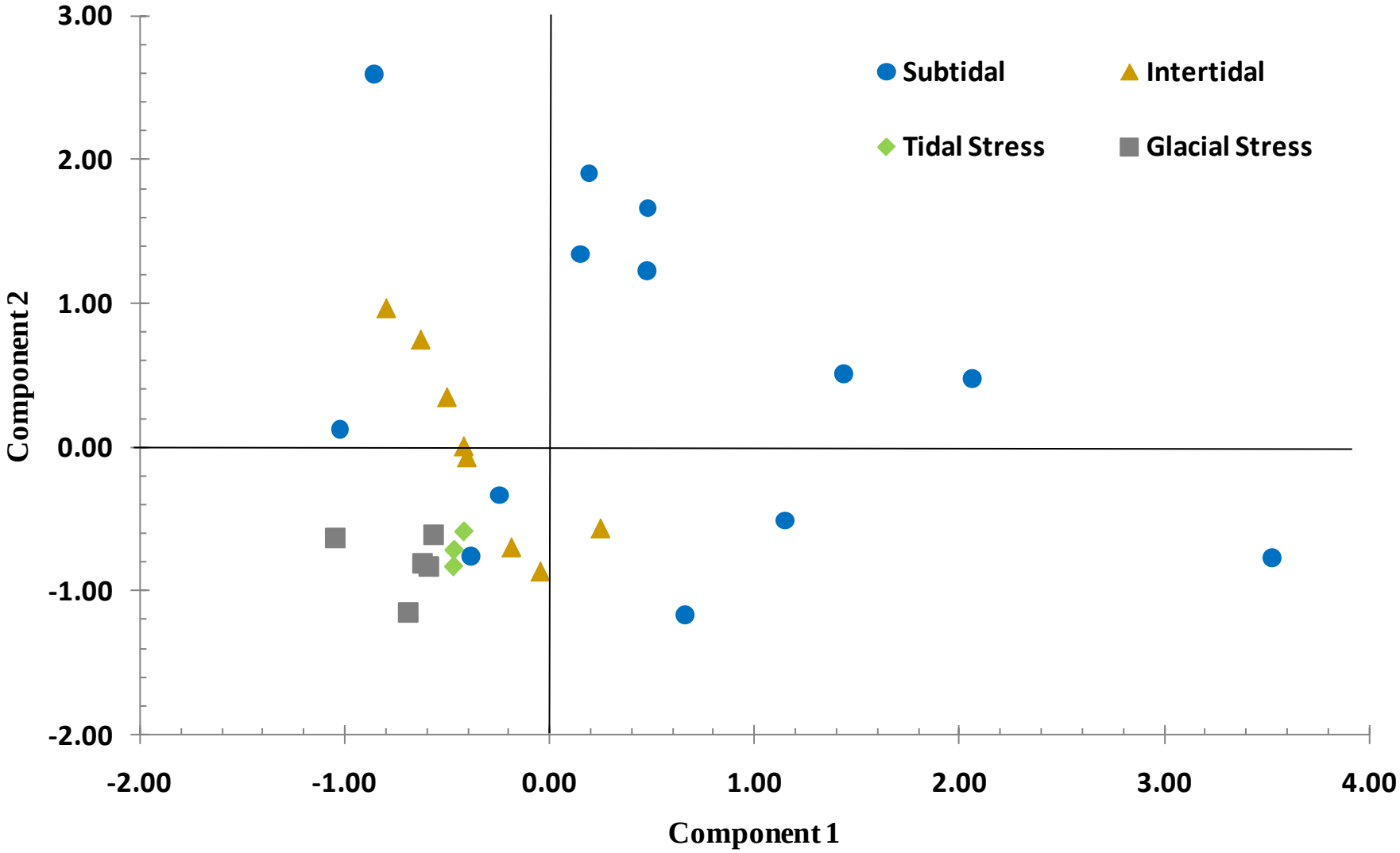


Figure 54. Principal component analysis of species abundance using nodal designations as the grouping criterion.

5. CONCLUSIONS

The objectives of this project were to 1) identify natural and anthropogenic stressors that influence habitat quality and affect infaunal community spatial distribution in inner Kachemak Bay; 2) provide chemical concentrations for a suite of trace metals and organic contaminants; and 3) produce a comprehensive taxonomic list and distribution of infaunal species in soft bottom substrates.

Organic contaminants, including PAHs, were shown to be relatively low in Kachemak Bay. There was no evidence of residual oil from past major spills. Concentrations were similar to other locations in the Gulf of Alaska. Homer Harbor sediments do contain elevated levels of pyrogenic and petrogenic PAHs relative to the open Bay, but concentrations were below acutely toxic levels. Concentrations of alkanes indicated a predominance of terrestrial sources of hydrocarbons. Tributyltin was found in Homer Harbor at levels that may begin to threaten sensitive species, but was not detected outside the harbor. Planned expansion of the harbor should include pollution control practices. Selected metal concentrations were found to be relatively elevated compared to other data collected in the region. Concentrations were below Sediment Quality Guidelines in all but one case. Metal concentrations are likely influenced by sediments from glacial meltwater. While trace metals and, to some extent, PAHs are naturally occurring chemicals in sediment, the presence of organic compounds of anthropogenic origin (e.g. synthetic pesticides) also indicate a low degree of contamination of the bay. With no significant known point source of contaminant discharge, the presence of manmade organic chemicals in the bay may result from non-point sources and/or long-range oceanic or atmospheric transport. The area appeared to be a healthy environment with a rich and biologically diverse benthic assemblage with more than 240 taxa recorded and abundances greater than 3,000 animals m-2 at most locations. The benthic communities in the eastern portions of the bay are impacted by glacial meltwater runoff and its associated sediment load but significant chemical toxicity was virtually absent. Species richness and diversity was lower in the eastern end near the Fox River input. Abundance was also lower in the east end of the bay, and in the intertidal areas near Homer. The

deeper subtidal areas in the western section of the bay are robust habitats for benthic communities and should be protected as they are likely to be an important source area for benthic species recruitment. Additional samples from the Port Graham area offered a useful contrast that illustrated a difference in metals concentrations due to local geology and hydrologic processes. Port Graham also contained a distinctly different benthic assemblage than the main bay. Depositional areas in Homer Harbor and Port Graham do accumulate low levels of harmful contaminants. This assessment was conducted only in the northern side of the inner Kachemak Bay, and an appraisal of sediment quality of the entire bay is warranted to characterize the entire inner bay. This study also produced a georeferenced chemistry dataset that characterizes sediment quality in northern Kachemak Bay available at http://www8.nos.noaa.gov/cit/nsandt/download/bi_monitoring.aspx.

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6. ADDENDUM – Additional Samples

6.1 Summary

In collaboration with the 2008 CIRCAC Integrated Cook Inlet Environmental Monitoring and Assessment Program (ICIEMAP, 2010), additional sediment samples were collected at five sites from the deeper portions of Kachemak Bay to supplement the NOAA data collected during the 2007 study. Samples were taken from areas deeper than 10fa (~ 18m) in the inner Bay, but excluded the fjords and embayments on the south side of the Bay. Separate samples were taken for an assessment of the benthic community and for analysis of a suite of organic and trace element contaminants. Chemical concentrations were contrasted to data from the shallow strata samples and sediment quality guidelines. The larger Cook Inlet study sieved benthos samples through a 1.0mm screen instead of a 0.5mm screen. The samples from Kachemak Bay were sieved through nested 1.0 and 0.5 mm screens to allow a comparison of the relative efficacy of the two techniques. Benthic community associations were assessed in relation to physical and chemical habitat parameters, and contrasted with communities in the shallower areas of the Bay.

The water column showed a small degree of stratification, particularly at the eastern end where a layer of fresher, turbid water from glacial meltwater was present at the surface. Bottom sediments were primarily fine grained material, with significant amounts of sand present at the west end where tidal currents are strongest, and to a lesser degree at the east end where sediments from glacial runoff enter the Bay.

Metals concentrations were elevated in the deep portions of the Bay relative to the shallow areas. Some of the increase were attributable to grain size differences, but selenium appeared to be accumulating in the deeper areas. Some metals exceeded threshold sediment quality guidelines, but only nickel exceeded the median effects guideline. Organic contaminants were slightly elevated above concentrations observed in shallow areas, but were well below concentrations in Homer Harbor. The mixture of PAHs and alkanes indicated negligible anthropogenic sources. Pesticides and PCBs were present at very low levels.

Processing methods for biological samples strongly impacted results. Sieving through 1.0mm mesh missed approximately 40% of the species and captures only half the abundance of a 0.5mm mesh screen. The deep benthic community was highly diverse and abundant. The community was dominated by polychaetes. The communities found in the shallow areas and the deep areas are distinctly different in terms of species makeup. Only 20-30% of the species were found in common. Unlike the shallow areas, the deep benthic community did not appear to be strongly influenced by geographic location because habitat parameters at depth do not appear to be strongly impacted by surface phenomena.

For further detailed interpretation of the 2008 Kachemak Bay data with respect to the overall Integrated Cook Inlet EMAP, the reader is referred to that report (Integrated Cook Inlet Environmental Monitoring & Assessment Program (ICIEMAP) 2010).

6.2 Methods

Sediment from five sites from the deeper portions of Kachemak Bay were collected in 2008 (Figure A.1) in collaboration with CIRCAC as part of the larger Cook Inlet assessment. The sampling design was also based on a stratified random site selection. The target area was defined as areas deeper than 10fa (~18m) in the inner Bay, but excluding the fjords and embayments on the south side of the Bay. Field sampling methods were exactly the same techniques as employed in the 2007 survey. Benthic infauna samples were sorted and taxonomy performed by the same laboratory as in 2007. Samples were taken for the same suite of organic contaminants which were analyzed by the same laboratory as 2007, except TBT, which was not measured in 2008. No toxicity samples were taken. In 2008, metals were analyzed at the Florida Inst. of Technology using comparable techniques as in 2007. The metals analyte list included barium, but did not include antimony, tin, or silicon.

A brief summary of the analytical methods for metals is provided here (Trefry pers. communication). Freeze dried sediment was used for analysis of all metals except Hg. Homogenized sediment and standard reference material (SRM) #2709, San Joaquin soil, issued by the National Institute of Standards and Technology (NIST), were totally digested in Teflon

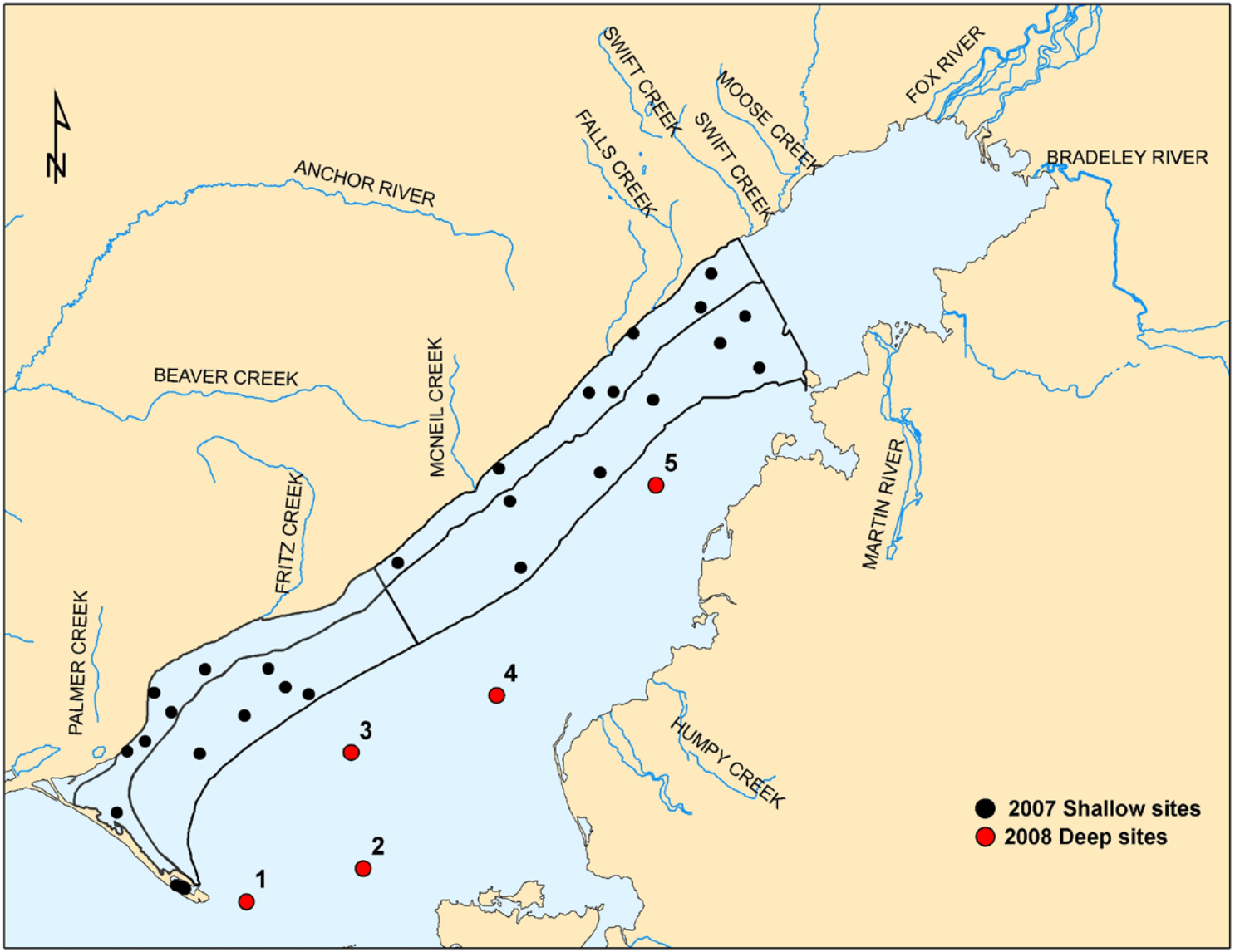

Figure A.1. Map of Kachemak Bay showing strata and site locations from the 2007 and 2008 studies.

beakers using concentrated, high-purity hydrofluoric acid (HF), nitric acid (HNO_3) and perchloric acid ($HClO_4$). Sediment samples and certified reference material (CRM) MESS-3, from the National Research Council (NRC) of Canada, were digested for Hg analysis by heating 2 to 4 grams of wet sediment in acid-washed, glass centrifuge tubes with 4 mL HNO_3 and 2 mL sulfuric acid (H_2SO_4). Sediment samples, reference materials, and procedural and reagent blanks were analyzed by flame atomic absorption spectrometry (FAAS) using a Perkin-Elmer Model 4000 instrument, cold vapor atomic absorption spectrometry (CVAAS) using a Laboratory Data Control Model 1235 Mercury Monitor, or inductively coupled plasma-mass spectrometry (ICP-MS) using a Varian Model 820-MS instrument with Collision Reactor Interface and SPS3 sample preparation system. Sample preparation and analytical methods used were based on U.S. EPA methods described for Series 7000 (FAAS), Series 7470 (CVAAS) and Series 6010A (ICP-MS) (U.S. EPA, 1991).

Two procedural blanks, two duplicate samples, and two matrix-spiked samples, and two portions of the SRM #2709 or CRM MESS-3 were prepared with each set of 40 samples. Routine QC measures included balance calibration, instrument calibration (FAAS, CVAAS, ICP-MS and CVAFS), matrix spike analysis for each metal, duplicate sample analysis, analysis of CRMs and SRMs, procedural blank analysis and standard checks. Analysis of complete three- to five-point calibrations and/or single standard checks alternated every 5-8 samples until all the analyses were complete. Matrix spikes were prepared for a minimum of 5% of the total number of samples analyzed and included each metal to be determined. Duplicate samples from homogenized field samples (as distinct from field replicates) were prepared in the laboratory for a minimum of 5% of the total samples for each set of sample digestions.

Chemical concentrations were contrasted to the shallower strata samples and to the ERL and ERM sediment quality guidelines. Box-plot statistics were used to assess concentration variations among strata for metals. Data were also normalized to the overall mean. This was applied to each element and to the summed organic contaminants (derived as the sum of individual compounds; e.g. total PCBs). Thus, all metals and organics can be contrasted against each other, or metals against organics in consistent units.

The larger Cook Inlet study sieved benthos samples through a 1.0 mm screen instead of a 0.5 mm screen. The samples from Kachemak Bay were sieved through nested 1.0 and 0.5 mm screens to allow a comparison of the relative efficacy of the two techniques. Nodal analyses were constructed for the benthos data, using all the data from the 0.5 mm sieved samples.

6.3 Results and Discussion

6.3.1 Habitat Conditions

Water quality parameters were comparable to conditions in 2007. Being deeper, the 2008 stations exhibited greater differences between the surface and bottom indicating a greater degree of stratification (Table A.1). Sampling in 2008 included turbidity measurements at the surface and bottom using a nephelometer (NTU). The turbidity measurements are consistent with the visual Secchi depth measurements, and also indicate a layer of more turbid water that is fresher and with lower dissolved oxygen at the surface in the eastern end of the bay. This phenomenon was not seen at depth.

Sediment grain size in the deep stations was primarily fine grained mud (Table A.2). Only station 1 near the end of Homer Spit contained a significant proportion of sand, although the eastern most site also contained 16% sand. TOC was relatively low compared with the shallower stations in Coal Bay, but was similar to the shallow sites in the eastern strata. Consistent with the shallow data from 2007, there was a gradient in TOC from east to west.

6.3.2 Trace Metal and Organic Chemical Concentrations

6.3.2.1 Metals

All metals concentrations were higher in the deep sites than in the average shallow sites except for arsenic (Table A.3). Concentrations were the same or higher in the deep sites as in the harbor sites except copper, and zinc. Box-plot statistics and Chi-square approximation tests indicated the deep portion of the bay accumulated metals to the same degree as Homer Harbor (Figure A.2). Selenium was significantly higher in the deep sites than anywhere else. Normalized metals concentrations plotted for all sites illustrated the relative concentrations of the trace elements between sites (Figure A.3) where each individual metal has been normalized to the study mean across all stations for the 2007 Kachemak Bay study. There does not appear to be a gradient from west to east in the deep sites. With the exception of selenium, the metals were more uniform in Kachemak Bay than at Port Graham (Figure A.4).

Table A.1. Water quality characteristics at Kachemak Bay deep stations in 2008.

	Depth	Secchi	Surface				Bottom			
Site	Meters	Feet	NTU	Temp	Salinity	DO	NTU	Temp	Salinity	DO
1	72.2	6.5	3.58	10.4	28.6	10.4	4.03	6.8	31.4	8.7
2	79.2	5.9	4.93	11.5	27.9	10.9	5.83	6.6	31.4	8.4
3	28.7	6	4.48	10.2	28.2	10.1	6.28	6.7	31.3	8.5
4	51.2	6.5	4.03	11.8	27.2	11.2	6.74	6.3	32.4	8.3
5	57.0	2.5	11.25	10.7	24.8	8.2	4.93	6.4	31.4	7.9

Table A.2. Sediment characteristics at Kachemak Bay deep stations in 2008.

Site	% Gravel	% Sand	% Silt	% Clay	% Fine Grain	% TOC
1	0.0	36.5	38.0	25.5	63.5	1.37
2	0.0	6.0	50.0	43.9	94.0	1.16
3	0.0	9.6	42.9	47.5	90.4	0.94
4	0.0	2.7	47.1	50.2	97.3	0.98
5	0.0	16.2	53.1	30.8	83.8	0.94

Table A.3. Metal concentrations (ug/g) at five deep sites in Kachemak Bay compared to average values from the shallow and Homer Harbor sites sampled in 2007. Aluminum and iron expressed as percent. (Average marine sediment concentrations from Salomons and Förstner, 1984)

Site	1	2	3	4	5	Shallow	Homer	Ave. Marine
Element						Mean	Harbor	Sediment
Ag	0.11	0.11	0.12	0.11	0.13	0.08	0.13	0.1
As	14.1	15.3	15.3	19.3	22.3	22.0	15.4	7.7
Ba	754.0	781.0	838.0	886.0	843.0			460.0
Cd	0.18	0.18	0.15	0.16	0.17	0.10	0.20	0.2
Cr	93.4	113.0	112.0	118.0	108.5	74.0	95.2	72.0
Cu	35.7	48.8	47.6	52.0	53.2	31.8	64.8	33.0
Hg	0.11	0.14	0.13	0.13	0.10	0.09	0.11	0.2
Mn	721.0	814.0	939.0	942.0	1115.0	639.7	685.0	770.0
Ni	41.2	51.8	50.6	54.1	50.1	37.8	45.7	52.0
Pb	11.8	13.1	14.5	14.8	14.1	10.6	14.2	19.0
Se	0.42	0.57	0.45	0.56	0.49	0.16	0.32	0.4
Zn	99.7	120.0	121.0	129.0	116.0	87.8	151.3	95.0
Al	7.9	8.3	8.4	8.0	8.6	7.0	8.0	7.2
Fe	4.4	5.3	5.2	5.5	4.9	4.0	4.8	4.1

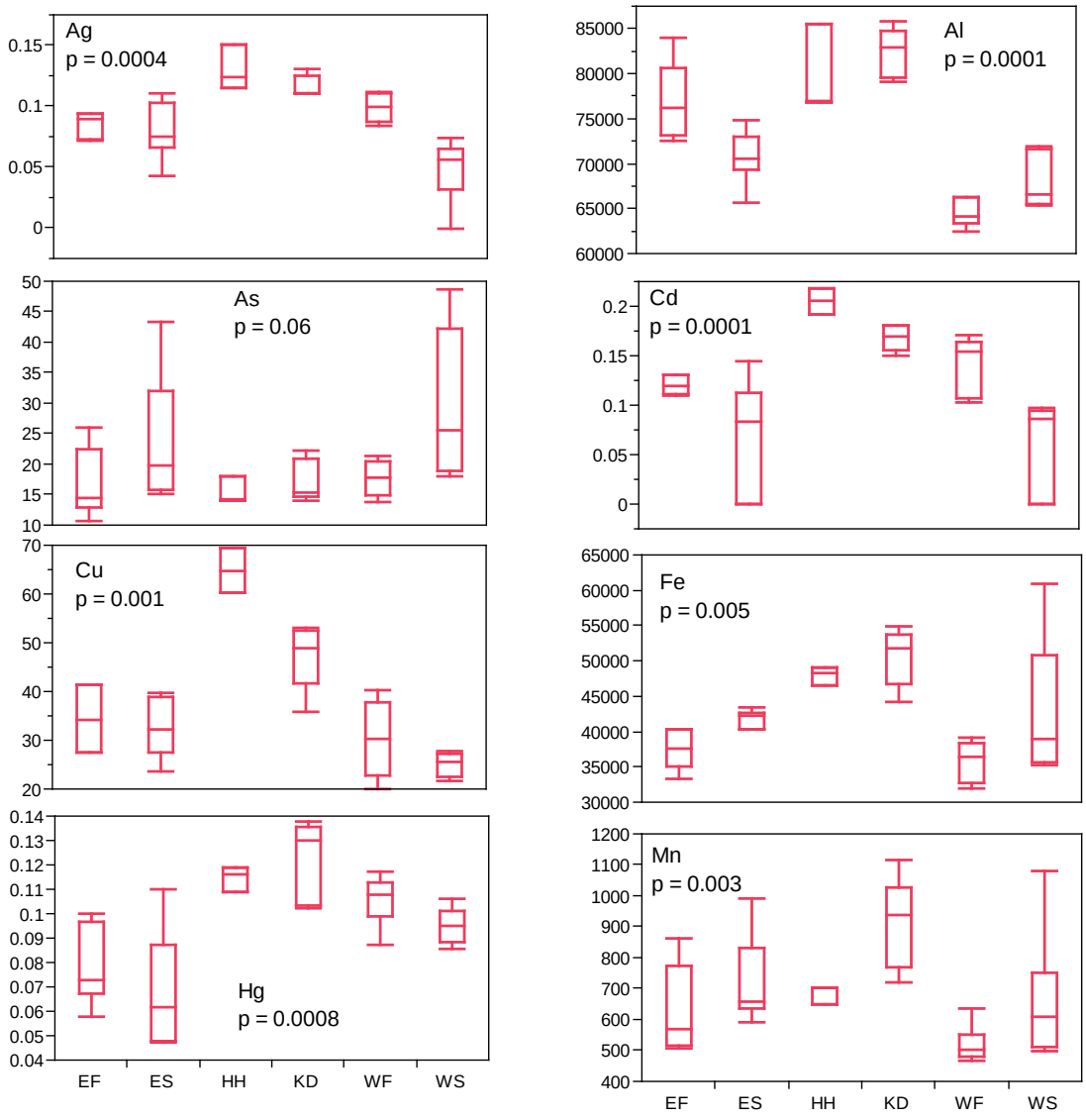

Figure A.2. Box-plot statistics illustrating metal distribution in each stratum. The p-value indicates the significant of nonparametric inter-stratum comparison based Wilcoxon test. The horizontal lines of the box illustrate the data range in each stratum as the 25th , median, and 75th percentiles, while the top and bottom whiskers of the box represent the 10th and 90th percentiles. (EF=Eastern flats, ES=Eastern subtidal, HH=Homer Harbor, KD=Kachamak deep, WF=Western flats, WS=Western subtidal)

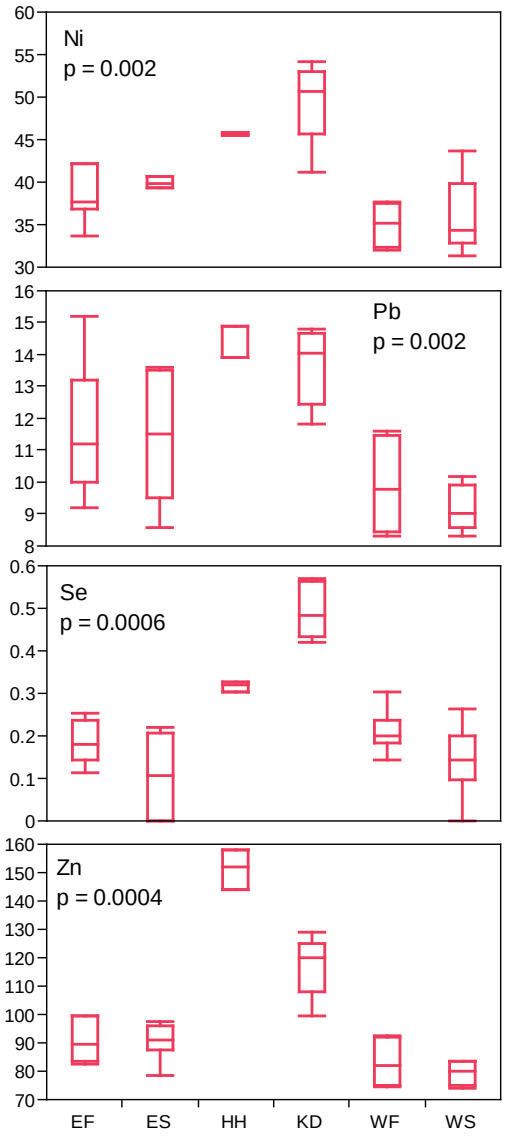

Figure A.2. (cont.) Box-plot statistics illustrating metal distribution in each stratum. The p-value indicates the significant of nonparametric inter-stratum comparison based Wilcoxon test. The horizontal lines of the box illustrate the data range in each stratum as the 25th , median, and 75th percentiles, while the top and bottom whiskers of the box represent the 10th and 90th percentiles. (EF=Eastern flats, ES=Eastern subtidal, HH=Homer Harbor, KD=Kachamak deep, WF=Western flats, WS=Western subtidal)

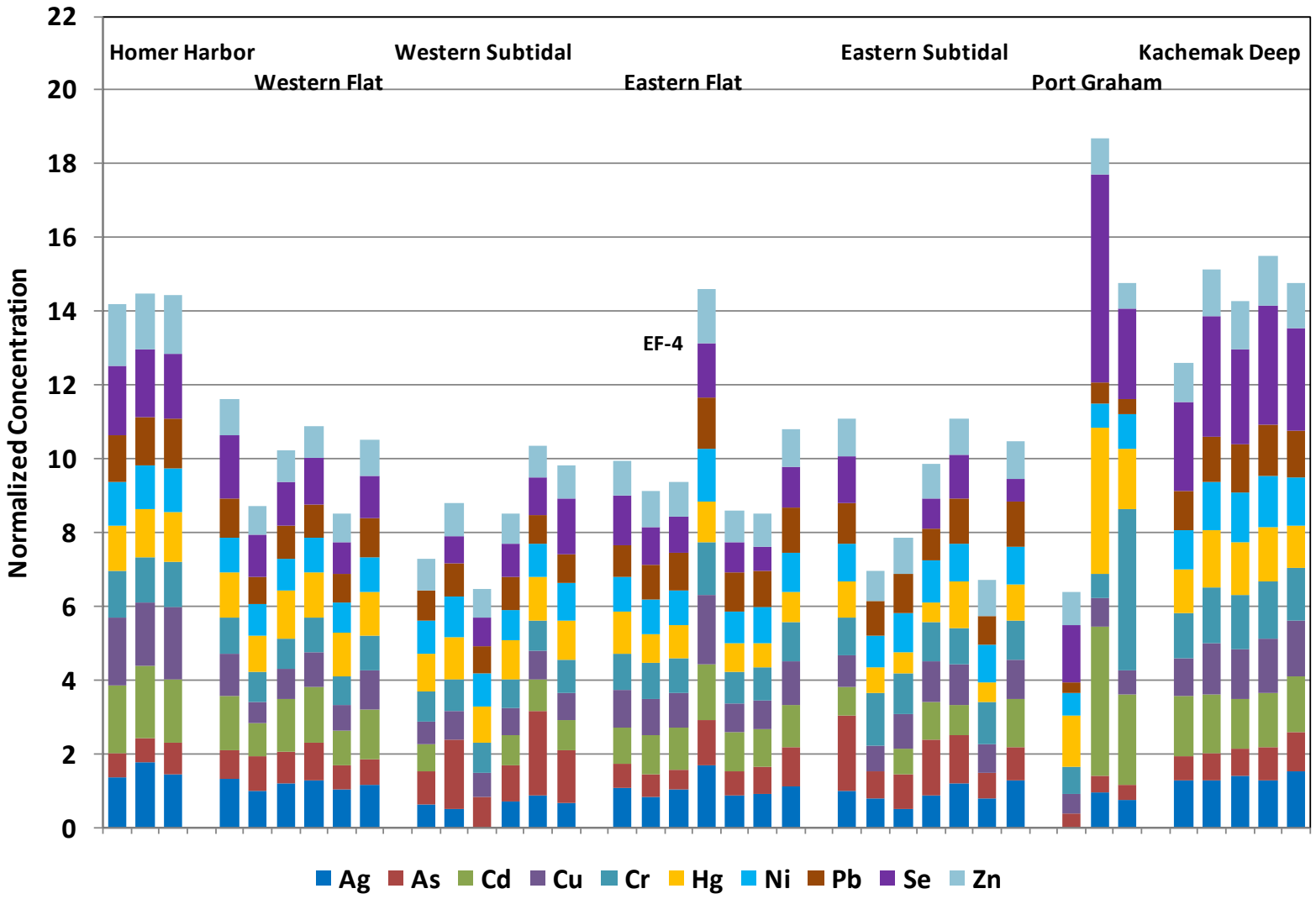

Figure A.3. Mean normalized concentrations for trace metals in Kachemak Bay and Port Graham sediments (each site concentration of each metal was divided by the overall mean of the respective metal). EF4 is eastern flat station #4.

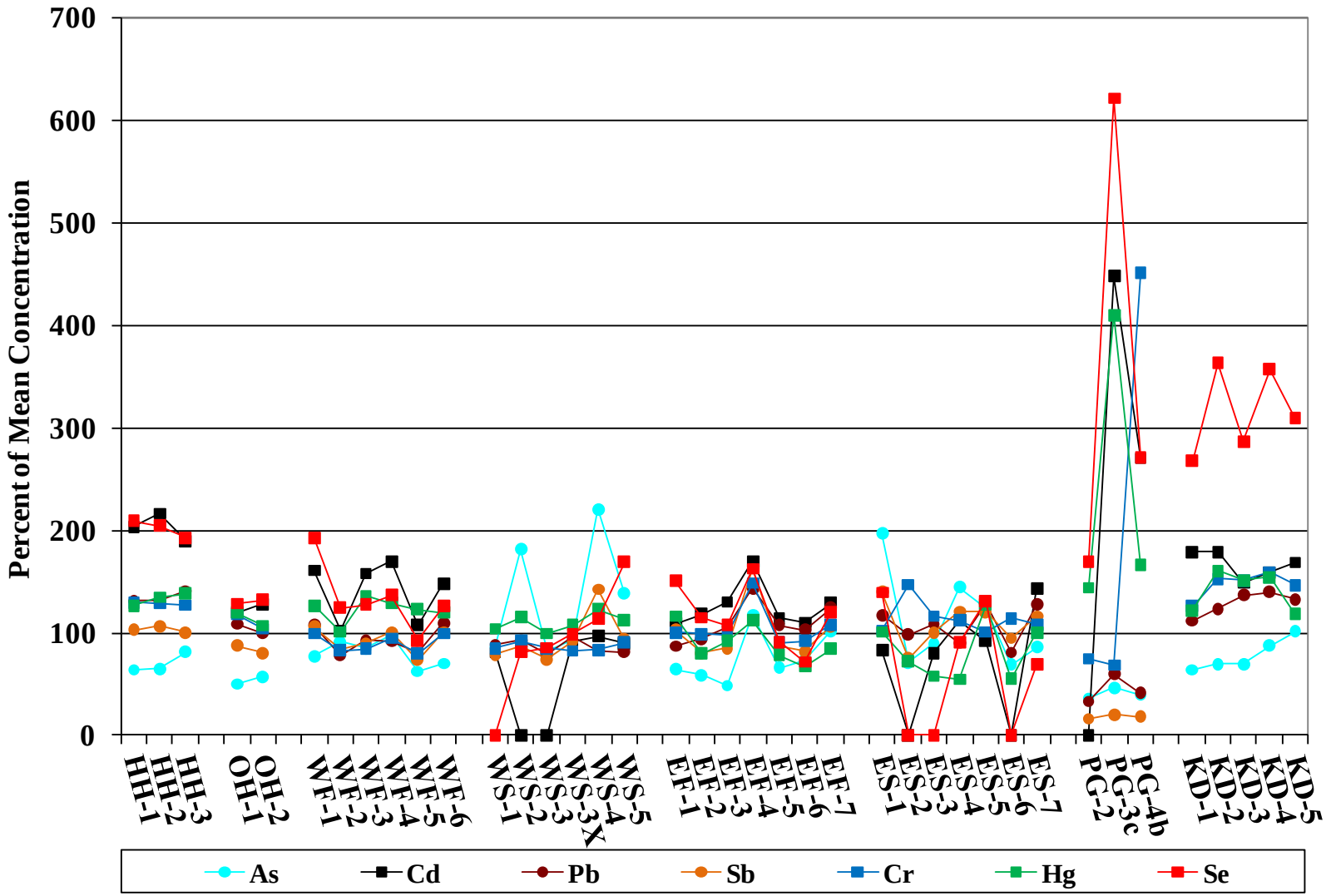

Figure A.4. Relative concentrations of seven elements in Kachemak Bay shallow stations, outside Homer Harbor, at Port Graham, and the deep sites. Concentrations are normalized to the overall mean concentration in the Kachemak Bay and expressed as a percentage.

6.3.2.2 Organic contaminants

The concentrations of total PAHs in the deep sites were slightly elevated relative to the shallow sites, but were well below the concentrations in Homer Harbor sediments (Figure A.5). As with the shallow sites, the distribution of individual PAHs did not indicate contamination from anthropogenic sources. Perylene was the dominant compound (Figure A.6). Straight chain aliphatic compound concentrations are shown in Table A.4. Total alphatic concentrations in the deep stations were slightly less than in the shallow stations. Total petroleum concentrations were less than half the concentrations seen in the shallower stations. There was a trend from low to high values going east to west. The highest individual alkane concentrations were n-C29 and/or n-C27 in the deep stations. Compounds with an odd number of carbons predominated over even numbered compounds but the ratio was slightly lower than in the shallow stations, outside of Homer Harbor. Higher molecular weight compounds predominated over low weight compounds. The carbon preference index (CPI) (Boehm et al. 1984) were well above 1.0. Petrogenic hydrocarbons generally have CPI ratios of approximately one while uncontaminated sediments and terrestrial plant residues have higher values as a result of much higher odd numbered hydrocarbons relative to even numbered hydrocarbons from these sources. The ratio of pristine to phytane was greater than one in all cases.

The mean concentrations of chlorinated organic contaminants are summarized in Table A.5. As with the shallow stations in 2007, all concentrations were uniformly low. The distribution of HCHs was unlike the other contaminants in that it was higher in the mudflats and in the deeper stations, and was absent from Homer Harbor (Figure A.7). However, most of the concentrations of individual cyclohexane compounds were at or below the detection limit (0.04-0.09 ng/gm). Concentrations of organic compounds normalized to the mean are plotted in Figure A.8. Consistent with the 2007 analyses, the 'mean' value used to normalize the data included only the data from the shallow sites. Because the 2007 data contained extremely low values for HCH (Table A. 5), the mean normalization exaggerates the relative significance of the 2008 HCH values. Concentrations of HCH were significantly higher in the deep sites (t-test p= 0.0287). However, the noteworthy question pointed out by the data is not how high the concentrations

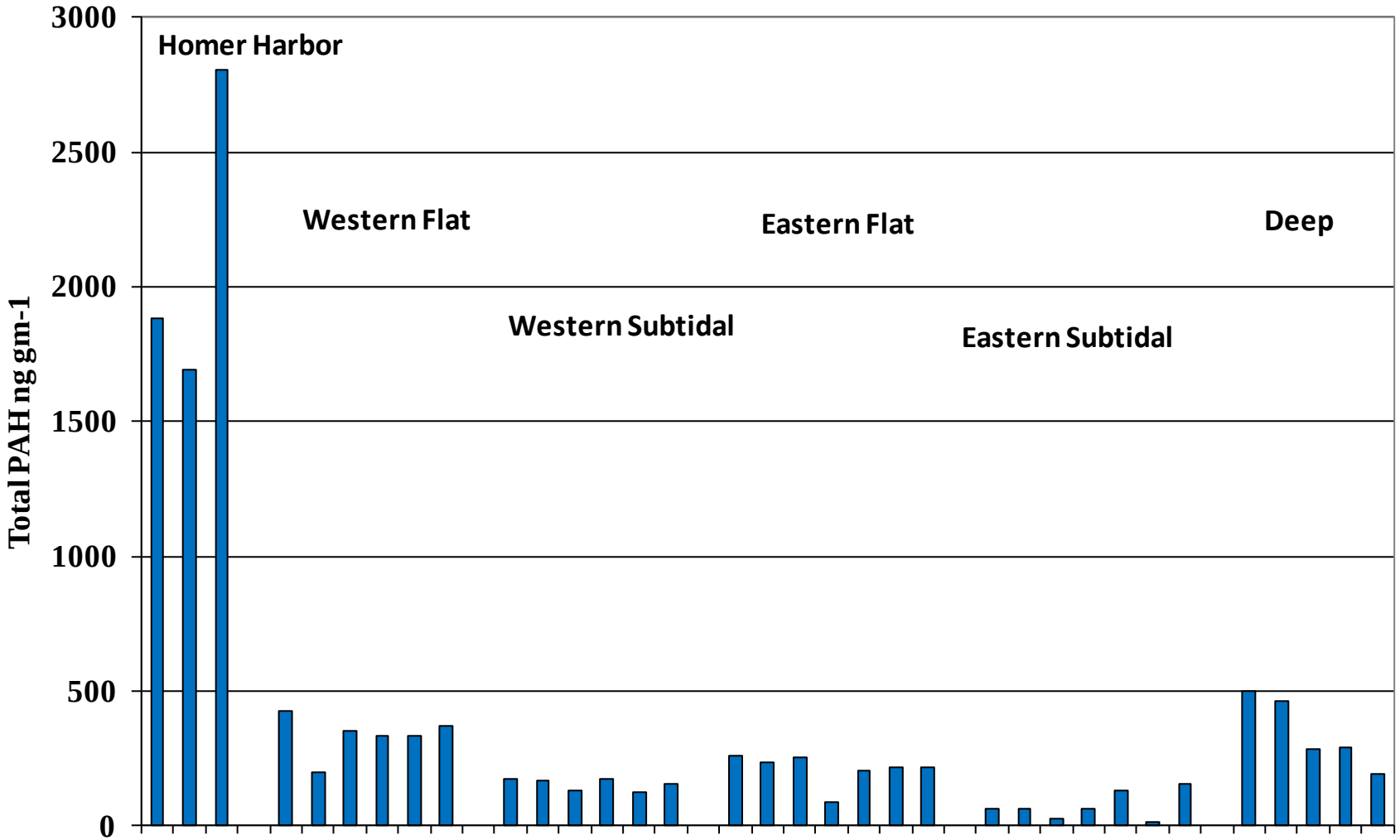

Figure A. 5. Distribution of total PAHs (sum of low and high molecular weight PAHs) in Kachemak Bay shallow and deep sites

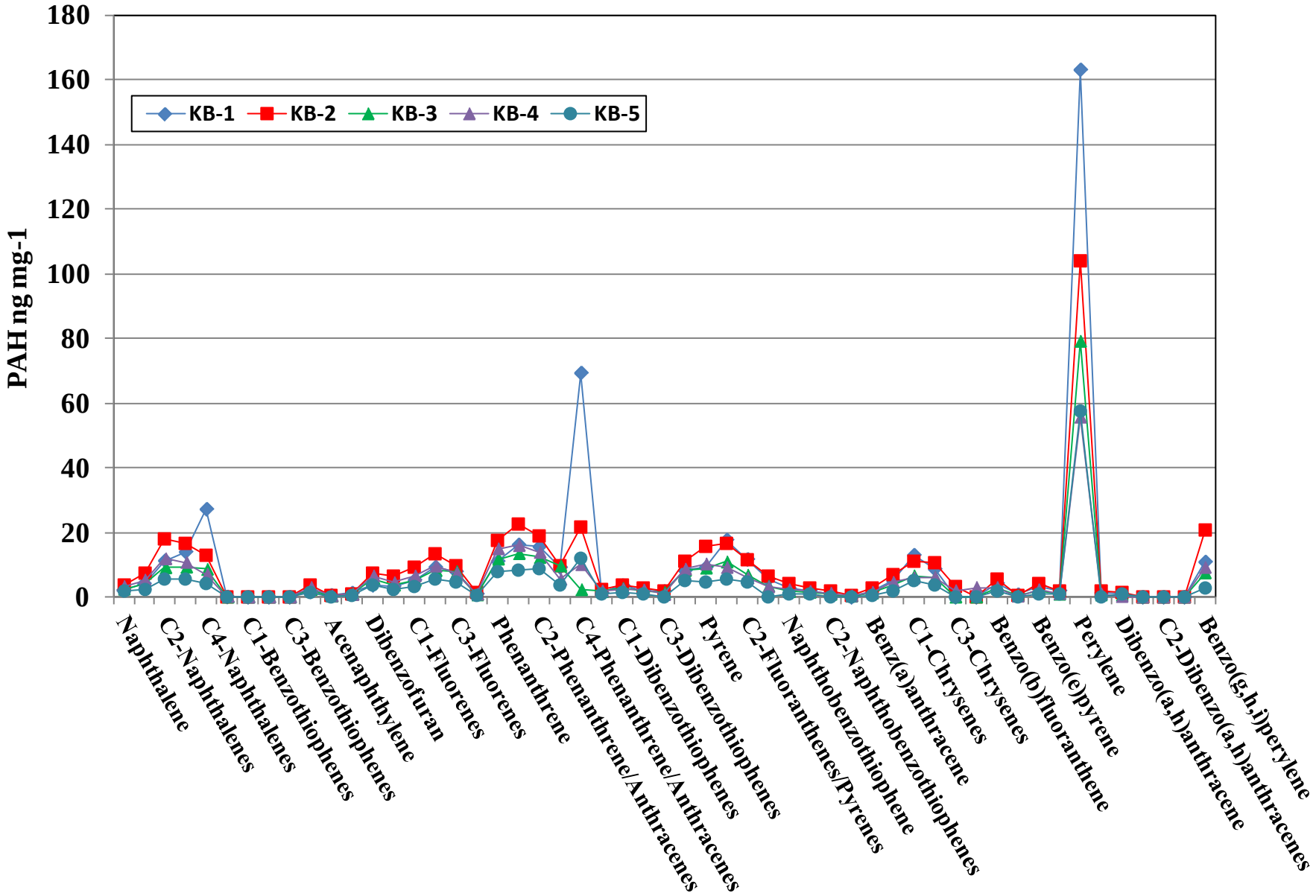

Figure A.6. Concentrations of individual PAHs in deep station sediments in Kachemak Bay.

Table A.4. Concentrations of aliphatic compounds (straight chain hydrocarbons) in deep sampling locations in Kachemak Bay, and five diagnostic ratios.

	Sample Station				
Compound	**1**	**2**	**3**	**4**	**5**
n-C_{10}	0.06	0.04	0.03	0.16	0.03
n-C_{11}	0.06	0.03	0.02	0.03	0.04
n-C_{12}	0.02	0.01	0.01	0.01	0.03
n-C_{13}	0.01	0.01	0.01	0.01	0.01
n-C_{14}	0.02	0.03	0.02	0.03	0.02
n-C_{15}	0.05	0.08	0.04	0.07	0.05
n-C_{16}	0.06	0.07	0.04	0.06	0.04
n-C_{17}	0.07	0.06	0.04	0.04	0.04
n-C_{18}	0.06	0.07	0.01	0.01	0.05
n-C_{19}	0.07	0.16	0.02	0.02	0.02
n-C_{20}	0.05	0.04	0.03	0.02	0.03
n-C_{21}	0.13	0.07	0.05	0.06	0.07
n-C_{22}	0.09	0.07	0.05	0.04	0.05
n-C_{23}	0.62	0.30	0.28	0.17	0.25
n-C_{24}	0.19	0.13	0.11	0.09	0.12
n-C_{25}	0.73	0.49	0.38	0.35	0.51
n-C_{26}	0.28	0.17	0.14	0.11	0.15
n-C_{27}	1.67	1.22	0.92	0.87	1.54
n-C_{28}	0.29	0.20	0.16	0.11	0.18
n-C_{29}	2.41	1.52	1.25	1.00	1.21
n-C_{30}	0.31	0.20	0.16	0.15	0.10
n-C_{31}	1.31	0.82	0.71	0.67	0.76
n-C_{32}	0.26	0.12	0.14	0.13	0.08
n-C_{33}	0.93	0.52	0.42	0.42	0.40
n-C_{34}	0.22	0.09	0.12	0.07	0.07
Pristane	0.05	0.03	0.02	0.03	0.02
Phytane	0.01	0.01	0.01	0.01	0.01
Total Alkanes ug/gm	10.0	6.6	5.2	4.8	5.9
Total Petroleum Hydrocarbons	53.7	37.9	26.2	24.9	21.5
Total Resolved Hydrocarbons	32.7	23.3	16.0	15.6	15.3
Unresolved Complex Mixture	21.0	14.6	10.2	9.3	6.2
Odd:Even	4.2	4.2	3.9	3.7	5.1
Σ Alkanes/n-C_{16}	172	98	127	84	134
CPI	7.0	7.2	6.8	7.7	9.1
Σ n-C10-20:Σ n-C21-34	0.06	0.10	0.06	0.11	0.07
Pristane:Phytane	4.0	3.0	2.0	3.0	2.0

Table A. 5. Mean concentrations for classes of chlorinated organic contaminants measured in Kachemak Bay sediments. (ng gm-1 dry weight)

	HCH	Chlordanes	DDT	PCB
Homer Harbor	0.00	0.41	0.58	3.72
Western Flats	0.12	0.11	0.21	1.09
Western Subtidal	0.00	0.02	0.21	0.73
Eastern Flats	0.09	0.09	0.11	0.37
Eastern Subtidal	0.02	0.06	0.07	0.58
Deep	0.36	0.06	0.04	0.52

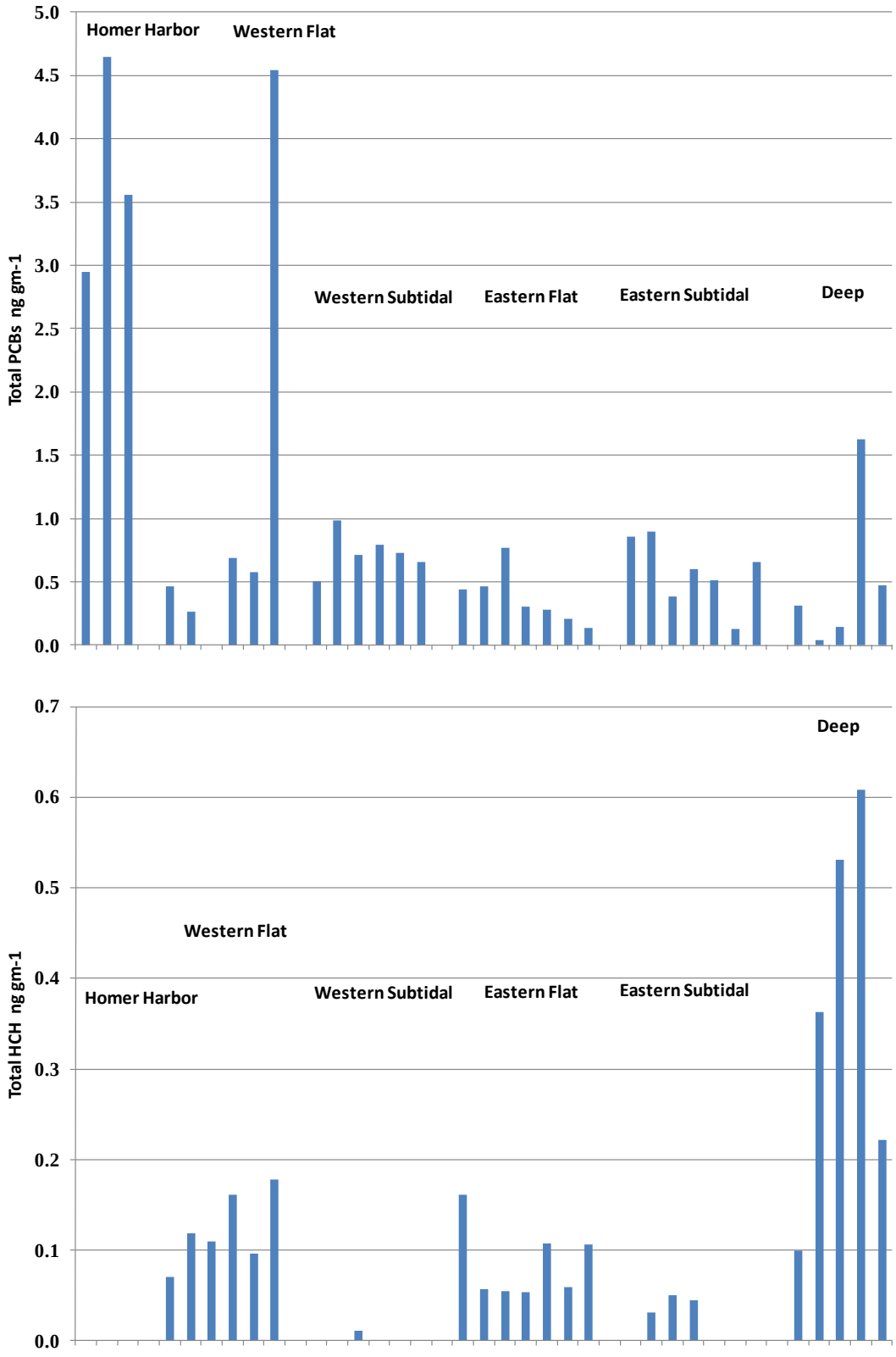

Figure A.7. Total PCB and HCH concentrations in sediment from Kachemak Bay study sites.

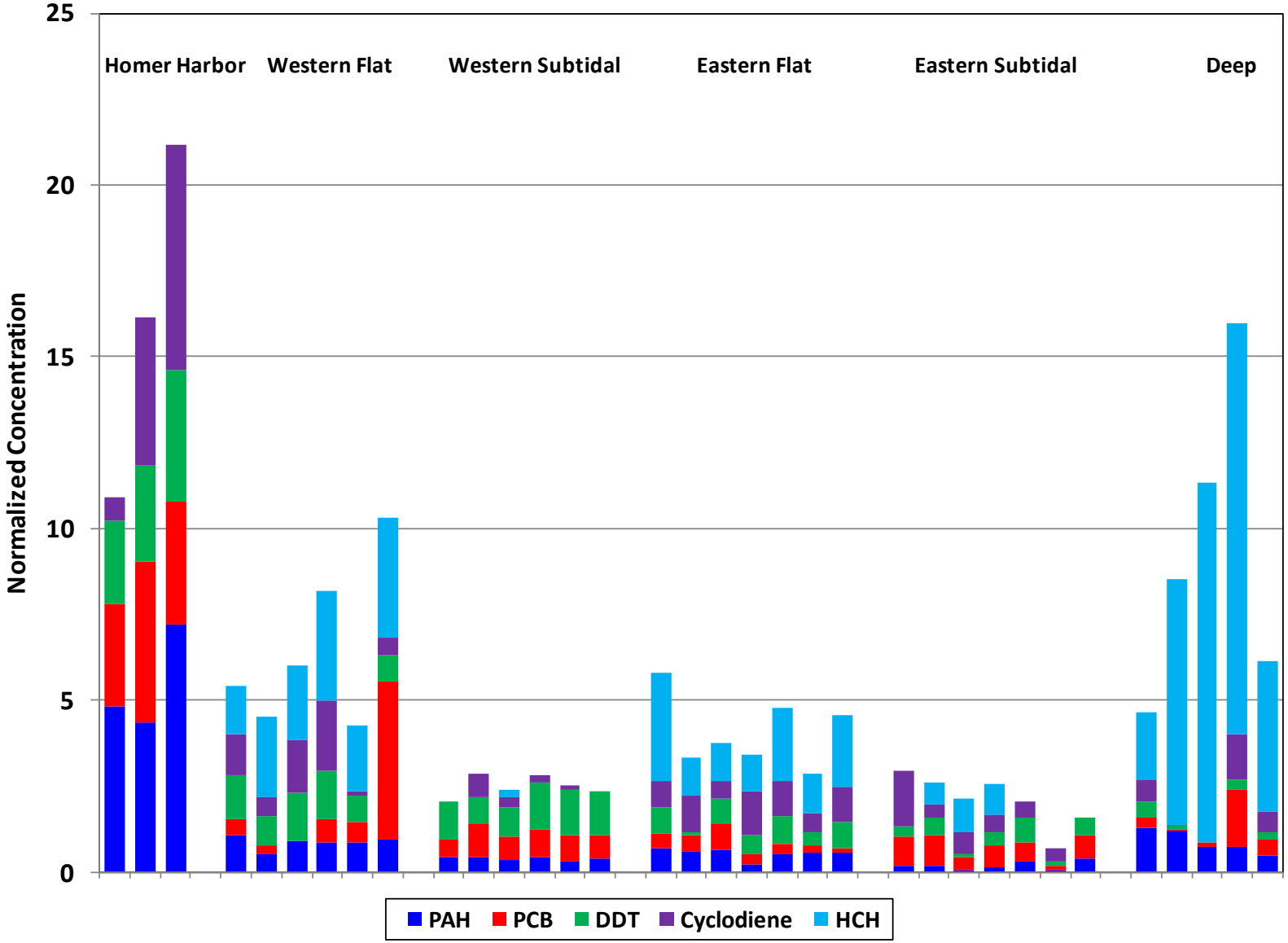

Figure A.8. Mean normalized concentrations for six classes of organic contaminants in Kachemak Bay sediments. (site concentration of organic class divided by the mean of each respective organic class from the shallow water sites).

were, but why are these contaminants distributed differently than the other organic compounds in the environment. It may be that the HCH compounds were primarily from atmospheric inputs as a result of the global atmospheric distillation process whereas PCBs and DDTs sources may be a combination of both local and global inputs.

6.3.2.3 Sediment quality guidelines

Contrasts with ERL and ERM sediment quality guidelines are shown in Table A.6. The concentrations of organic contaminants were well below the ERLs. Silver, cadmium, mercury, lead, and zinc were all less than their ERLs. Arsenic, chromium, and copper, exceeded ERLs at some stations, but only nickel exceeded the ERM. This is consistent with data from the shallow sites where arsenic, chromium, copper, and mercury, exceeded ERLs, and nickel exceeded the ERM. Grain size and mineralogy largely determine background trace metal content of sediment. Plotting trace metals concentrations against major elements such as aluminum to normalize for the relative background input of minerals from the watershed can reveal associations between specific locations and contaminant input. Metals tend to accumulate in fine grained sediment (silt and clay) more so than in coarse grained sediment due to physicochemical interactions with the surface of sediment particles. Finer grained sediments generally have higher aluminum concentrations due to the results of mineral weathering. Plots of selected metals concentrations vs aluminum are shown in Figure A.9. Most of the plots indicated that metals concentrations were higher in the deep sediments at least partly due to the fine grained nature of the sediment. In contrast, arsenic showed an inverse relationship with aluminum. This is due to diagenic processes that impact equilibrium of some elements between pore water and the overlying water column. Selenium appeared to be selectively accumulating in the deeper sediments.

6.3.3 Benthic Community Characterization

6.3.3.1 Sieve size assessment

The contrasts between the data sets resulting from sieving the samples through 1.0 mm and 0.5 mm mesh are summarized in Table A.7. Sieving through 1.0 mm mesh lost approximately 40% of the species. Some of the taxa are ‘artificial species’ in that they may not have been identified to species because they were juveniles. However, few were eliminated by combining taxa into higher order groups on a site-by-site basis, indicating a significant number of additional

Table A. 6. Comparison of ERLs and ERMs with sediment concentrations in Kachemak Bay deep stations (organics ppb, metals ppm, dry wt.).

				Sample Station				
	ERL	**ERM**		**1**	**2**	**3**	**4**	**5**
Total DDT	1.58	46.10		0.09	0.03	0.00	0.06	0.04
Total PCBs	22.7	180.0		0.31	0.04	0.14	1.63	0.47
Total PAHs	4,022	44,792		498	463	283	289	189
Ag	1.00	3.70		0.11	0.11	0.12	0.11	0.13
As	8.2	70.0		14.1	15.3	15.3	19.3	22.3
Cd	1.2	9.6		0.18	0.18	0.15	0.16	0.17
Cr	81	370		93.4	113	112	118	108.5
Cu	34	270		35.7	48.8	47.6	52.0	53.2
Hg	0.15	0.71		0.11	0.14	0.13	0.13	0.10
Pb	46.7	218.0		11.8	13.1	14.5	14.8	14.1
Ni	20.9	51.6		41.2	51.8	50.6	54.1	50.1
Zn	150.0	410.0		99.7	120.0	121.0	129.0	116.0

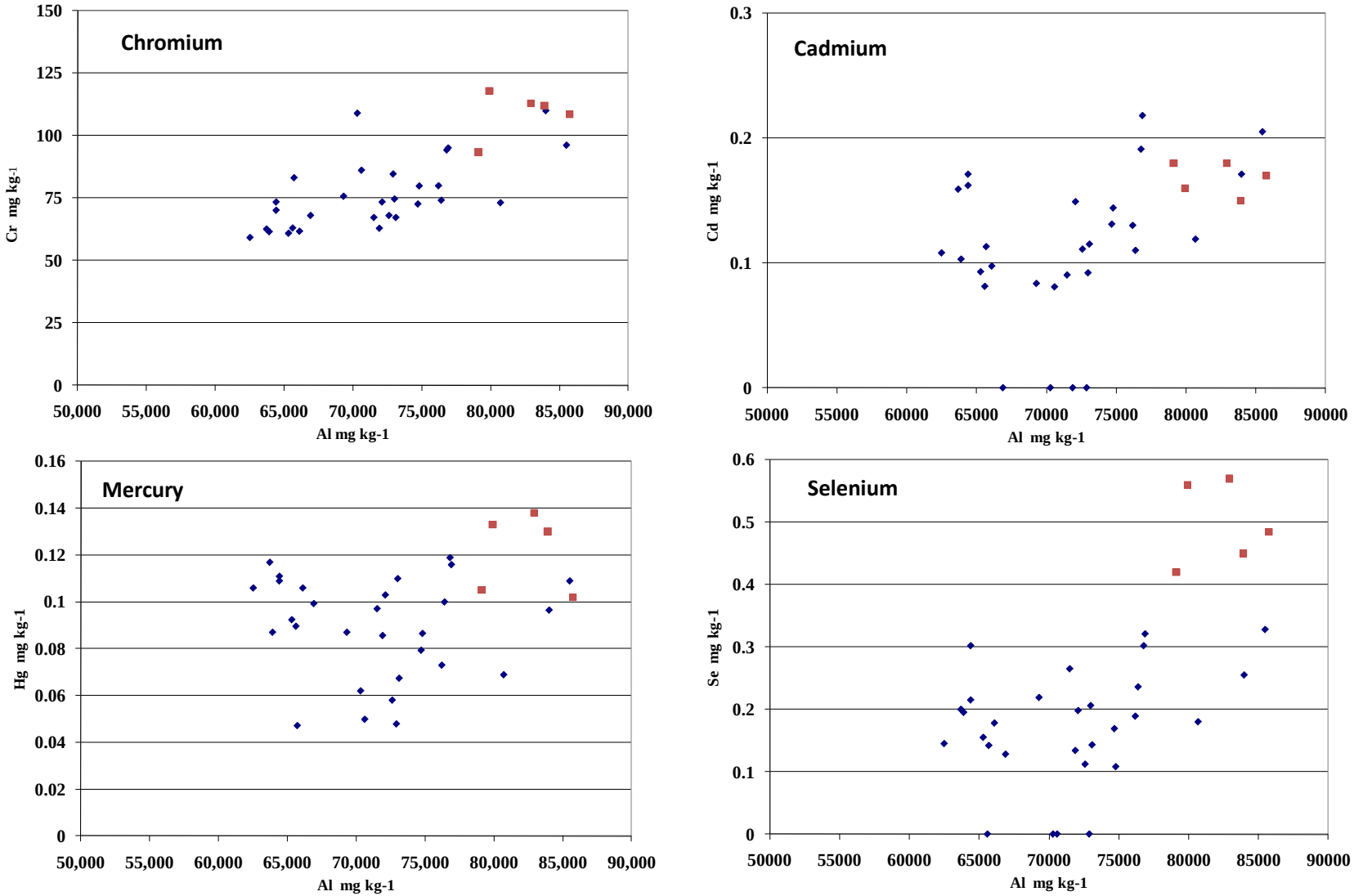

Figure A. 9. Plots of chromium, cadmium, mercury, and selenium (mg kg-1) as a function of aluminum concentration in Kachemak Bay sediments. Deep stations – red squares; Shallow stations – blue diamonds.

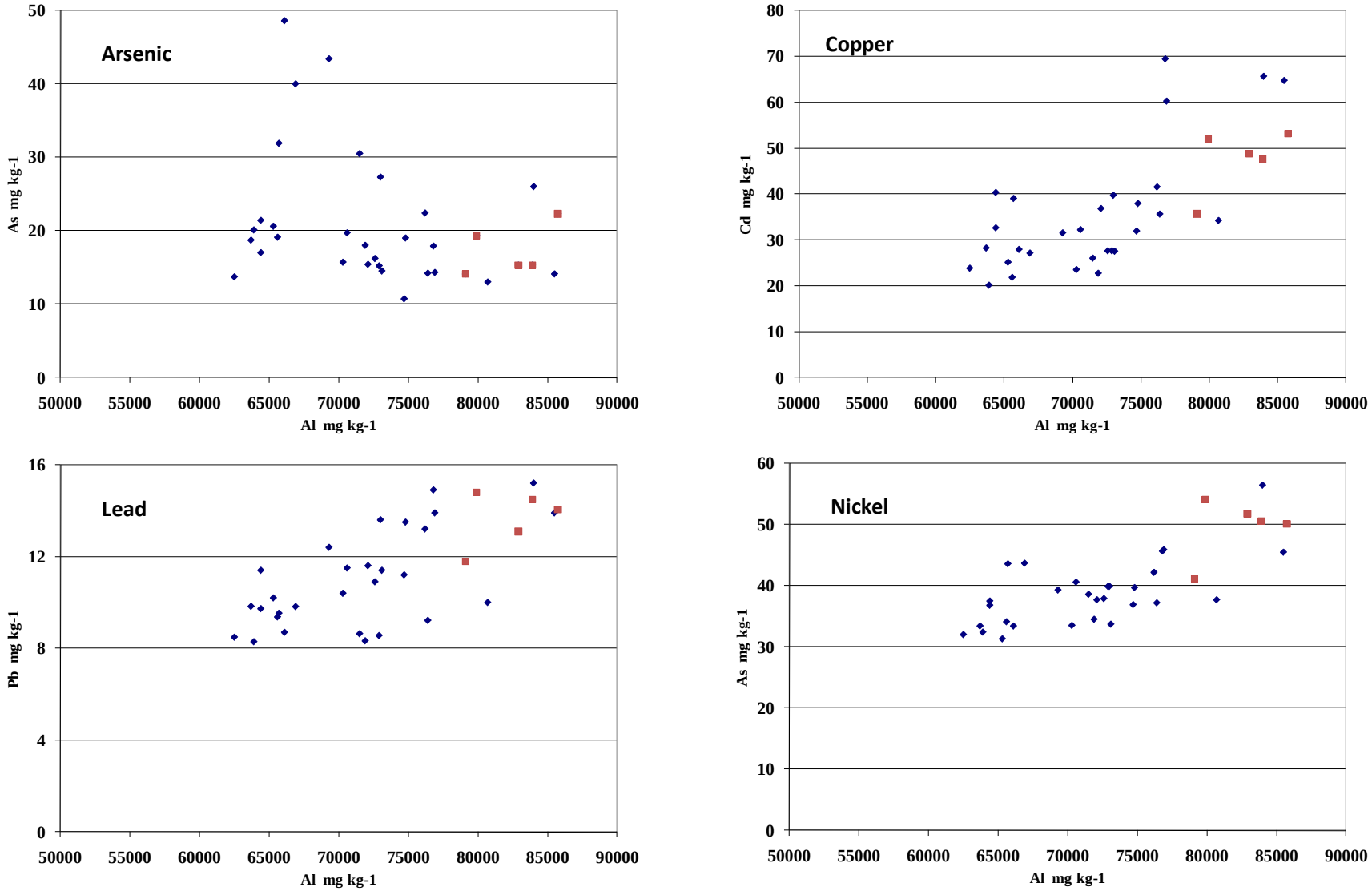

Figure A. 9 (cont). Plots of chromium, cadmium, mercury, and selenium (mg kg-1) as a function of aluminum concentration in Kachemak Bay sediments. Deep stations – red squares; Shallow stations – blue diamonds.

Table A.7. Comparison of species richness and abundance of benthos from deep sites in Kachemak Bay using different sieve sizes. Combined number of taxa is the total number of taxa of the combined data sets without duplication. Filtered number of taxa is the number of taxa following elimination of 'artificial species' (not identified to species because they were juveniles or too small, see text, pg 30-31).

Site	**KB01**	**KB01**	**KB02**	**KB02**	**KB03**	**KB03**	**KBO4**	**KB04**	**KB05**	**KB05**
Sieve Size	0.5mm	1.0mm	0.5mm	1.0mm	0.5mm	1.0mm	0.5mm	1.0mm	0.5mm	1.0mm
Abundance	477	369	333	247	676	350	248	185	560	588
# Taxa	40	46	41	40	56	56	37	41	35	32
Combined #Taxa	67		65		89		62		56	
Filtered #Taxa	64		62		84		61		52	

taxa in the smaller size fraction were identified to species or a novel taxon for the site in question. More importantly, over half the abundance was lost in the larger sieve mesh size. This has major implications for derived indices such as diversity and evenness, and assessment of benthic community condition.

6.3.3.2 Diversity and abundance

The infaunal communities in the deep stations were very diverse (Table A.8). All the H' values were greater than 3.0 and the number of taxa ranged from 57-90 per station. Organism abundance was considerably higher than in the shallow stations in some cases, but varied by a factor of 2X. There were 136 taxa identified among all five stations. The taxonomic make-up of the assemblage was dominated by polychaetes, followed by bivalves, malacostracans, and gastropods. Polychaetes were by far the most dominant taxa both in terms of species and abundance (Table A.9). Like the shallow sites, the abundance of all species was dominated by a small group of cosmopolitan species that were more numerous than the rest (Figure A.10). Sixty percent of the enumerated taxa were found at densities of less than 10 per grab. Unlike the shallow stations, there were no apparent gradients of increasing abundance and diversity from east to west. Neither was there an apparent pattern in the dominant feeding guilds found at each station (Figure A.11). Unlike the shallow areas, the deep benthic community did not appear to be strongly influenced by geographic location because habitat parameters at depth do not appear to be strongly impacted by surface phenomena (e.g. glacial runoff).

6.3.3.3 Benthic Community Nodal Analysis

Combining the data from 2007 and 2008 resulted in a list of 328 taxa. The taxa can be generally separated into two groups: (1) deep water taxa and (2) shallow water taxa. The deep water group consisted of 136 taxa. Out of this deep water group, 90 taxa were restricted only to the deep water stations, and the remaining 46 taxa were also found at least once in the shallow stations. The shallow water group contained 240 taxa. Out of the shallow water group, 193 taxa were restricted to the shallow water stations, and the remaining 47 taxa were also found at least once in the deep stations. The communities found in the shallow subtidal areas and the deep subtidal areas were distinctly different.

Table A.8. Total number of taxa, abundance m-2, and species diversity for deep stations in Kachemak Bay.

Station	# Taxa	Abundance #/m_2	Diversity H'
1	67	21,150	3.14
2	66	14,525	3.59
3	90	25,700	3.58
4	62	10,825	3.52
5	57	28,725	3.03

Table A.9. Dominant taxa at each station (numbers are actual counts in the sample, not number per square meter).

	Polychaeta		Malacostraca		Bivalvia		Gastropoda	
Station	**#taxa**	**abund**	**#taxa**	**abund**	**#taxa**	**abund**	**#taxa**	**abund**
1	48	711	3	13	8	84	0	0
2	39	389	3	14	9	110	3	8
3	48	685	12	193	13	95	7	13
4	38	282	6	44	9	84	3	5
5	33	509	4	37	11	586	3	4

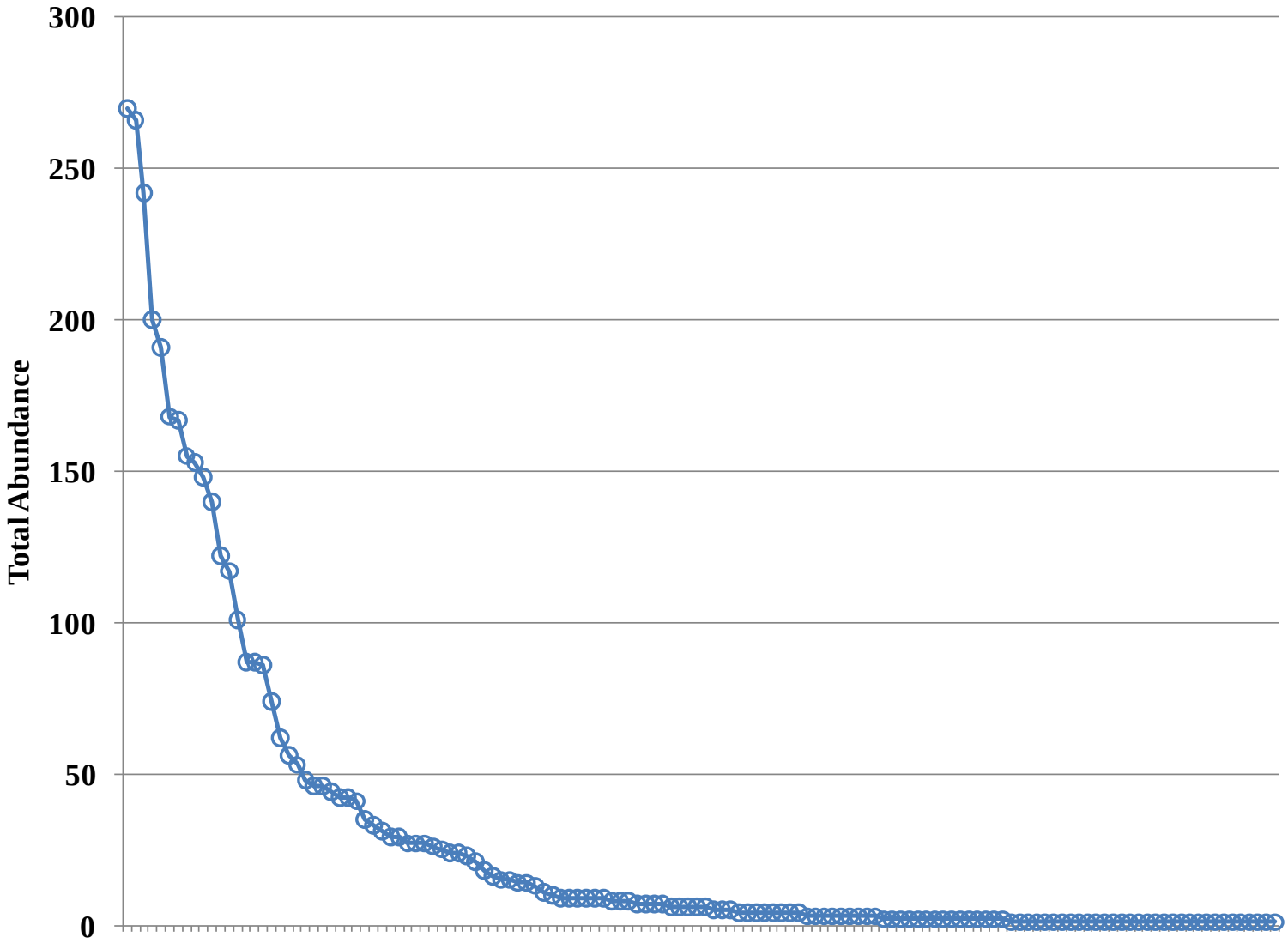

Figure A.10. Total abundance of each species collected. Species are arranged on the X axis by abundance. Each dot represents the total number of individuals of a species collected at all five deep stations. The abundance of all species is dominated by a small group of cosmopolitan species

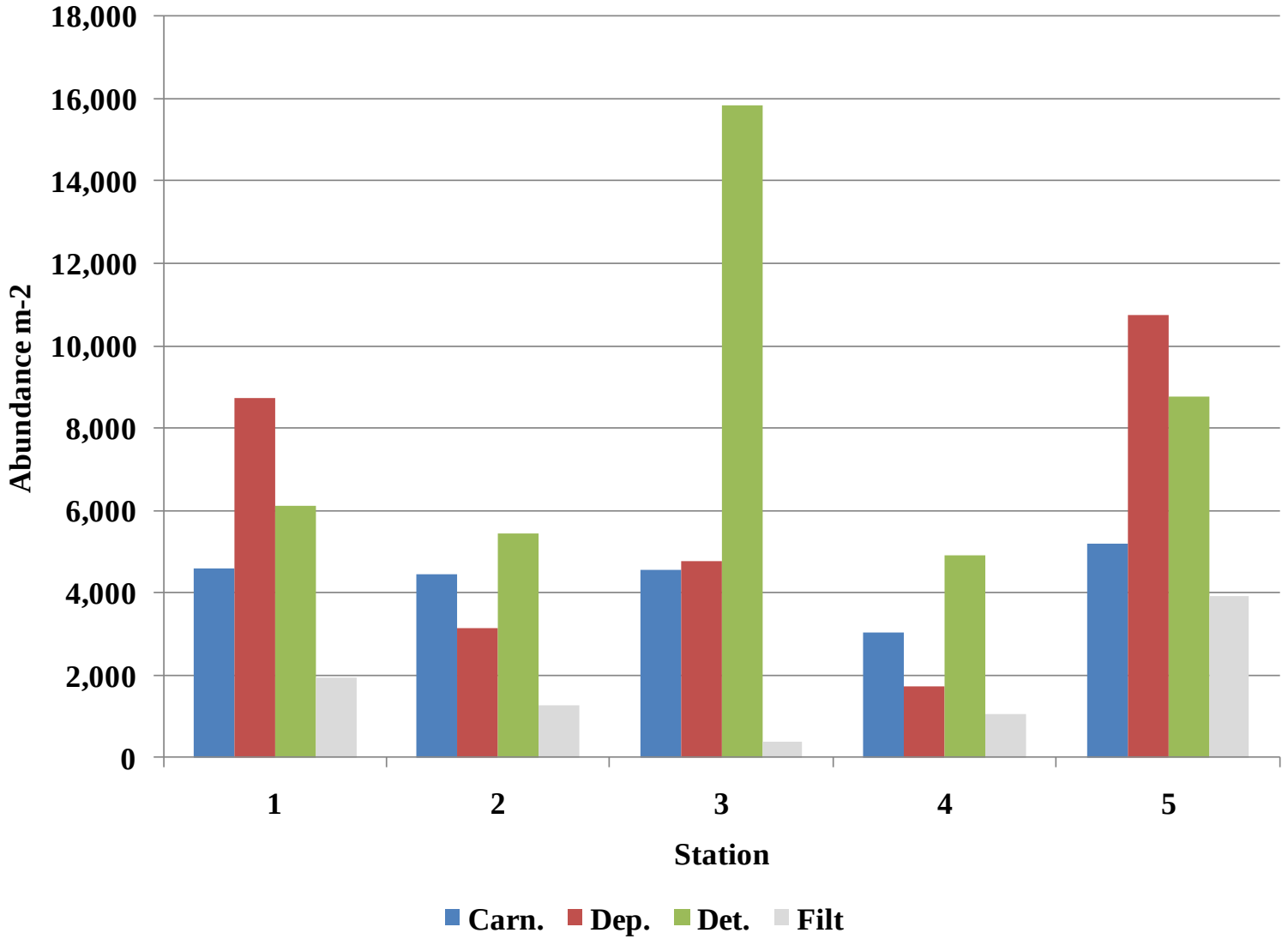

Figure A. 11. Abundance of organisms with different feeding modes in the deep stations of Kachemak Bay. Carn.- Carnivore; Dep. – Deposit feeder; Det. – Detritivore; Filt. – Filter feeder;

Consequently, the cluster analyses of sites and species with combined 2007 and 2008 data did not greatly alter the patterns of association seen in the shallow stations. The station groups were designated by the following names: deep, shore, stressed, subtidal (2 groups, sandy and muddy), and intertidal (Figure A.12; the nodal plot figure from 2007 is also reproduced for reference). A large cosmopolitan group of species was found across all of the stations. The deep water station group contained primarily the deep species group in addition to some of the cosmopolitan species. The shore station group contained a subset of the cosmopolitan species group and the intertidal species group. The stressed site group included only a subset of the cosmopolitan species. The sandy subtidal station group contained the same group of species found in the original subtidal deep sandy node from the 2007 analyses (Figure A.12 (cont)). The species from the 2007 subtidal muddy sites were dispersed among the deep, cosmopolitan and miscellaneous site groups in the combined 2007/2008 results. The intertidal species were segregated between clear water sites and turbid sites in both analyses.

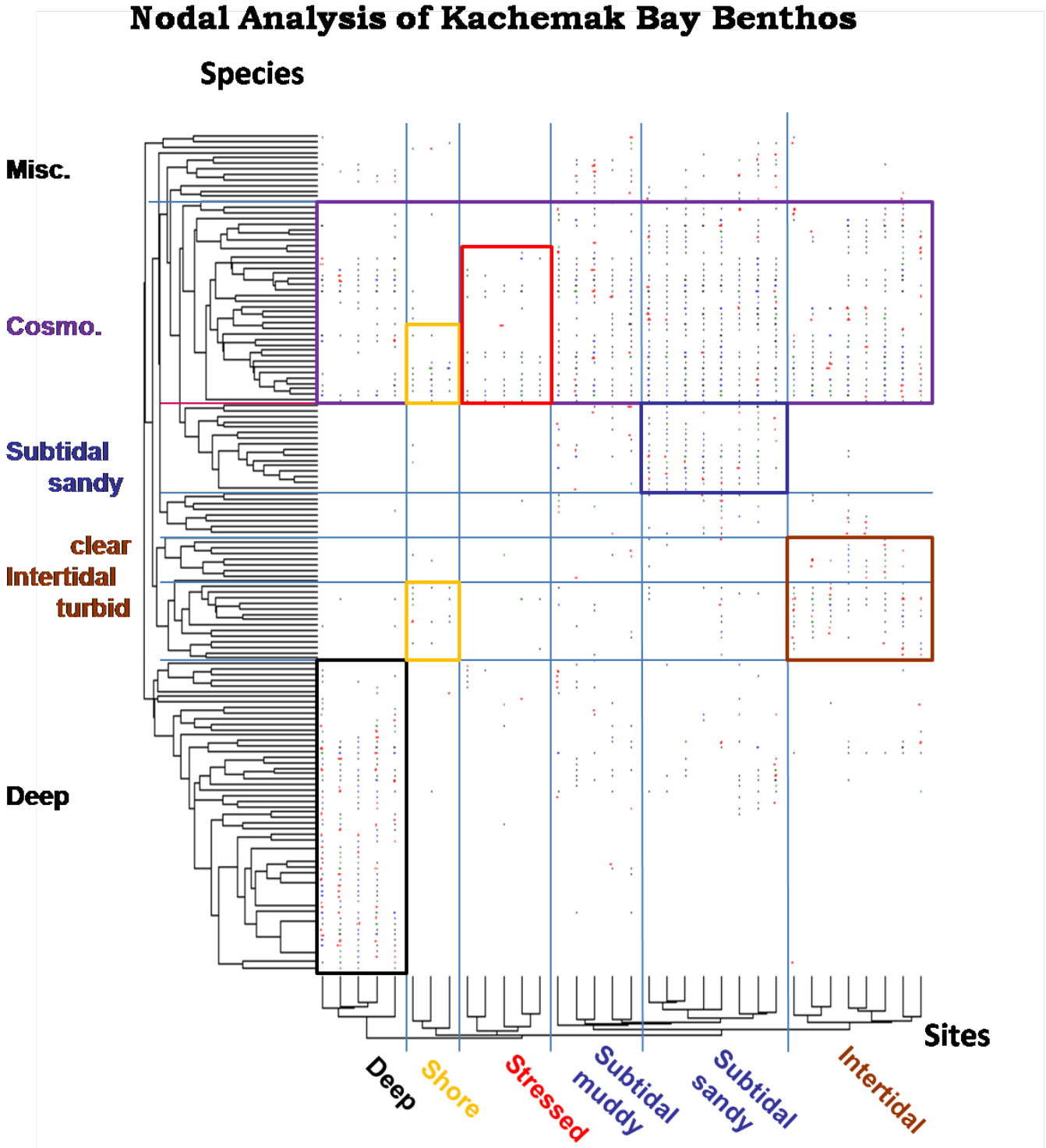

Figure A.12. Nodal plot of site vs. species clusters showing the distribution of species among sites sampled in 2007 and 2008. Dots indicate that a species on the Y axis was present at the corresponding site on the X axis. Stressed sites have reduced diversity. Dot color indicates species-by-species abundance in quartiles (highest red – green – blue – black lowest).

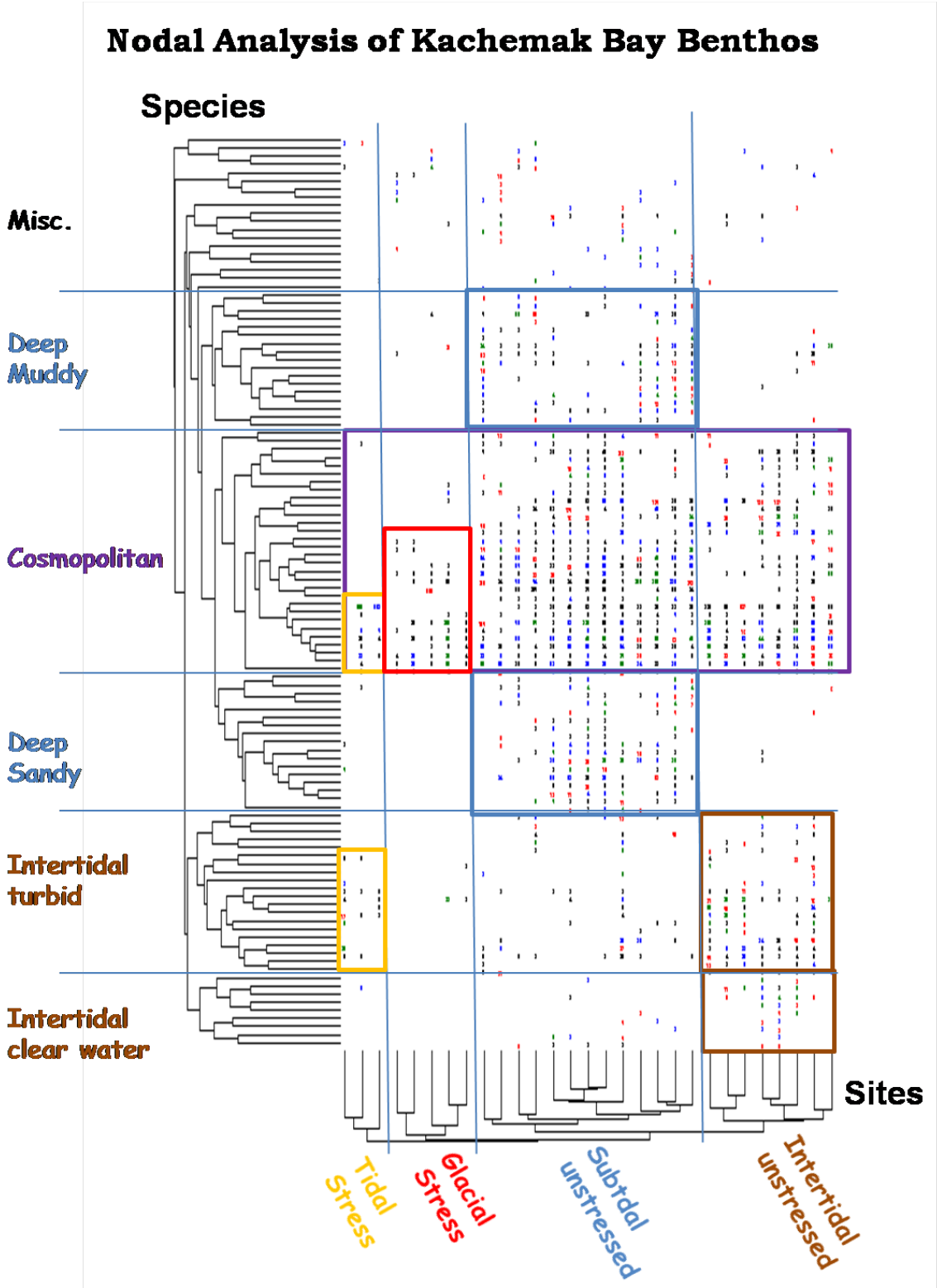

Figure A. 12 (cont). Nodal plot of site vs. species clusters showing the distribution of species among sites sampled in 2007. Dots indicate that a species on the Y axis was present at the corresponding site on the X axis. Stressed sites have reduced diversity. Dot color indicates species-by-species abundance in quartiles (highest red – green – blue – black lowest)

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APPENDIX A

Chemicals and chemical groups for which ERLs and ERMs have been derived (organics ppb, metals ppm, dry weight).

	ERL	ERM
Total DDT	1.58	46.1
pp'-DDE	2.2	27
Total PCBs	22.7	180
Total PAHs	4022	44792
High weight PAHs ($\geq$ 4 rings)	1700	9600
Low weight PAHs ($\leq$ 3 rings)	552	3160
Acenaphthene	16	500
Acenaphthylene	44	640
Anthracene	85.3	1100
Flourene	19	540
2-Methyl Naphthalene	70	670
Naphthalene	160	2100
Phenanthrene	240	1500
Benzo-a-anthracene	261	1600
Benzo-a-pyrene	430	1600
Chrysene	384	2800
Dibenzo(a,h)anthracene	63.4	260
Fluoranthene	600	5100
Pyrene	665	2600
Ag	1.0	3.7
As	8.2	70
Cd	1.2	9.6
Cr	81	370
Cu	34	270
Hg	0.15	0.71
Pb	46.7	218
Ni	20.9	51.6
Zn	150	410

APPENDIX B

Percent survival in whole sediment bioassays with *A. abdita* and *E. estuarius,* and indication of statistical significance.

Station	Lat	Long	*A. abdita* Survival	Sig	*E. estuarius* Survival	Sig
EF 1	59.6973	-151.2895	87.5			
EF 2	59.7236	-151.2283	92.5		88.75	
EF 3	59.7446	-151.1739	93.75		88.75	
EF 4	59.7683	-151.1066	91.25		25	*
EF 5	59.7446	-151.1596	93.75		95	
EF 6	59.7614	-151.1466	92.5			
EF 7	59.7779	-151.0998	91.25			
ES 1	59.6943	-151.2182	95			
ES 2	59.7139	-151.2228	95			
ES 3	59.7651	-151.0811	95		96.25	
ES 4	59.7575	-151.0964	92.5		90	
ES 5	59.7418	-151.1368	93.3			
ES 6	59.7499	-151.0740	87.5		98.75	
ES 7	59.7213	-151.1695	96.25		92.5	
HH 1	59.6050	-151.4225	95.63			
HH 2	59.6044	-151.4208	91.25			
HH 3	59.6056	-151.4256	91.25			
WF 1	59.6275	-151.4586	83.75	*	86.25	
WF 2	59.6563	-151.4247	97.5			
WF 3	59.6480	-151.4406	88.75			
WF 4	59.6684	-151.4040	100		91.25	
WF 5	59.6453	-151.4511	97.5		97.5	
WF 6	59.6621	-151.4342	96.25		90	
WS 1	59.6545	-151.3824	96.25		96.25	
WS 2	59.6599	-151.3446	96.25			
WS 3	59.6440	-151.4090	87.5			
WS 3X	59.6379	-151.4139	93.75		95	
WS 4	59.6623	-151.3579	93.75		93.75	
WS 5	59.6673	-151.3693	92.5		96.25	
PG 2	59.3629	-151.8274	93.75			
PG 3C	59.3449	-151.8196	68.75	*	92.5	
PG 4B	59.3397	-151.7876	90		93.75	

* = $0.5 \leq p \geq 0.01$

APPENDIX C

Appendix C. List of all benthic infaunal species (excluding epifauna) found in 2007 Kachemak Bay samples, including the number of stations each species was found, and total abundance over all stations (#/M^2).

Phylum/Subphylum	Class	Taxa Name	# Stations	tot/M2
Annelida	Oligochaeta	Oligochaeta	3	100
Annelida	Polychaeta	Ampharete acutifrons	5	175
Annelida	Polychaeta	Ampharete cf crassiseta	3	175
Annelida	Polychaeta	Ampharete finmarchica	2	75
Annelida	Polychaeta	Ampharete sp juv	6	150
Annelida	Polychaeta	Ampharetidae juv	2	75
Annelida	Polychaeta	Aphelochaeta nr glandaria	7	3425
Annelida	Polychaeta	Aphelochaeta nr monilaris	2	675
Annelida	Polychaeta	Aphelochaeta sp	16	16450
Annelida	Polychaeta	Apistobranchus tullbergi	11	1175
Annelida	Polychaeta	Arenicolidae juv	6	950
Annelida	Polychaeta	Aricidea lopezi	16	2500
Annelida	Polychaeta	Aricidea pseudoarticulata	5	375
Annelida	Polychaeta	Armandia brevis	1	25
Annelida	Polychaeta	Asabellides sibirica	2	50
Annelida	Polychaeta	Barantolla nr americana	26	21600
Annelida	Polychaeta	Brada sp juv	1	25
Annelida	Polychaeta	Capitella capitata Cmplx	14	3175
Annelida	Polychaeta	Chaetozone nr setosa	14	18800
Annelida	Polychaeta	Chaetozone sp	1	50
Annelida	Polychaeta	Chone sp juv	1	125
Annelida	Polychaeta	Cirratulidae	5	1325
Annelida	Polychaeta	Cirratulus sp	1	75
Annelida	Polychaeta	Cossura pygodactylata	3	375
Annelida	Polychaeta	Dipolydora cardalia	3	100
Annelida	Polychaeta	Dipolydora quadrilobata	6	425
Annelida	Polychaeta	Dipolydora socialis	4	175
Annelida	Polychaeta	Dipolydora sp	1	25
Annelida	Polychaeta	Eranno bicirrata	3	100
Annelida	Polychaeta	Eteone sp	16	1150
Annelida	Polychaeta	Euchone analis	4	175
Annelida	Polychaeta	Euchone incolor	1	25
Annelida	Polychaeta	Euclymene cf zonalis	2	50
Annelida	Polychaeta	Euclymeninae	4	425
Annelida	Polychaeta	Eusyllis blomstrandi	1	25
Annelida	Polychaeta	Eusyllis habei	1	75
Annelida	Polychaeta	Exogone dwisula	8	475
Annelida	Polychaeta	Galathowenia oculata	12	2050
Annelida	Polychaeta	Gattyana ciliata	1	25
Annelida	Polychaeta	Gattyana cirrosa	7	525
Annelida	Polychaeta	Gattyana sp	1	25
Annelida	Polychaeta	Glycera nana	3	125

Annelida	Polychaeta	Glycinde sp	2	3375
Annelida	Polychaeta	Goniada maculata	1	25
Annelida	Polychaeta	Harmothoe sp	2	3675
Annelida	Polychaeta	Heteromastus filobranchus	2	125
Annelida	Polychaeta	Idanthyrsus saxicavus	1	25
Annelida	Polychaeta	Lanassa nordenskioeldi	1	25
Annelida	Polychaeta	Lanassa venusta	1	25
Annelida	Polychaeta	Laonice cirrata	2	50
Annelida	Polychaeta	Laonome kroeyeri	8	750
Annelida	Polychaeta	Laphania boecki	4	175
Annelida	Polychaeta	Leitoscoloplos sp	1	75
Annelida	Polychaeta	Levinsenia gracilis	6	600
Annelida	Polychaeta	Lysippe labiata	5	825
Annelida	Polychaeta	Magelona longicornis	12	1500
Annelida	Polychaeta	Magelona sacculata	1	25
Annelida	Polychaeta	Magelona sp	1	25
Annelida	Polychaeta	Mediomastus sp	13	3150
Annelida	Polychaeta	Melinna oculata	1	25
Annelida	Polychaeta	Nephtys caeca	11	400
Annelida	Polychaeta	Nephtys ciliata	9	1475
Annelida	Polychaeta	Nephtys cornuta	6	250
Annelida	Polychaeta	Nephtys sp	8	400
Annelida	Polychaeta	Nereis procera	9	575
Annelida	Polychaeta	Nicomache personata	2	250
Annelida	Polychaeta	Ophelina acuminata	2	50
Annelida	Polychaeta	Owenia sp juvenile	1	29425
Annelida	Polychaeta	Paleanotus bellis	2	75
Annelida	Polychaeta	Parougia caeca	1	25
Annelida	Polychaeta	Pectinaria sp	13	1850
Annelida	Polychaeta	Pherusa plumosa	1	25
Annelida	Polychaeta	Pholoe minuta	26	11975
Annelida	Polychaeta	Pholoe sp (gray)	7	825
Annelida	Polychaeta	Pholoides asperus	6	325
Annelida	Polychaeta	Phyllodoce groenlandica orientalis	12	875
Annelida	Polychaeta	Phyllodoce madeirensis	5	175
Annelida	Polychaeta	Phyllodoce mucosa	13	975
Annelida	Polychaeta	Phyllodoce sp juv	5	175
Annelida	Polychaeta	Pista estevanica	1	100
Annelida	Polychaeta	Polycirrinae	1	75
Annelida	Polychaeta	Polydora brevipalpa	1	25
Annelida	Polychaeta	Praxillella gracilis	2	50
Annelida	Polychaeta	Prionospio multibranchiata	3	175
Annelida	Polychaeta	Prionospio steenstrupi	19	7675
Annelida	Polychaeta	Pseudochitinopoma occidentalis	1	25
Annelida	Polychaeta	Rhynchospio glutaea	7	2950
Annelida	Polychaeta	Scalibregma californicum	7	600
Annelida	Polychaeta	Scalibregma sp	1	25
Annelida	Polychaeta	Scolelepis sp	4	100
Annelida	Polychaeta	Scoletoma luti	19	29600
Annelida	Polychaeta	Scoloplos sp juv	28	7025
Annelida	Polychaeta	Sphaerodoropsis minuta	4	125

Annelida	Polychaeta	Sphaerodoropsis sphaerulifer	7	800
Annelida	Polychaeta	Sphaerosyllis sp N1	11	1275
Annelida	Polychaeta	Spio filicornis	1	25
Annelida	Polychaeta	Spio sp	3	1725
Annelida	Polychaeta	Spiophanes bombyx	4	525
Annelida	Polychaeta	Terebellides horikoshii	1	25
Annelida	Polychaeta	Terebellides sp juv	1	25
Annelida	Polychaeta	Terebellides stroemi	1	25
Annelida	Polychaeta	Tharyx sp N1	12	9650
Annelida	Polychaeta	Typosyllis cornuta	3	100
Arthropoda	Pycnogonida	Achelia chelata	1	25
Arthropoda	Pycnogonida	Phoxichilidium femoratum	1	25
Cnidaria	Anthozoa	Halcampa duodecemtentaculata	2	925
Cnidaria	Anthozoa	Halcampa sp.	1	25
Cnidaria	Anthozoa	Nynantheae sp.	1	25
Crustacea	Malacostraca	Ampithoe kussakini	1	25
Crustacea	Malacostraca	Anonyx sp.	2	50
Crustacea	Malacostraca	Argissa hamatipes	2	75
Crustacea	Malacostraca	Atylus collingi	1	25
Crustacea	Malacostraca	Byblis sp.	1	75
Crustacea	Malacostraca	Caprellidae sp.	1	25
Crustacea	Malacostraca	Cheirimedeia sp.	9	3775
Crustacea	Malacostraca	Crangonidae sp.	1	25
Crustacea	Malacostraca	Crassicorophium crassicorne	7	3475
Crustacea	Malacostraca	Cumella vulgaris	9	725
Crustacea	Malacostraca	Diastylis alaskensis	23	4750
Crustacea	Malacostraca	Diastylis cf. rathkei	4	550
Crustacea	Malacostraca	Eudorellopsis biplicata	6	575
Crustacea	Malacostraca	Eudorellopsis integra	1	25
Crustacea	Malacostraca	Foxiphalus sp.	4	1000
Crustacea	Malacostraca	Guernea reduncans	7	1175
Crustacea	Malacostraca	Heptacarpus brevirostris	1	25
Crustacea	Malacostraca	Ischyrocerus sp.	4	100
Crustacea	Malacostraca	Lamprops sp.	1	25
Crustacea	Malacostraca	Megamoera sp.	3	750
Crustacea	Malacostraca	Microjassa sp.	1	25
Crustacea	Malacostraca	Monocorophium carlottensis	1	275
Crustacea	Malacostraca	Monocorophium sp.	1	125
Crustacea	Malacostraca	Munna sp.	1	50
Crustacea	Malacostraca	Oedicerotidae sp.	1	25
Crustacea	Malacostraca	Oregonia gracilis	5	200
Crustacea	Malacostraca	Pacifoculodes zernovi	2	50
Crustacea	Malacostraca	Paguridae sp.	5	125
Crustacea	Malacostraca	Photis sp.	5	200
Crustacea	Malacostraca	Pleurogonium rubicundum	1	25
Crustacea	Malacostraca	Pleusymtes sp.	6	475
Crustacea	Malacostraca	Pontoporeia femorata	6	975
Crustacea	Malacostraca	Protomedeia cf. microdactyla	9	950
Crustacea	Malacostraca	Stenothoidae sp.	1	25
Crustacea	Malacostraca	Telmessus cheiragonus	1	25
Crustacea	Malacostraca	Vaunthompsonia pacifica	1	25
Crustacea	Malacostraca	Wecomedon similis	1	25

Crustacea	Maxillopoda	Ectinosomatidae sp.	2	50
Crustacea	Maxillopoda	Harpacticus uniremis	1	25
Crustacea	Maxillopoda	Huntemannia jadensis	1	275
Crustacea	Maxillopoda	Parathalestris sp.	4	600
Crustacea	Maxillopoda	Peltidiidae sp.	1	25
Crustacea	Maxillopoda	Podocopida sp.	2	225
Crustacea	Maxillopoda	Scleroconcha sp.	2	150
Echinodermata	Echinoidea	Echinoidea sp.	1	25
Echinodermata	Holothuroidea	Aspidochirotida sp.	1	25
Echinodermata	Holothuroidea	Dendrochirotida sp.	2	50
Echinodermata	Ophiuroidea	Amphiodia sp.	1	25
Echinodermata	Ophiuroidea	Amphiodia urtica/periercta	1	25
Echinodermata	Ophiuroidea	Amphipholis sp.	1	25
Echinodermata	Ophiuroidea	Amphiuridae sp. juv.	6	200
Echiura	Echiurida	Echiurus echiurus alaskanus	1	25
Hemichordata	Enteropneusta	Enteropneusta sp.	9	3850
Hemichordata	Enteropneusta	Saccoglossus sp.	1	25
Mollusca	Aplacophora	Chaetoderma sp.	2	50
Mollusca	Bivalvia	Astarte elliptica	2	225
Mollusca	Bivalvia	Astarte esquimalti	2	50
Mollusca	Bivalvia	Axinopsida serricata	17	8000
Mollusca	Bivalvia	Bivalvia sp.	1	400
Mollusca	Bivalvia	Clinocardium californiense	3	125
Mollusca	Bivalvia	Clinocardium sp. juv.	5	1275
Mollusca	Bivalvia	Cyclocardia ventricosa	1	25
Mollusca	Bivalvia	Ennucula tenuis	17	1625
Mollusca	Bivalvia	Hiatella arctica	10	3225
Mollusca	Bivalvia	Lasaeidae sp. juv.	1	25
Mollusca	Bivalvia	Lyonsia californica	1	25
Mollusca	Bivalvia	Macoma balthica	22	40250
Mollusca	Bivalvia	Macoma calcarea	2	1300
Mollusca	Bivalvia	Macoma golikovi	3	175
Mollusca	Bivalvia	Macoma inquinata	1	100
Mollusca	Bivalvia	Macoma sp. juv.	1	100
Mollusca	Bivalvia	Mactridae sp.	5	925
Mollusca	Bivalvia	Mya pseudoarenaria	2	200
Mollusca	Bivalvia	Mya sp.	11	1950
Mollusca	Bivalvia	Nuculana minuta	2	150
Mollusca	Bivalvia	Nuculana sp. juv.	3	100
Mollusca	Bivalvia	Parvilucina tenuisculpta	2	50
Mollusca	Bivalvia	Protothaca staminea	4	200
Mollusca	Bivalvia	Rochefortia sp. juv.	2	75
Mollusca	Bivalvia	Rochefortia tumida	2	150
Mollusca	Bivalvia	Saxidomus gigantea	10	600
Mollusca	Bivalvia	Thyasira flexuosa	5	250
Mollusca	Bivalvia	Yoldia sp. juv.	6	275
Mollusca	Gastropoda	Acteocina cf eximia	2	450
Mollusca	Gastropoda	Alvania compacta	15	8300
Mollusca	Gastropoda	Cephalaspidea sp.	1	125
Mollusca	Gastropoda	Lacuna vincta	14	4225
Mollusca	Gastropoda	Margarites pupillus	2	50
Mollusca	Gastropoda	Melanochlamys diomedea	4	175

Mollusca	Gastropoda	Nucella sp. juv.	1	25
Mollusca	Gastropoda	Odostomia sp.	8	725
Mollusca	Gastropoda	Oenopota sp.	8	575
Mollusca	Gastropoda	Onchidoris bilamellata	8	650
Mollusca	Gastropoda	Retusa sp.	3	100
Mollusca	Gastropoda	Turbonilla sp.	3	150
Mollusca	Gastropoda	Velutina velutina	2	75
Nemertea	Anopla	Carinoma mutabilis	1	25
Nemertea	Anopla	Heteronemertea sp.	27	10675
Nemertea	Anopla	Micrura sp.	3	200
Nemertea	Anopla	Paleonemertea sp.	4	2100
Nemertea	Anopla	Tubulanus pellucidus/polymorphus	3	100
Nemertea	Enopla	Amphiporus sp.	2	50
Nemertea	Enopla	Tetrastemma sp.	4	250
Nemertea	Enopla	Zygonemertes sp	1	25
Nemertea		Nemertea sp.	5	350
Phoronida		Phoronis sp.	1	25
Platyhelminthes	Turbellaria	Leptoplanidae sp.	6	350
Priapulida	Priapulimorpha	Priapulus caudatus	4	150
Sipuncula	Sipunculidea	Thysanocardia nigra	1	25