National Coastal Assessment Program: The Condition of Southcentral Alaska's Bays and Estuaries Technical Report and Statistical Summary

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Preface

This document is the first statistical summary for the State of Alaska coastal bays and estuaries component of the nationwide Environmental Monitoring and Assessment Program (EMAP). EMAPWestern Pilot Coastal Monitoring began in 1999 as a partnership of the States of California, Oregon and Washington, the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Environmental Protection Agency (EPA). In 2001, the State of Alaska Department of Environmental Conservation (DEC) developed a Cooperative Agreement with EPA to join collaboratively in the Western States Coastal EMAP project. The program administered through the EPA Office of Research and Development and implemented through partnerships with a combination of federal and state agencies, universities and the private sector.

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Disclaimer

This is a summary report for the ecological conditions in Alaska's coastal bays and estuaries along the southcentral coast of Alaska based ondata collected in June, July, and August 2002. Sampling was conducted in accordance with the Environmental Protection Agency's Environmental Monitoring and Assessment Program (EMAP) design and standardized protocols. Typically, the EMAP-Western Pilot Coastal Monitoring (EMAPWPCM) design incorporates all U.S. West Coast estuaries in which a large portion of the extensive population is sampled annually. For Alaska, though, in many cases this is the first opportunity to sample many of these estuaries providing a valuable beginning of a baseline for future assessments. The design supports probabilitybased estimates of the percent area of total estuary area represented by particular ecological conditions defined by measured values of assessment indicators. However, this design offers limited support for detailed assessments of pollutant distributions, etc. within an estuary.

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EXUCUTIVE SUMMARY

In 2001, the Alaska Department of Environmental Conservation (DEC) developed a Cooperative Agreement with the Environmental Protection Agency (EPA) to join collaboratively in the Western States Coastal Environmental Monitoring and Assessment Program (EMAP). The Western States Coastal EMAP was initiated as one component of the national EMAP coastal program called the National Coastal Assessment (NCA), led by EPA to monitor and assess the status and trends of significant estuarine and coastal resources as an end to providing a report on the condition of the Nation's coast (bays and estuaries). This effort will provide an integrated and comprehensive coastal monitoring program among all coastal states and is being accomplished through strategic partnerships between the U.S. EPA and all 24 U.S. coastal states, Guam, and Puerto Rico. As the state agency facilitating and administering the EMAP program for Alaska, the DEC developed partnerships with other federal, state, and local agencies to develop the Alaska EMAP program. The data collected from this initial survey are envisioned as the beginning of an DEC statewide ambient water monitoring program that will include interior as well as coastal waters.

Each state uses a compatible, probabilistic design and a common core set of analyses and indicators to conduct their independent survey and for assessing the condition of their coastal resources. The core set of parameters that are included in the EMAP that ensures the consistency and comparability of data from all coastal states includes several oceanographic and water quality parameters, sediment toxicity analyses, sediment chemistry, tissue chemistry, fish pathology, benthic community analyses, and fish community analyses. Because of the
compatible design and common set of core analyses and indicators, the estimate provided by each state can be aggregated to assess conditions at the state, EPA Region, biogeographical, and National levels.

Given the extent of Alaska's coastline (greater than the rest of the coastline in the lower 48 states), a coastal assessment of all of Alaska's coastal bays and estuaries was not feasible logistically or financially within one survey. Thus, the EPA identified five biogeographical provinces of Alaska's coastline to be surveyed individually; Southeast Alaska, Southcentral Alaska, the Aleutian Islands/Alaska Peninsula, the Bering Sea, and the Chukchi/Beautfort Seas (Arctic). This report is a presentation of the statistical results from the first of these surveys conducted in 2002 in Southcentral Alaska.

The survey collected data at a total of 55 sites that covered the geographic range from Unimak Island in the southwest study area to the Copper River Delta area in the northeast study area. The target study area included coastal bays and estuaries in Southcentral Alaska, including the Alaska Peninsula, Kodiak Island archipelago, Cook Inlet, the Kenai Peninsula, and Prince William Sound.
The survey collected data at a total of 55 sites that covered the geographic range from Unimak Island in the southwest study area to the Copper River Delta area in the northeast study area. The target study area included coastal bays and estuaries in Southcentral Alaska, including the Alaska Peninsula, Kodiak Island archipelago, Cook Inlet, the Kenai Peninsula, and Prince William Sound.

1. BACKGROUND AND INTRODUCTION

1.1 Program background

One of the charges of the U.S. Environmental Protection Agency is to evaluate the efficacy of environmental regulations in preserving the Nation's natural resources. Based on their findings, he EPA can set environmental policy, conduct research, and develop new methods or indicators to improve the ability to conduct assessments and to ensure clean air and water. To help in this effort, the federal Clean Water Act (CWA) also requires individual states to report the condition of their aquatic resources (Section 305b) and list those that do not meet designated users of water quality standards (Section 303d).

An evaluation by the General Accounting Office (GAO 2000) found that many states were unable to sufficiently evaluate their coastal aquatic resources leading to inadequate water quality management and regulation. To address monitoring deficiencies and improve efforts for meeting the requirements of the CWA, the U.S. EPA Office of Research and Development (ORD) developed an Environmental Monitoring and Assessment Program (EMAP) coastal component. The main goal of the overall EMAP is to "monitor the condition of the Nation's ecological resources to evaluate the cumulative success of current policies and programs and to identify emerging problems before they become widespread or irreversible." The EMAP design provides a way to obtain quantitative assessments of the regional extent of environmental problems by measuring status and change in a core set of selected ecological condition indicators. This provides a strategy to identify and bound the extent, magnitude, and location of environmental degradation and gauge the effects of changes in regulations and management strategies.

The Western States Coastal EMAP was initiated as one component of the national EMAP coastal program called the National Coastal Assessment (NCA), led by EPA to monitor and assess the status and trends of significant estuarine and coastal resources as an end to providing a report on the condition of the Nation's coast (bays and estuaries). This effort will provide an integrated and comprehensive coastal monitoring program among all coastal states and is being accomplished through strategic partnerships between the U.S. EPA and all 24 U.S. coastal states, Guam, and Puerto Rico (Figure 1).

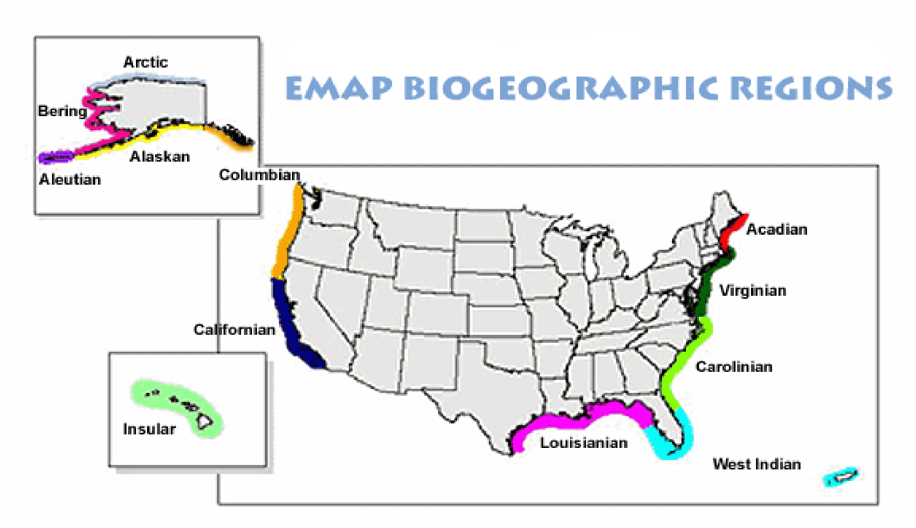


Figure 1. North American Coastal Bigeographic Provinces for the EPA's National Coastal Assessment Program.

Figure 2
Alaska coastal EMAP provinces. The 2002 Southcentral Alaska EMAP study area is shown as green.

Each state uses a compatible, probabilistic design and a common core set of analyses and indicators to conduct their independent survey and for assessing the condition of their coastal resources. The core set of parameters that are included in the EMAP that ensures the consistency and comparability of data from all coastal states includes several oceanographic and water quality parameters, sediment toxicity analyses, sediment chemistry, tissue chemistry, fish pathology, benthic community analyses, and fish community analyses.

Because of thecompatible design and common set of core analyses and indicators, the estimate provided by each state can be aggregated to assess conditions at the state, EPA Region, biogeographical, and National levels.In 2001, the Alaska Department of Environmental Conservation (DEC) developed a Cooperative Agreement with the Environmental Protection Agency (EPA) to join collaboratively in the Western States Coastal Environmental Monitoring and Assessment Program (EMAP). Through this agreement, the state of Alaska's DEC accepted funds from the EPA to conduct a coastal EMAP program in southcentral Alaska's coastal waters. The field program took place during the summer 2002.

Alaska was the last coastal state to receive funding to conduct field monitoring as part of the NCA's Western States Coastal EMAP. The DEC is the lead agency facilitating sampling for EMAP in Alaska. Partnerships with other federal, state, and local agencies was incorporated into the Alaska program in southcentral Alaska. The data collected from this initial survey are envisioned as the beginning of an DEC statewide ambient water monitoring program that will include interior as well as coastal waters.

Given the extent of Alaska's coastline (greater than all of the coastline in the lower 48 states), a coastal assessment of all of Alaska's coastal bays and estuaries was not feasible logistically or financially within one survey. Thus, the EPA identified five biogeographical provinces of Alaska's coastline to be surveyed individually (Figure 2). One of these biogeographical provinces is contained within the northwestern Gulf of Alaska extending from the Alaska Peninsula to the northern Gulf coast east of Prince William Sound. DEC sampled this first sub-region of Alaska's coastline in the summer of 2002. An additional survey took place in 2004 in the eastern Gulf of Alaska that included the inside waters of the southeastern Alaska "panhandle" and extended west to include Yakutat and Icy Bays. A survey is planned for 2006-2007 along the Aleutian Chain and as additional funds become available in future years, Alaska will extend the EMAP sampling to incorporate the additional two regions that encompass the Bering, Chukchi, and Beaufort Seas coastal waters.

DEC's current focus is to complete an initial EMAP survey for each coastal province, thereby providing a water quality and ecological benchmark for each region. In the national coastal EMAP program, five years has been considered the potential recurring sampling interval, but alternative sampling schemes are currently being developed and assessed. Once DEC, EPA and other partners have had the chance to assess the results of the Southcentral and southeast Coastal EMAP sampling efforts, a long–term, integrated, probabilistic and targeted monitoring program will be implemented. Monitoring frequency cannot yet be determined, but will not be less than every five years.

EMAP provides the opportunity for integration and synthesis of additional coastal data into the Alaska's new DEC statewide STORET water data management system, which incorporates water quality, habitat, and quantity information. The data management system, which is part of the Alaska Clean Waters Action (ACWA) initiative, is intended to serve as a basis for tracking the status and trends of Alaska's water resources and evaluating and prioritizing Alaska's waters for restorative action, which includes interior watersheds as well as coastal waters, and to be a vehicle for incorporating state water quality data into the national STORET database.

This purpose of this report is to provide a statistical summary and assessment of the data from the first year of sampling (2002) for the coastal bays and estuaries of the Southcentral Alaska coast.

Partners in Alaskan EMAP Program

The DEC is the state agency responsible for developing and administering the EMAP program in Alaska. For this first coastal EMAP survey, the DEC developed numerous partnerships to begin developing the capacity within the department for building an DEC ambient coastal monitoring team. The success of the planning, field sampling, laboratory analyses, data analyses and interpretation, and reporting relied on the expertise and participation of numerous other organizations in partnership with the DEC's program and project managers. The Lead Scientist for the program was provided through a Memorandum of Understanding between the DEC and the Cook Inlet Regional Citizens Advisory Council (CIRCAC) and through this agreement CIRCAC provided program planning, field sampling, data analyses and management, and report writing. For the field program, scientific sampling crew were provided by CIRCAC, National Marine Fisheries Service (Northwest Fisheries Science Center), International Halibut Commission, Washington Department of Ecology, University of Washington, and EPA. Numerous agreements and contracts were established for laboratory analyses and included the NMFS Northwest Fisheries Science Center, University of Washington, the Washington Department of Ecology, and the University of Alaska Fairbanks School of Fisheries and Ocean Sciences.

1.2 The Alaskan Context

Alaska Coastal Monitoring

Alaska has approximately 45,000 miles of coastal marine shoreline, constituting more than 50% of the total United States coastline. The surface area of coastal bays and estuaries in Alaska is 33,211 square miles, almost three times the estuarine area of the contiguous 48 states. In addition, much of the southeast and Southcentral Alaskan coast is very convoluted, a result of the hundreds of bays, estuaries, coves, fjords, and other waterbodies. Accordingly, the area of Alaska's coastal bays and estuaries is almost three times that of the continental U.S. Most of this coastline is inaccessible by road, making a state-wide coastal monitoring program logistically challenging and expensive.

Due to Alaska's expansive coastline and associated monitoring costs, historical coastal assessments in Alaska have mainly been targeted for relatively small specific coastal areas and were generally designed to assess impacts from specific activities, such as oil exploration and production, fish processing, and municipal discharges.

Due to Alaska's expansive coastline and associated monitoring costs, historical coastal assessments in Alaska have mainly been targeted for relatively small and specific coastal areas designed to assess impacts from specific activities, such as oil exploration and production, fish processing, or municipal discharges. Other assessments have been completed, and continue to take place, along the coastlines impacted by the Exxon Valdez oil spill, specifically to assess the effects of that event. There are also a few data sources for contaminants in Alaska, collected in the context of national assessments such as NOAA's National Status and Trend program that analyzed contaminants in sediments and bottom fish at a few sites along Alaska's coast. Also, under their Benthic Surveillance program, NOAA measured contaminants in intertidal mussels and sediments as part of their Mussel Watch Program. For most data collected in coastal Alaska to date, concentrations of contaminants have been measured at levels significantly lower than in the rest of the coastal U.S. However, there are areas of concern based on the State of Alaska's monitoring program to fulfill their 305(b) reporting requirements. This program, however, has focused almost exclusively on known or suspected impaired waterbodies.

Recently, there has been increasing concern that local sources, as well as long distance transport of certain contaminants of concern, have the potential to accumulate in Alaska's coastal resources (AMAP 1998). Alaska's Section 303(d) list includes 20 coastal bays, estuaries, or harbors, which are considered water-quality-limited waterbodies, some of which are impacted by a specific industry and others by non-point source pollution. This amounts to less than 1% of the total coastal bays, and the listing is based on data collected only from known or suspected impaired waterbodies - not an assessment of all waterbodies. There is concern that non-point source pollution is increasing in Alaska,which has lead the state to implement a Non-point Source Pollution Strategy (DEC 2002). The State of Alaska's Department of Environmental Conservation also sponsored the development of a Cruise Ship Waste Disposal and Management plan due to concerns about the general increase in cruise ship traffic, especially in southeast and Southcentral Alaska.

A recent report was published that provided a synthesis of what is known about persistent organic pollutants (POPs) in Alaska (Chary 2000). Data from other Arctic areas, such as in Canada and Europe, show that POPs are depositing in northern latitudes after being transported from more industrialized areas. The report identified POP contamination as a particular concern in Alaska due, in part, to the subsistence lifestyle of many Native Alaskan communities.

Principal Operational Objectives for DEC Division of Water EMAP

1) Estimate current status, trends and changes in selected indicators of Alaska's aquatic ecological resources on a regional and statewide basis with know statistical confidence;

2) Estimate geographic coverage and extent of Alaska's aquatic ecological resources within a know statistical confidence interval;

3) Seek to establish associations between selected indicators of natural and anthropogenic stresses and indications of the condition of aquatic ecological resources;

4) Provide for statistical summaries and periodic assessments of Alaska's aquatic ecological resources.

(Adapted from EPA, 1997)

By incorporating EPA's unbiased, probabilistic survey design and common set of survey indicators, Alaska's Environmental Monitoring and Assessment Program (EMAP) will allow DEC to conduct a statistically unbiased, objective assessment of the overall environmental condition of Alaska's waters (EPA, 2001).

Unlike targeted studies, EMAP is focused on the "state of the region," providing resource managers with scientifically based data of known statistical confidence. EMAP protocols are standardized, and are used by all participating states. This improves the comparability of data among the EMAP participants allowing for better regional assessment and prioritization of stressors and impacts. In addition, EMAP provides standard methods and procedures for sharing and managing comparable data sets held in a quality-controlled, data management system.

For DEC, EMAP provides essentially two tools: a bioassessment framework (integrated physical, chemical and biological measurements) and a statistically-based design procedure. The statistical design is critical for inferring aquatic ecological condition and assessing trends over time to all waters in a region from a sub-set of waters actually sampled. EMAP protocols are designed to provide general conclusions about the biotic and abiotic conditions within a study area, which can then be used for comparison with other regions of Alaska and the United States.

Southcentral Alaska Study Area: Background

The coastline along much of the northwest Gulf of Alaska study area (Figure 3) is characterized by mountains with steep topography down to the irregular shoreline, which is indented by many inlets, fjords, bays, and estuaries, including two major estuaries – Cook Inlet and Prince William Sound. The study area also includes many major island systems (e.g. Kodiak Island archipelago and dozens of large islands in Prince William Sound). The overall Southcentral Alaska EMAP study area extends from Unimak Pass in the southwest to the Copper River Delta, just east of Prince William Sound and includes the southern coast of the Alaska Peninsula, Shelikof Strait, the Kodiak Island archipelago, Cook Inlet, the Kenai Peninsula, and Prince William Sound. The coastline has been shaped by glaciers, rivers, active plate tectonics, and ocean currents that erode or deposit sediments. The shelf system is relatively narrow (typically less than 100km) although there are areas where the shelf extends up to 200 km, such as the area just east of Cook Inlet. There are areas where the water depth is highly variable and can include seastacks, underwater canyons, or deep holes such found in the center of Prince William Sound (over 750 meters deep).

This EMAP study uses multiple sediment quality in its evaluation of the condition of Southcentral Alaska's coastal bays and estuaries and, thus, it is important to understand the sedimentation regime in the study area. Major sediment sources include the Copper River and the Bering and Malaspina glaciers east of Prince William Sound, and the Knik, Matanuska, Beluga, and Susitna Rivers draining into upper Cook Inlet. Some of these riverine sources of sediments can be seen in the satellite imagery in Figure 3, especially the rivers entering upper Cook Inlet and Copper River sediments entering the Gulf of Alaska just east of Prince William Sound. Ocean currents carry entrained suspended sediments in a counter-clockwise direction along the northern Gulf of Alaska, depositing sediment in areas where the current slows such as eddies and deep troughs.

A significant amount of the sediments introduced by upper Cook Inlet rivers and by the Copper River Delta have been detected hundreds of miles down-current in lower Cook Inlet and in Shelikof Strait (ADL 1997). Heavy sediment loads introduced into upper Cook Inlet are deposited down-current and, although these suspended sediment concentrations are high in upper Cook Inlet, their deposition into the upper and central Inlet is minimal due to scouring by tidal currents. Nearshore, and in some embay

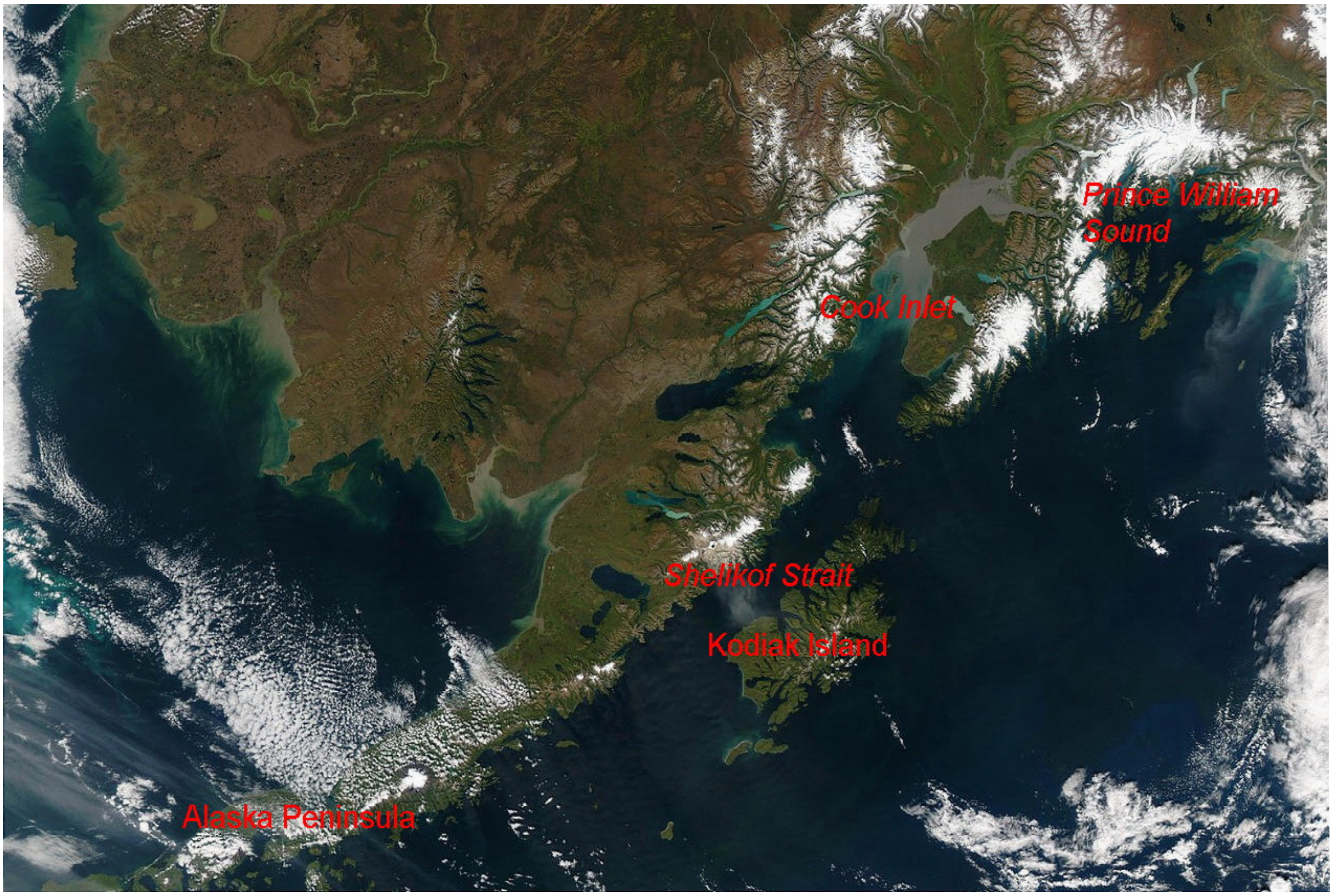


Figure 3. Study area geography from the western extent of the Alaska Peninsula to just east of Prince William Sound. Image is from MODIS satellite and provided by

ments, the current slows, and the sediments can accumulate and create very wide sand or mud flats that can extend along the coastline for tens of miles and be over a mile wide in the intertidal zone.

Offshore circulation in the Gulf of Alaska (Figure 4) is dominated by the Alaska Current/Alaska Stream which is the northern counter-clockwise component of the North Pacific Current that generally parallels the continental slope. This current is called the Alaska Current in the eastern Gulf of Alaska as it is a typical northern latitude eastern boundary current; northward flowing and relatively wide and slow. West of about 150^{o} W the current narrows and speeds up and is called the Alaska Stream to delineate it from the Alaska Current. Inshore of the Alaska Current/Alaska Stream, large seasonal differences in coastal salinity indicate variations in freshwater input into the area. This distribution of surface salinity results in a nearshore, westward coastal current running counter-clockwise around the Gulf of Alaska inside of the Alaska Current/Alaska Stream. This nearshore, density-driven coastal flow is called the Alaska Coastal Current.

The offshore and nearshore currents affect the distribution of sediments and can carry potential contaminants from areas upstream. Figure 4 also shows an example of how contaminants can be carried by these currents from a source to areas downstream – oil spilled by the Exxon Valdez into Prince William Sound was carried to coastal areas downstream along the Kenai and Alaska Peninsulas and to Cook

Inlet and Kodiak Island.

Although there are significant sediments introduced into the study area as described above, rocky coastline is the dominant habitat along much of the nearshore study area. Excluding most of Cook Inlet, the Copper River Delta, and the heads of many bays and estuaries, the steep and rocky topography continues as steep and rocky bathymetry. For a sediment quality study, such as this Southcentral EMAP assessment, habitat type is important in determining what portions of the overall study region provide sampleable sediment habitat.

The waters of Southcentral Alaska slong the northern Gulf of Alaska study area are highly productive and include some of the highest primary productivity rates reported in Alaska (Sambratto and Lorenzen 1986, Cooney 2004). This production provides carbon to rich and diverse pelagic and benthic food king crab, scallops, and shrimp.

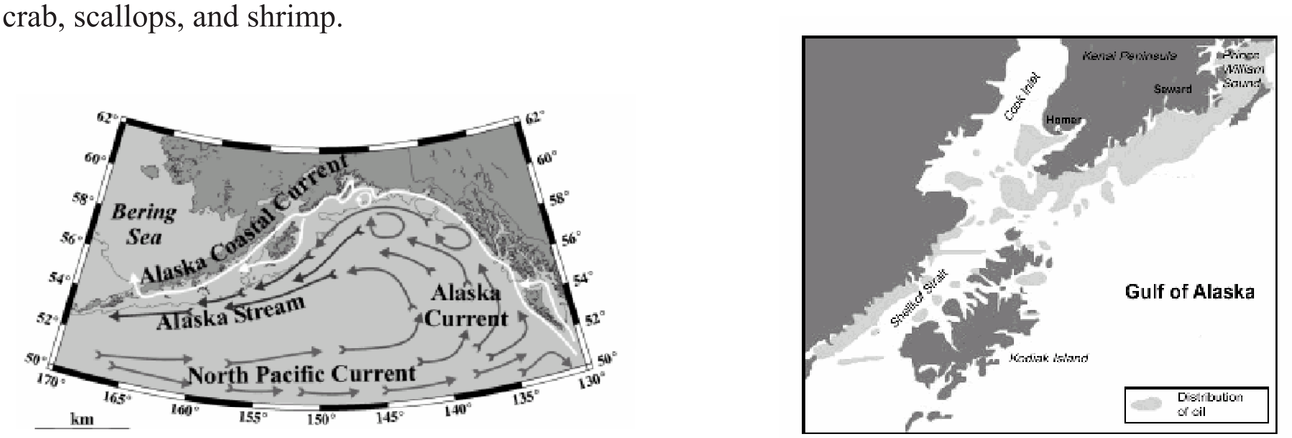


Figure 4. Major water circulation patterns in the Gulf of Alaska (left) and distribution of spilled Exxon Valdez oil in areas downstream of Prince William Sound (right).

The two largest bays in the study area include the estuaries of Cook Inlet and Prince William Sound, which combined comprise a significant portion of the entire study area. Cook Inlet is a 370 km long estuarine system that includes Kamishak Bay, Kachemak Bay, Turnagain and Knik Arms. The northern part of the inlet has a tidal range of about 9 m, one of the highest in the world. Three major riverine systems, the Knik, Matanuska, and Susitna Rivers, drain into the northern inlet and constitute the largest riverine drainage into the Gulf of Alaska. These huge freshwater inputs establish density-driven currents that cause a net flow of water along the west side towards the mouth of Cook Inlet and introduce huge amounts of glacial silt downstream into the coastal Gulf of Alaska. The southern areas of Cook Inlet include Kamishak Bay on the west side and Kachemak Bay on the east side. These waters in southern Cook Inlet are highly productive, due in part to upwelling of nutrient rich waters through Kennedy and Stevenson entrances at the mouth of the inlet.

The Cook Inlet watershed drains an area of 100,000 square kilometers and includes the largest urban area in Alaska with a population that is approximately two-thirds of the state's population. Thus, the potential for non-point source pollution run-off is greatest in this watershed. Other possible sources of water-quality stressors in this watershed include onshore- and offshore-oil and gas exploration and production, municipal discharges, mining wastes, vessel traffic, fish-processing discharges, as well as numerous smaller industries.

> *Prince William Sound is shaped like a great spider: an open irregular body of water eighty miles or more across, fringed by numerous arms and inlets that reach far in amid the mountains. Across the head of most of these arms are huge glaciers; others hang upon the mountain sides, or cascade down them.*
>
> John Burroughs, *Harriman Alaska Series, Vol. I.(1901-1905)*

Prince William Sound is a nearly enclosed glacially carved embayment in northern Gulf of Alaska that covers over 9,000 square kilometers. In comparison to east and west coast estuaries included in EMAP coastal assessments, Prince William Sound alone is roughly 15 times the size of the San Francisco Bay embayment and twice the area of Chesapeake Bay. There are over 100 glaciers within the Sound, many of which are tidewater glaciers. As described earlier, several produce large plumes of glacial sediments in their fjords. Prince William Sound is bordered on three sides by mountains, including the Chugach Mountain Range which is the highest coastal range in the world. Prince William Sound has over 4,500 km of convoluted shoreline. The bathymetry resembles the adjacent topography of the coastal mountains as the shoreline drops rapidly to considerable depths with only a narrow, often rocky, shelf immediately nearshore. There are many areas where the bathymetry comprises vertical walls along the deep fjords, especially in the northwestern part of the Sound.

Prince William Sound is considered estuarine due to the freshwater runoff from rain and snow, melting snowpack, and from glacial rivers, all of which help to form a lens of freshwater above the deeper, higher salinity waters. Another major source of freshwater in the Sound is the relatively fresh portion of the Alaska Coastal Current flowing through Hinchenbrook Entrance. Water depth averages 300 m (deeper than the adjacent Gulf of Alaska shelf) and can reach depths over 750 meters. During winter, wind-induced cooling and mixing creates deep renewal by bringing colder, nutrient-rich waters to the surface. The Sound is semi-protected from the Gulf of Alaska by a series of large islands, up to 50-miles long, and contains complex gradients among its fresh water, estuarine, and marine settings.

There have been two major releases of hydrocarbons into Prince William Sound, 25 years apart. After the 1964 earthquake, which was centered in the Sound, its subsequent tsunami caused a release of asphalt (originally from the California Monterey formation) from storage tanks in the town of Valdez. Remnants of this spilled asphalt have persisted and were recently detected throughout Prince William Sound (Short et. al. 2004). In 1989, the oil tanker Exxon Valdez grounded on Bligh Reef in Prince William Sound and spilled a minimum of 11 million gallons of Alaska North Slope crude oil. The oil spread throughout the western Sound, was subsequently entrained in the Alaska Coastal Current, and smeared along downstream shorelines of the Gulf of Alaska. Fate studies immediately after the spill indicated that deep subtidal habitats were not impacted. Much of the stranded Exxon Valdez oil has been removed by cleanup operations and natural processes. Recent studies, however, have shown that oil does remain on some beaches in Prince William Sound in a relatively unaltered (fresh and unweathered) state (Short et. al 2004, Peterson et. al. 2003).

2. METHODS

2.1 Sample Design and Statistical Inference

Background

The EMAP approach to evaluating the condition of ecological resources is described in reports such as Diz-Ramos et a. (1996), Stevens (1997), and Stevens and Olsen (1999) and is also presented in summaries provided at http://www.epa.gov/wed/pages/EMAPDesign/OverviewPages/overview.htm. A brief summary from these documents follows since it is very important the that underlying study design and sampling frame selection is clear so that the strengths and limitations of the dataset are clear.

Given that it is impractical to completely census a resource such as all estuaries on the west coast, a more practical approach to evaluating a resource's condition is to sample selected portions of the resource using probability-based sampling. "Sample surveys" are studies based on random samples of the resource rather than on a complete census. Sample surveys offer the advantages of being affordable, and of allowing extrapolations to be made of the overall condition of the resource based on the random samples collected. Survey methodologies are widely used in national programs such as forest inventories, agricultural statistics surveys, national resource inventories, consumer price indices, labor surveys, and such activities as voter opinion surveys.

A probabilistic survey design provides the approach to selecting samples in such a way that they provide valid estimates for the entire resource of interest. Designing and executing a sample survey involves five steps: (1) creating a list of all units of the target population from which to select the sample, (2) selecting a random sample of units from this list, (3) collecting data from the selected units, (4) summarizing the data with statistical analysis procedures appropriate for the survey design, and (5) communicating the results. The list or map that identifies every unit within the population of interest is termed the sampling frame.

The sampling frame for the EMAP Western Coastal Program was developed from USGS 1:100,000 scale digital line graphs and stored as a GIS data layer in ARC/INFO program. A series of programs and scripts (Bourgeois et. Al. 1998) were written to create a random sampling generator (RSG) that runs in ARCView. Site selection consisted of using the RSG to first overlay a user-defined sampling grid of hexagons over the spatial resource which consisted of all estuaries of the west coast, including Alaska. The area of the hexagons was controlled by adjusting the distance to hexagon centers, and by defining how many sample stations were to be generated for each sampling region. After the sampling grid was overlaid on the estuarine resource, the program randomly selected hexagons and randomly located a sampling point within the hexagon. Only one sampling site was selected from any hexagon selected. The program determined whether or not a sampling point fell in water or on land, and sites that fell on land were not included. The RSG is run iteratively until a hexagon size is determined which generates the desired number of sampling sites within the resource (Bourgeois et. Al. 1998).

Hexagon size may be different for classes of estuarine systems of different areal extent. The final data analysis which provides the estimates of resource condition then weights the samples based on the area of the estuarine class. Stevens (1997) terms this a "random tessellation stratified" (RTS) survey design applied to each bay or estuarine resource class. For the Southcentral Alaska study, the area was classified using a simple classification system based on physical dimensions to determine which hexagon size would be used during site selection. Six hexagon grid sizes were overlaid over the study area to ensure

ensure that the smaller coastal bays and estuaries would have an equal chance of being selected compared to the large bays and estuaries. For example, Cook Inlet is a large embayment and the hexagon size that was overlain for this portion of the study area was larger than the hexagon frame overlain for all of the small indentations along the northern Gulf of Alaska, or even the small bays within Cook Inlet. Appendix A provides information on the hexagon strata, including the six hexagon sizes, the total summed area for each hexagon size, the area of each bay and estuary and whether it was classified as Cook Inlet, Prince William Sound, or "Alaska," which included the outer coast bays and estuaries and the Kodiak Island archipelago, as well as the target sites selected through this process. Fifty sites were determined to be the minimum number to represent the sampling frame of Southcentral Alaska coastal bays and estuaries.

The different hexagon sizes affect the "weight" that each station contributes to the overall study area. A station selected from a larger hexagon represents a larger portion of the entire study area. However, an individual station does not represent the bay that it is in; each station is a replicate of the population of sampling hexagons, which, as mentioned previously, includes all of Southcentral Alaska coastal bays and estuaries. Study results thus emphasize the aerial percentage of the study area that has an indicator value above or below some criteria. However, although an individual station does not represent the bay or estuary that it is inside of, this report does include results shown as geographic distributions along the study area to illustrate potential trends or areas that may require more detailed study to statistically characterize a particular study area.

Inherently, probability-based sampling with a statistical survey design provides unbiased estimate over a large geographic area from a small number of samples where:

- Every element in population has the opportunity to be sampled with a known probability
- Sample selection is carried out by a random process
- Samples taken at regular intervals from a random start (systematic random)
- grid positioned randomly
- ensures spatial separation
- equal chance
- potential for stratifying (weighted design)

Alaska Sampling Design

There were 50 base sites selected for Alaska using the EMAP sampling approach of probabilistically generating sampling locations within three coastal strata: estuary/bay < 100 km2, estuary/bay >100 km2 and <250 km2, and estuary/bay >250 km2. These strata were selected within three systems: Cook Inlet [Cook Inlet and Shelikof Strait]; Alaska [Alaska Peninsula, Kenai Peninsula, Kodiak Island, and other portions of the outer coast of the northern Gulf of Alaska], and; Prince William Sound.

Additional "intensive" sites were also selected within the Cook Inlet and the Prince William Sound systems. These sites were considered alternate sites for the base EMAP sites within these systems. The order with which alternate sites replaced un-sampleable sites was determined through random sampling. The sampling frame utilized six hexagonal grid sizes to cover the size range of estuaries and to ensure that some level of sampling occurred in each of the estuarine size classes. Appendix A shows the sampling frame and includes the target and alternate "intensive" sites.

This report is a statistical summary of the 2002 Southcentral Alaska EMAP results. Samples were collected between June 14 and August 2, 2002. Data from all stations (55 sampled sites) were combined for analyses of the coastal bays and estuary populations. No comparisons are made between or among strata or between base and intensive sites.

Table 1 includes station information for the 55 stations sampled. In many cases it was not possible to sample the exact target location so the locations reflect the actual sampling locations and not the original target locations. Figure 5 shows these sites on a study area map. For data analyses and presentations that report by percent of study area, each site was weighted appropriately. Figure 6 shows which hex-size category from which each station was selected.

Table 1. Southcentral Alaska EMAP sites sampled in 2002 from the original target sites, including base and alternate sites.

EMAP Station ID	Depth, Meters	Date	LatDegrees	LatMin	LongDegrees	LongMin
AK02-0002	4.1	10-Jul-02	60	12.580	152	44.305
AK02-0003	3.9	08-Jul-02	59	49.752	153	7.701
AK02-0004	65	30-Jul-02	59	37.232	151	14.851
AK02-0005	4.5	14-Jul-02	59	12.579	151	49.34
AK02-0008	24	18-Jun-02	57	58.581	154	57.378
AK02-0009	102	05-Jul-02	57	58.851	153	4.258
AK02-0010	24	18-Jun-02	57	42.525	155	34.034
AK02-0011	9.2	01-Aug-02	61	1.954	151	14.259
AK02-0012	4	31-Jul-02	60	42.169	151	51.588
AK02-0015	5.2	01-Aug-02	60	29.976	151	57.831
AK02-0016	12	31-Jul-02	60	14.971	151	31.653
AK02-0017	39	10-Jul-02	60	2.504	152	24.008
AK02-0019	87	16-Jun-02	59	17.379	152	50.526
AK02-0020	30	07-Jul-02	59	6.482	153	33.131
AK02-0021	116	14-Jun-02	59	8.723	152	19.847
AK02-0023	130	14-Jun-02	59	5.294	153	5.281
AK02-0024	168	15-Jun-02	58	47.094	152	49.042
AK02-0026	155	06-Jul-02	58	30.316	152	49.976
AK02-0027	182	19-Jun-02	58	5.412	153	30.145
AK02-0028	215	17-Jun-02	57	55.568	154	17.451
AK02-0029	232	17-Jun-02	57	51.151	154	33.132
AK02-0030	274	18-Jun-02	57	37.170	155	11.169
AK02-0032	25.9	23-Jul-02	60	54.930	147	48.460
AK02-0034	125	25-Jul-02	60	43.650	148	38.362
AK02-0035	148	26-Jul-02	60	14.696	148	17.708
AK02-0036	206	24-Jul-02	61	8.366	147	52.837
AK02-0038	5.4	24-Jul-02	60	48.686	148	1.88
AK02-0040	19	19-Jul-02	60	42.704	146	21.661
AK02-0041	230	25-Jul-02	60	44.446	148	1.504
AK02-0045	325	26-Jul-02	60	10.081	147	52.689
AK02-0046	23.9	22-Jul-02	60	55.491	147	19.252
AK02-0050	282	27-Jul-02	60	39.511	146	46.194
AK02-0051	122	22-Jul-02	60	35.413	146	18.771
AK02-0053	219	18-Jul-02	60	30.647	147	7.220
AK02-0054	20	18-Jul-02	60	35.320	146	39.319

EMAP Station ID	Depth, Meters	Date	LatDegrees	LatMin	LongDegrees	LongMin
AK02-0055	158	18-Jul-02	60	29.552	147	27.052
AK02-0056	352	27-Jul-02	60	32.351	146	58.763
AK02-0058	138	17-Jul-02	60	18.383	147	39.258
AK02-0059	181	17-Jul-02	60	2.454	147	42.030
AK02-0060	72	28-Jul-02	59	54.667	148	19.902
AK02-0061	30	21-Jul-02	60	14.614	145	34.028
AK02-0062	56	21-Jul-02	60	15.446	145	44.824
AK02-0063	117	16-Jul-02	59	48.546	149	32.924
AK02-0064	210	14-Jul-02	59	23.507	150	30.267
AK02-0065	129	02-Jul-02	58	27.442	152	21.762
AK02-0067	12.5	29-Jun-02	57	11.780	153	12.510
AK02-0068	94	29-Jun-02	57	3.751	153	34.540
AK02-0070	132	26-Jun-02	56	25.245	158	13.515
AK02-0071	128	25-Jun-02	55	59.506	158	35.517
AK02-0072	32	24-Jun-02	55	32.259	161	34.324
AK02-0073	26	24-Jun-02	55	22.358	160	37.363
AK02-0074	17	23-Jun-02	55	4.521	163	8.539
AK02-0075	62	22-Jun-02	55	9.064	160	25.995

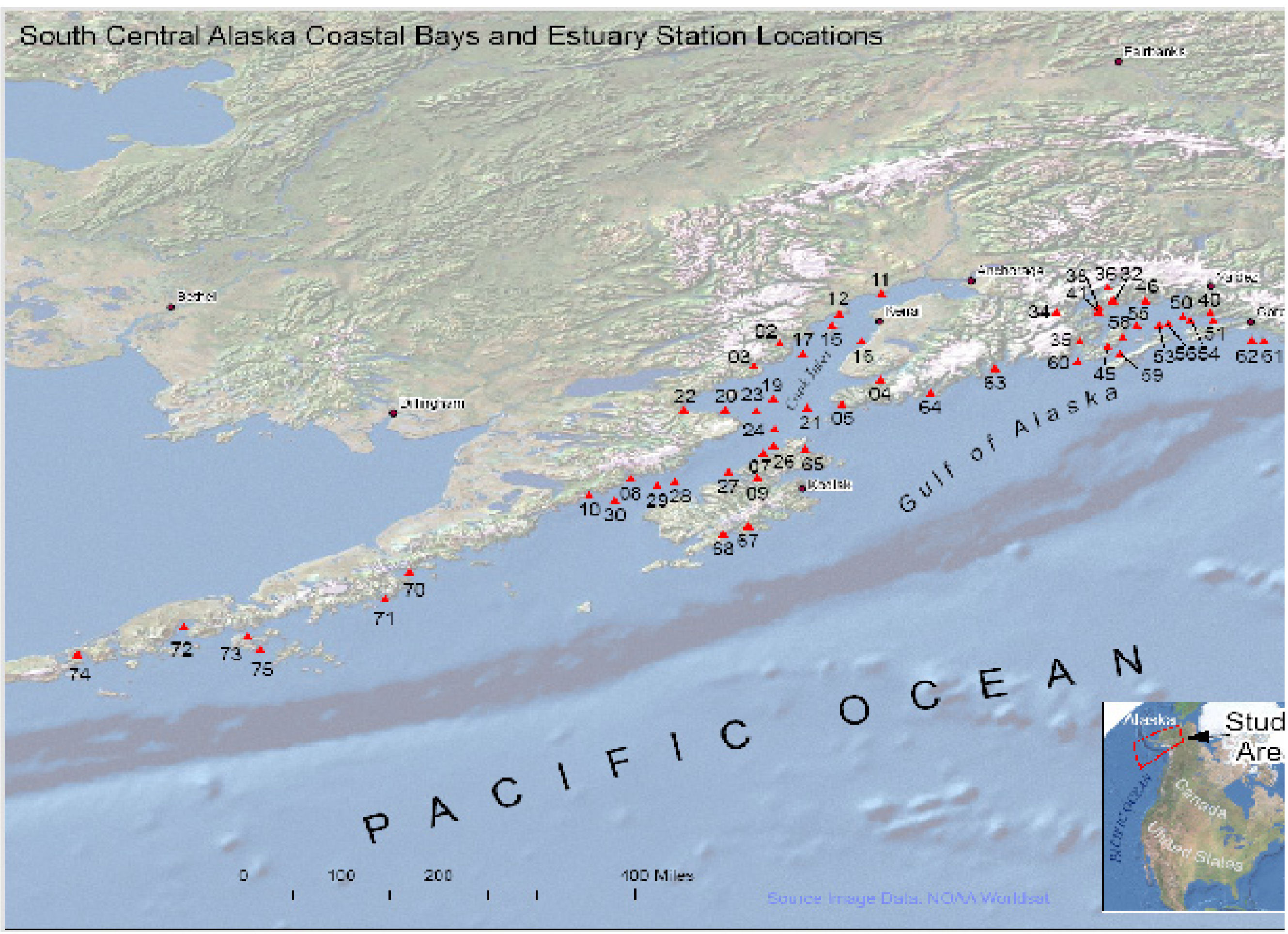


Figure 5. Location of Southcentral Alaska EMAP 2002 sampling locations. The two digit numbers are the last two digits of the EMAP Station number listed in Table 1.

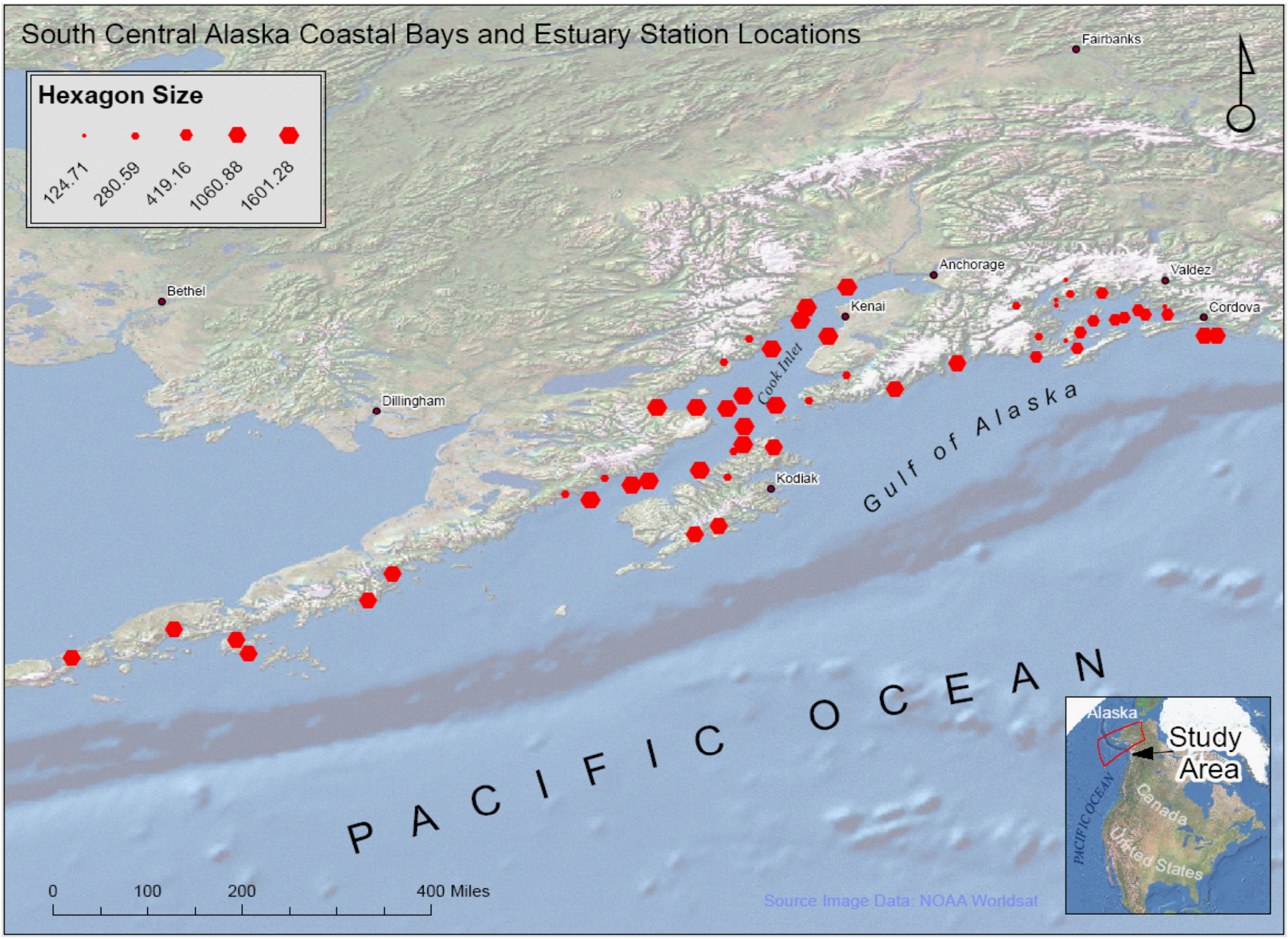


Figure 6. Hexagon size (km2) categories from which each of the Southcentral Alaska EMAP 2002 sampled sites were selected. The numbers are the last two digits of the Alaska EMAP Station Number shown in Table 2.1.2. Note that the hexagons are not to scale to the area that they represent and the symbol sizes were selected to only reflect that there are six different hex size categories.

Alaska Field Sampling Platforms

The Southcentral Alaska sampling frame included more than 1500 linear miles and hundreds of coastal bays and estuaries, many of which were several days transiting time away from the nearest port. Thus, the sampling program required a vessel that could carry the entire scientific and vessel crew, and sampling equipment, and that had the ability to sample at sea for up to ten days. In addition, most of the coastal ports in the study area are small villages with no road access so there is little opportunity for resupplying except for water and fuel.

The sampling sites ranged from several meters of water depth to more than 350 m and included nearshore areas and offshore stations. Thus, the sampling vessel also needed to carry a smaller vessel that was large enough to handle the sampling gear nearshore and yet could be easily deployed.

The DEC contracted with the vessel Ocean Cape, a 90 foot steel Bering Sea long-line crab vessel. The vessel was designed for long periods at sea and had more than sufficient fuel and water capacity for up to 8 people onboard for two weeks as well as significant deck space, storage space, and freezer and refrigerator space for samples and food. The vessel was also very stable and capable for northern Gulf of Alaska seas, especially during long unprotected transits such as the 36 hour run between Kodiak and the lower Alaska Peninsula sites. The vessel owners completed several modifications to the vessel to meet the sampling needs of the program, such as installing trawl gear and an oceanographic winch. The Ocean Cape carried onboard a 22 foot catamaran skiff with twin 50 hp engines that was a stable platform even in some of the exposed nearshore sampling areas. It also had the power to trawl even against the extreme currents at some Cook Inlet stations.

2.2 Quality Assurance/Quality Control

The EPA's Office of Research and Development (ORD) has developed standardized quality assurance and control protocols for all coastal assessments conducted through their EMAP National Coastal Assessment Quality Assurance Project Plan (NCA QAPP) 2001-2004 (U.S. EPA 2001). This document describes National Coastal Assessment (NCA) method and data quality objectives. The goal is that for each indicator of condition, the portion of the resource in a degraded condition can be estimated within ±10% for the overall system (e.g. U.S. coastal waters) and for each subregion (e.g. Southcentral Alaska) with 90% confidence. By reference, the Alaska EMAP program adopted the criteria defined in the NCA QAPP 2001-2004 which describes procedures for site selection, site evaluation, field-team training, site sampling, analytical procedures, laboratory and data QA/QC procedures, data management, and reporting. In the various methods sections below, these procedures are described specifically for the Southcentral Alaskan coastal bays and estuaries assessment.

The NCA QAPP 2001-2004 lists Target Method Detection Limits (MDLs) for laboratory analyses of samples for the National Coastal Assessment program. MDLs are calculated for the detection above background of low levels of each analyte and takes into consideration instrument signal, sample size, and the steps required to prepare samples for analyses. All laboratories contracted for the Southeast Alaska 2002 EMAP sample analyses were given copies of the target MDLs and were expected to use appropriate laboratory and analytical methods to achieve as many of these goals as possible. The analytical laboratories used by the Alaska program had been approved by the EPA for meeting analytical requirements during previous assessments.

To ensure sample quality, very specific sample containers, size, storage, and holding times are identified in the NCA QAPP 2001-2004 (U.S. EPA 2001). Table 2 lists these guidelines for appropriate field sampling and laboratory storage until analyses are completed. Samples were typically shipped every 10 to 14 days to appropriate analytical laboratories. The geographic distances between sample locations and between ports at which samples could be delivered did not allow more frequent shipping of samples. During this time, they were stored onboard the vessel using "laboratory storage" protocols and at the nearest port were packed to ensure that they maintained temperature during shipping. The shipping container temperatures were taken when the samples arrived at the individual laboratories to assess whether the sample temperatures were out of compliance. They were then immediately placed again into appropriate laboratory storage until sample preparation and analysis.

To ensure that the field crew conducting the Southcentral Alaskan coastal bays and estuaries assessment collected samples and data according to the EPA NCA QAPP (EPA 2001), initial field training was provided by field crew from the Washington Department of Ecology who conducted the coastal EMAP programs there. An additional field audit was conducted by EPA Western **Ecology Division's Alaska** EMAP Project Manager who compared the Alaska field team sampling methods against those defined in the NCA QAPP (EPA 2001, Saupe 2002).

Each data generating activity, field measurements and laboratory analyses, were thoroughly documented in accord with the guidelines that are presented in the NCA QAPP 2001-2004.

2.3 Ecological Indicators and Field Sampling Protocols

The required EMAP core habitat, benthic, and pollutant exposure indicators were measured using methods comparable to other coastal EMAP program as shown in Table 3, which describes the core environmental indicators for the Southcentral Alaska EMAP program and reflects whether the parameter is an indicator of habitat, biotic, or abiotic/pollutant exposure conditions. Procedure details for each indicator are described in the following sections.

Station Evaluation

The field crew used GPS to locate the sampling site based on the latitudes and longitudes of the target sites provided by EPA. At most sites, the vessel was not at anchor due to the depth and the potential swing of the vessel in the strong tidal currents found throughout the area. Instead, the vessel held the station using the engine powered into the current. In many instances, the current was so strong that the vessel was allowed to "drift" with the bow held into the current to minimize the wire angle during equipment deployments. In the Southcentral Alaska study area, many of the sites were unsampleable directly on the target location due to the nature of the bottom substrates. Due to the long distances between many of the sites that required up to 24 hours of running time, sites were not always dropped if sampling could not take place within the EPA target distances. Every effort was made to sample on target, but often sampling took place outside of this distance when the site was moved to the nearest sampleable habitat (up to several miles away). These instances were documented and justified with physical information and the reasons for the limitations. Reasons for moving the site included rocky habitat, steep bathymetry, subsea cables or pipelines, vessel traffic areas, floating ice, or the original site selection placed the target site on shore or in the intertidal zone. If there was no sampleable habitat within the general area, the station was dropped and an alternate site was sampled from the list of alternate sites.

Table 2.
Summary of sample collection, containers, storage, and holding times for field sampling

Sample Type	Container	Field Holding	Lab Storage	Max. Holding
Sediment				
Organic Compounds	Pre-cleaned I-Chem jars	Freezer (-20°C)	Freezer (-20°C)	1 year
Inorganic Contaminants	Pre-cleaned I-Chem jars	Freezer (-20°C)	Freezer (-20°C)	1 year*
Total Organic Carbon	Glass jar	Freezer (-20°C)	Freezer (-20°C)	1 year
Grain Size	Nalgene jar	Refrigerator (4°C)	Refrigerator (4°C)	1 year
Toxicity	Pre-cleaned HDPE jar	Refrigerator (4°C)	Refrigerator (4°C)	28-days
Water Quality				
Chlorophyll *a*	25 mm GF/F in HDPE snap-tube (foil-wrapped)	Freezer (-20°C)	Freezer (-20°C)	6 months
Nutrients	60 ml Nalgene bottle	Freezer (-20°C)	Freezer (-20°C)	6 months
Total Suspended Solids (TSS)	25 mm preweighted GF/F in petri-dish	Freezer (-20°C)	Freezer (-20°C)	3 months
Biota				
Benthos (0.5 and 1.0 mm sieved)	100-1000 ml wide-mouth Nalgene	10% buffered formalin	Transfer to isopropyl alcohol	Indefinately
Fish contaminants	Individuals wrapped in foil and combined in Zip-lock bag	Freezer (-20°C)	Freezer (-20°C)	1 year*
Histopathy specimens	Dependent on fish population showing abnormalities	Dietrich's fixative	Transfer to 70% ethanol	6 months

*Except for Hg, which has a recommended maximum recommended holding time before laboratory analyses of 28 days.

Habitat Indicators

Water QualityIndicators-CTD Cast (Hydrographic Profile)

Water QualityIndicators-CTD Cast (Hydrographic Profile)

Continuous water column profiles were taken at each site using a Conductivity Temperature and Depth (CTD) instrument with additional sensors for measuring dissolved oxygen, fluorescence, and turbidity. Water pressure (depth), salinity, temperature, and dissolved oxygen were measured using a Seabird SBE19 CTD. Sensors included Seabird temperature (S/N 3036), pressure (SBE S/N 1925532-3036), conductivity (S/N 3036), and SBE 23y (Yellow Springs Instruments type) dissolved oxygen sensor. The NCA QAPP 2001-2004 requires monthly calibration of CTD sensors. However, during the approximately 55-day field sampling program in Alaska, there was no access to a laboratory to conduct monthly calibration checks. The sensors were re-checked at the end of the research cruise when the CTD and sensors were back in a laboratory setting. In the field, calibration checks were conducted every few

Habitat Indicators	Benthic Condition Indicators
Dissolved oxygen concentration	Infaunal species composition
Salinity	Infaunal abundance
Water Depth	Infaunal species richness and diversity
pH	Fish species composition
Water temperature	Fish abundance
Total Suspended Solids	Fish species richness and diversity
Chlorophyll *a* concentration	External pathological anomalies in fish
Transmittance	**Exposure Indicatores**
Secchi depth	
Percent silt-clay of sediments	Sediment contaminants
Nutrient concentrations (nitrates, nitrites, ammonia and phosphate)	Fish tissue contaminants
Percent Total Organic Carbon (TOC) in sediments	Sediment toxicity (*Ampelisca abdita* acute toxicity test-amphipod survival)

Table 3. Ecological indicators of habitat, exposure, and biotic condition for Southcentral Alaska 2002 EMAP.

days using a refractometer for salinity with accuracy ± 1.0 °/oo and daily using a LaMotte Winkler titration kit for dissolved oxygen (code 5860) with accuracy ± 0.5 mg/L.

Water quality indicators were recorded throughout the water column with the CTD averaging a descent rate of 1.0 m/s and a recording rate of 0.5 seconds. The instrument soaked at the surface for 2 minutes to ensure that the additional pump had cleared all air from the tubing. Near-bottom measurements were taken after a 2 minute delay to minimize any effects from a sediment surface that had been disturbed. Data was recorded for descending and ascending profiles. Seabird processing software was used to process the CTD cast data.

Water QualityIndicators - Secchi Depth

Secchi depth was determined by using a standard 16-inch diameter black and white Secchi disk. The disk was lowered to the depth at which it could no longer be seen. It was then slowly raised until it was just visible again and that depth was recorded to the nearest 0.5 m in most cases. For extremely high sediment loads, where the Secchi depth was less than 1.0 m, the distance was recorded to the nearest 0.1 m.

Water Qualiy Indicators-Discrete Water Samples

Water grab samples were collected with 5.0 L polycarbonate Niskin bottles at the surface (~0.5 m), mid-water, and near the bottom (~1 m above bottom). If the depth at the station was less than 6 m, water samples were collected only at the surface and bottom (~1 m above). The Niskin bottles were rigged for wire-casts and triggered to sample at depth using messengers. After the water was collected in the Niskin bottles, water was collected into the appropriate sample containers (each pre-rinsed three times with the sample water) for the following analyses as follows:

Chlorophyll a

Chlorophyll a samples were filtered within one hour after collection A 25 mm filter rack was used with a vacuum pressure less than 12 psi to minimize cell lysis. The volume of water required to turn the filter green was recorded. A standard volume was not used as the suspended sediment loads affected the volume that could be realistically filtered. The filter was removed using forceps, folded with the pigment side on the inside of the fold, and placed into a prelabeled, disposable screw-top polypropylene tube. The tube was wrapped in aluminum foil and labeled with the station and sample name.

Dissolved Nutrients

Up to 50-ml of sample filtered through a GF/F filter was collected into a prelabeled, clean 60-ml polyethylene screw-capped bottle which was labeled with sample depth, sample ID, bottle number and date. The samples were stored in dark, frozen conditions until prepared for analysis at the University of Washington (within three months of acquisition). The salinity for each sample was recorded and provided to the analytical laboratory for adjusting their procedures to the appropriate salinity.

Total Suspended Solids

Up to one liter of seawater was collected for TSS at each water sampling depth and filtered through a pre-weighed, numbered 25-mm GF/F filter. A sufficient amount of the sample was filtered (measured in a graduated cylinder) until the filter was almost clogged; the total volume varied at each station depending on the amount of glacial flour in the water. In areas with high TSS, such as upper Cook Inlet, relatively small (<100 ml in some cases) volumes were filtered. After filtration, the filter was removed with forceps and stored in the original container (flat petri-type dish) that the pre-weighed filter was removed from. These containers were pre-numbered and correlated to the known weights of each filter for subsequent laboratory analyses. The filters were stored in dark, frozen conditions until prepared for analysis at the University of Washington. The filter apparatus was rinsed with pre-filtered seawater between samples.

pH

An Orion Model 250A pH meter was used to measure pH at the surface, mid-depth, and bottom using the discrete water samples. A water sample was collected into a polypropylene jar and the pH determined within two hours of sampling. The sample was kept cold until the measurements were made. Before each set of measurements, the instrument was manually calibrated with at least two buffer solutions.

The chlorophyll *a*, nutrient, and total suspended solid samples were analyzed at the University of Washington's School of Fisheries and Ocean Sciences Lab. Nutrient analyses were performed using an autoanalyzer with spectrophotometric detection. The accuracy and precision goals for discrete water indicators were measurements ± 10% and 30 % respectively.

Sediment Habitat Indicators

Sediment samples were collected with a Young-modified, double Van Veen grab sampler (two side-by-side 0.1 m gravity Van Veen samplers). All sediment sampling gear was decontaminated with diluted LiquiNox detergent and rinsed with site water just prior to sample collection. Acceptable grabs were ≥ 7 cm penetration, not canted, not overflowing, not washed out, and had an undisturbed sediment surface. Water overlying the sediment grab, if present, was siphoned off with clean teflon tubing without disturbing the surface. The top 2-3 cm of sediment were removed with a stainless steel spoon and transferred to a 20 L stainless steel mixing bowl. Sediments from a minimum of two grabs were composited, mixed, and covered to prevent on-deck contamination. Samples were transferred to clean jars, field stored on wet ice, and later refrigerated or frozen until analysis. The composited sediment was used for the habitat indicators, percent silt-clay (< 63 um fraction) and percent total organic carbon (TOC), and for the biotic and exposure indicators for sediments described below.

Sediment silt-clay and TOC were analyzed by chemists at Washington Department of Ecology Manchester Chemistry Lab. Grain size analysis was by wet and dry sieving. Sediment digestion for TOC analysis followed EPA standard method 415.1. Replicates were performed on all TOC samples and no replicated analysis was done for sediment grain size. Precision goals for grain size and TOC measurement are within 10 %. There are no accuracy goals for grain size, and TOC accuracy goal is measurements ± 10 %.

Benthic Exposure Indicators - Sediment Contaminants

As described above, a Van Veen sampler was used to collect benthic sediments. Following the water collections, several replicate grab samples were collected at each station. Enough sediment was acquired to provide sediment for infaunal species analyses, sediment contaminants, sediment toxicity, sediment grain size, and TOC. Additional sediments were archived and kept separate from the shipped samples, to provide additional sediment in the event that a sample would need to be reanalyzed or a sample was lost or broken during shipping. Since only the top 2-3 cm of sediments was collected from each undisturbed grab sample for contaminant analyses, two to four grabs were required to provide enough sediment for all analyses. One entire 0.1 m grab sample was used for the benthic infaunal analyses. All other grabs were composited, mixed, and subsampled into each of the individual analyte containers. As described earlier, full decontamination procedures were conducted between stations but not between grabs at each station.

Concentrations of 15 metals, 39 polycyclic aromatic hydrocarbons (PAHs), 21 polychlorinated biphenyls (PCB) congeners, 20 pesticides (DDTs, DDT metabolites, and other chlorinated pesticides) were measured in composited surface sediments collected as described above. This suite of compounds (Table 4) is comparable to pollutants measured in the NOAA National Status &Trends Program, with the addition of PAH analytes that are not included in either the national EMAP or National Status & Trends required suites of PAHs. These added analytes are critical for identifying petroleum source contaminants, a matter of high interest to local investigators and regulators.

All sediment contaminant analyses were performed by chemists at the Washington Department of Ecology's Manchester Laboratory. This laboratory was required to complete initial performance evaluation tests to demonstrate adequate technical and analytical capability prior to field sample analyses. The Manchester lab followed approved EPA standard protocols (U.S. EPA 1994, U.S. EPA 1988) for all sediment contaminant analyses.

Additional quality control procedures included routine evaluation of measurement accuracy and precision by analysis of certified reference and laboratory control materials, and the use of calibration standards, laboratory spiked sample matrices, reagent blanks, and sample replicates. A reporting limit (RL) concentration was also determined for every batch of samples for each contaminant. The RL concentration is the lowest concentration of an analyte reliably measured on laboratory reference material on a routine basis with optimal analytical methods. Accuracy goals were ± 35% for organic contaminants (PAHs, PCBs, pesticides) and +20% for metals. The precision goal for all sediment contaminants was ± 30 %

Benthic Exposure Indicator - Fish Tissue Contaminants

Benthic trawls were used to collect benthic fish for analyses of tissue contaminants. Fish and large invertebrates were also used for abundance, species richness, and diversity indices. Due to various factors, such as limited sampleable habitat near a station and trawl permit limits, the time that the trawl was allowed to fish on the bottom varied by station. The times and GPS locations for when the trawl reached the bottom and when it was hauled back were recorded, as well as the average trawl speed during the deployment. These values along with the trawl measurements allowed for calculation of the area swept by each trawl so that the data could be normalized and compared by unit area. Two different trawls were used for the sampling. For shallow, nearshore stations, a small tri-net otter trawl with a 16' footrope, 0.5"stretch mesh, and 0.25" cod end was used. For most stations (typically any > ~10 m depth), an Eastern 400 research trawl with a 94' foot rope, 4" body mesh, and 3.5" cod-end mesh was used.

Several fish species ubiquitous to the Southcentral Alaska coast were designated as targets for contaminant analyses. Ideal target species are demersal fishes, such as flatfish, that feed along the benthos and also hold higher trophic level positions in aquatic food webs. The target demersal fishes for Southcentral Alaska coastal bays and estuaries were arrowtooth flounder (Atheresthes stomias), flathead sole (Hippoglossoides elassodon), yellowfin sole (Limanda aspera), because of their geographic range across the study area and the fact that they live on or within the sediments much of the time. Other similar benthic flatfish commonly found in the study area include the Pacific halibut (Hippoglossus stenolepis), English Sole (Parophrys vetulus), Dover sole (Microstomusu pacificus), rex sole (Glyptocephalus zachirus), and starry flounder (Platichthys stellatus).

The actual fish collected and analyzed for contaminant analyses was based on their presence in the trawls and their distribution throughout the entire study areas. Multiple species were collected from each trawl and analyses were conducted on a target species that occurred at the most sites. For sites where that species did not occur, the next most abundant species throughout the study area was selected until there was one species analyzed for each site.

Individuals of a single species were combined for a whole-body composite sample. Fish (ideally 5-10) were rinsed with site water, individually wrapped in aluminum foil, packed in plastic freezer bags, and kept frozen until analysis. Approximately 200-300 g of tissue (wet-weight) was needed to complete all chemical analyses.

Fish tissue contaminant analyses were conducted at Washington Department of Ecology Manchester Laboratory. The concentration of 14 metals, 21 PCBs, 18 pesticides (DDT, DDT metabolites, and other chlorinated compounds), percent moisture, and lipid content were measured on single-species whole-body composite samples (Table 4). Fish metabolize PAHs, so they were not analyzed in fish tissue.

Benthic Exposure Indicator – Sediment Toxicity (Amphipod Toxicity Bioassays)

Static 10-day, amphipod bioassays were performed to measure acute sediment toxicity. The response criteria are mortality and emergence from the sediment during exposure. Approximately 3.5 liters of composited surface sediments were collected at each station and used to fill two pre-cleaned ½ gallon wide-mouth glass jars. The bioassay jars were kept at 4^{o}C in the dark until shipped to and analyzed at Northwestern Aquatic Sciences, Toledo, Oregon. All bioassay tests were performed within 28 days of field collection using the benthic amphipod, Ampelisca abdita. Standard EPA amphipod bioassay procedures were followed (US EPA 1994b) based on the American Society for Testing and Material guide for conducting these test (ASTM 1991).

The Ampelisca abdita were collected from San Francisco Bay, CA by Brezina and Associates, Dillon Beach, CA. Amphipods were acclimated, un-fed, for 2-9 days prior to testing. Immature amphipods, size 0.5–1.0 mm, were used in the bioassays. Each batch of amphipods was evaluated in a reference toxicity test (positive control). These tests were run for 96 h in a dilution series with seawater (no sediment phase) using cadmium chloride and sodium dodecyl sulfate (SDS) as reference toxicants. LC50 values were computed for comparison with other reported toxicity ranges for the same reference toxicants and test species. Amphipods were not used in tests unless acceptable reference toxicant results were obtained.

Bioassay treatments consisted of 5 replicates of sample sediments from a station and a negative control. Control sediments were taken from the amphipod collection site in San Francisco Bay and sieved through a 0.5 mm screen to remove infauna prior to testing. Sample sediments were not sieved before testing. Approximately 175 ml of sediments and 775 ml of seawater were placed in 1 L covered borosilicate glass beakers. All beakers received 20 healthy amphipods. Tests were run under static conditions: 20o C, 30 ‰ salinity, continuous aeration 2 cm above sediment surface, and constant light to discourage amphipod emergence from sediments during the test. Sediment salinity was not adjusted, seawater was not exchanged, and amphipods were not fed throughout the tests.

At the conclusion of a test, the sediment from each chamber was sieved through a 0.5 mm screen to remove amphipods. The numbers of dead, alive, or missing animals were recorded. Death was defined as no visible appendage movement or response to tactile stimulation. Sediments with >10% missing animals were re-examined under a dissecting microscope to ensure that no living specimens had been missed. Amphipods still unaccounted for were considered to have died and decomposed in the sediment. The percent amphipod mortality was calculated from initial and final test observations by the following formula:

Percent Mortality = 100[(initial amphipods-surviving amphipods)/ initial amphipods]

A variety of quality control procedures were incorporated to assure acceptability of amphipod bioassay results and comparability of the data with other studies. These provisions included the use of standard protocols, positive controls run with a reference toxicant, negative controls run with reference sediment from the amphipod collection site, routine monitoring of water quality variables to identify any departures from optimum tolerance ranges. Test conditions such as temperature, dissolved oxygen, salinity, and pH were measured in one replicate daily. Sulfide and ammonia-N were measured in the overlying water of one replicate on days 0 and 10. Additional beakers containing just sediment and seawater were sampled for interstitial ammonia-N and sulfide on days 0 and 10, and interstitial salinity on day 10. Data acceptance criteria were based on negative control mortality. Results were accepted as valid if mean control mortality did not exceed 10 %, and did not exceed 20 % in any one control beaker

Benthic Condition (Response) Indicators

Benthic Infauna Community Composition

Benthic infaunal collections provide taxonomic composition, abundance, species richness, and the Shannon-Weaver diversity index H' (Shannon and Weaver 1949). One sediment grab was retrieved at each station for collection of benthic infauna using a 0.1 m2 Van Veen sampler. The grab sediments were transferred into stacked 1.0 mm and 0.5 mm nested sieves and gently sieved using site-water supplied by an adjustable flow hose. Material caught on the screens was fixed with 10% buffered formalin. Samples were re-screened and preserved with 70% ethanol within two weeks of field collection. The 0.5mm fraction was archived, and the 1.0 mm fraction was sorted under a dissecting microscope for enumeration and identification of benthic infauna. Samples were processed according to the protocols

Polycyclic Aromatic Hydrocarbons (PAHs)	Polychlorinated Biphenyls (PCBs) Congener Number and Compound	DDT and Other Chlorinated Pesticides	Metals and Misc.
Low Molecular Weight PAHs 1-methylnaphthalene 1-methylphenanthrene 2-methylnaphthalene 2,6-dimethylnaphthalene 2,3,5-trimethylnaphthalene Acenaphthene Acenaphthylene Anthracene Biphenyl Fluorene Naphthalene High Molecular Weight PAHs Benz(a)anthracene Benzo(a)pyrene Benzo(b)fluoranthene Benzo(k)fluoranthene Benzo(g,h,i)perylene Chrysene Dibenz(a,h)anthracene Fluoranthene Indeno(1,2,3-c,d)pyrene Pyrene Addditional non-EMAP PAHs C1-C3 Napthalenes C1-C3 Fluorenes C1-C4 Dibenzothiophenes C1-C3 Chrysenes	8: 2,4'-dichlorobiphenyl 18: 2,2',5-trichlorobiphenyl 28: 2,4,4'-trichlorobiphenyl 44: 2,2',3,5'-tetrachlorobiphenyl 52: 2,2',5,5'-tetrachlorobiphenyl 66: 2,3',4,4'-tetrachlorobiphenyl 77: 3,3',4,4'-tetrachlorobiphenyl 101: 2,2',4,5,5'-pentachlorobiphenyl 105: 2,3,3',4,4'-pentachlorobiphenyl 110: 2,3,3',4',6-pentachlorobiphenyl 118: 2,3',4,4',5-pentachlorobiphenyl 126: 3,3',4,4',5-pentachlorobiphenyl 128: 2,2',3,3',4,4'-hexachlorobiphenyl 138: 2,2',3,4,4',5'-hexachlorobiphenyl 153: 2,2',4,4',5,5'-hexachlorobiphenyl 170: 2,2',3,3',4,4',5-heptachlorobiphenyl 180: 2,2',3,4,4',5,5'-heptachlorobiphenyl 187: 2,2',3,4',5,5',6-heptachlorobiphenyl 195: 2,2',3,3',4,4',5,6-octachlorobiphenyl 206: 2,2',3,3',4,4',5,5',6-nonachlorobiphenyl 209: 2,2'3,3',4,4',5,5',6,6 '-decachlorobiphenyl	**DDTs** DDT 2,4-DDD 4,4'-DDD 2,4'-DDE 4,4'-DDE 2,4'-DDT 4,4'-DDT Cyclopentadienes Aldrin Dieldrin Endrin **Chlordanes** Alpha Chlordane Heptachlor Heptachlor Epoxide Trans-Nonachlor (SO) **Others** Endosulfan I Endosulfan II Endosulfan Sulfate Lindane (gamma BHC) Mirex Toxaphene (SO)	**Metals** Aluminum Antimony (SO) Arsenic Cadmium Chromium Copper Iron Lead Manganese Mercury Nickel Selenium Silver Tin Zinc **Miscellaneous** Total organic carbon (SO) % moisture (TO) Lipids (TO)

Table 4. Contaminants analyzed in sediments and fish tissues.
SO = sediments only, TO= tissues only, otherwise analyzed for both tissues and sediments.

described in the EMAP-E Lab Method Manual (US EPA 1994). Both indigenous and exotic organisms were identified to the smallest practical taxonomic level (species level when possible). Samples were returned to 70% ethanol and archived.

Several measures were taken to ensure QA/QC of benthic infauna data. Sorting technicians were required to demonstrate proficiency by sorting ≥ 95 % of organisms from sediment in five consecutive samples. In addition, 10 % of all benthic infaunal samples were resorted by QA sorters to ensure ≥ 95 % of organisms had been removed from the sample by primary sorters. Organism identification was performed by proficient taxonomists who were provided standardized taxonomic keys and references. These primary taxonomists also archived voucher specimens with a complete list of information including major taxon, family, genus and species, the sample from which the specimen was taken, and references used in the identification. Secondary QA taxonomists re-identified organisms in voucher specimens and in 10 % of all infaunal samples. The secondary taxonomists ensured the use of uniform nomenclature throughout the entire EMAP-WPCM region and identified and resolved taxonomic discrepancies among the sets of primary taxonomists. Any discrepancies were discussed by taxonomists and resolutions were documented.

Benthic Fish and Macroinvertebrate Community Composition

Benthic trawling was conducted at each station as described under the heading "Benthic Exposure Indicator - Fish Tissue Contaminants" above. When the trawl was retrieved, all fish and invertebrates were sorted and counted. The first thirty of each species were randomly selected and measured for length (to the nearest cm) and checked for any external anomalies. After being counted, target species for contaminant analyses were removed and treated as described above. When thousands of a single species was caught as sometimes happened for urchins or some sea stars, a 5 gallon basket was filled and counted. The rest of that species were measured by volume in the baskets and the number of baskets multiplied by the number counted in one basket.

External Fish Pathology

Any external abnormalities observed on fish (i.e. parasites, growths, lesions, etc.) were photographed, excised with a stainless steel scalpel, placed into labeled pathology containers, and preserved immediately in Dietrich's solution. These samples were used for histopathological examinations. Excised tissue included the entire abnormality and some adjacent healthy tissue. Supplemental information was recorded on fish species, length, trawl number, abnormality location, description, and sample depth. All fish pathology samples were analyzed by Mark Meyers at NOAA/Nation Marine Fisheries Service, Seattle, WA.

Data Analysis

Cumulative distribution functions (CDFs) describe the distribution of indicator values in relation to areal extent of the sampled population. This statistical approach has been used extensively in other EMAP coastal monitoring studies (Summers et al. 1993, Strobel et al. 1995, Hyland et al. 1996, 1998). Details for calculation of the Horvitz-Thompson (H-T) CDF (Method 1) and variance (Method 10) estimates for continuous resources can be found in the EMAP Statistical Methods Manual (Diaz-Ramos et al. 1996: http://www.epa.gov/nheerl/arm/documents/intro.pdf). Population CDF estimates for each indicator value of interest (xk) were computed by calculating the CDF estimates for each stratum separately then applying a standard stratified estimating procedure to combine across all strata within a defined population.

Data Management

Data management for the Southcentral Alaska EMAP is incorporated in the EMAP-WPCM Information Management Program. This program is based on a centralized data storage model using standardized data transfer protocols (SDTP) for data exchange among program participants.

Data flow consisted of interactions among several management levels. Field and laboratory coordinators were responsible for compiling data into standardized data format tables. The State Lead Scientist was responsible for compiling all state data into a standardized, unified database and submitting the data to the Western Coastal EMAP Information Manager (WIM) located at the EPA ORD Western Ecology Division for entry into the west coast EMAP database. The WIM was responsible for working with the state of Alaska to develop SDTPs, and for creation and management of the centralized West Coast EMAP database.

Data quality assurance (QA) was accomplished through feedback between the Western EMAP Quality Assurance Coordinator (WQAC), WIM, and State Lead Scientist. The WIM compiled all state QA-certified data into integrated multi-state data tables. These tables were reviewed by WQAC with respect to scientific content. Recommended data corrections were returned to the WIM who worked with SIMs to make the necessary changes. Once all WPCM data were QA-certified, the WIM submitted the data to the EMAP Information Manager (EMAP IM), located at the EPA-Atlantic Ecology Division, Narragansett, Rhode Island. The EMAP IM was responsible for placing WPCM data into the national EMAP database and for transferring the data to other EPA databases, such as STORET. The EMAP IM is the contact for data requests about the integrated database.

3. RESULTS AND DISCUSSION

3.1 Results Formats

In this section, results are presented as habitat condition (water and sediment quality), exposure indicators (sediment), or benthic condition indicators. These results may be presented as Cumulative Distribution Functions (CDF), histogram or pie chart, statistical summary table, distribution map, or a combination of these formats.

Ecological condition indicators were characterized using CDF to describe the indicator (water, sediment or biota) distribution in relation to its spatial extent within the sampled population of Southcentral Alaska coastal bays and estuaries. The CDFs are used to present the proportion of the study area that is above or below some threshold or indicator value (e.g. water quality standards). Use of the probability-based sampling design allows for these statistical estimates, within known confidence limits. For example, Figure 7 represents a CDF of bottom dissolved oxygen (DO) measurements taken across the Southcentral sampling area. The dotted lines show upper and lower 95% confidence limits. Based on this data, none of the Southcentral Alaska coastal bays and estuaries had bottom dissolved oxygen concentrations lower than 4 mg/L or above 17 mg/L, which are the limits set in the State of Alaska's Water Quality Standards.

The Alaska Department of Environmental (DEC) Alaska Water Quality Standards (AWQS) (18 Alaska Administrative Code 70) that regulate human activities that result in alterations in waters within the state's jurisdiction (http://www.dec.state.ak.us/regulations/pdfs/70mas.pdf). These standards are based on an anti-degradation policy that "…existing water uses and the level of water quality necessary to protect existing uses must be maintained and protected." Standards are defined for each marine water class and subclass and for marine water these are:

(A) Water supply
(i)aquaculture;
(ii) seafood processing;
(iii) industrial;
(B) Water recreation
(i) contact recreation;
(ii) secondary recreation;
(C) Growth and propagation of fish, shellfish, other aquatic life, and wildlife; and
(D) Harvesting for consumption of raw mollusks or other raw aquatic life.

The water quality standards typically fall into three categories; some as absolute threshold concentrations, some as concentration ranges, and others as limitations to the change that can be made above or below a natural background. When AWQS exist for a particular indicator, comparisons of the study area that do not meet that standard will be presented. In other cases, where AWQS have not been defined, other applicable comparison values will be discussed (e.g. Effects Range-Low and Effects Range–Median for sediments).

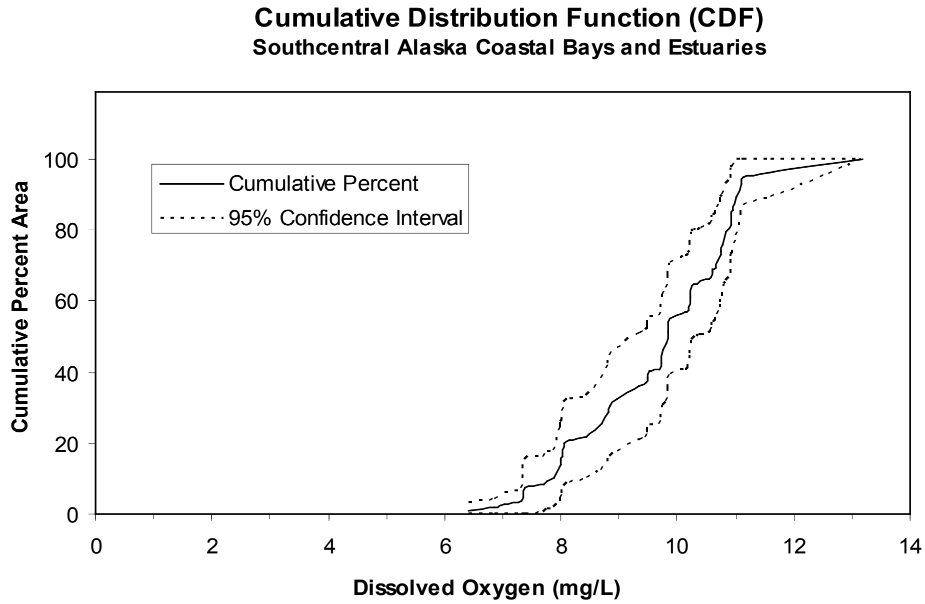


Figure 7. CDF for DO at the bottom of the water column.

3.2. Station Array

Fifty-five sites, as shown in, Figure 8 were sampled during the 2002 Southcentral Alaska EMAP field program. Numbers reflect the last two digits of the Station Identification Number, which were provided in the latitude and longitude Table 1. For example, number 71 represents site AK02-0071. This map presentation format will be used throughout the Results section so note that the eastern-most portion of the study area (Prince William Sound) is presented as an inset.

3.3 Habitat Indicators – Water Quality

Station Depth

Summary statistics for station depth across the 55 sampled sites are shown in Table 5. Depths ranged from 3 to 352 meters (m). The depths associated with each individual station were presented in Table 1 and are shown in Figure 10. Three of the four shallowest stations occurred in Cook Inlet, which is a highly depositional environment in much of the nearshore area, and four out of five of the deepest stations occurred in Prince William Sound, which has several very deep holes and passages.

The CDF for station depth is shown in Figure 9. Based on these weighted distributions, 16.3 % of the study area had water depths less than 10 m, 17.0 % of the study area had depths greater than 200m, and 62.7% had depths between 10 and 200 m. It is important to note that the weighted station depths do not necessarily reflect the true distribution of depths in the study frame. There were many instances where the target location for a sampling frame was too steep and rocky for sampling and the station was moved to nearest sampleable habitat, which was usually further offshore. Thus, the distribution more

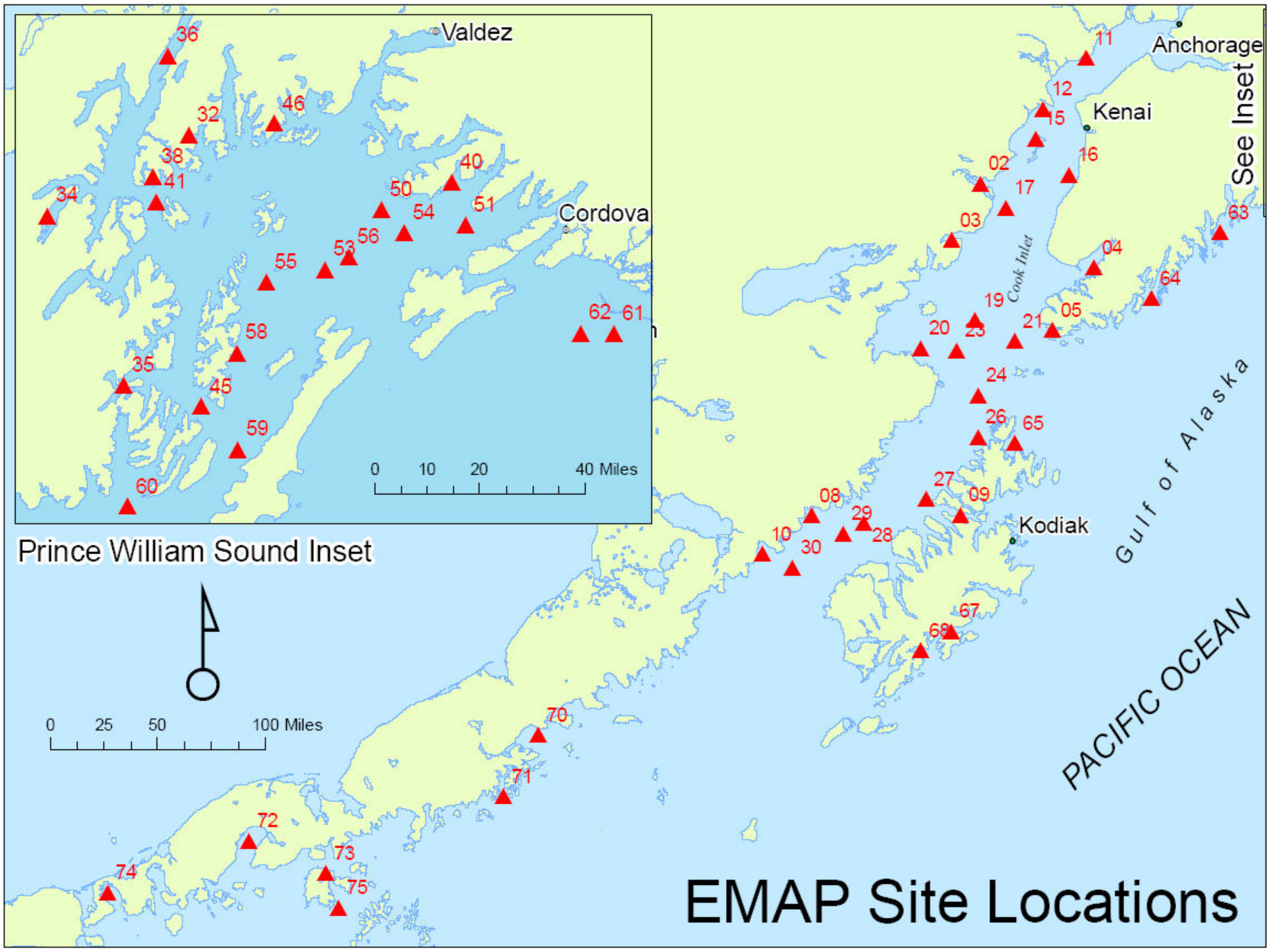


Figure 8. Sampling locations for Southcentral Alaska 2002 EMAP. The two digit numbers refelct the last two numbers of each stations. For example, site AK02-0075 is represented by 75 in the map. Note that Prince William Sound is an inset. This map format will be used to represent much of the data in this report.

closely reflects sediment habitat depths than it does overall habitat depths which would have included the nearshore rocky habitat found in many areas of the coast. This information is useful, though, when comparing study area habitats among the various national regions and provinces included in the National Coastal Assessment.

Table 5. Summary statistics for station depth (m).

Statistic	Station Depth (m)
Mean	108.8
Stadard Deviation	90.5
Median	110.0
Maximum	347
Minimum	3
N	55

Habitat Indicators – Water Quality

Water quality measurements where made either continuously through the water column using sensors on a CTD instrument or from discrete water samples at the surface, mid-depths, and ~ 1 m off of the bottom. For the summaries presented here, the values for most water quality indicators are reported for the bottom and surface, unless otherwise noted. Table 6 and Error! Reference source not found. provide summary statistics for all stations across the study area. The indicators will be discussed separately in this section under individual headings.

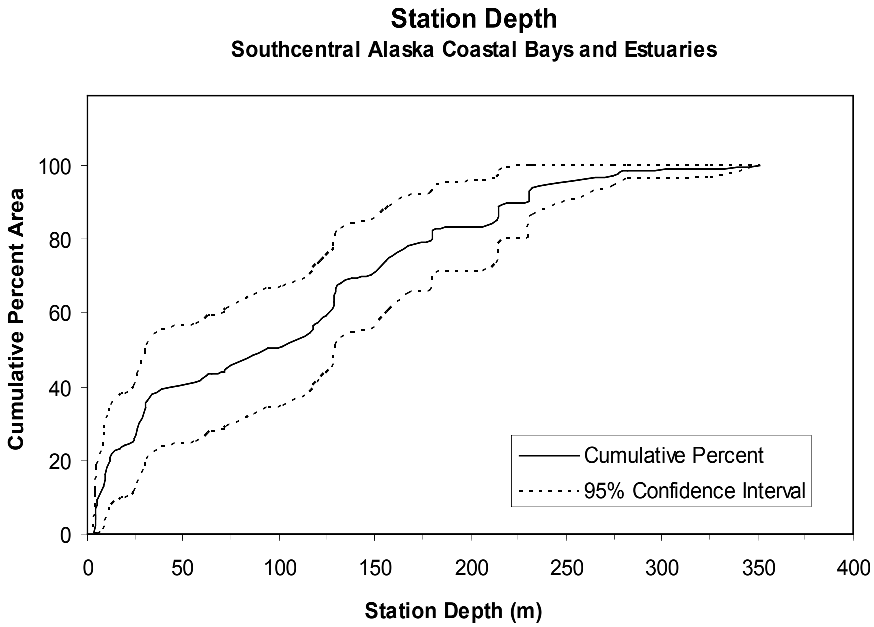


Figure 9. Cumulative percent of study area vs. station depth.

Temperature

The study took place from mid-June to early August, 2002 and included periods of very warm and dry weather that lasted for weeks to periods of cooler temperatures and low-pressure systems that result in significant wind mixing (i.e., these data should not be considered synoptic for the region). The sampling area ranged over 1500 linear miles and was sampled in general from a southeast to northwest direction except for the upper Cook Inlet and Kachemak Bay sites which were sampled at the very end of the cruise. In other words, there were potential seasonal temperature effects built into the study plan. Temperature data were primarily collected to relate with other water quality variables that are affected by this parameter (e.g. dissolved oxygen) and are used to calculate density measurements, with salinity and depth, to provide a measure of gross stratification of the water column.

Surface seawater temperature ranged from 5.1 to 16.5oC, averaging 11.1± 2.6^{o} C, and bottom temperatures ranged from 4.3 to 14.6^{o} C, averaging a cooler 7.0 ± 2.7^{o} C. Figure 12 and Figure 13 provide CDFs for water column surface and bottom, respectively. Contours of temperature based 54 sites that had surface temperature data are shown in Figure 14 to illustrate general spatial differences. Temperature data was not available at Site AK02-0022 due to a corrupted CTD file.

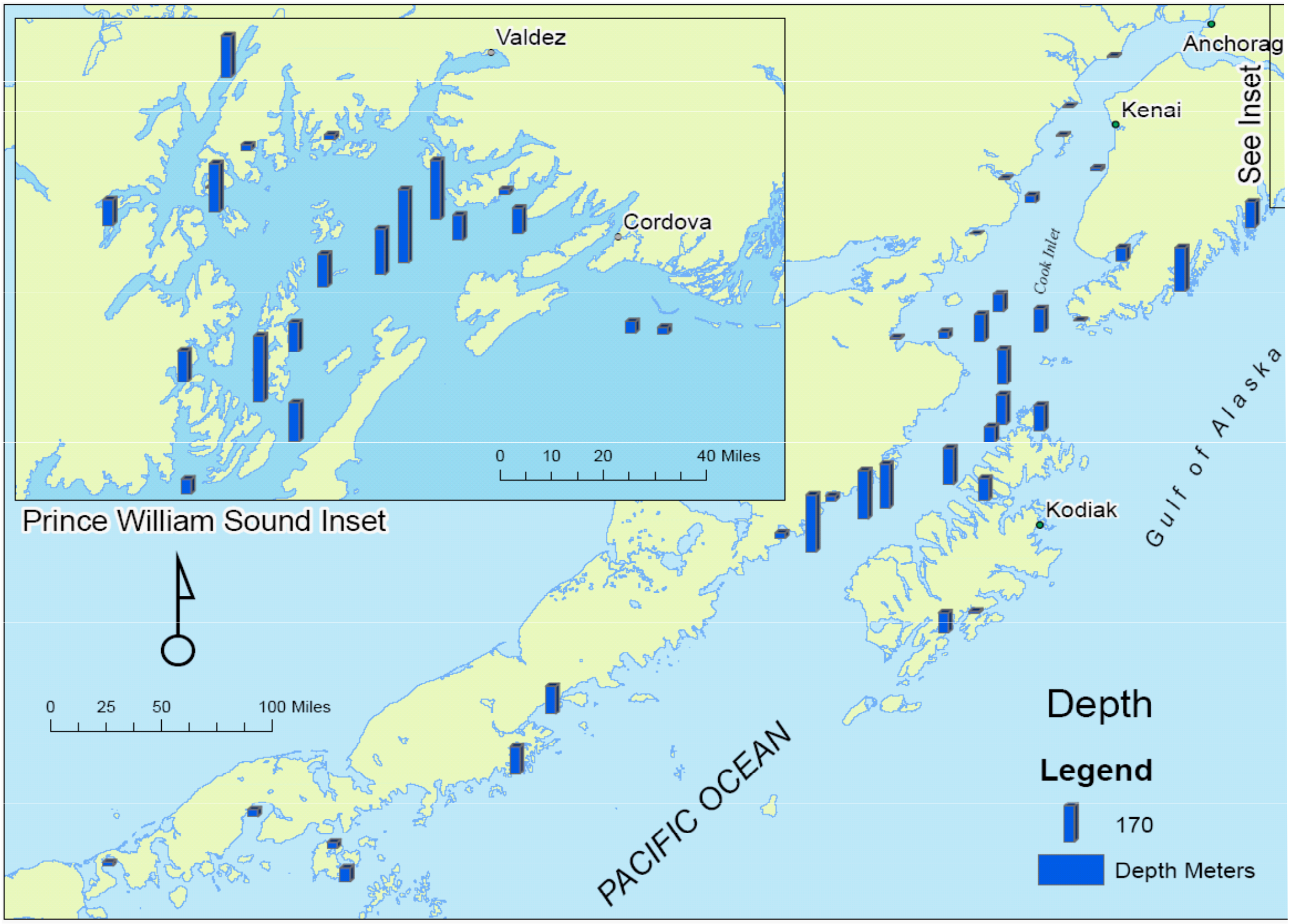


Figure 10. Map showing relative depths for all stations sampled during the Southcentral Alaska 2002 EMAP study. Height of example in the legend is to scale for 170 m. All other bars are scaled relative to that from the shallowest station at 3.9 m to the deepest station at 352m.

Table 6. Summary statistics for the water property and quality indices Temperature (°C), Salinity (psu), sigma-t (density in kg/m3 – 1000), Delta sigma-t, Dissolved Oxygen (mg/L), Turbidity (NTU), Total Suspended Solids (mg/L), and Chlorophyll-a (μg/L). Values are shown for the Overall Mean, standard deviation, and median of individual values (not weighted). N values are vary depending on whether a sample was lost during field collections, shipping or analysis.

	Mean	stdev	median	Max.	Min.	N
Temperature (C°)						
Surface	11.10	2.618	10.794	16.476	5.093	54
Bottom	6.999	2.679	5.887	14.556	4.304	54
Salinity (psu)						
Surface	27.663	4.508	27.996	32.021	13.023	54
Bottom	30.814	2.429	31.591	32.201	17.590	54
Sigma-t(kg/m^3-1000)						
Surface	21.028	3.715	21.972	24.865	9.324	54
Bottom	24.097	2.222	24.823	25.456	12.736	54
Delta sigma-t (bottom-surface) pH	3.068	3.454	1.419	14.625	0.019	54
Surface	7.88	0.32	7.96	8.55	7.01	52
Bottom	7.60	0.35	7.62	8.43	6.74	53
Dissolved Oxygen (mg/L)						
Surface	10.814	1.118	10.654	13.171	8.596	54
Bottom	9.546	1.417	9.789	13.194	6.403	54
Total Suspended Solids (mg/L)						
Surface	25.01	21.67	17.77	135.20	10.80	55
Bottom	27.29	34.17	16.77	234.13	9.34	54
Chlorophyll a (μg/L)						
Surface	1.057	1.010	0.696	4.643	0.000	55
Bottom	0.534	0.873	0.176	3.933	0.000	53

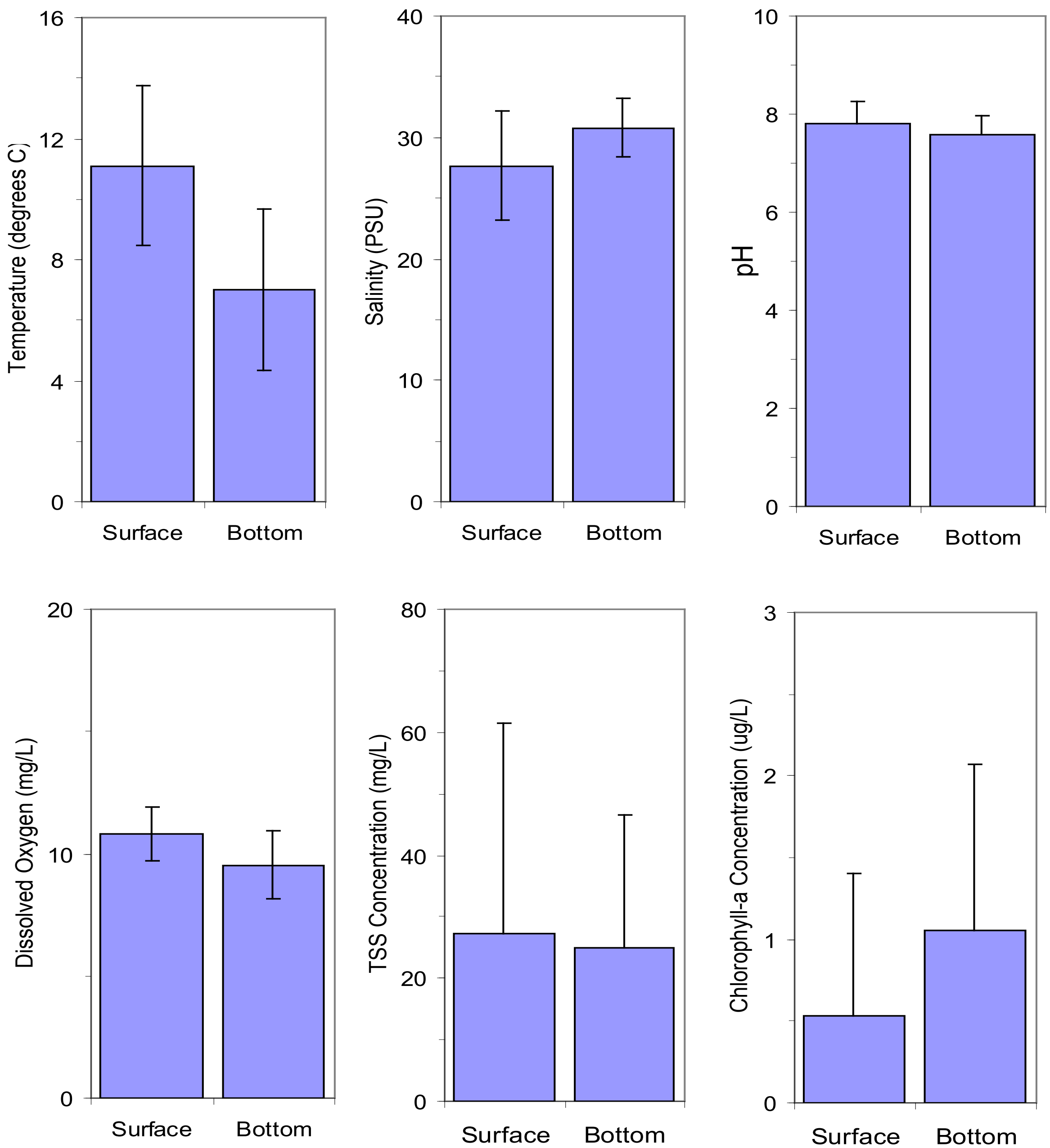


Figure 11. Means and standard deviations for water quality indicators shown in Table 6.

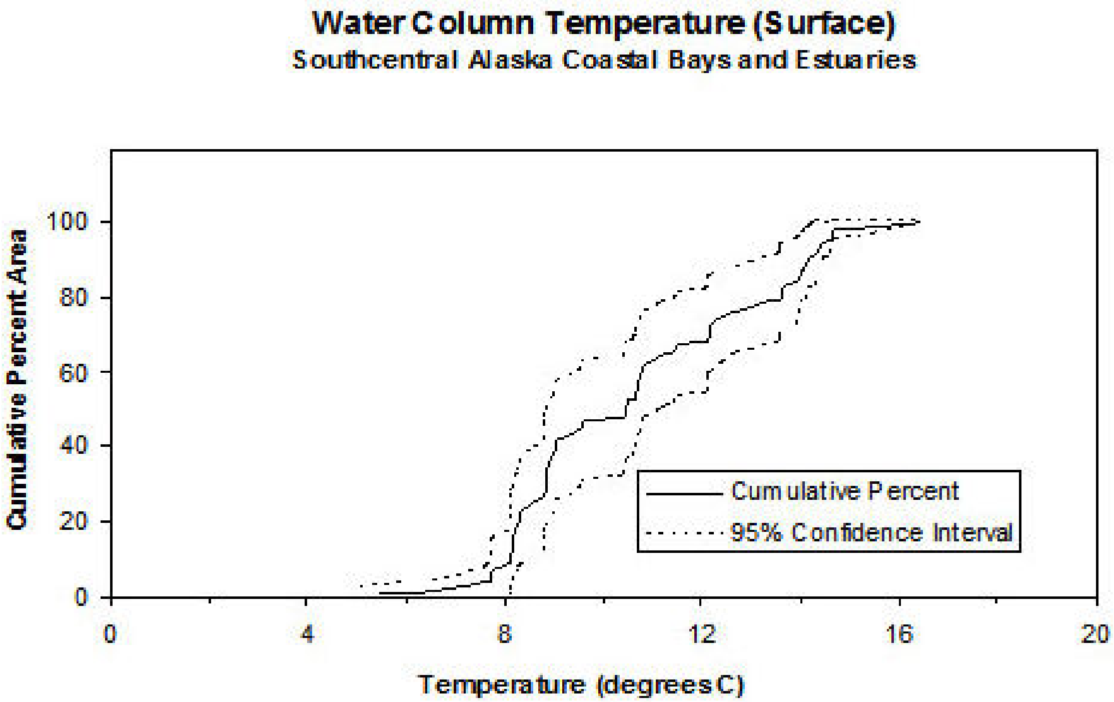


Figure 12.
Cumulative percent of study area and 95% confidence intervals of Southcentral Alaska coastal bays and estuaries vs. instantaneous measurements of surface temperature.

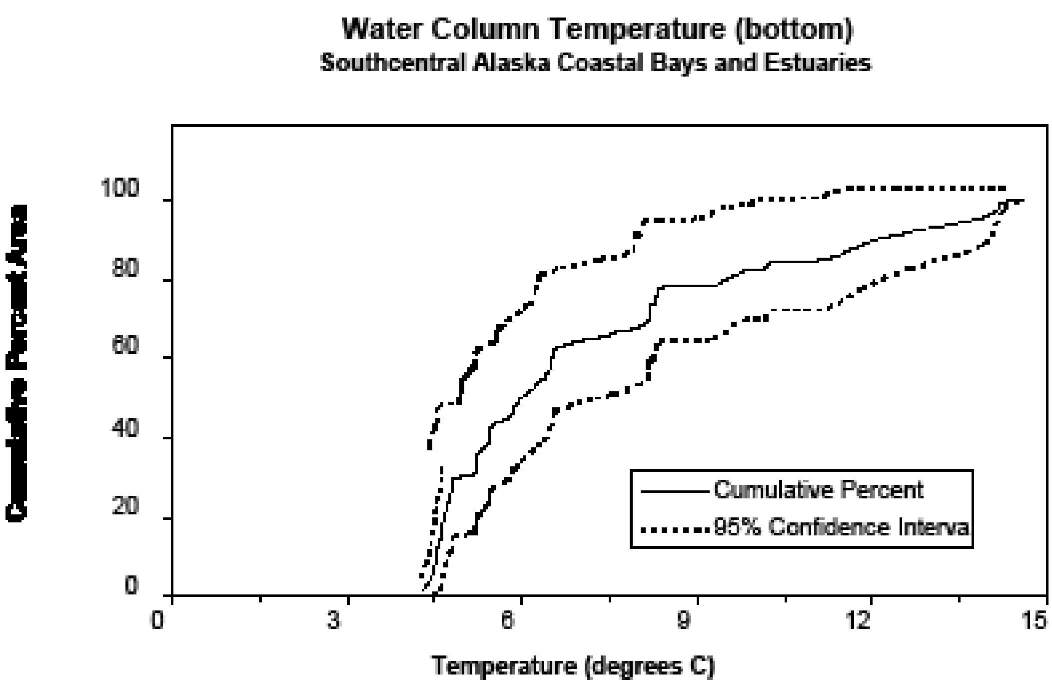


Figure 13. Cumulative percent of study area and 95% confidence intervals of Southcentral Alaska coastal bays and estuaries vs. instantaneous measurements of bottom water column temperature.

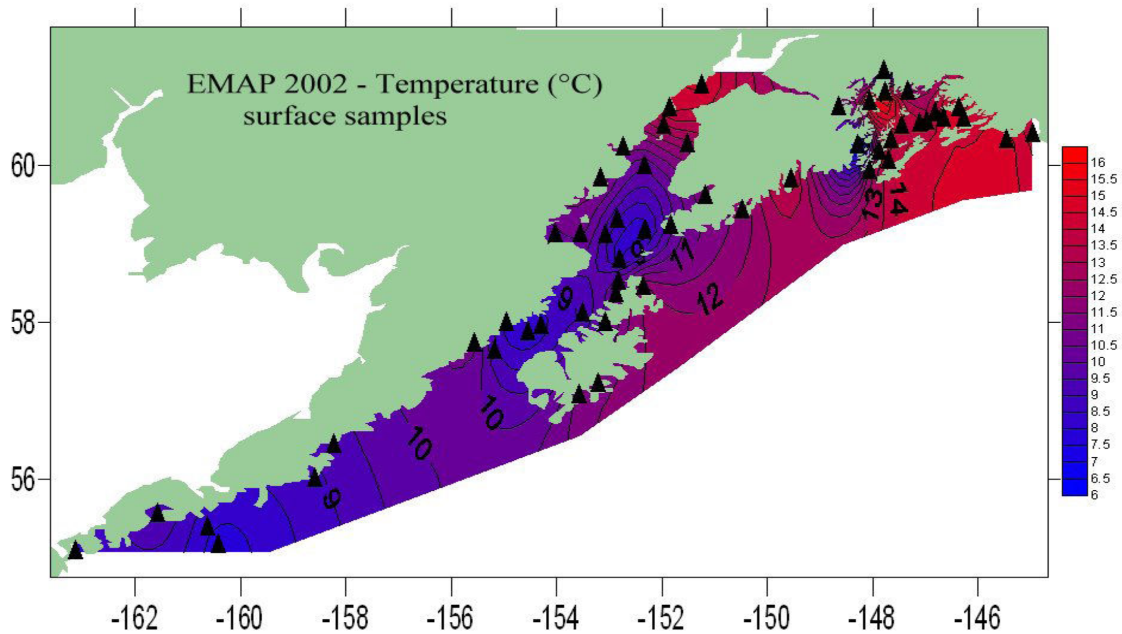


Figure 14. Surface temperature contours estimated from the 54 sampled stations (triangles) showing the warmest temperatures in the northeast study area and upper Cook Inlet.

Salinity

Salinity influences water column density and, thus, the stability or stratification of the water column. This, in turn, can influence many other water quality factors. Salinity can also be an important influence on benthic community abundance. Salinity was measured throughout the water column during the conductivity temperature depth (CTD) cast, but as a water quality indicator it is presented here for surface and bottom only.

Surface salinity ranged from 13.0 to 32.0 practical salinity units (psu) across the study area, with the lowest salinities occurring in upper Cook Inlet where high volumes of freshwater enter from the Matanuska, Susitna, and Knik rivers discharging glacial meltwater. This freshwater plume also carries significant sediment loads as will be discussed below. The highest surface salinity was measured in lower Cook Inlet, an area influenced by deep oceanic upwelling in Kennedy and Stevenson entrance.

Bottom salinities ranged from 17.6 to 32.2 psu, with the most saline water occurring at those sites that were furthest offshore such as Shelikof Strait, offshore of Resurrection Bay, and central Prince William Sound.

Figure 15 and Figure 16 show CDFs of the study area against surface and bottom water column salinity, respectively. 28.9% of the study area had surface salinities less than 28 psu, 66.6% had salinities less than 31%, and 96.5% had salinities less than 32%. The CDF for bottom salinity shows that 7.7% of the study area had salinity less than 28 psu, 25.6% less than 31 psu, and 85% less than 32 psu. A plot of bottom salinity against station depth (Figure 17) shows that only stations less than 36 meters deep had bottom salinities less than 30 psu. Stations with salinity of 30 psu or higher had depths ranging from 4 to 357 meters. Contours of salinity based on the 54 sampled sites are shown in Figure 18 to illustrated general spatial differences across the study area, even though they represent a 50 day sampling period.

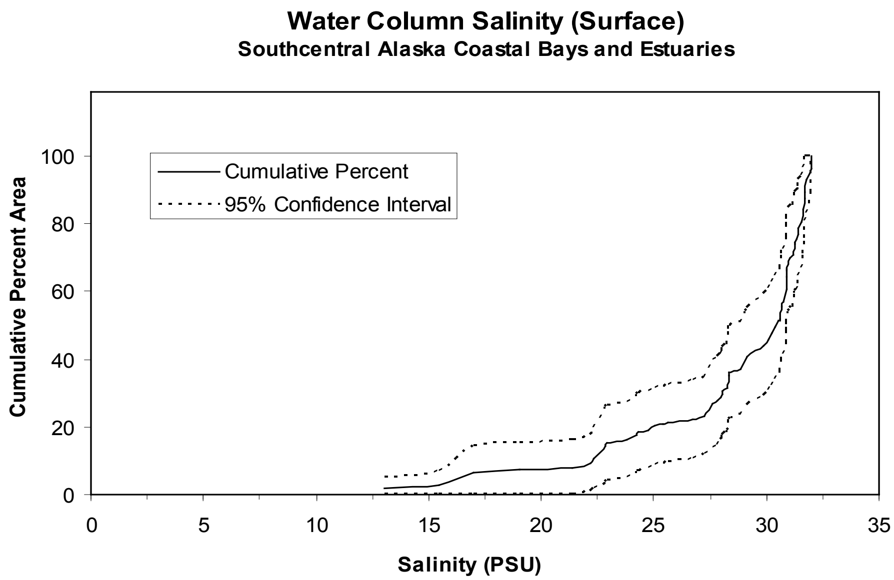


Figure 15. Cumulative percent of study area and 95% confidence intervals of Southcentral Alaska coastal bays and estuaries vs. measurements of the surface water column salinity.

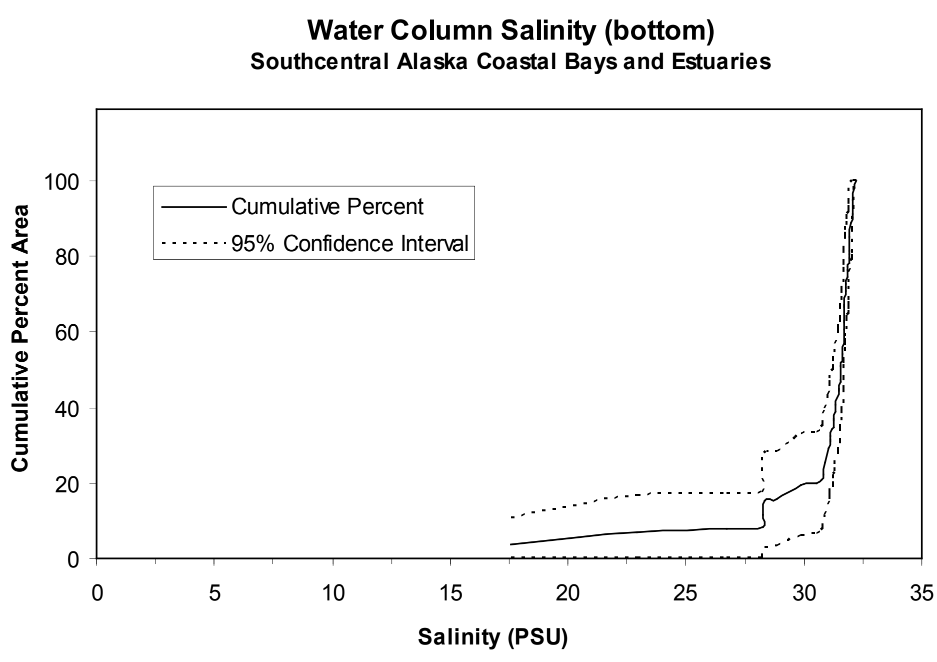


Figure 16. Cumulative percent of study area and 95% confidence intervals of Southcentral Alaska coastal bays and estuaries vs. measurements of bottom water column salinity.

It is interesting to note that most of the known major freshwater sources can be seen even with only one-time measurements at only 55 sites across a geographic range covering a significant portion of western Gulf of Alaska and spanning a 50-day sampling period. These coastal freshwater sources are shown in the northeast study area such as the Copper River and other freshwater inputs in Prince William Sound that are carried southwest along the coast by the Alaska Coastal Current, as well as the huge volumes of freshwater introduced into upper Cook Inlet by the Matanuska, Susitna, and Knik Rivers.

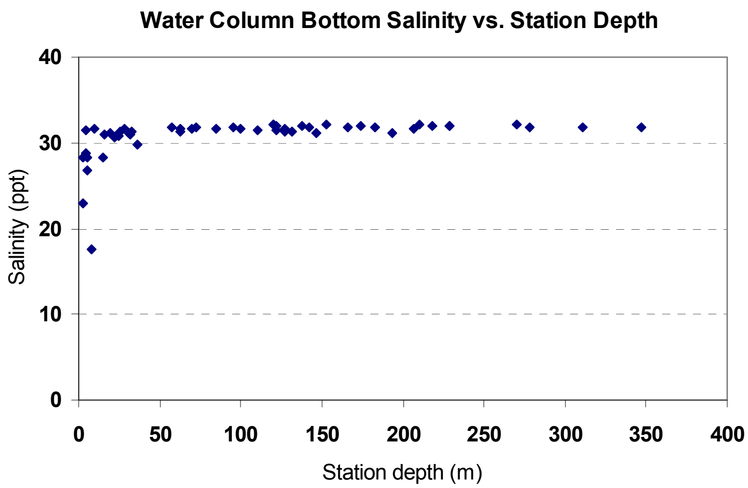


Figure 1. Salinity at the bottom vs. station depth.

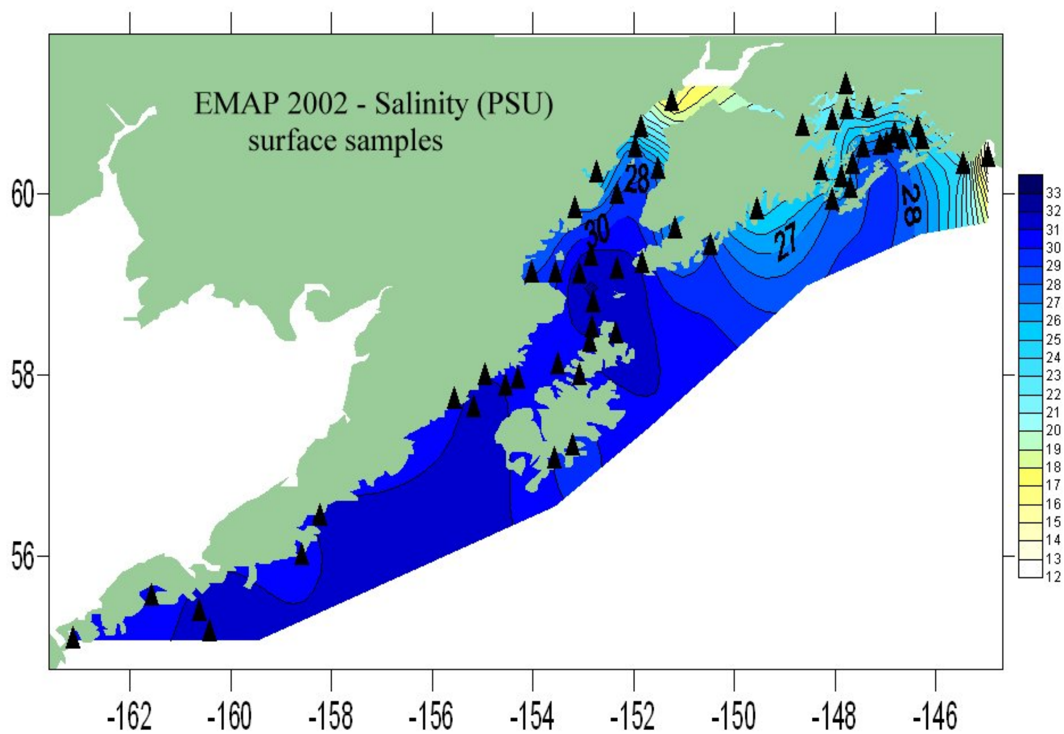


Figure 1. Surface salinity contours estimated from the 54 sampled stations (triangles) showing the lowest salinities occur relative to the major inputs of the principal rivers..

Stratification Index (Delta sigma-t)

A simple water column stratification index was calculated for the 54 stations where temperature and salinity data were available at the surface and bottom of the water columns. This simple index is just the difference between bottom and surface densities which were calculated from the respective salinities, temperatures, and depths. The stratification indices ranged from 0.02, very little stratification, to 14.6 in areas with stronger temperature and salinity gradients. Figure 19 shows the cumulative percent area plotted against the difference between the bottom and surface water column densities. The majority of the study area had relatively little density stratification with 76.3% of the area having a stratification index less than 2 and the other 33.7% of the study area showed more stable water columns with stratification indices that range from 2 to 14.6.

When the salinity and temperature differences between top and bottom are correlated to Delta sigma-t, salinity has a much stronger correlation ($r^2 = 0.984$) than temperature ($r^2 = 0.1656$) and Figure 20 plots the surface and bottom differences for each of these parameters.

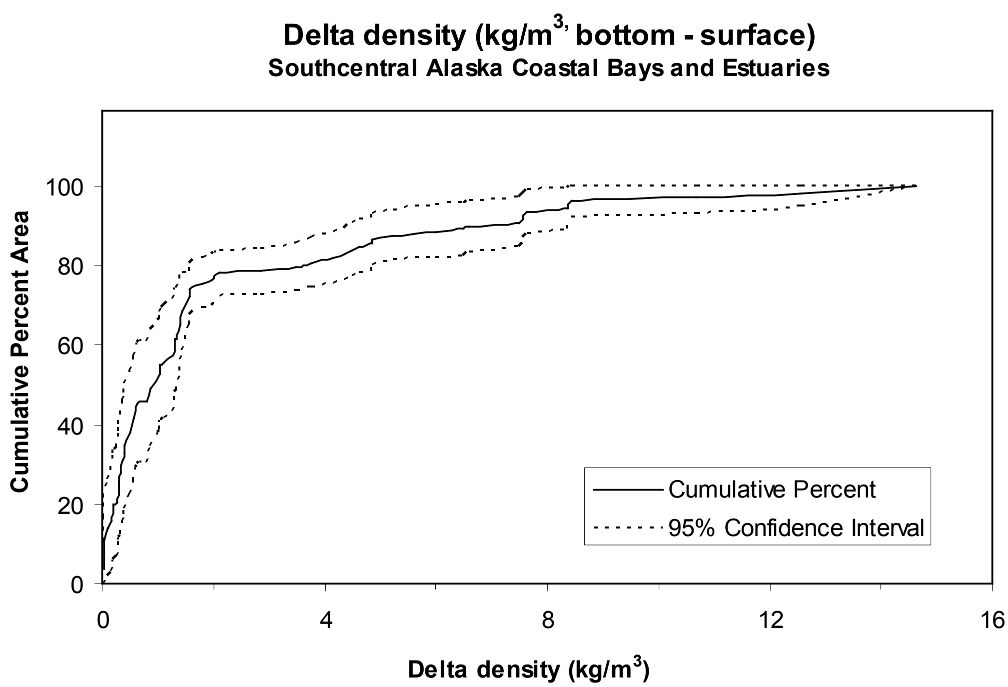


Figure 19. Cumulative percent area of the Southcentral Alaska 2002 EMAP study area against the stratification index Delta density, or Delta sigma-t.

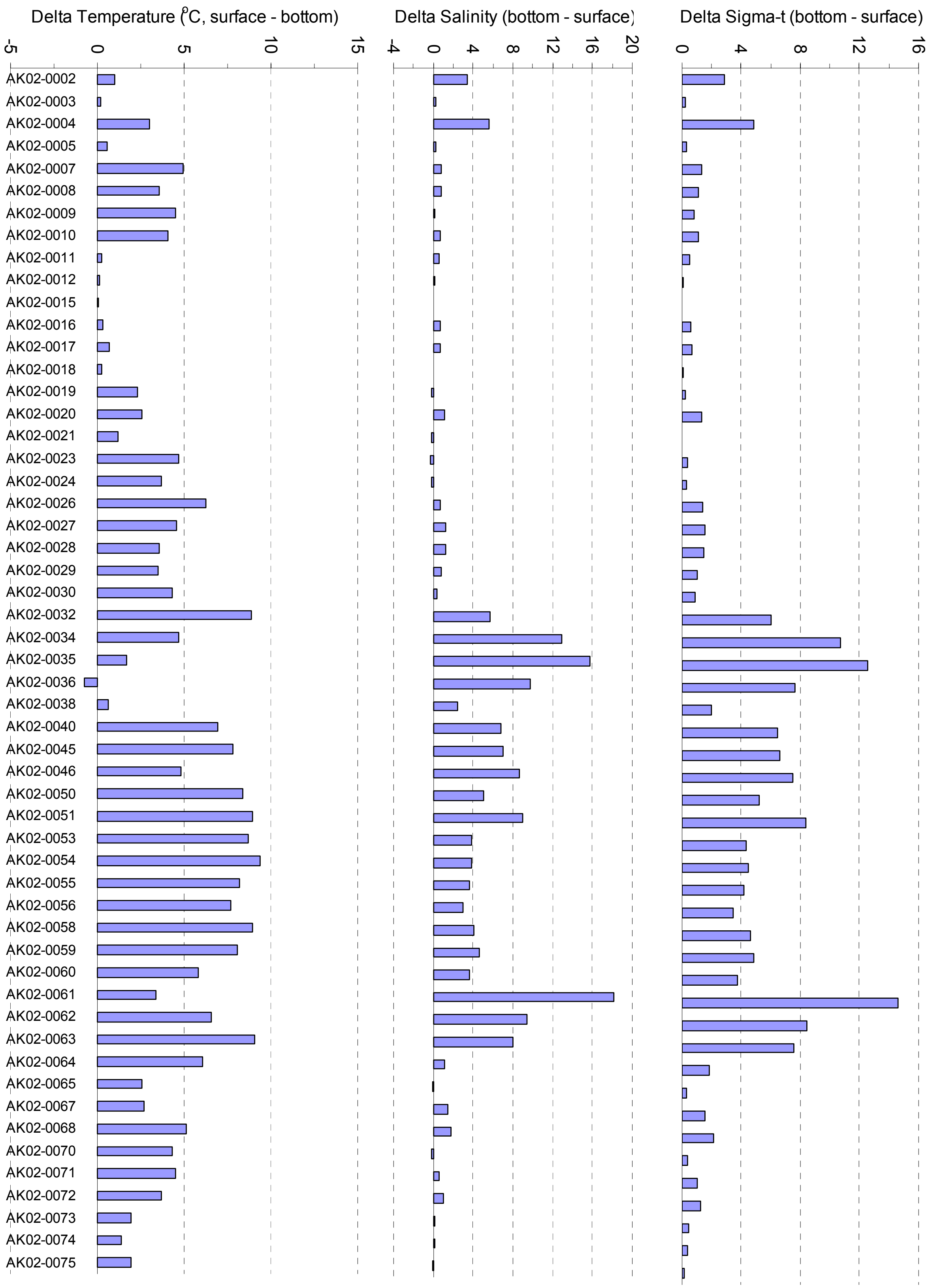


Figure 20. Histogram plots of the difference between bottom and surface Delta sigma-t, salinity, and temperature. Delta sigma-t and salinity were calculated by subtracting surface values bottom values. For temperature, bottom values were subtracted from surface values.

Dissolved Oxygen

The cumulative percent area distribution of surface and bottom water column dissolved oxygen (Figure 21 and Figure 22) shows that 100% of the study area met Alaska Water Quality Standards (AWQS) criteria for all marine water uses (i.e. aquaculture, growth and propagation of fish, shellfish, and other aquatic life and wildlife, and harvesting mollusks or other raw aquatic life). These criteria state that for coastal waters, dissolved oxygen may not be reduced below 4 mg/L at any point beneath the surface, surface waters to one meter may not be below 6.0 mg/L, and no values may exceed 17 mg/L. The same standards hold for estuaries except that dissolved oxygen may not be less than 5 mg/L, except where natural conditions cause this value to be depressed. The lowest value found in the entire study area, 6.4 mg/L, occurred at the bottom of the deepest station, AK02-0056 in central Prince William Sound, at a depth of 352 meters. There was a strong correlation between bottom dissolved oxygen and depth (Figure 23), reflecting the distance from surface resupply of dissolved oxygen.

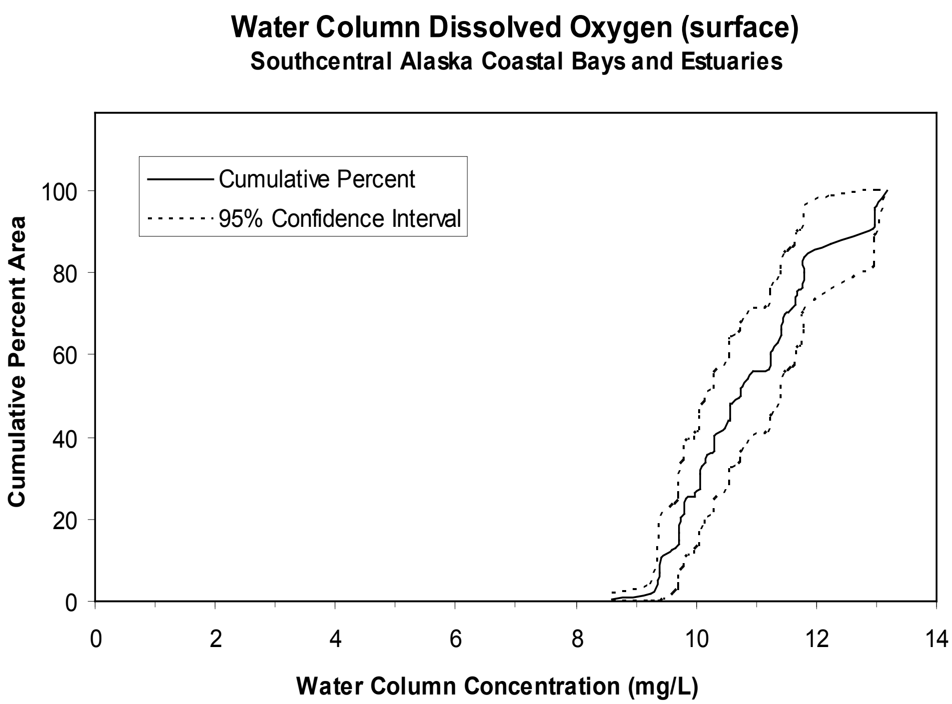


Figure 21. Percent of southcentral Alaska coastal bays and estuaries vs. surface water column dissolved oxygen concentration.

Figure 22. Percent of Southcentral Alaska coastal bays and estuaries vs. surface water column dissolved oxygen concentration

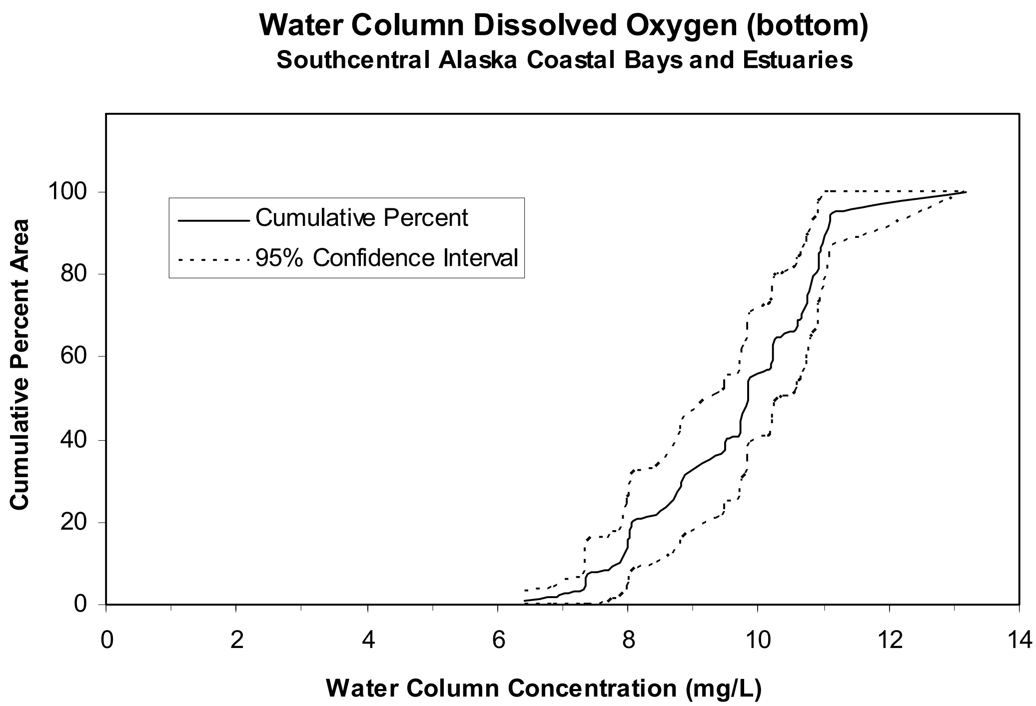
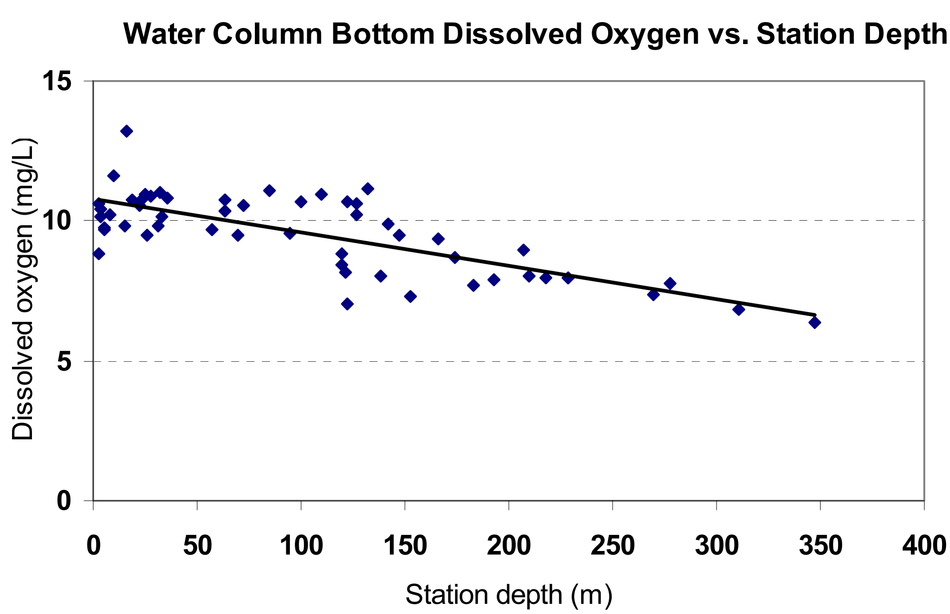


Figure 23. Water column dissolved oxygen (mg/L) vs. station depth. The line represents a best fit linear regression line.



Water Clarity - Transmissivity and Total Suspended Solids

Two indices that reflect water clarity were measured, Secchi depth and Total Suspended Solids (TSS). Secchi depth alone (or converted to extinction coefficient or transmittance) cannot distinguish whether light attenuation is a result of suspended particulates or by colored substances in the water column (e.g. phaeopigments), thus a combination of transmittance and suspended particulate data help in interpreting the differences in available subsurface light across the study area. Figure 24 shows the CDF for percent transmittance at one meter, calculated from the Secchi depth. Secchi depths ranged from 0.1 meters to 10.5 meters and calculated transmittance at 1 meter ranged from 0% to 88 % of surface light. The CDF shows that 7.5% of the area had less than 1% light transmittance at one meter and 12% of the area had less than 10% light transmittance at one meter. The four sites that had light transmittance less than 10% were (in order of increasing transmittance) sites AK02-0011, -0015, -0012, all located in upper Cook Inlet where huge volumes of glacial flour are introduced into the upper inlet by several rivers, and site AK02-0002 in Tuxedni Bay on the west side of Cook Inlet, which is influenced by glacial flour introduced by the Tuxedni River. The highest transmittance at 1 meter occurred at site AK02-0040, which is in eastern Prince William Sound. In fact, the six highest transmittance values were all in Prince William Sound (Sites AK02-0040, -0041, -0032, -0055, and -0056). Figure 25 shows the distribution of transmittance values across the study area.

TSS at the surface (0.5 m below surface) of the water column in Figure 26 compared to that for transmittance (Figure 24) shows the reversed relationship for the spatial distribution of the transmittance (i.e. greatest cumulative percent area at lower end of TSS range and highest range of transmittance). Across the study area, mean surface TSS was 25.0 mg/L and ranged from 10.8 to 135.2 mg/L. Twenty-five percent of the area had TSS < 14.2 mg/L, 75% had less than 35.43, and 90% had less than 68 mg/L.

The stations with the two highest suspended sediment loads at the surface (AK02-0011 and -0012) also had the lowest % transmittance. Figure 27 compares Transmittance and surface TSS for all sites.

The cumulative spatial distribution of total suspended sediments at the bottom of the water column are shown in Figure 28. The highest value for TSS at the bottom of the water column was 234.1 mg/L, also at Station AK02-0011.

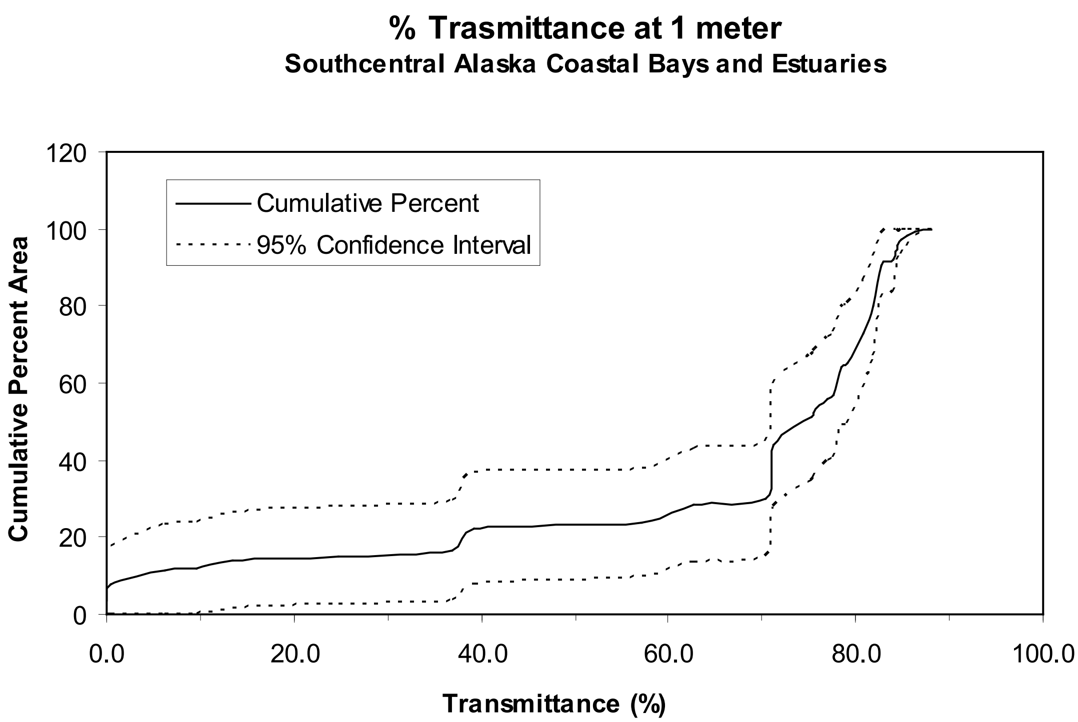


Figure 24. Percent area of Southcentral Alaska coastal bays and estuaries vs. light transmittance at 1 m water column depth.

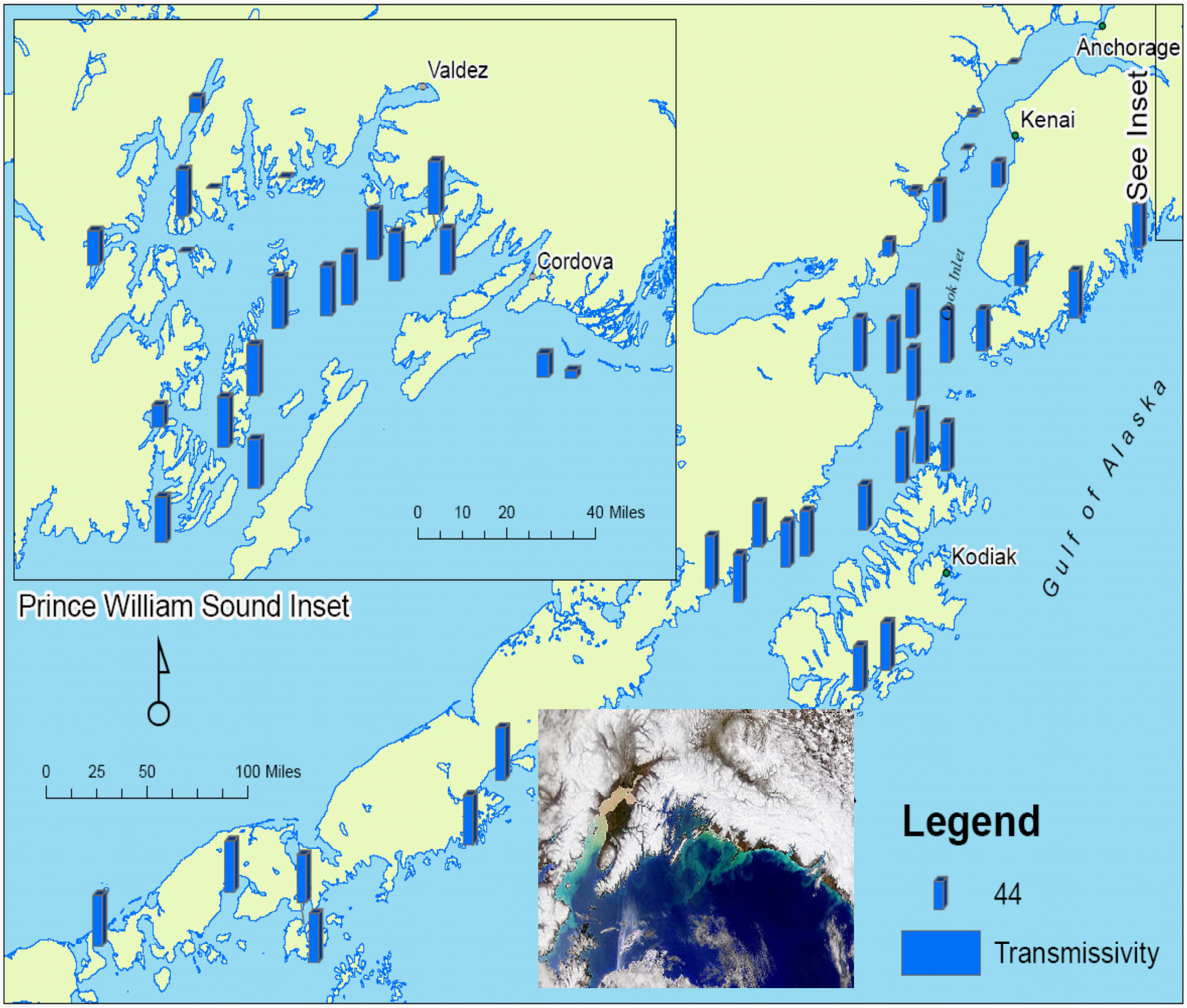


Figure 25. Map showing relative transmittance (% at one meter) for all stations sampled during the Southcentral Alaska 2002 EMAP study. Height of example in the legend is to scale for 44%, half of the highest value. All other bars are proportional to that scale. Superimposed is a SeaWiFS Satellite image (visible range) showing high suspended sediments in Cook Inlet (upper left of inset image) and along portions of the northern coast, especially immediately downstream of the Copper River delta area (center of inset image).

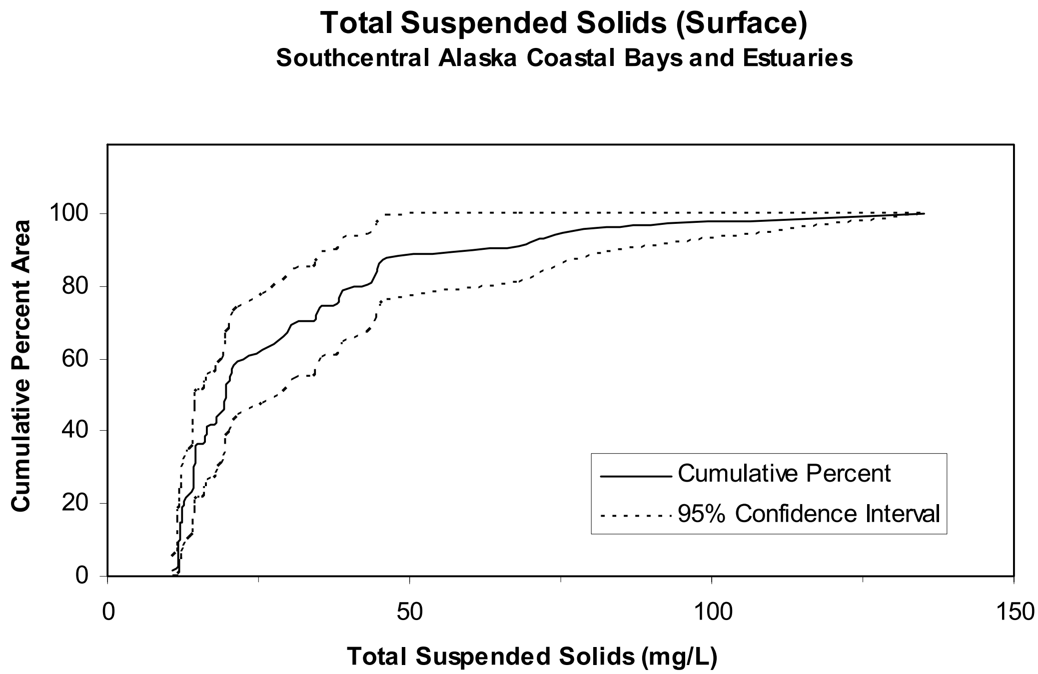


Figure 26. Percent area of Southcentral Alaska coastal bays and estuaries vs. surface water column Total Suspended Solids (mg/L).

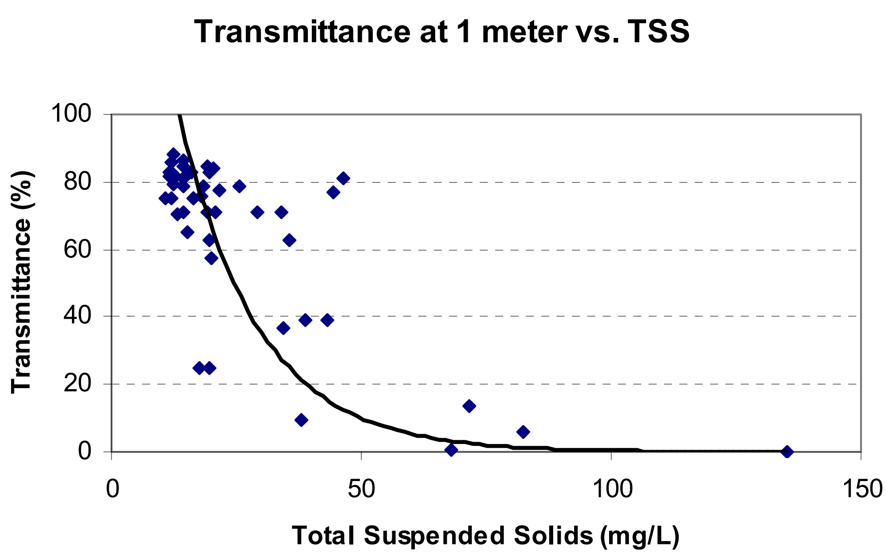


Figure 27. Scatterplot between % Transmitttance at 1 meter depth to Total Suspended Solids (mg/L) at the surface (0.5 m depth).

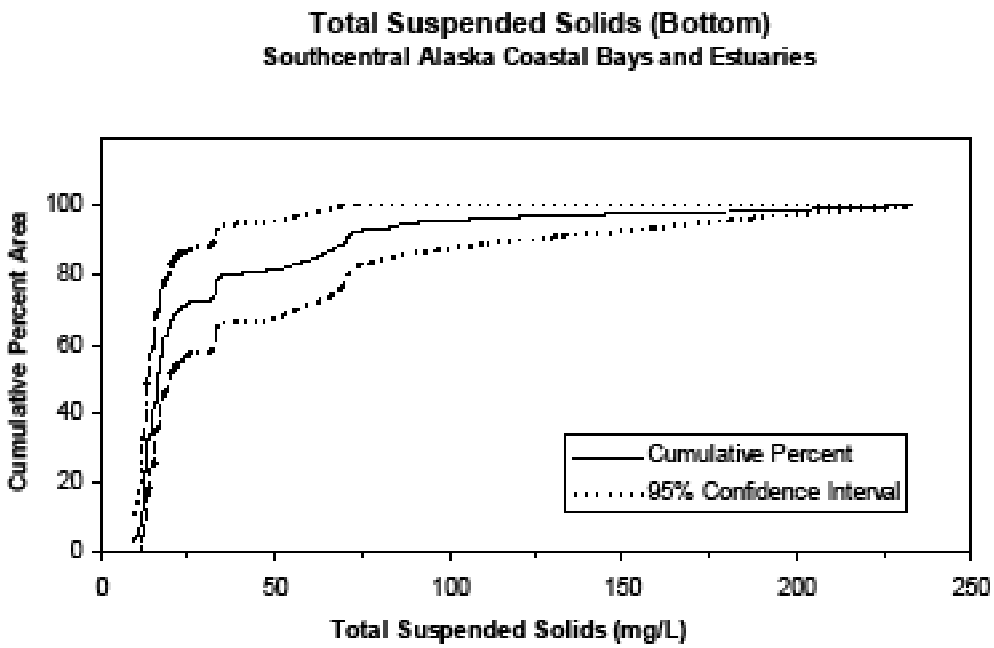


Figure 28. Percent area of Southcentral Alaska coastal bays and estuaries vs. bottom water column Total Suspended Solids (mg/L).

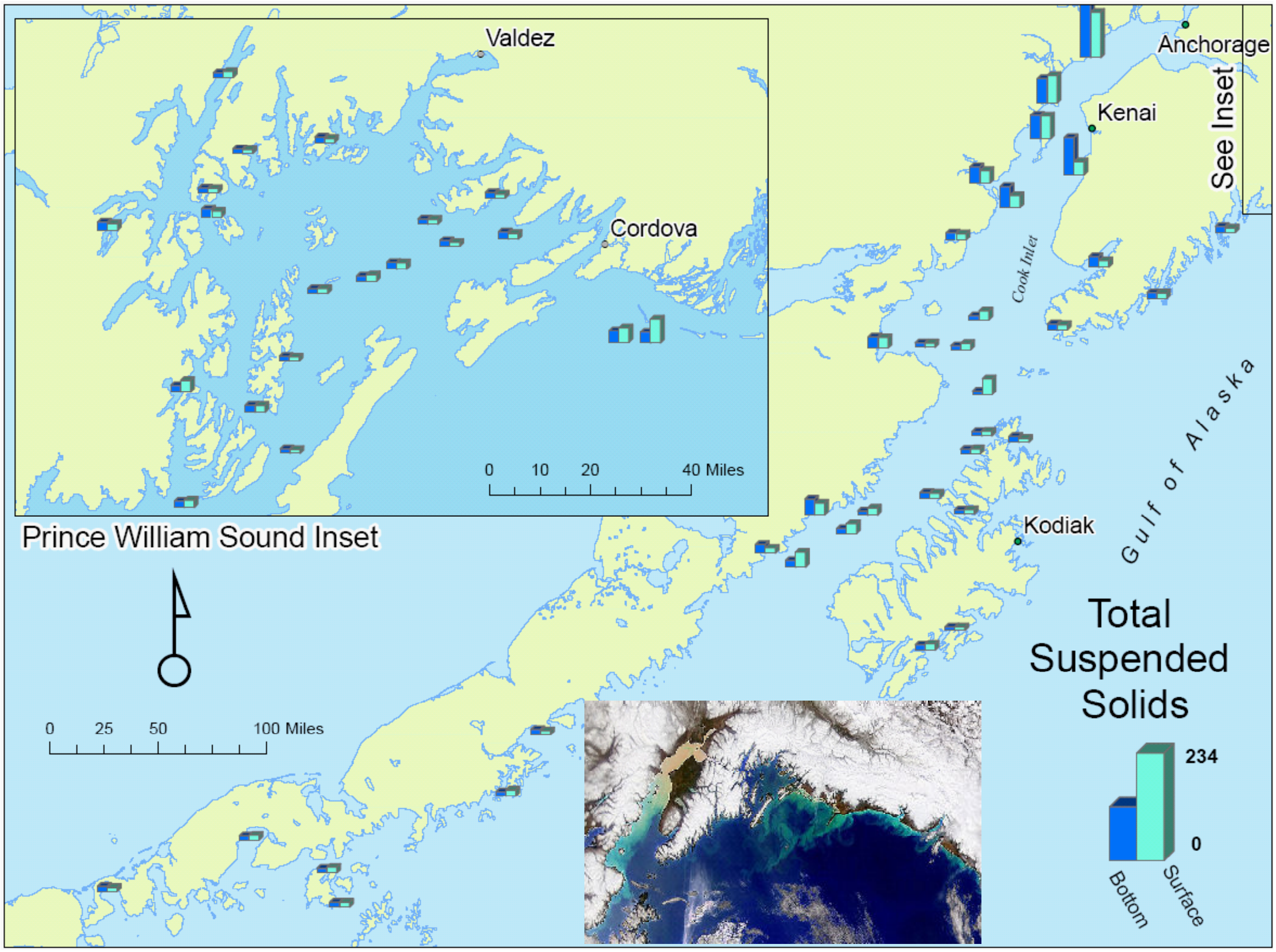


Figure 29. Distribution of station Total Suspended Solids (mg/L) at the surface and bottom of the water column. Superimposed is a SeaWiFS Satellite image (visible range) showing high suspended sediments in Cook Inlet (upper left of image) and along portions of the northern coast, especially immediately downstream of the Copper River delta area (center of image). Inserteded is a SeaWiFS Satellite Image of the central study area.

Chlorophyll *a*

The concentration of the chlorophyll-a pigment reflects phytoplankton standing stocks in the water column and can be used as one measure for evaluating eutrophication. Summary statistics for chlorophyll-a concentrations are shown in Table 2 and Figure 11. The surface mean was 1.06 ± 1.01 µg/L across the study area, with a maximum value of 4.64 µg/L at the surface and 3.93 µg/L at the bottom. There are no defined state or national criteria for chlorophyll-a concentrations, but the threshold values identified by NOAA (Brecker et al. 1999) for eutrophicity based on chlorophyll-a in coastal waters are: hypereutrophic >60 µg/L, high at > 20 and ≤ 60 µg/L, medium at > 5 and ≤20 µg/L, and low at ≤5 µg/L. Figure 30. and Figure 31 are CDFs for surface and bottom water column chlorophyll-a concentrations across the study area, respectively. For both surface and bottom, water column chlorophyll-a concentrations were less than the 5 µg/L threshold value at 100% of the study area.

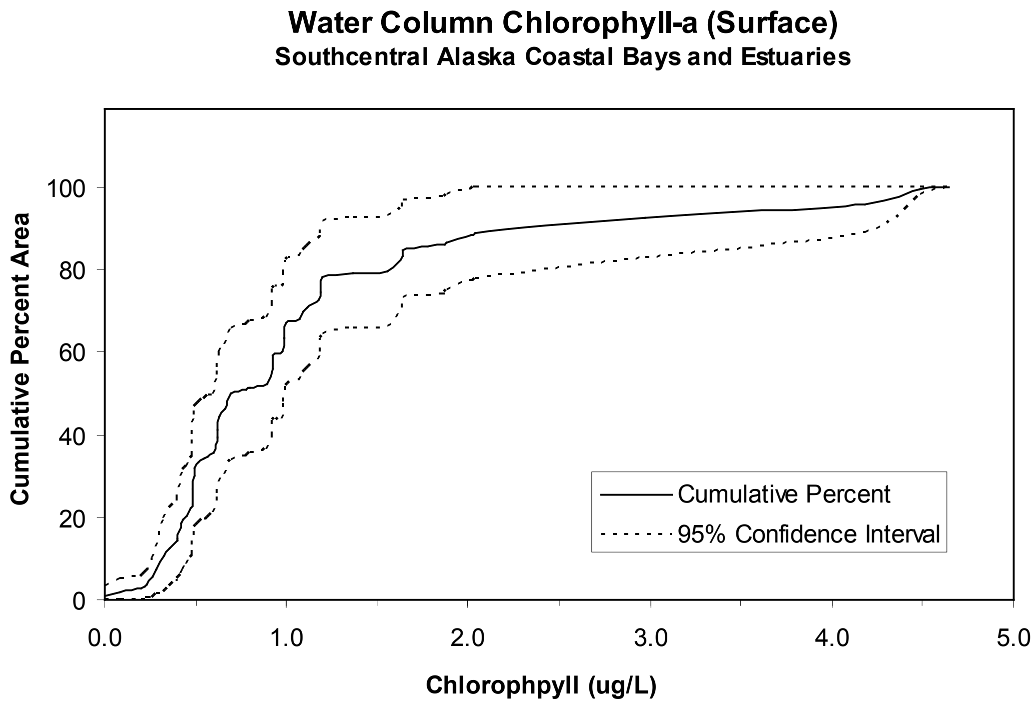


Figure 30. Percent area of Southcentral Alaska coastal bays and estuaries vs. surface water column Chlorophyll-a concentrations (ug/l).

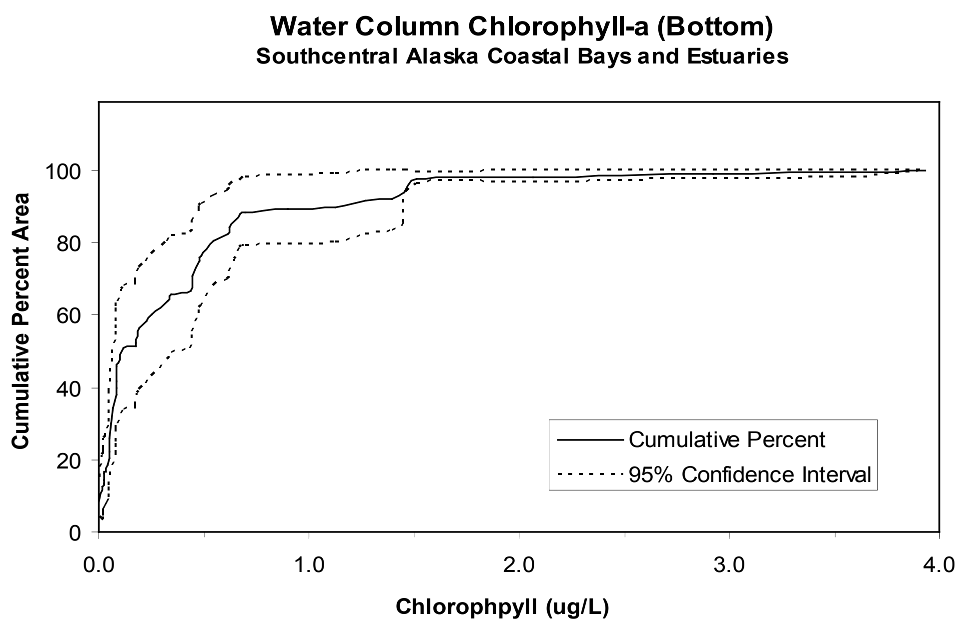


Figure 31. Percent area of Southcentral Alaska coastal bays and estuaries vs. bottom water column Chlorophyll *a* concentrations (ug/l).

Dissolved Nutrients

Nutrient loading in coastal waters is of growing concern for many areas nationwide and measures of this condition are included as part of these coastal assessments. Nutrient concentrations are not always the only variable for determining eutrophication or potential eutrophication; chlorophyll-a concentrations in surface waters, bottom dissolved oxygen concentrations, total organic carbon in the sediments, and water clarity, as discussed previously, can all be indicators of this condition and should, ideally, be interpreted together in order to determine eutrophication potential. High nutrient levels alone do not necessarily mean the potential for eutrophication is high. As well, low levels do not necessarily indicate a non-eutrophic system. However, nitrogen and phosphorous compounds are commonly linked to eutrophication, as they support phytoplankton growth. These nutrients are typically supplied from land and river run-off and the oceanic influx of either upwelled or regenerated nitrogen from bacterial breakdown of organic matter.

Phytoplankton need nitrogen and phosphorous in a relatively fixed ratio, 16:1 (N:P), and of the two, nitrogen is often limiting in natural coastal waters. However, in areas with excessive run-off or discharges of nitrogen or phosphorous–bearing compounds, such as fertilizers from agriculture or golf courses, run-off from animal husbandry, municipal wastewater discharges, and other point-source and non-point source pollution, excessive nutrients are available. If the temperatures and light are available for phytoplankton growth, excessive primary production can take place and create an overabundance of organic matter in the water column that can cut out light to sub-aquatic vegetation, sink to the bottom and create anoxic conditions from the bacterial decay, and ultimately can cause die-off of benthic animals.

Most of the nutrient studies in the Alaskan marine environment have been part of oceanic studies in areas further offshore than this study. Nutrient concentrations change seasonally, even hourly, in response to upwelling, surface mixing, phytoplankton uptake, microbial degradation of organic material, as well as potential human-introduced sources from discharges or run-off. Although nutrients in this study were measured only one time at each station, providing only a snap-shot in time, the data can be interpreted in conjunction with other water quality parameters to provide a measure of whether eutrophication from nutrient loading is of concern in Southcentral Alaska coastal bays and estuaries.

Dissolved Inorganic Nitrogen

Nitrogen was measured as Nitrate-N (NO^3-), Nitrite-N (NO^{2-}), and Ammonium-N (NH^4+), and is reported also as the sum of these nutrients as dissolved inorganic nitrogen (DIN). Data are reported in µg/L of elemental nitrogen or phosphorous. Table 7 and Figure 32 show summary statistics for nutrients for the sampled stations and Figure 33 shows the relative geographic distribution of total dissolved inorganic nitrogen (summed nitrate + nitrite + ammonium nitrogen converted to micromolar units (µM). Figure 32 shows that total DIN is dominated by nitrate-N, especially below the surface. At the surface, ammonium is a higher relative percent of total dissolved inorganic nitrogen compared to the bottom. In the absence of ammonium introduction via anthropogenic sources, ammonium-N is often considered as regenerated nitrogen, from organism excretions or as the first dissolved inorganic nitrogen component in the remineralization of organic matter by bacteria. Nitrate and nitrite are mixed back into the surface water column with fall and winter storms so that these components will be much more dominant in the spring, before primary production reduces them in the spring and summer.

Figure 34 andFigure 35 and how CDFs for total DIN at the surface and bottom of the water column. Of the total study area, 50% had DIN concentrations less than 67.1 mg/L (1.1 µM) and 100% had concentrations less than 200 µg/L (14.3 µM). At the bottom of the water column, 50% had less than 67.1 mg/L (4.8 µM) and 100% had less than 401 µg/L (28.6 µM). There are no State of Alaska or national EPA standards for dissolved nitrogen nutrients (except for ammonia) in coastal waters. Therefore, these Southcentral Alaska coastal bay and estuary data are compared with threshold values identified by Bricker et .al. (1999) for NOAA based on data obtained for coastal regions across the U.S. For DIN, this NOAA threshold value is 1.0 mg/L and 0% of the study area exceeded this value for water column nutrients.

Ammonium

Summary statistics for surface and bottom water column ammonium across the study area are shown in Table 7 and Figure 32. The maximum surface ammonium concentration was 54.4 µg/L and the maximum at the bottom was 122.8 µg/L. AWQS identify dissolved ammonium criteria based on temperature, pH, and salinity ranges. For the ranges of those parameters measured in surface and bottom waters during this study, the most conservative limit for any combination of pH, salinity, and temperature is 1.8 mg/L for total ammonia acute criteria and 0.59 mg/L for chronic criteria. The CDFs for surface and bottom water column ammonium during this study are shown in Figure 36 and Figure 37, respectively. 100% of the study area's ammonium concentrations fall far below both acute and chronic AWQS ammonia criteria.

Phosphate and N/P Ratio

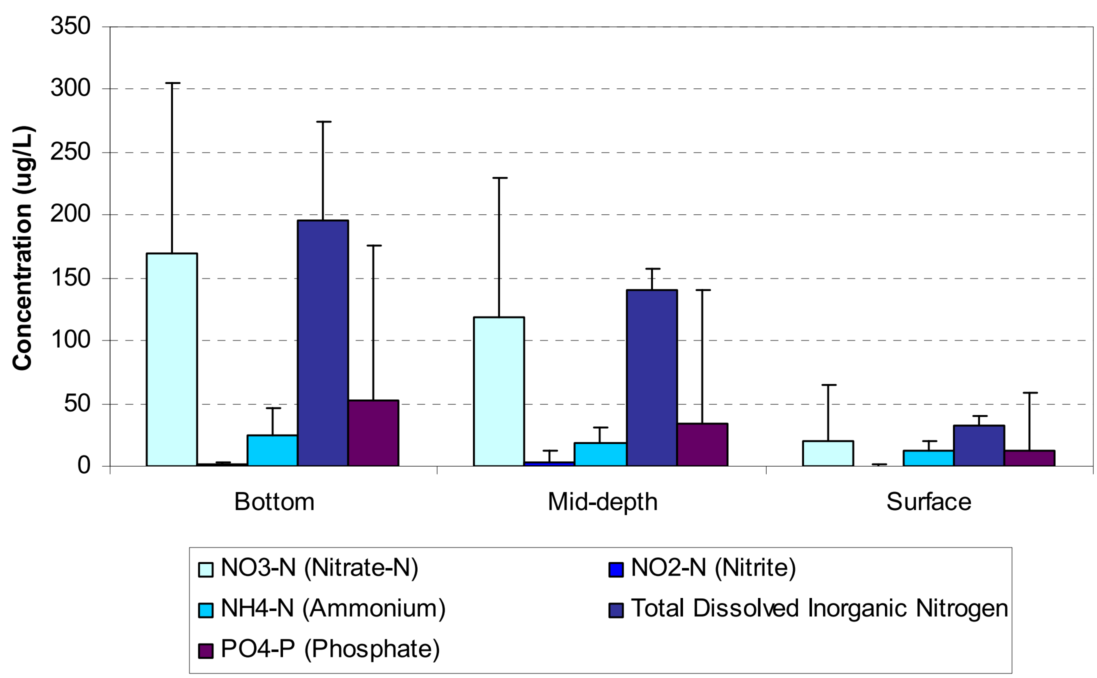
Summary statistics for surface and bottom water column dissolved inorganic phosphorous (as phosphate-P) are shown in Table 7 and Figure 32. The average surface phosphate-P measured across the study area was 12.7 µg/L and 52.9 µg/L at the bottom. Figure 38 and Figure 39 show CDFs for surface and bottom phosphate-P. Compared to a NOAA threshold value of 0.1 mg/L (Bricker et. al. 1999), 100% of the study area fell well below this value considered as high phosphate for surface waters. The maximum value at the surface of 30.5 µg/L occurred at site AK02-0016, on the east side of Cook Inlet. For phosphate concentrations at the bottom of the water column, 96.2% of the study area fell below this threshold value. The maximum value for the bottom water column occurred at station AK02-0023, in lower Cook Inlet at the northern end of Shelikof Strait. This value of 613.5 µg/L is far above the NOAA threshold value for surface nutrients, but threshold values for nutrients are developed around potential availability of nutrients to the photic zone. Even for an area of strong deep ocean-water upwelling, this value is an outlier. Maximum concentrations of phosphate measured during the World Ocean Circulation Experiment (WOCE) for transects near Kodiak Island and Shelikof Strait show phosphate concentrations rarely exceeding 3 µM phosphate (~93 µg/L phosphate-P), even in upwelling areas. Thus, this high value is most likely from contamination, possibly from soaps used to clean the deck. Without this outlier, 100% of the study area's bottom water has phosphate-P concentrations below the NOAA threshold value of 0.1 mg/L. Even though the high number is most likely due to contamination, historical measurements have shown that there is significant influence of deeper Gulf of Alaska waters through Kennedy and Stevenson Entrances, supplying nutrients to surface waters of lower Cook Inlet. This area sustains high production rates even in late summer (Larrance et al., 1977) and the area has some of the most productive high-latitude shelf waters in the world (Sambrotto & Lorenzen, 1986).

Total molar dissolved inorganic nitrogen (DIN, nitrate + nitrite + ammonium) is compared to the molar dissolved inorganic phosphate (DIP) for the surface and bottom of the water column in Figure 40. At most of the stations, surface DIN concentrations have been drawn down below the values seen at the bottom, giving N:P ratios for dissolved nutrients far lower than typical upwelled, or deep ocean, ratios which are near 16:1. The sites with the highest molar DIN, especially relative to DIP, are those in upper and mid-Cook Inlet, possibly reflecting reduced primary production rates due to the high suspended sediment loads. At the bottom, the N:P ratios are much closer to 16:1 across all sites. These data do not reflect site AK02-0023, which had DIN concentrations of 16.46 µM and DIP of 17.53 µM, and was suspected to be contaminated by soap on deck.

Table 7. Summary statistics for nutrients at the Southeast Alaska 2002 EMAP stations.

Nutrient (µg/L)	mean	std	median	max	min	N
NH4-N (surface)	12.0	8.4	11.4	54.4	0.0	55
NH4-N (bottom)	23.9	23.0	14.0	122.8	3.4	54
NO2-N (surface)	0.6	1.0	0.2	4.4	0.0	55
NO2-N (bottom)	1.8	1.5	1.3	6.1	0.0	54
NO3-N (surface)	20.3	43.8	2.5	183.5	0.0	55
NO3-N (bottom)	169.3	136.0	131.1	396.6	0.0	54
PO4-P (surface)	12.7	7.7	11.0	30.5	1.6	55
PO4-P (bottom)	52.9	80.1	43.0	613.5	1.9	54
Total_Dissolved N (surface)	32.8	45.6	15.1	191.1	0.3	55
Total_Dissolved N (bottom)	195.1	123.2	175.4	400.6	9.6	54

Figure 32. Summary statistics (mean plus standard deviation) for data presented in Table 7



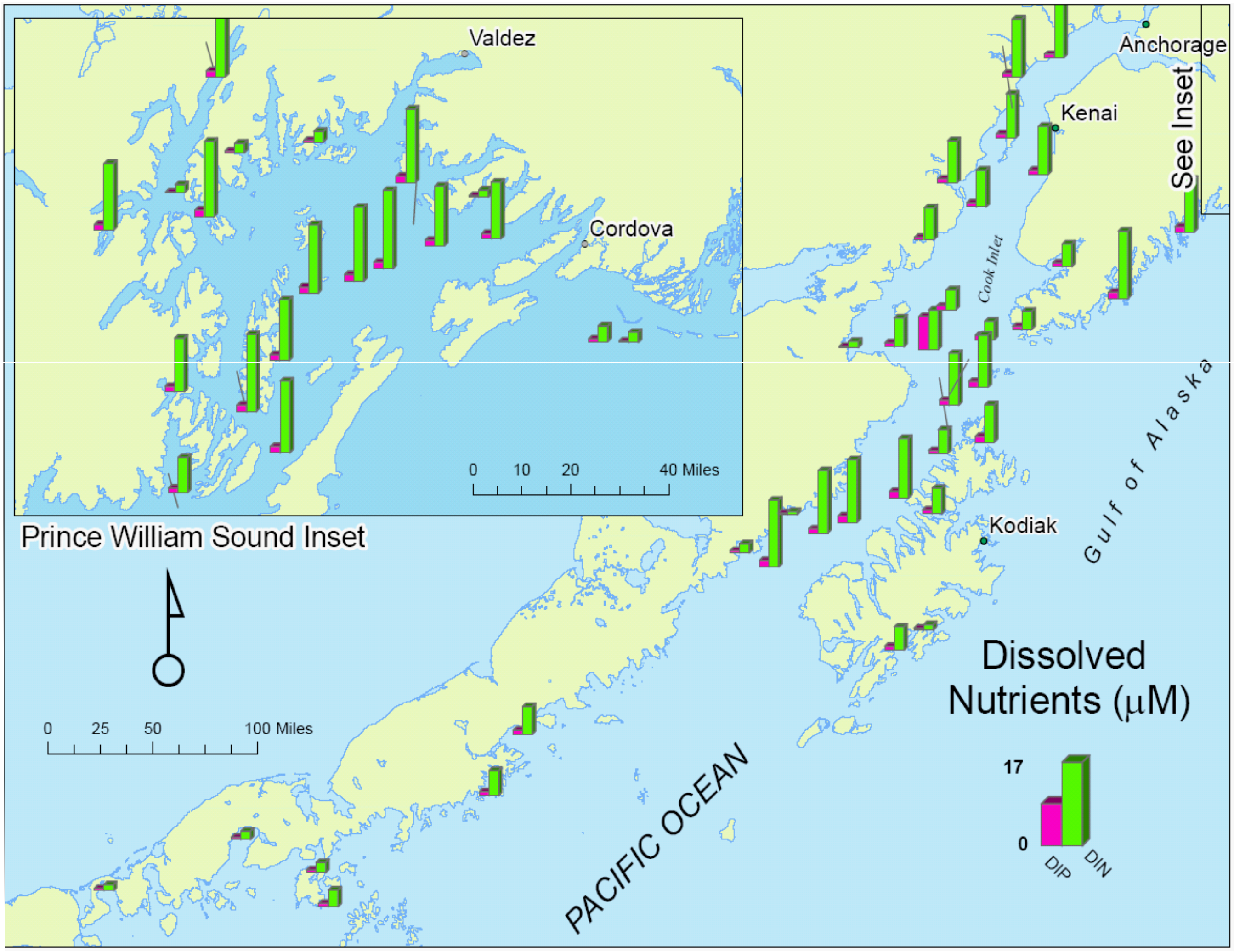


Figure 33. Total surface dissolved inorganic nitrogen as summed nitrate, nitrite and ammonium (µM) for each station sampled.

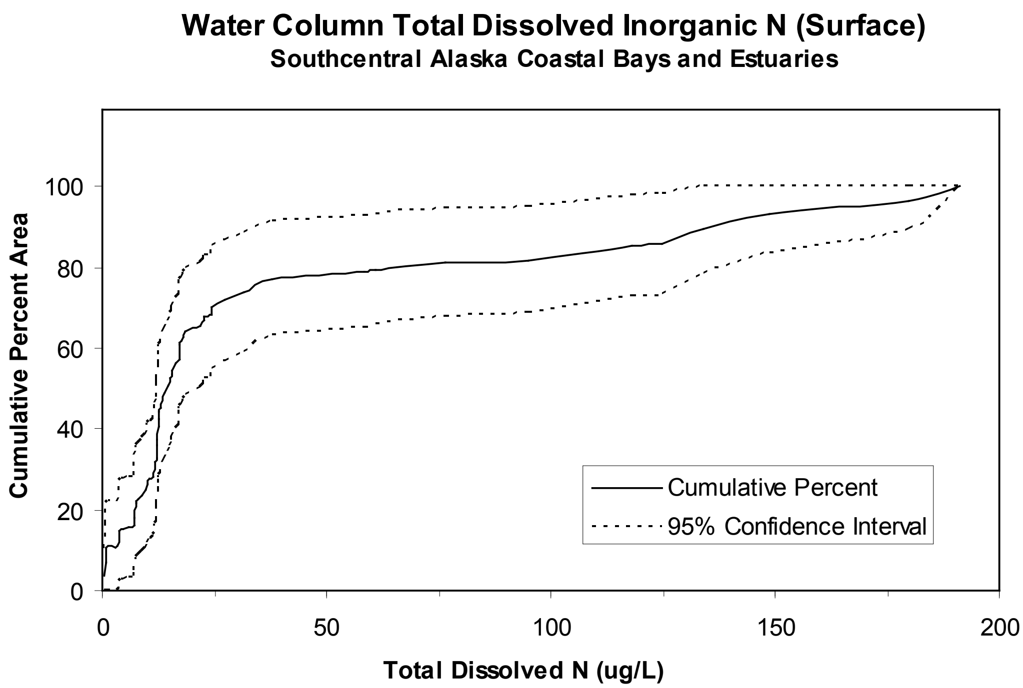


Figure 34. Cumulative distribution function (CDF) of surface water column total dissolved inorganic nitrate-N + nitrite-N + ammonium-N (µg/L).

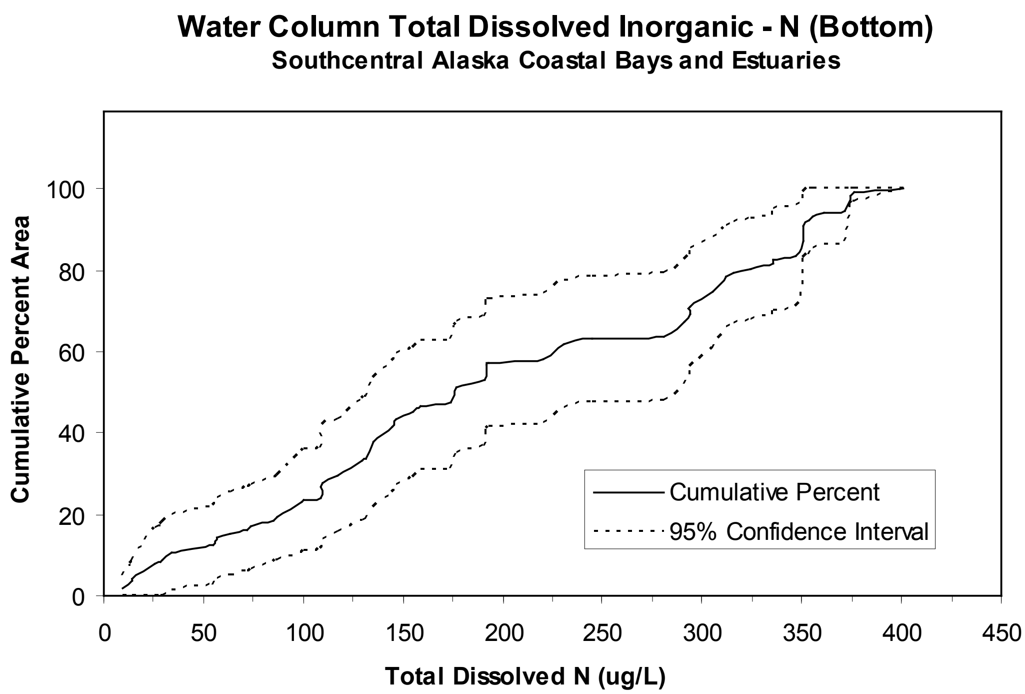


Figure 35. Cummulative distribution function (CDF) of bottom water column total dissolved inorganic nitrate N+nitrate+ammonium-N (µg/L).

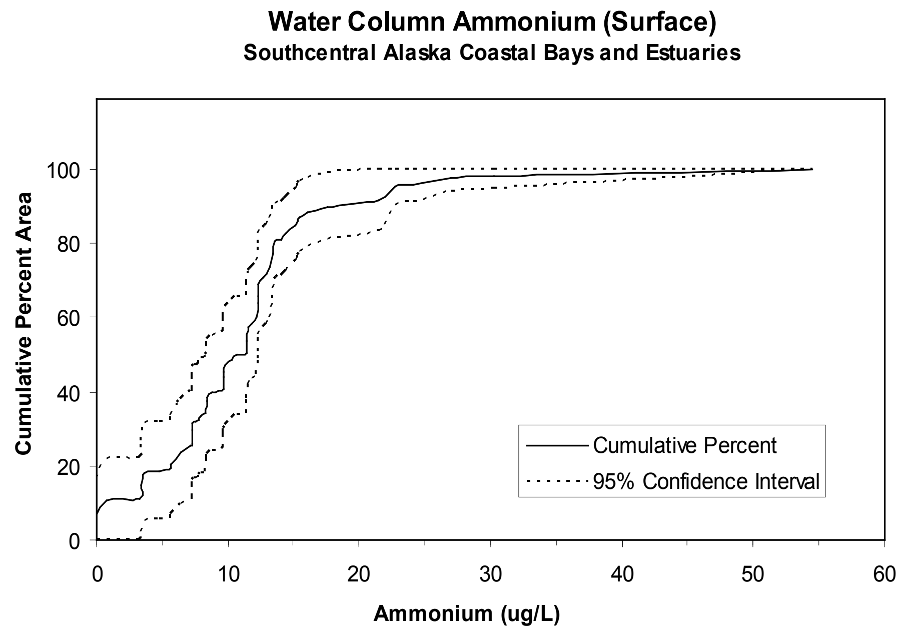


Figure 36. Cumulative distribution function (CDF) of surface water column ammonium-N (µg/L).

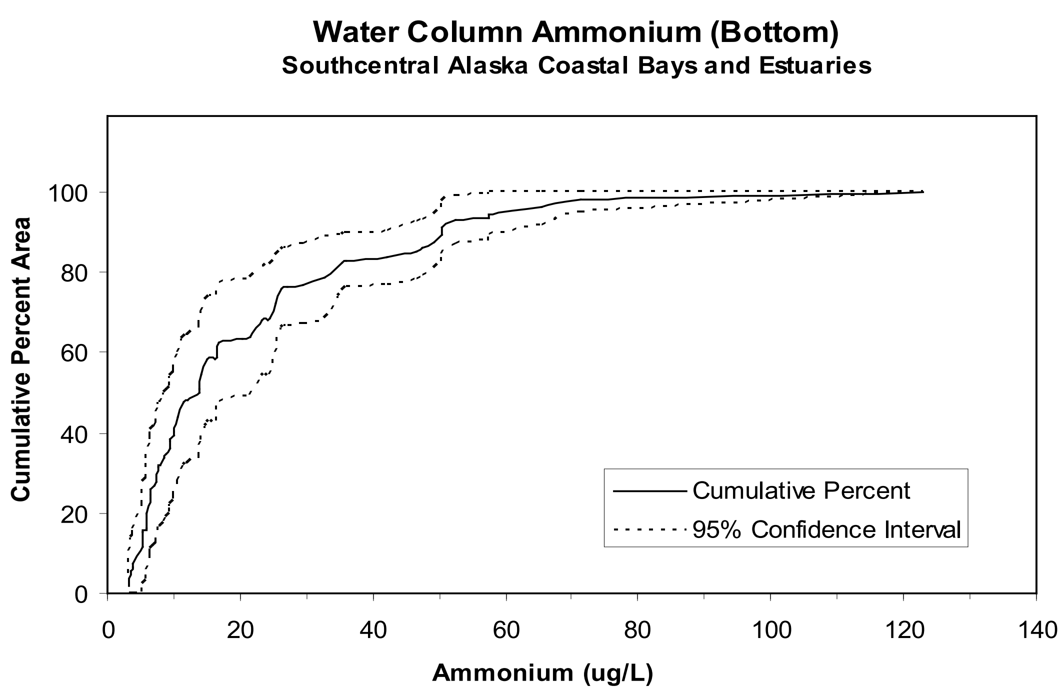


Figure 37. Cummulative distribution function (CDF) of bottom water column ammonium-N (µg/L).

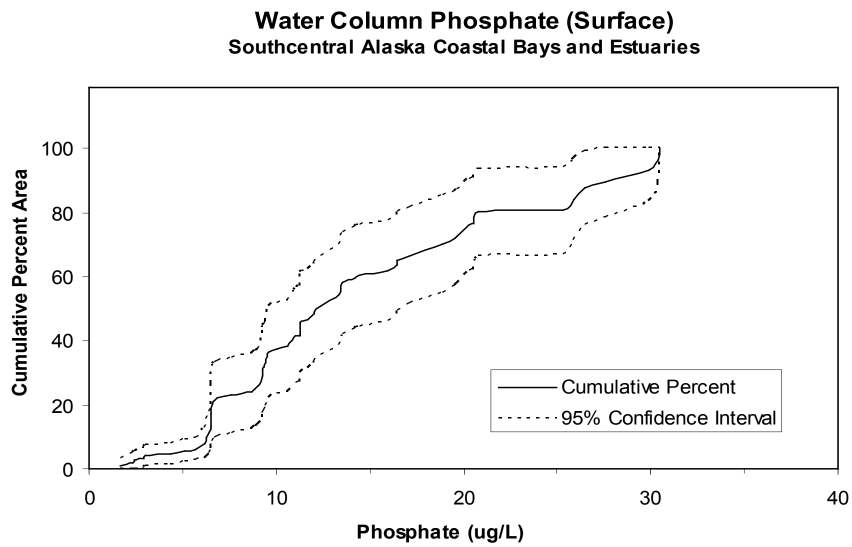


Figure 38. Cumulative distribution function (CDF) of surface water column phosphate-P (µg/L).

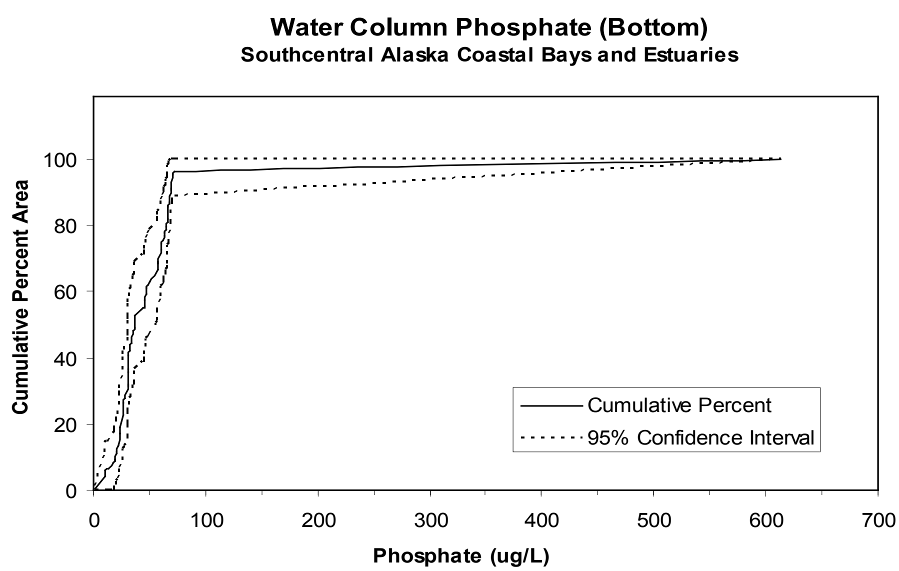
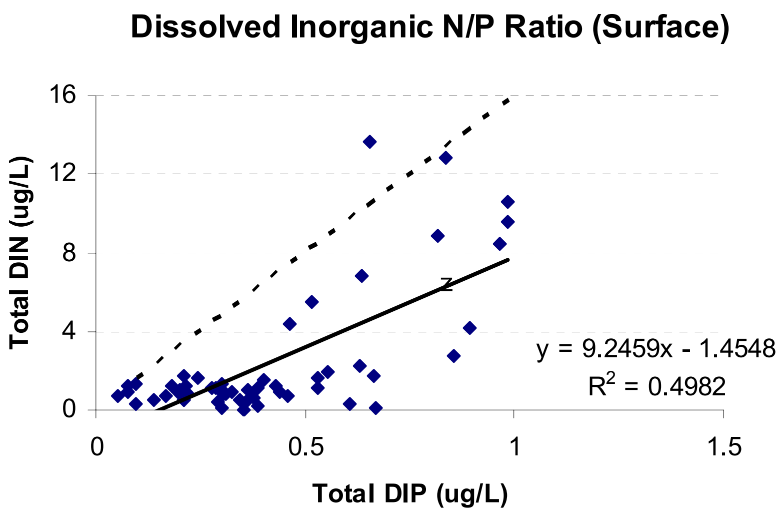
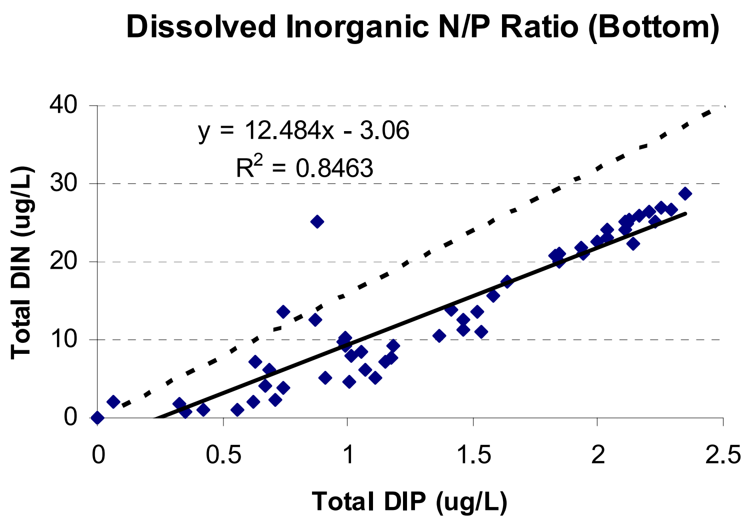


Figure 39. Cummulative distribution function (CDF) of bottom water column phosphate-P (µg/L)

Figure 40. Total Dissolved Nitrogen (DIN) plotted against Total Dissolved Phosphorous (DIP) for the surface (top graph) and bottom (bottom graph) of the water column. Solid line shows linear regression results. Dotted lines show a DIN:DIP ratio of 16:1. These data do not include the major outlier at site AK02-0023.





3.4 Habitat Condition – Sediment Quality

Measures of sediment habitat condition are important since they can strongly influence the relative distribution of exposure indicator values, such as sediment contaminant concentrations. Organic-rich, fine-grained sediments have increased surface to volume ratios relative to coarser sediments and can more efficiently sorb contaminants; in effect, scavenging and concentrating them so that fine-grained sediments generally have higher contaminant concentrations than larger sand particles. Finer sediments are also able to stay in the water column longer than heavier particles and can be swept far downstream of their source, which is why silt and clay from glacial streams in upper Cook Inlet and the Copper River Delta have been traced hundreds of miles down current in Shelikof Strait (ADL 2001, Feely and Massoth 1982). The relative amount of fine-grained silt and clay fractions (mud) in sediments can also drive benthic species assemblages. For this study, habitat condition indicators for evaluating sediment quality were percent silt and clay (% silt + clay) and percent total organic carbon (TOC).

Percent Silt + clay

Summary statistics for all silt + clay sediment fractions across all stations are shown in Table 8. Sediment % silt + clay in the study area ranged from 2.0 to 99.2%. The percentages of as a component of the sediments at each station are shown on a study area map in Figure 41. Depositional areas are scattered throughout the study and are dependent on numerous factors. One of the lowest fractions of silt + clay measured was at site AK02-0009, which was located in a narrow passage between northern Kodiak Island and Raspberry Island and is exposed to extreme tidal currents, while several other sites that are exposed to extreme tidal currents showed higher than expected percent silt + clay (e.g. sites AK02-0011 (45.8%) and AK02-0016 (87.7%). These two sites are near the major source of the fine-grained riverine flour in upper Cook Inlet. Yet, a nearby site, AK02-0012, had only 3.0% silt + clay. It is apparent that there are localized effects, such as eddies, that affect deposition of fine particulates to specific sites. There was no correlation between the amount of suspended sediments and the percent fines in the sediments below (correlation coefficient = -0.028 for surface TSS and 0.008 for bottom TSS). Figure 42 shows more sediment grain size fractions than just % fines (silt + clay). This gives a better visual indication of where the finest sediments have accumulated (e.g. Prince William Sound has relatively high fractions of the finest clay grain sizes).

All stations deeper than 210 meters (9 stations) had more than 96% silt + clay. However, there was no significant correlations between station depth and % silt + clay (Figure 43), with some of the very shallowest stations also having very high silt + clay fractions.

The CDF of sediment silt + clay fraction for the study area is shown in Figure 44. Sandy sediments (< 20% silt + clay) were found at 28.5% of the study area, and 40.1 % of the area had muddy sediments (>80% silt + clay).

<u>Percent Total Organic Carbon</u>

Sediment total organic carbon (% TOC) reflects all carbon compounds expect for carbonate, which is removed during sample preparation. Organic carbon can be introduced to the sediments through a number of sources, including settling phytoplankton and fecal matter, and transport of terrigenous material. Organic matter in the sediments influences the biological, physical, and chemical environment of benthic sediments. As a food source it can determine the presence or absence of particular organisms, ligands associated with organic material can increase the scavenging of contaminants to the surface of the sediments; and the microbial degradation of organic matter in the sediments can create hypoxic or anoxic conditions at depth.

Summary statistics of sediment organic carbon content measured in Southcentral Alaska coastal bays and estuaries are presented in Table 9. Sediment organic carbon ranged from 0% at site AK02-0012 to 6.43% TOC at site AK02-0038. Site AK02-0012 is on the west side of Cook Inlet and had the third lowest % silt + clay (3%) for all sites. Site AK02-0038, located in a small bay in northern Prince William Sound, had huge amounts of decomposing eelgrass mixed into the sediments when sampled by the Van Veen Grab.

The CDF of percent area as a function of sediment total organic carbon for all stations is shown in Figure 45. For the Southcentral Alaska coastal bays and estuaries, 3.5% of the study area had TOC < 0.5% and 1.55% had TOC > 3%. There was no statistically significant correlation between % silt + clay and TOC. Previous work (Hyland et. al. 2000, 2005) describes adverse effects on benthic communities for very low and very high TOC; TOC concentrations less than 0.05% and > 3.0% were tied to decreased benthic infaunal abundance, biomass, and diversity. The authors caution that, although the predictive ability across these ranges was high, they are not a measure of causality and can only be used as a general screening-level indicator for evaluating potential for reduced sediment quality and biological condition over coastal areas that receive organic wastes and pollutants from human activities.

Table 8. Summary statistics for the percent Silt + Clay fraction for stations sampled during the Southcentral Alaska EMAP.

Statistic	% Silt + Clay
Mean	59.3
Standard Deviation	36.7
Median	67.2
Maximum	99.2
Minimum	2.0
N	55

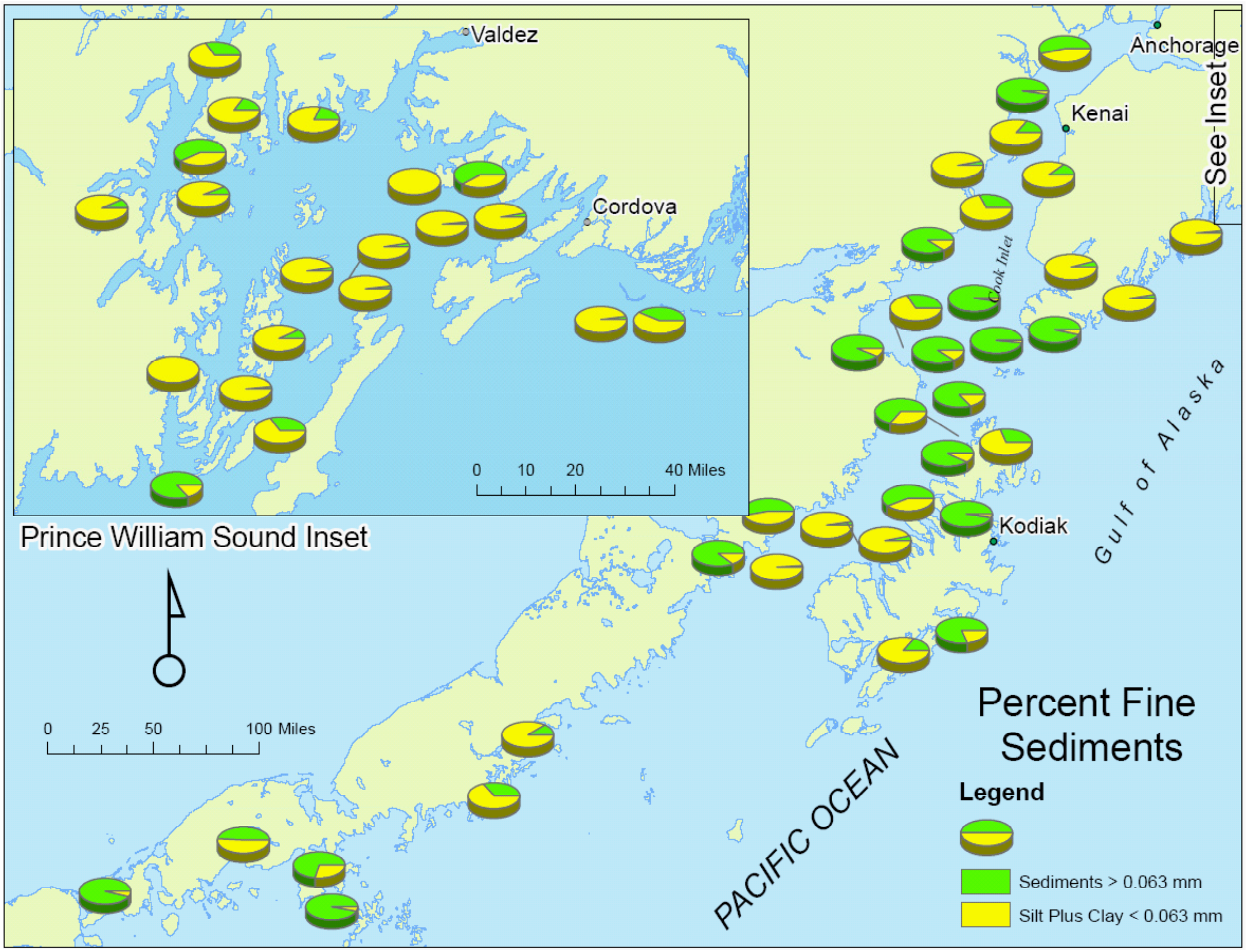


Figure 41. Sediment percent silt + clay at sampled stations across the study area's geographic range. Note that Prince William Sound is an inset on the left instead of at its normal geographical position at the eastern edge of the study area.

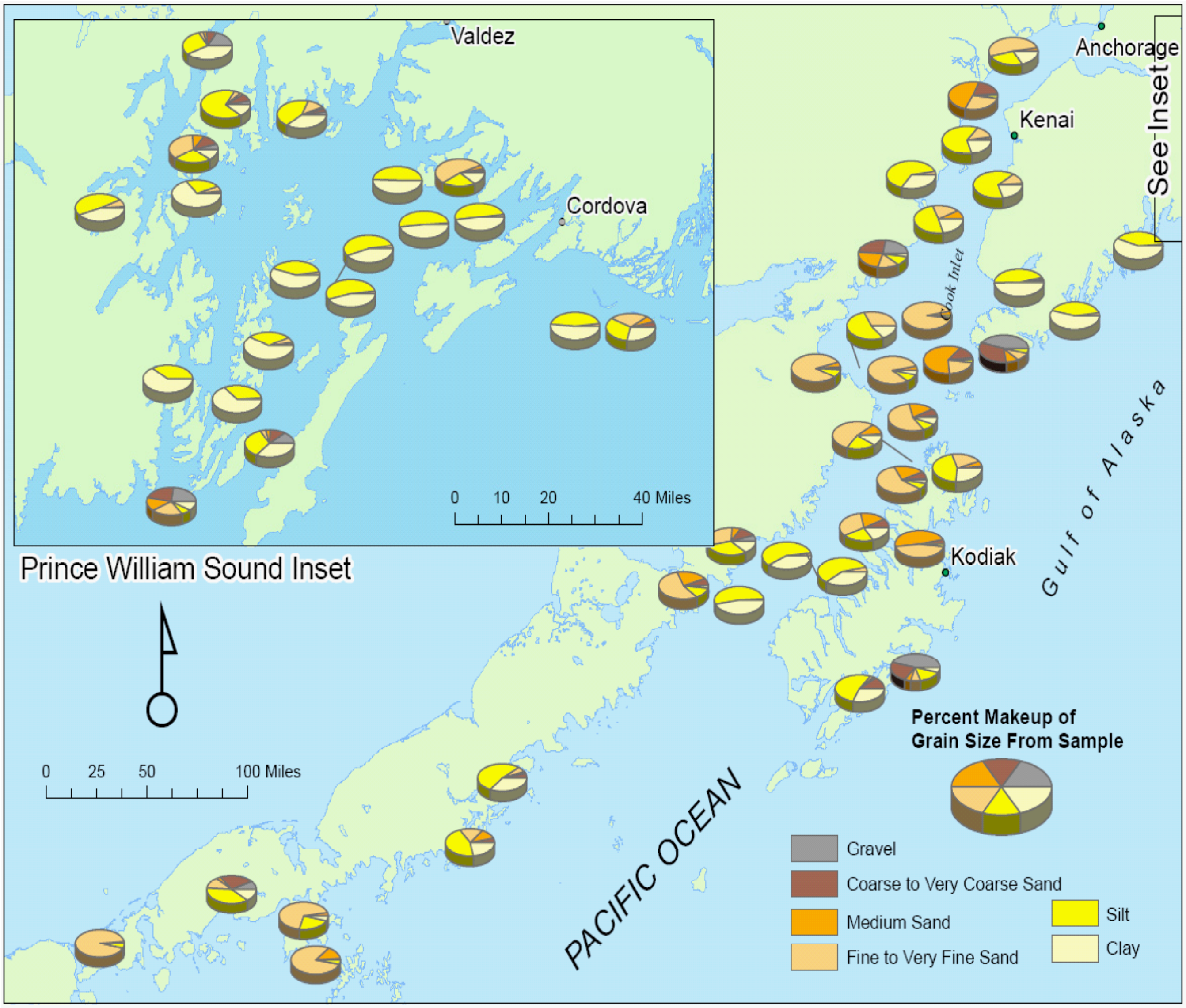


Figure 42. Sediment percent grain size categories at sampled stations across the study area. Grain size categories are: Gravel (> 2.0 mm), Coarse to Very Coarse Sand (0.5 to 2 mm), Medium Sand (0.25 – 0.5 mm), Fine to Very Fine Sand (0.0625 – 0.25 mm), Silt (0.00390-00.0625 mm), and clay (< 0.0039 mm). Note that Prince William Sound is an inset on the left instead of at its normal geographical position at the eastern edge of the study area.

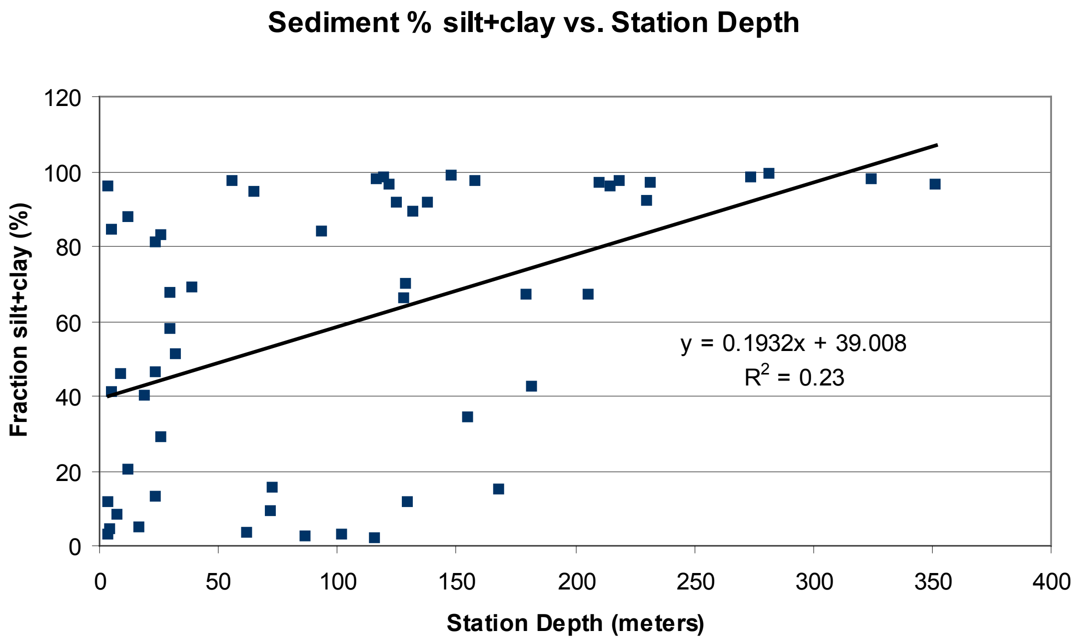


Figure 43. Regression of sediment silt+clay (%) and station depth.

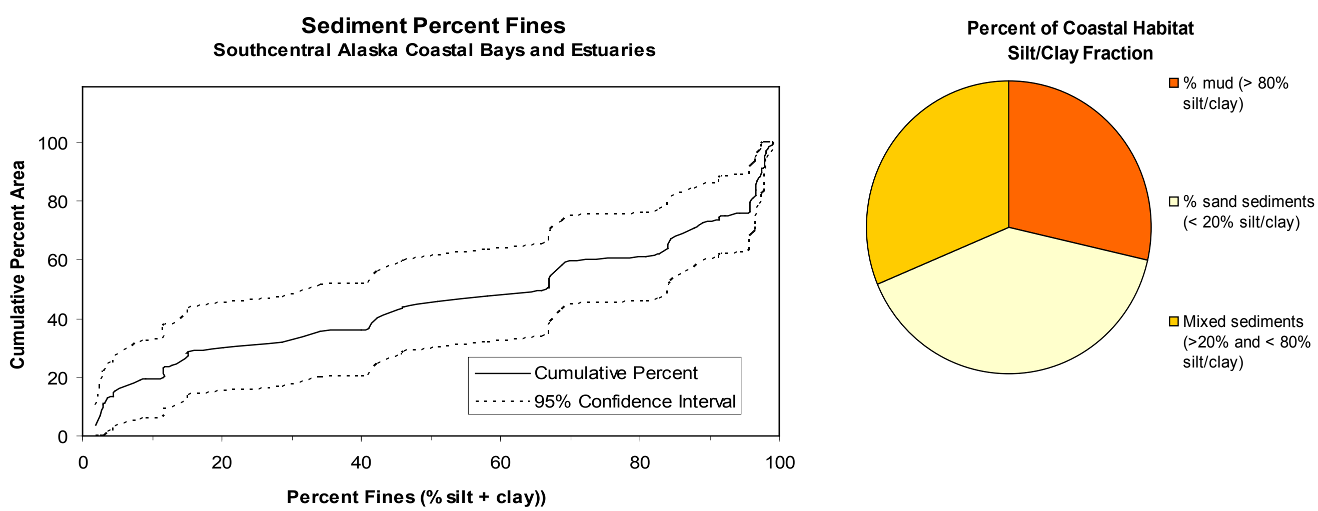
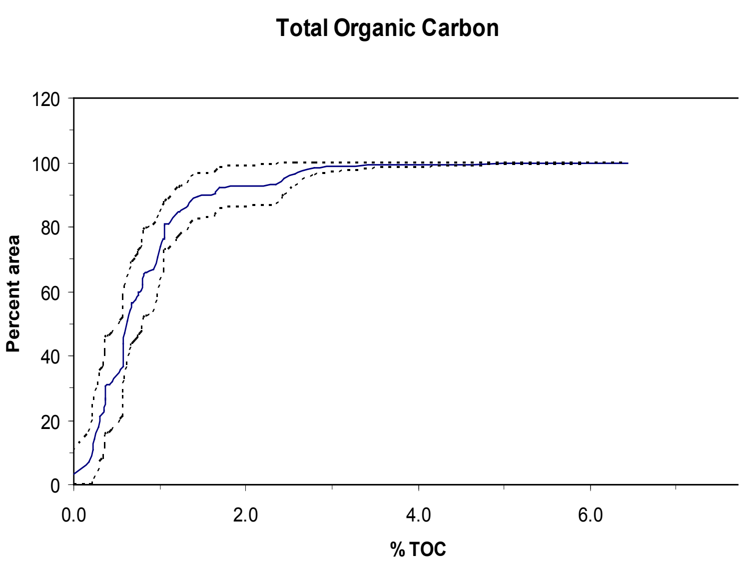


Figure 44. Cumulative distribution of sediment % silt + clay as a percent of area in the Southcentral Alaska EMAP study area (left) and estimates of the proportion with habitat that has predominantly sandy (< 20% silt + clay), mixed (20-80% silt + clay), or muddy (> 80% silt + clay) sediments.

Table 9. Summary statistics for the percent total organic carbon content at stations sampled during the Southcentral Alaska EMAP.

Statistic	% Silt + Clay
Mean	1.03
Standard Deviation	1.03
Median	0.78
Maximum	6.43
Minimum	0
N	55



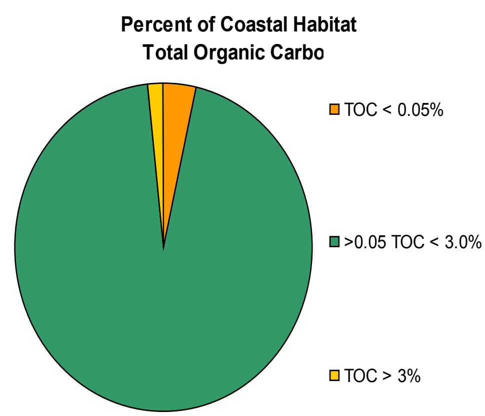


Figure 45. Cumulative distribution of sediment percent total organic carbon (TOC) as a percent of area in the Southcentral Alaska EMAP study area (left) and estimates of the proportion of Southcentral Alaska coastal bays and estuaries with habitat having TOC levels which may cause stress in benthic communities (< 0.05 or > 3.0%).

3.5 Exposure Indicators –Sediment Contaminants and Toxicity Bioassay

Sediment Contaminants

Sediment contamination is of major environmental concern in many U.S. coastal waters because elevated levels of metals and organic pollutants have been associated with impacts on benthic organisms that feed or live in or on benthic sediments. Adverse affects can include abnormalities in bottom-feeders, bioaccumulation of contaminants in tissues that can be passed up the food chain to higher trophic levels (including humans), and disruption of natural species assemblages.

Human-introduced (anthropogenic) sediment contaminant sources include both point and non-point source discharges. Anthropogenic effects can also change natural sediment transport routes and chemical reactions so that natural sources of contaminants can become concentrated above a normal, or natural, background. Toxics that enter the water column can adsorb onto sediments in the water column and can ultimately end up concentrating the contaminants in the benthic environment where the sediments settle out of the water column. Common sources of human-introduced contaminants include industrial and municipal wastewater discharges, run-off from urban areas, deposition of combustion-source particulates from the air, mining, oil and chemical spills, and many other smaller sources. Contaminants introduced in one area can also be transported long distances by air or ocean currents.

There are several environmental factors that strongly influence the extent of contamination by introduced toxic compounds, including sediment grain size and associated organic matter in the sediments. Fine-grained sediments have a higher surface to volume ratio and for contaminants that can adsorb or absorb onto or into these particles, there is the potential for an increased concentration per unit volume compared to larger grained sediments. Fine particles are also more likely to be resuspended by currents or swept further from their source to be deposited in areas further downstream than are larger particles. Thus, silt and mud are often correlated with higher concentrations of contaminants. Also, increased organic matter in sediments can increase the capacity for adsorbing pollutants.

The assessment of some chemical contaminants of concern is relatively easy in that there are no known natural sources. (e.g. PCBs). Many others, however, are more difficult to evaluate due to natural sources that result in natural background concentrations in the sediments. Natural background is difficult to determine in many cases as there can be numerous sources of sediments and sediment contaminants. For example, coastal seafloor sediment metals can be derived from numerous sources such as riverine discharges of dissolved, colloidal, and particulate metals, from precipitated upwelled dissolved deep ocean sources, ground-water seepage, glacial erosion, as well as other sources. Different sediments, whether they are from natural or human-introduced sources, also vary in their affinities for scavenging dissolved or colloidal metals or organics. For example, dissolved metals in upwelled waters can associate with suspended particulates closer to the surface and ultimately precipitate out as components of benthic sediments.

Sediment Contaminants - Indicators

To help evaluate the possible toxicological significance of chemical concentrations to benthic organisms, sediment quality guidelines (SQGs) were developed as informal, interpretive tools by the National Oceanic and Atmospheric Administration's (NOAA) National Status and Trends (NS&T) Program (Long and Morgan 1990) and subsequently fine-tuned and updated for the saltwater environment (Long et. al. 1995). These SQGs were not promulgated as regulatory criteria or standards. Rather, the goal in developing the guidelines was to provide informal (non-regulatory) concentration values for use in interpreting chemical data from benthic sediment analyses. Their use can help rank areas that might need further detailed study for adverse effects or for ranking chemicals that might be of potential concerns. They are most useful when combined with other information, such as direct measures of adverse effects, such as toxicity bioassays.

Individual states have recognized the limitations of these guidelines for setting regulatory criteria or standards, for cleanup or remediation targets, or for discharge attainment targets. They have worked towards developing state- or area-specific sediment quality guidelines based on detailed information from their geographic region, such as the surrounding geology and oceanic circulation.

Currently, the State of Alaska has not identified specific sediment quality standards or criteria, but has relied on placing limits on permitted discharges of contaminants that are known to accumulate in sediments. In his evaluation of Alaska statues and water quality standards, Cormack (2001) outlined sediment quality guideline options for the State of Alaska. His findings were that, although specific sediment concentration criteria have not been established in Alaska Water Quality regulations, the language does specifically include sediments in the applicability section (18AAC 70.005). Sediment is defined to mean "solid material of organic or mineral origin that is transported by, suspended in, or deposited from water; 'sediment' includes chemical and biochemical precipitates and organic material, such as humus." These same regulations (18AAC 70.020) also disallow "concentrations of toxic substances in water or in shoreline or bottom sediments, that singly or in combination, cause or reasonably can be expected to cause, toxic effects on aquatic life, except as authorized by this chapter." This is repeated in both the fresh and marine water tables. Also in the Water Quality regulations, 18AAC 70.250 and 18AAC 70.255 stipulate that the potential for impact on sediments must be considered in establishing mixing zones.

For the purposes of this report, concentrations of contaminants measured during this study are compared to other thresholds, guidelines, or criteria such as the NS&T sediment quality guidelines (Long et. al. 1995), which are used as criteria to evaluate many of the coastal areas of the U.S. for the EPA National Coastal Assessment Program, or compared to Washington State's Sediment Management Standard's sediment quality chemical criteria (WDOE 1995). Table 10 lists these sediment guidelines. Effects Range Low (ERL) is the lower threshold bioeffects limit, below which adverse effects of contaminants on sediment-dwelling organisms are not expected to occur. Effects Range Median (ERM) designates values above which toxic effects are likely. ERL and ERM values for each parameter have varying levels of data quality on which they were derived and the reliability of some parameters as predictors of potential adverse effects have been identified as low. These include nickel, mercury, DDE, total DDTs, and total PCBs. The possibilities that the effects values for these substances will accurately predict adverse effects are lower than those for most chemicals.

Washington state guidelines do not include threshold values for nickel due to its known high concentration in background sediments associated with specific types of source rocks for the west coast, and are often naturally higher than ERL or ERM values. As well, they have adjusted the concentrations of most metals to reflect the natural backgrounds as well as to correct for varying organic content in the sediments.

Sediment - Metal Contaminants

Fifteen metals, including trace metals, were required for analyses by the National Coastal Assessment Program and were analyzed in benthic sediments for each station during this study. These included Aluminum (Al), Antimony (Sb), Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Iron (Fe), Lead (Pb), Manganese (Mn), Mercury (Hg), Nickel (Ni), Selenium (Se), Silver (Ag), Tin (Sn), and Zinc (Zn). Summary statistics for benthic sediment metal concentrations are shown in Table 11. Histograms reflecting individual site metal concentrations as well as summary statistics are shown in Figure 46 (Al, Sb, As), Figure 47 (Cd, Cr, Cu), Figure 48 (Fe, Pb, Mn), Figure 49 (Hg, Ni, Se), and Figure 50 (Ag, Sn, Zn). It is important to remember that each site is a replicate for the total population studied, i.e. it represents a percentage of the hexagonally-represented total bays and estuaries in Southcentral Alaska and individual values to not represent the individual bay or estuary location where it was sampled. However, as with discussions about sediment inputs and nutrient upwelling, the individual site data can be useful for identifying potential areas of elevated metals concentrations in the sediments that may require further study and sampling to characterize its location. An example of this is the high concentration of chromium detected at station AK02-0005, on the southern end of the Kenai Peninsula, where the concentration is almost an order of magnitude higher than any other sampled location. This high value will be discussed below along with other potential trends.

The individual site data are incorporated into CDFs to describe the distribution of each metal from all sampled sites in relation to their aerial extent within the study area in Figure 51 (Al, Sb, As, Cd, Cr), Figure 52 (Cu, Fe, Pb, Mn, and Hg), and Figure 53 (Ni, Se, Ag, Sn, Zn). Based on its CDF, the percent of the study area that falls within the ERL and ERM guidelines that were shown in Table 10 for each metal are summarized in Table 12 and Figure 54. These pie diagrams identify the percent study area that has concentrations above ERL and ERM guidelines for As, Cd, Cr, Cu, Mg, Ni, and Zn. None of these values have concentrations above Washington State Sediment Quality Standards, and are even lower compared to the standards when normalized to organic carbon content. Washington State standards were developed by considering known geology of source rocks and sediments absent of anthropogenic sources.

Sediment Metal Concentrations – Comparisons to Known Sources

Previous studies in Alaska have measured metal concentrations in study area and source sediments, including the Copper, Knik, Susitna, and Matanuska Rivers, as well as many other smaller rivers draining into Southcentral Alaska coastal bays and estuaries. These studies have shown that the same metals discussed above that have concentrations in some portion of the study above ERL or ERM (As, Cd, Cr, Cu, Hg, Ni, and Zn) are also higher than ERL or ERM in potential source rock material (Burrell, et. al. 1978 –continental shelf benthic sediments; ADL 1999 – continental shelf benthic sediments and riverine suspended sediments; Frenzel 2002 – stream bed sediments for rivers and streams entering Cook Inlet; Guay 2005 – dissolved and colloidal metals in Cook Inlet watershed rivers.

One of those studies evaluated metal concentrations in suspended particulates sources known to introduce large amounts of sediments to the study area, including the Knik, Susitna, Matanuska, and Copper Rivers in upper Cook Inlet and the Copper River at the northeastern edge of the study area (ADL 1999). This study also compiled historical information on Alaskan source rocks and continental crust data. Table 10 summarizes these results and highlights those potential sediment inputs to the study area that have metal concentrations that are higher than ERL or ERM. The three major rivers that discharge sediments to upper Cook Inlet, the Matanuska, Susitna, and Knik Rivers, have been combined in this table and report ranges within the three sources. These three rivers combined contribute over 115,000 kg of suspended sediment to upper Cook Inlet per day (USDOI 1995).

For each of the metals where a portion of the study area had concentrations above ERL, at least one source (and usually all three sources) shown in Table 13 are also above ERL for that same metal (see highlighted cells). For As, Cu, and Hg, the maximum concentration measured during the Southcentral Alaska EMAP was within the range reported for riverine sources. For Ni and Cr, however, each had a portion of the study area that was much higher than the ranges reported for the main sediment sources. This percent area corresponded to one site, AK02-0005, for both the high Cr and the high Ni values.

This site was located in a small bay on the south end of the Kenai Peninsula that was named Chrome Bay after the known chromite deposits that border the south side of the bay. During World War I, mining took place and over 2000 metric tons of chromite ore was shipped out of this bay from 1916-1918 (Gill 1922). There is a potential that either natural erosion of the source ore or tailings leftover in the nearshore environment have created these high levels of Cr and Ni. These values reported for AK02-0005 do not statistically characterize Chrome Bay, but nevertheless their significantly higher concentrations compared to all other sites indicate that this area should be sampled further to determine the extent and possible source for these metals. Chrome Bay and neighboring Port Chatham are popular subsistence species areas. In fact, a small interior portion of Chrome Bay is named Clam Cover after the abundant littleneck (Protothaca staminea) and Butter clams (Saxidomas gigantea) found there. Guay (2005, unpublished data) has collected stream and estuary samples of dissolved and colloidal metals in this watershed, as well as several other watersheds in Cook Inlet, and has found that samples from the watersheds on the southern Kenai Peninsula (Chrome Bay, Port Chatham, and Seldovia) contained very high concentrations of Cr and Ni relative to samples from the other watersheds.

Several heavy metals do not have ERL or ERM values associated with them, nor does Washington State have sediment quality guideline criteria identified for them. These include Antimony, Manganese, Selenium, and Tin. Aluminum and Iron are ubiquitous components of continental crust and fluvial sources, and their sediment concentrations are not associated with adverse effects on organisms. These metals can provide information on possible sources of sediments by comparing their relative ratios to other metals (see below).

Relative sediment metal concentrations for each site are shown geographically for Antimony (Figure 55), Arsenic (Figure 56), Cadmium (Figure 57), Chromium (Figure 58), Copper (Figure 59), Lead (Figure 60), Manganese (Figure 61), Mercury (Figure 62), Nickel (Figure 63), Silver (Figure 64), Tin (Figure 65), and Zinc (Figure 66). Again, each site is a replicate for the total population studied and does define a characterize its geographic location; that is, it represents a percentage of the total bays and estuaries in Southcentral Alaska. Individual values to not represent the individual bay or estuary location where it was sampled. The maps can, however, provide a general distribution across the entire geographic range to help identify potential areas needing further study or that can aid in interpreting potential backgrounds and sources of metals in and to the study area.

Sediment Metal Correlations

Correlations between and among metals and typical normalizing parameters, such as Al, Fe, %TOC, and % fines (silt + clay) over the entire Southcentral EMAP region are shown in Table 14. Only those correlations with $p < 0.05$ are listed in the table and those that also had $R > 0.7071$ (R2 > 0.5) are shown in red. No single significant correlation ($p < 0.05$ and $R > 0.7071$) were found between Al or Fe and any other metal (or with each other). These metals have been shown in other areas to correlate with other metals and are considered normalizing parameters to help determine concentrations above typical background sources. However, the West Coast National Status and Trends Program (WCNS&T) did not find strong correlations between Al or % TOC and other metals (Meador et. al. 1994) and contributed the difference between their program and the east coast program as due to high Al concentrations (> 4%). They did, however, find good correlation between Al and Fe in their Alaska data, as did another study (Robertson and Able 1990). Table 14 reflects a weaker correlation between these two metals (R=0.430, p< 0.001). There were no correlations between Mn, Hg, and Ag and any other metal or parameter.

Percent fines (silt + clay) correlated with Cr, Cu, Pb, N, Sn, and Zn. TOC only correlated with Cd and Se. Organic carbon can serve as a ligand for some elements and, thus, sediments with higher TOC often contain higher concentrations of certain elements. Meador et. al. (1994) reported highly variable TOC and % fine correlations in Alaska and considered their Alaska sites as outliers for their correlations for the rest of the west coast.

The WCNS&T program showed strong correlation between the non-pollutant associated metals Mn and Fe as did Robertson and Able (1990). Table 14 shows a weaker correlation, ($R=0.684$, $p = 0.000$). Significant correlations existed among the group Cr, Cu, Sn, and Zn. Ni also correlated with Cr. Each of these also correlated with % fines, which could indicate a source from the finer glacial sediments that are deposited throughout much of the study area. Cr and Ni also both occurred at the highest concentrations for both metals at one site, AK02-0005, which is an area known for producing ores high in both of these metals.

Generally, better correlations were found between metals/normalizing factors (Fe, Al, and % grain size) when looking at smaller sub-regions within the overall sampling region (data not shown). Areas of "down-gradient" sediment deposition showed good correlations with the trace metal signatures of the major freshwater river inputs into the sub-regional area. Within the areas identified as major upwelling zones, such as near Stevenson entrance, the sediment trace metals correlation more resembled sediments receiving trace metal depositional input from well mixed oceanic waters. These results tend to follow earlier findings of correlations between sediment trace metals and natural metals inputs observed in an earlier study of the Lower-Cook Inlet and Shelikof Strait region (Bohem, 2001). A factor analysis was performed using riverine end member data with the Southcentral Alaska EMAP metals data as follows.

Sediment Metal – Factor Analysis

In an attempt to evaluate the relative mixing of sediment source end-members within the study area, we conducted a factor analysis using known river source metals data and the sediment metals data.

Factor analysis is a statistical technique for extracting patterns of association from a large set of data. When analyzing chemical concentrations of marine sediments these factors should represent end-members such as sources of the material or chemical phases, for example, metal oxides or sulfides. The technique has been used to characterize suspended sediments in the New York Bight (Nelson, 1981), and to partition both suspended and surficial sediments near the East Pacific Rise into end-member sediment types (Heath and Dymond 1977, Leinen and Pisias 1984, and Feely et al 1996).

The program we used to analyze the sediment metals data was first introduced by Klovan and Imbrie (1971) and was modified by Clarke (1978) to give an oblique solution. This modification ensures that the loadings or relative importance of each factor can be interpreted as mixtures of the end-members.

The data that we used for this analysis were 14 of the elemental concentrations of the surficial sediments collected during the cruise and 8 suspended sediment samples collected by Arthur D. Little (ADL 2001) in 1997 and 1998 from the major rivers in the study area including the Matanuska, Susitna, Knik, and Copper Rivers. Figure 67 shows histograms of the factor scores of the three main factors that were identified. Factor 1 is composed of Cr, Ni, and Cu. This factor predominates in the suspended sediment input from the Copper River, but it is present in the rivers that discharge into upper Cook Inlet as well. The factor is distributed through out the study region especially eastern Prince William Sound and the western side of Cook Inlet. It is of lowest importance near Kodiak Island. Factor 2 is an Al, Fe, Mn grouping that is a ubiquitous aluminosilicate particle coated with iron and manganese oxides. It is found throughout the entire region. Factor 3 is composed of Ag, As, Sb, and Pb and is most important in the rivers in upper Cook Inlet. This factor is at a minimum at the stations where upwelling is known to occur at the southern end of Cook Inlet. Factors 1 and 3 are strongly associated with the suspended sediment samples from the rivers. Once the end-member assemblages are identified, each sediment sample can be viewed as a mixture of these three factors. One way to represent the results is on a ternary plot (Figure 68) where each of the three axes represents one of the three factors.

The plot shows that for the sediments over the entire study area, the relative importance of the three factors is nearly constant. The individual stations are all plotted together with roughly 40% of factor 1, 25 % of factor 2 and 35 % of factor three. These percentages are nearly identical to those found in the suspended sediments supplied by the major river systems. The sediments in this entire region appear to be derived almost entirely of river-borne sediments.

Table 10. Sediment Quality Guideline values used to evaluate sediment parameter concentrations. ERL is Effects Range Low and ERM is Effects Range Medium as defined by Long et. al. (1995).

CHEMICAL PARAMETERS	ERL Guidance Values	ERM Guidance Values	Washington State Sediment Quality Standards WAC 173-204-320
Metals	**(µ g/g), dry weight**	**(µ g/g) dry weight**	**(µ g/g), dry weight**
Arsenic	8.2	70	57
Cadmium	1.2	9.6	5.1
Chromium	81	370	260
Copper	34	270	390
Lead	46.7	218	450
Mercury	0.15	0.71	0.41
Nickel	20.9	51.6	---
Silver	1	3.7	6.1
Zinc	150	410	410
Organics			
Total PAH	4020	44800	
Low Molecular Weight PAH	552	3160	370
High Molecular Weight PAH	1700	9600	960
Acenapthene	16	500	16
Acenaphthylene	44	640	66
Anthracene	85.3	110	220
Benzo(a)anthracene	261	1600	110
Benzo(a)pyrene	430	1600	99
Chrysene	384	2800	110
Dibenzo (a,h) anthracene	60	260	12
Fluorathene	600	5100	160
Florene	19	540	23
2-Methylnaphthalene	70	670	38
napthalene	240	1500	100
Phenanthrene	240	1500	100
Pyrene	665	2600	1000
Indeno (1,2,3,-c,d) pyrene	---	---	34
DDT	1	7	---
DDD	2	20	---
DDE	2	27	---
Total DDT	1.6	46.1	---
Total PCBs	23	180	12
Chlordane	0.5	6	---
Dieldrin	0.02	8	---
Endrin	0.02	45	---

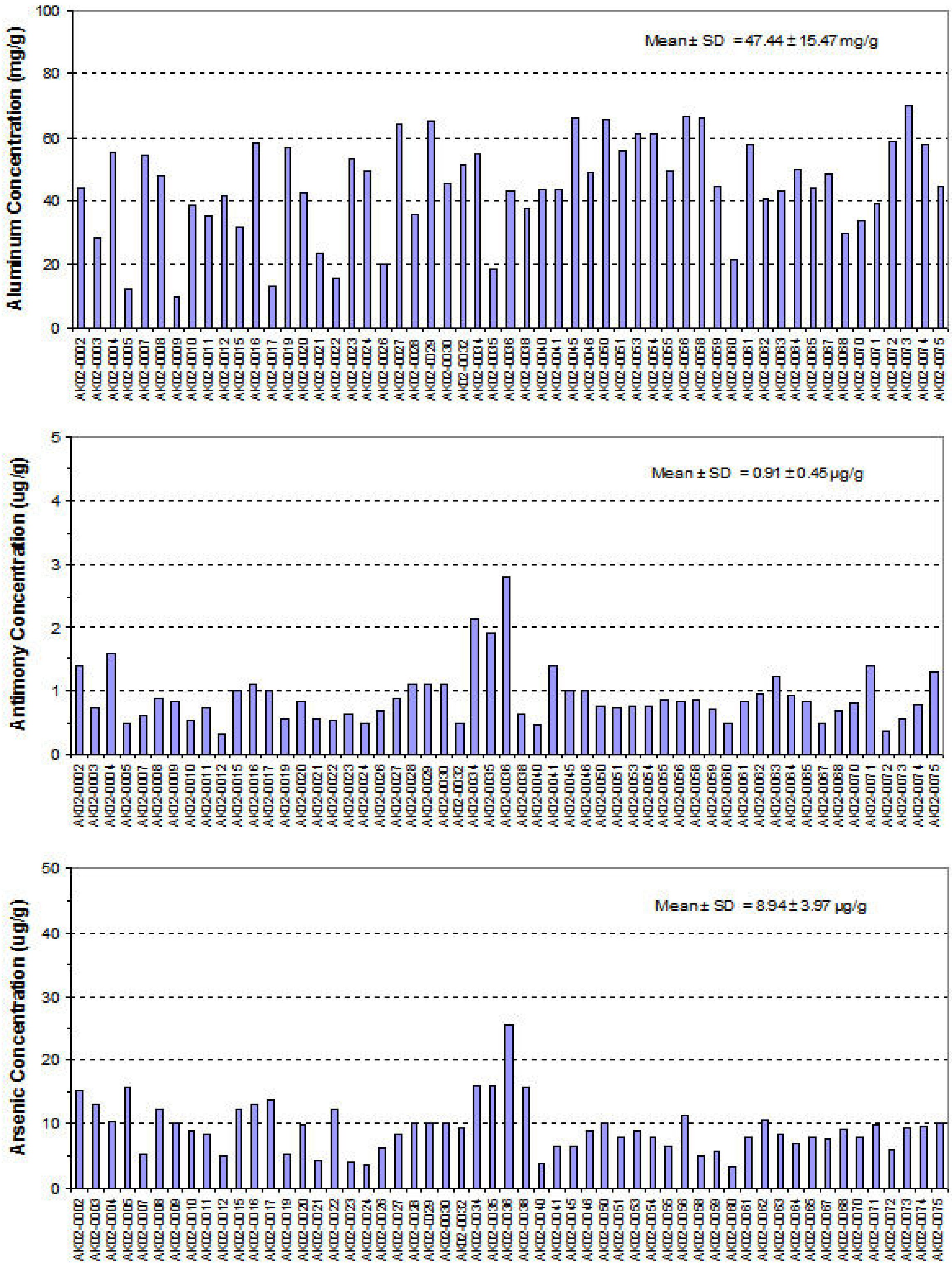


Figure 46. Histogram of individual station sediment metal concentrations for Aluminum (mg/g), Antimony (µ g/g), and Arsenic (µ g/g). Bar on the far right shows overall station mean and one standard deviation for the corresponding histograms to the left.

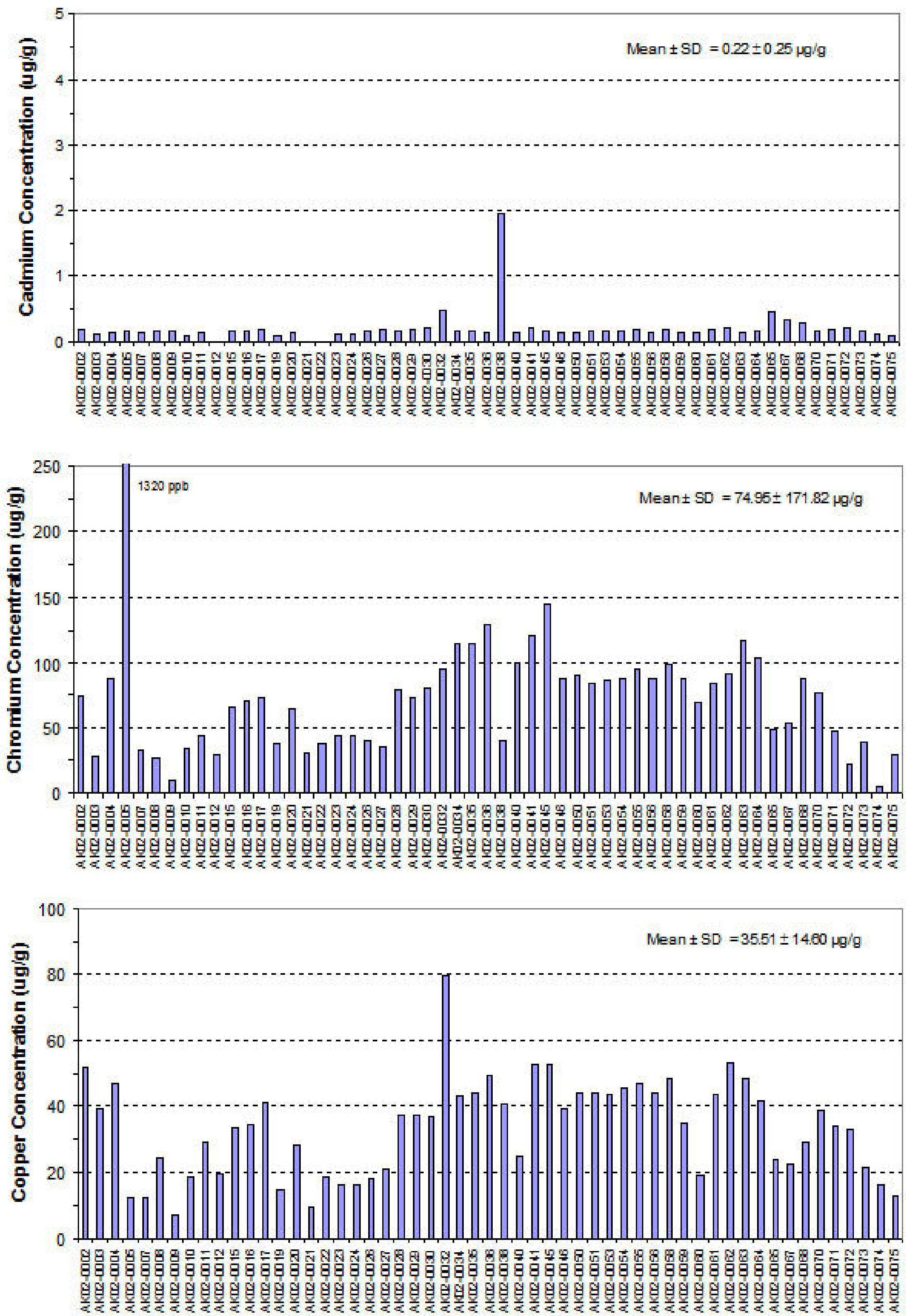


Figure 47. Histogram of individual station sediment metal concentrations for Cadmium (µg/g), Chromium (µg/g), and Copper (µg/g). Bar on the far right shows overall station mean and one standand deviation for the corresponding histograms to the left.

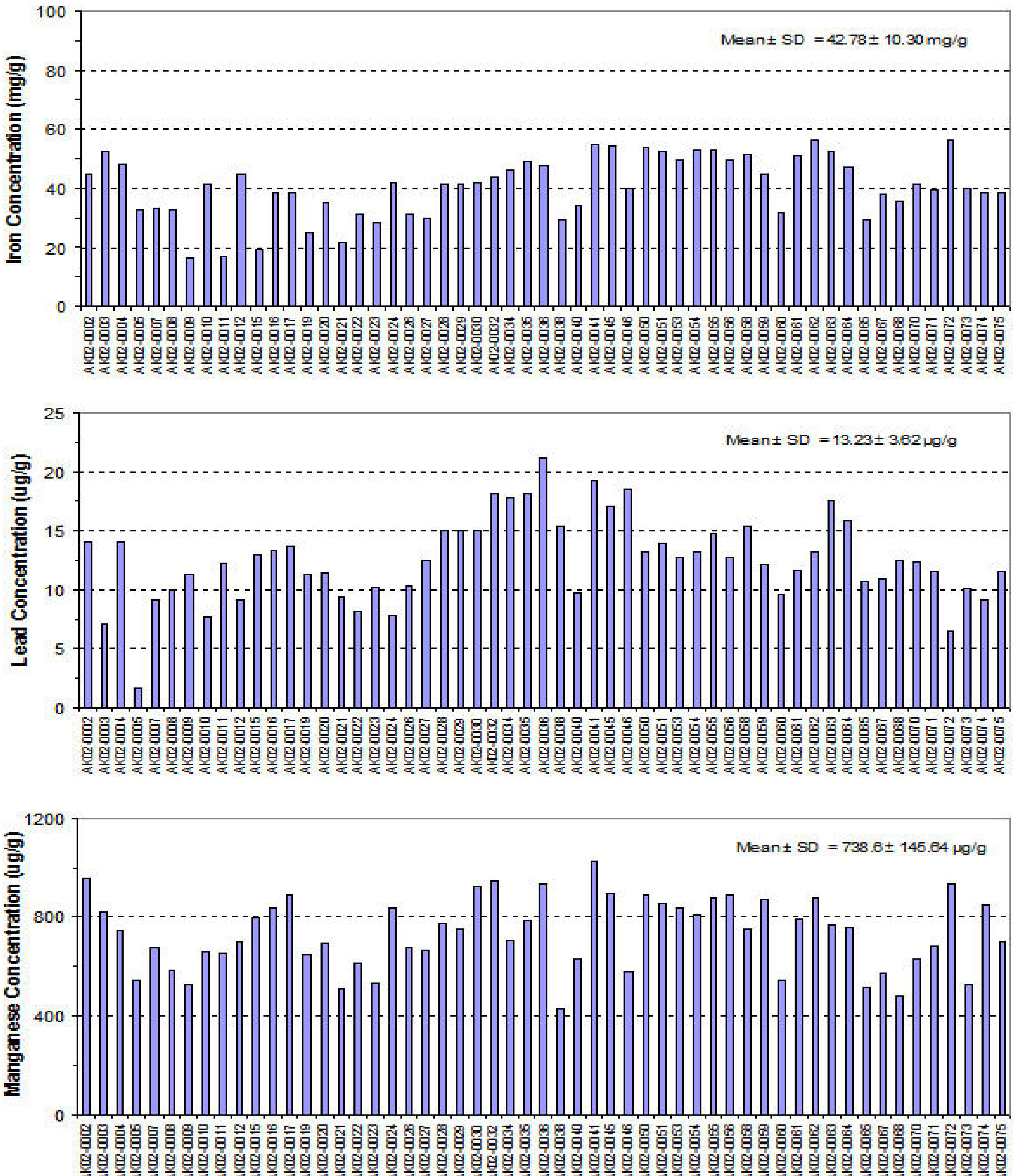


Figure 48. Histogram of individual station sediment metal concentrations for Iron (mg/g), Lead (μ g/g), and Manganese (μ g/g). Bar on the far right shows overall station mean and one standard deviation for the corresponding histograms to the left.

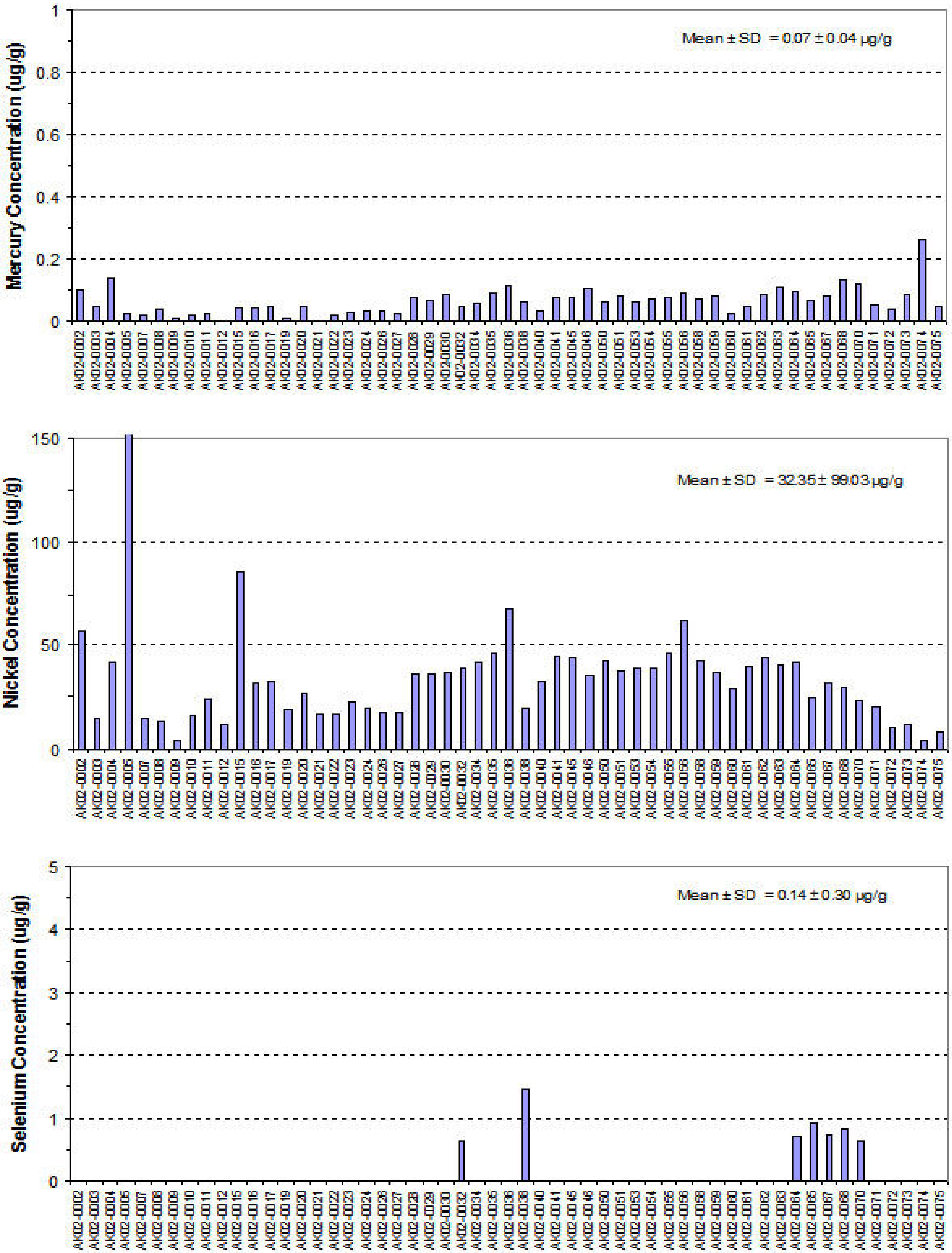


Figure 49. Histogram of individual station sediment metal concentrations for Mercury (µ g/g), Nickel (µ g/g), and Selenium (µ g/g). Bar on the far right shows overall station mean and one standard deviation for the corresponding histograms to the left.

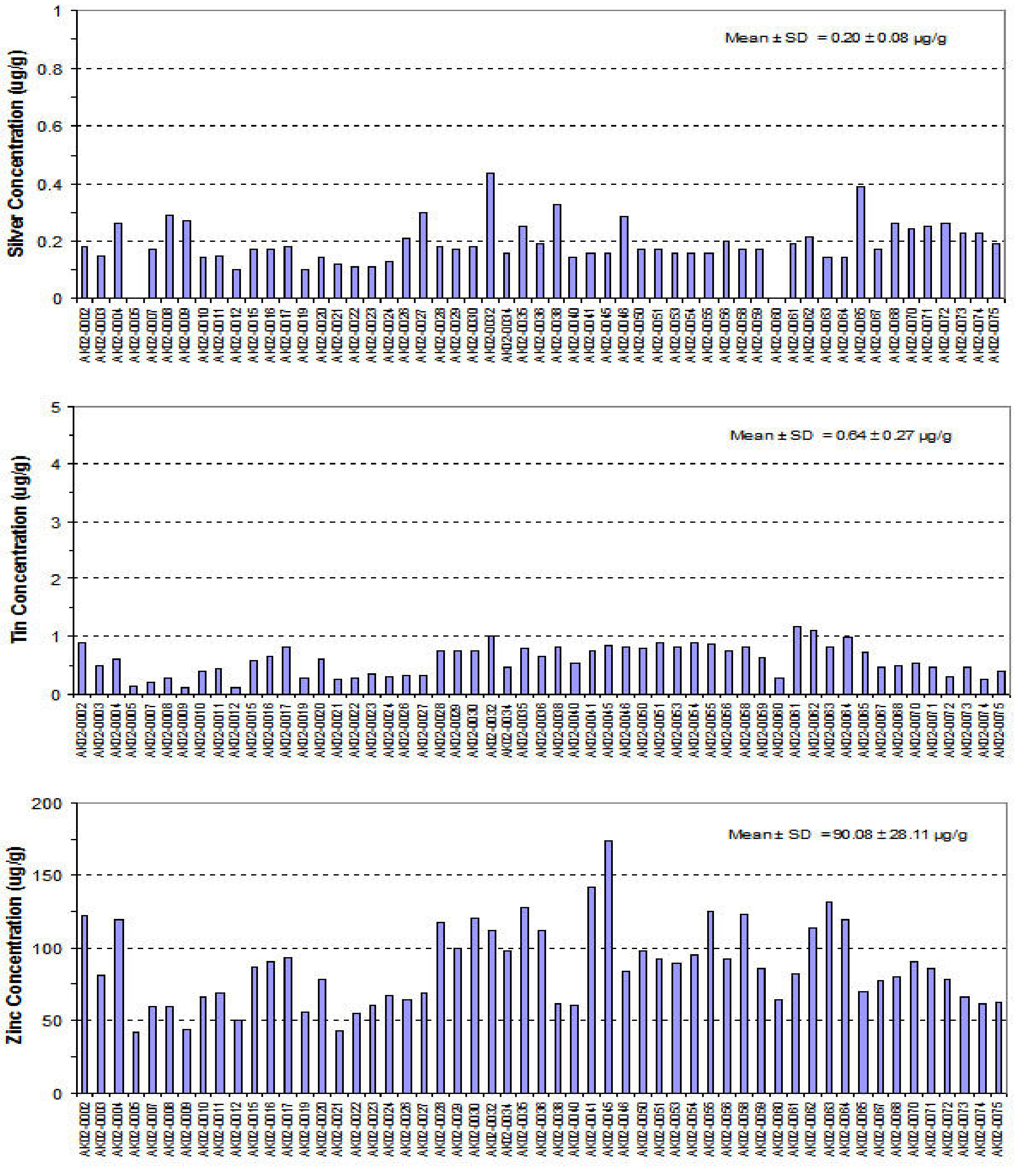


Figure 50. Histogram of individual station sediment metal concentrations for Silver (µ g/g), Tin (µ g/g), and Zinc (µ g/g). Bar on the far right shows overall station mean and one standard deviation for the corresponding histograms to the left.

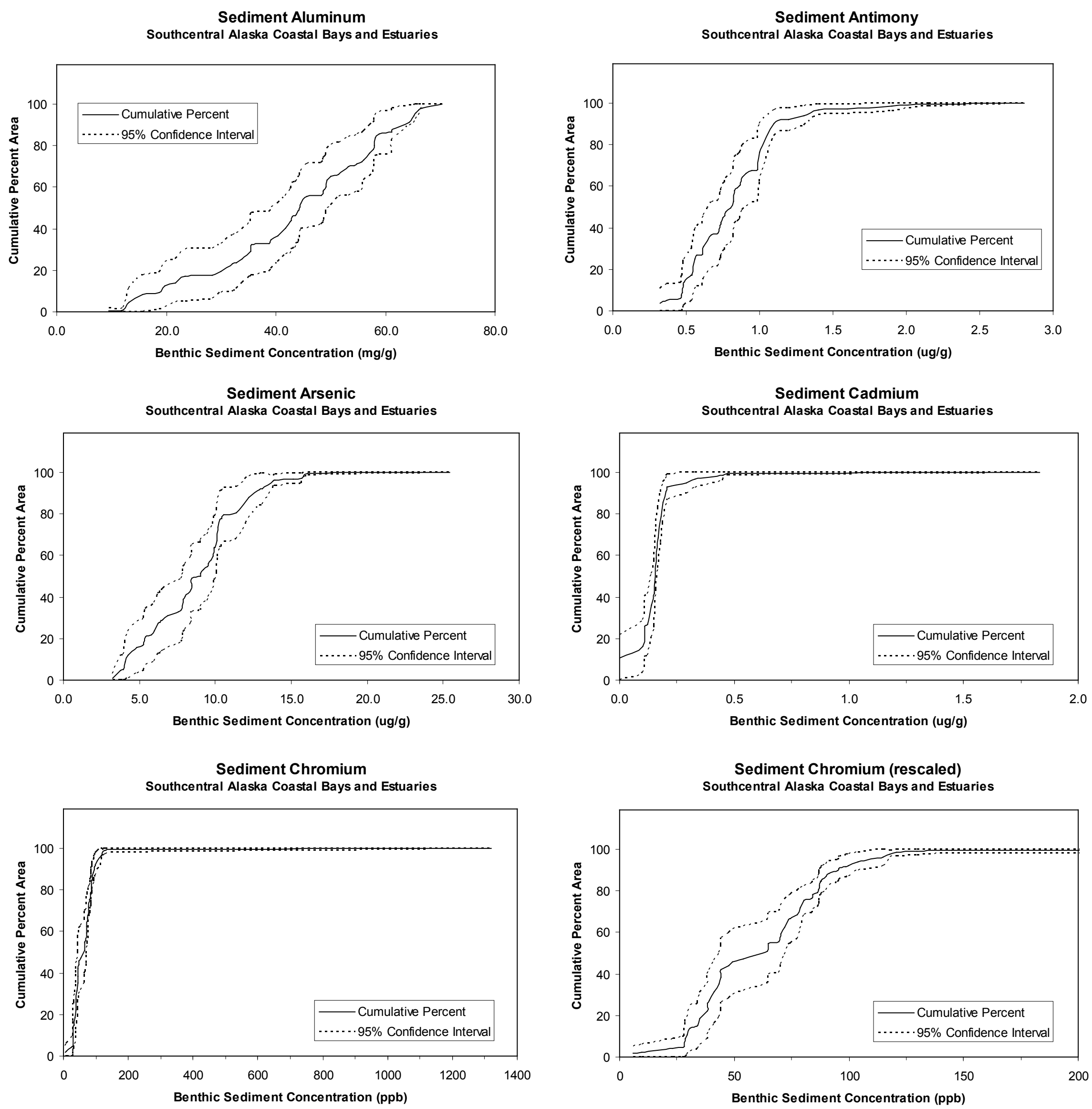


Figure 51. Cumulative Distribution functions of sediment metal concentrations (Aluminum, Antimony, Arsenic, Cadmium, and Chromium) as a percent of area in the southcentral Alaska EMAP study area. Dashed lines are the 95% confidence intervals. Note that Chromium is presented twice with the lower right CDF rescaling the axis from the lower left graph to expand the curve in the mid-value range.

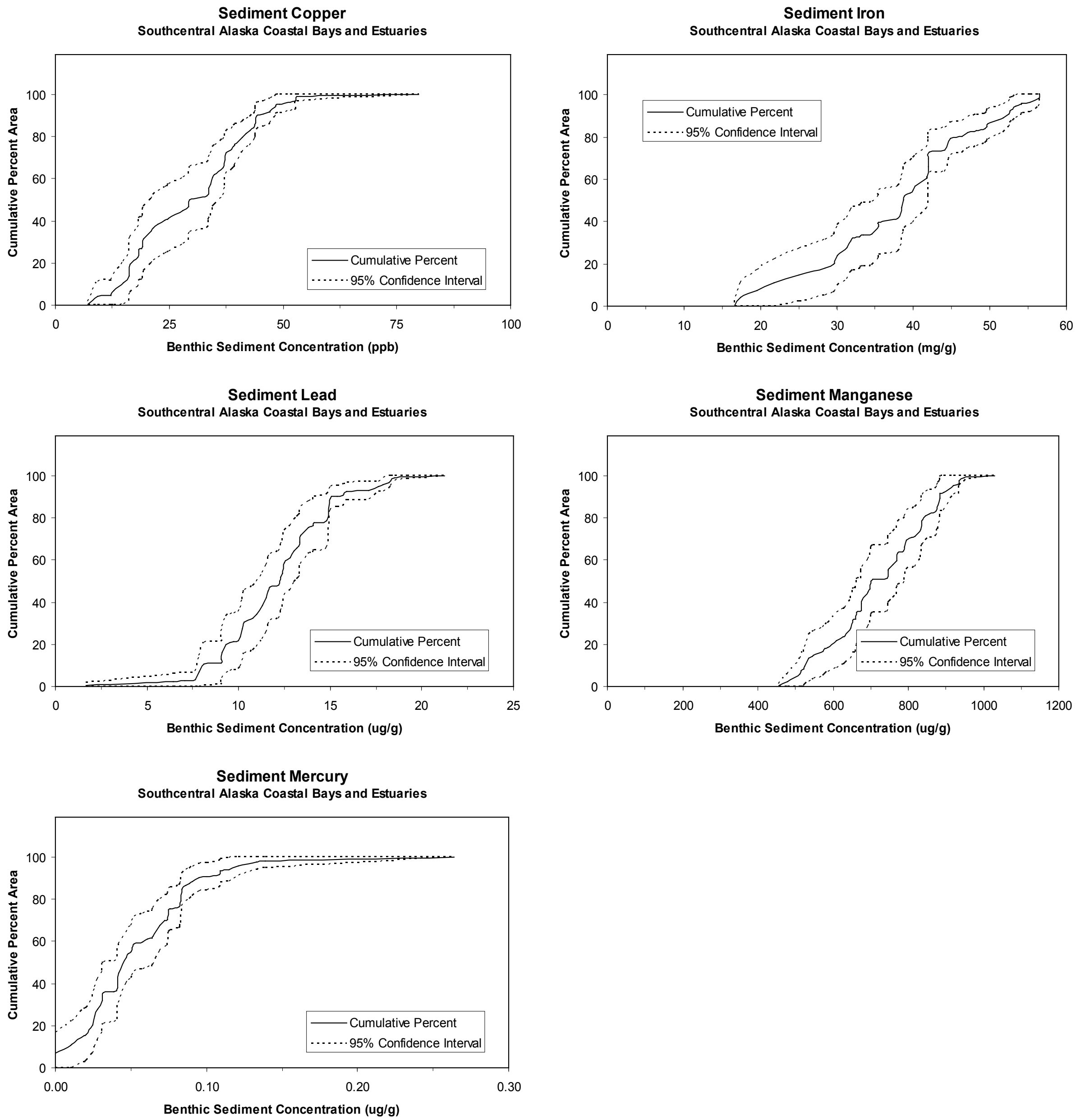


Figure 52. Cumulative Distribution functions of sediment metal concentrations (Copper, Iron, Lead, Manganese, and Mercury) as a percent of area in the southcentral Alaska EMAP study area. Dashed lines are the 95% confidence intervals.

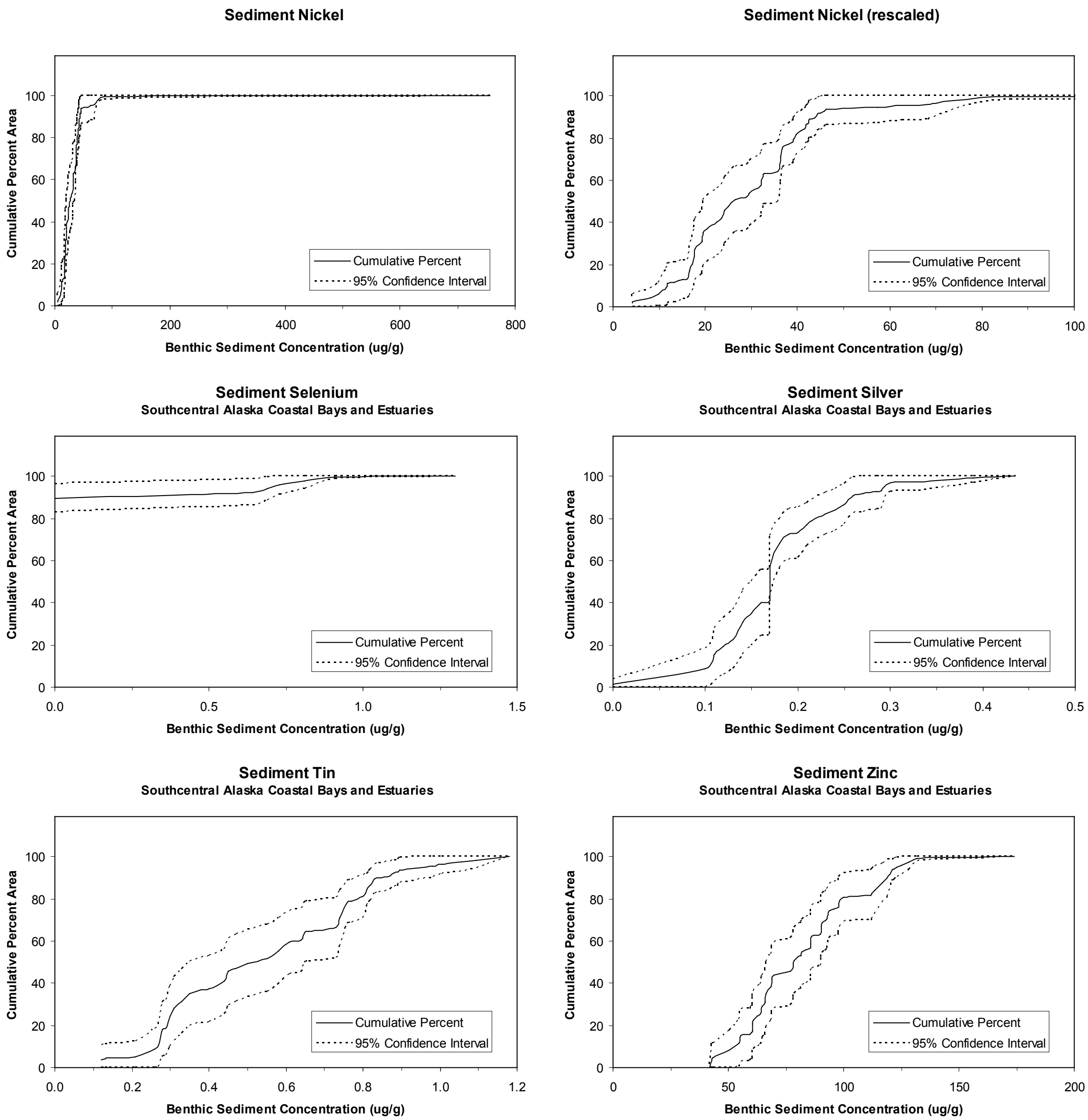


Figure 53. Cumulative Distribution functions of sediment metal concentrations (Nickel, Selenium, Silver, Tin, and Zinc) as a percent of area in the southcentral Alaska EMAP study area. Dashed lines are the 95% confidence intervals. Note that Nickel is presented twice with the upper right CDF rescaling the axis from the Upper left graph to expand the curve in the mid-value range.

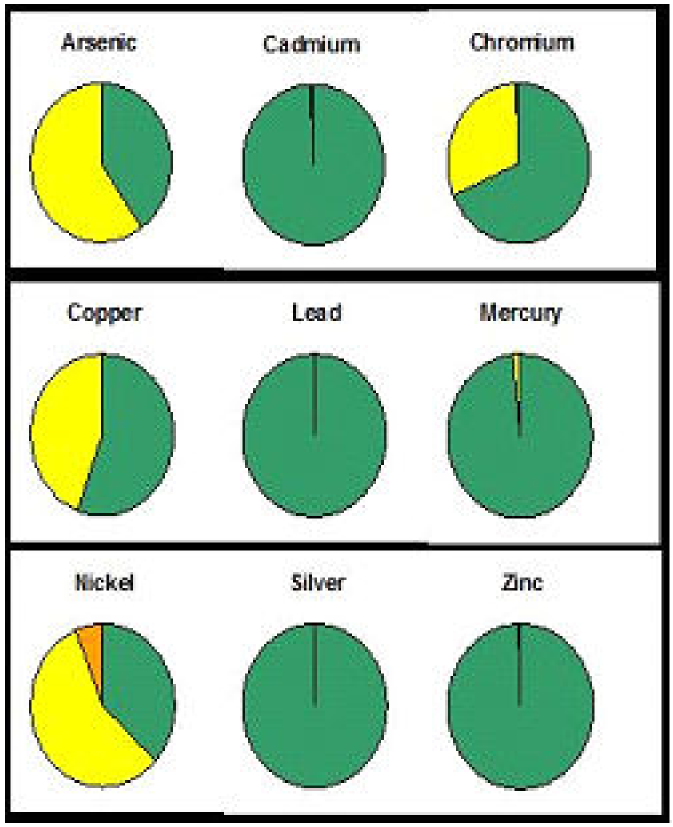


Figure 54. Percent of the study area with concentrations less than NOAA's sediment quality guidelines for Effects Range Low (green), less than Effects Range Median (yellow), and above Effects Range Median (orange).

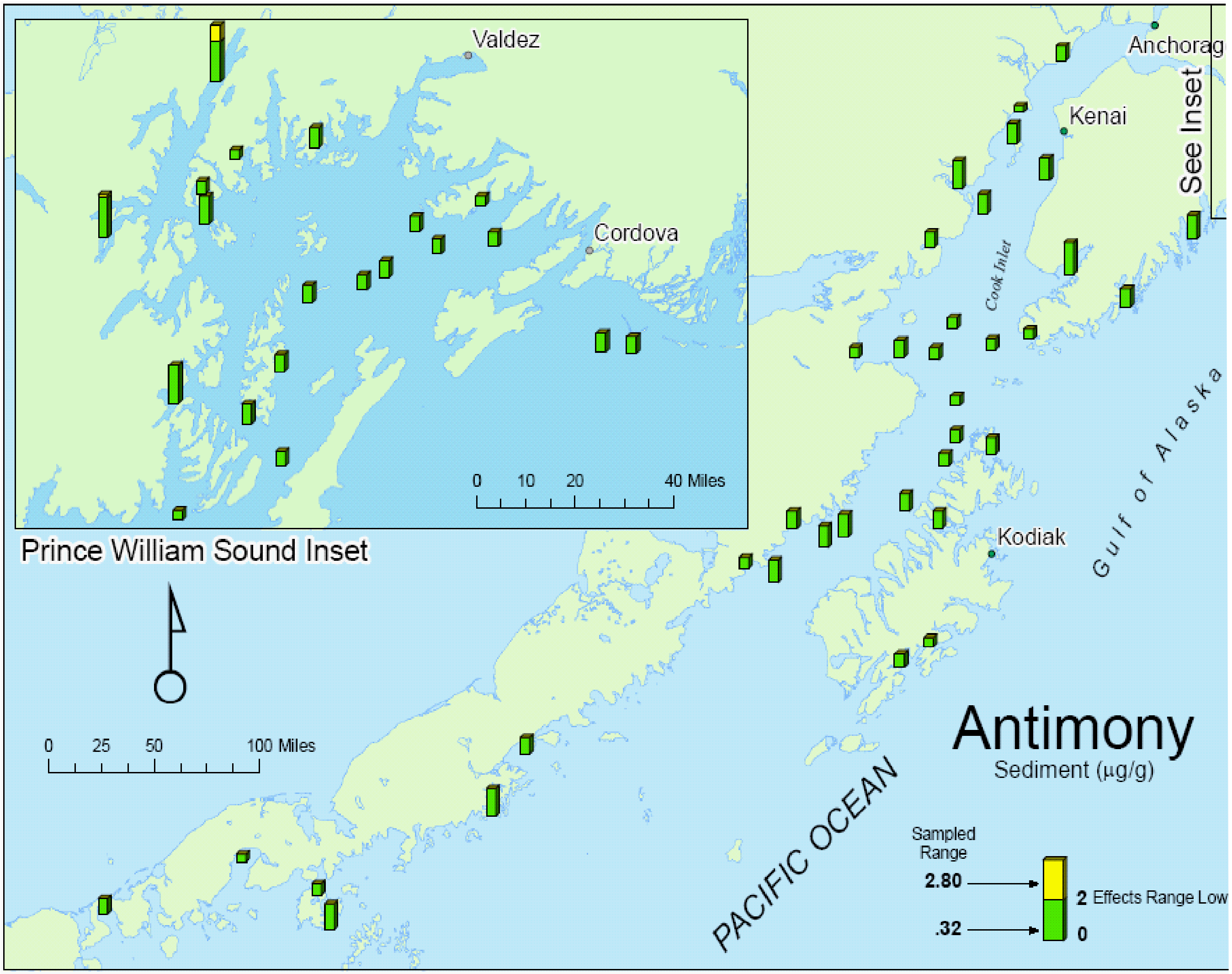


Figure 55. Sediment antimony concentrations (µ g/g) at sampled stations across the study area's geographic range. Note that Prince William Sound is an inset on the left instead of at its normal geographical position at the eastern edge of the study area. Legend shows range of concentrations measured for all sites relative to concentrations above (yellow) and below (green) Effects Range Low.

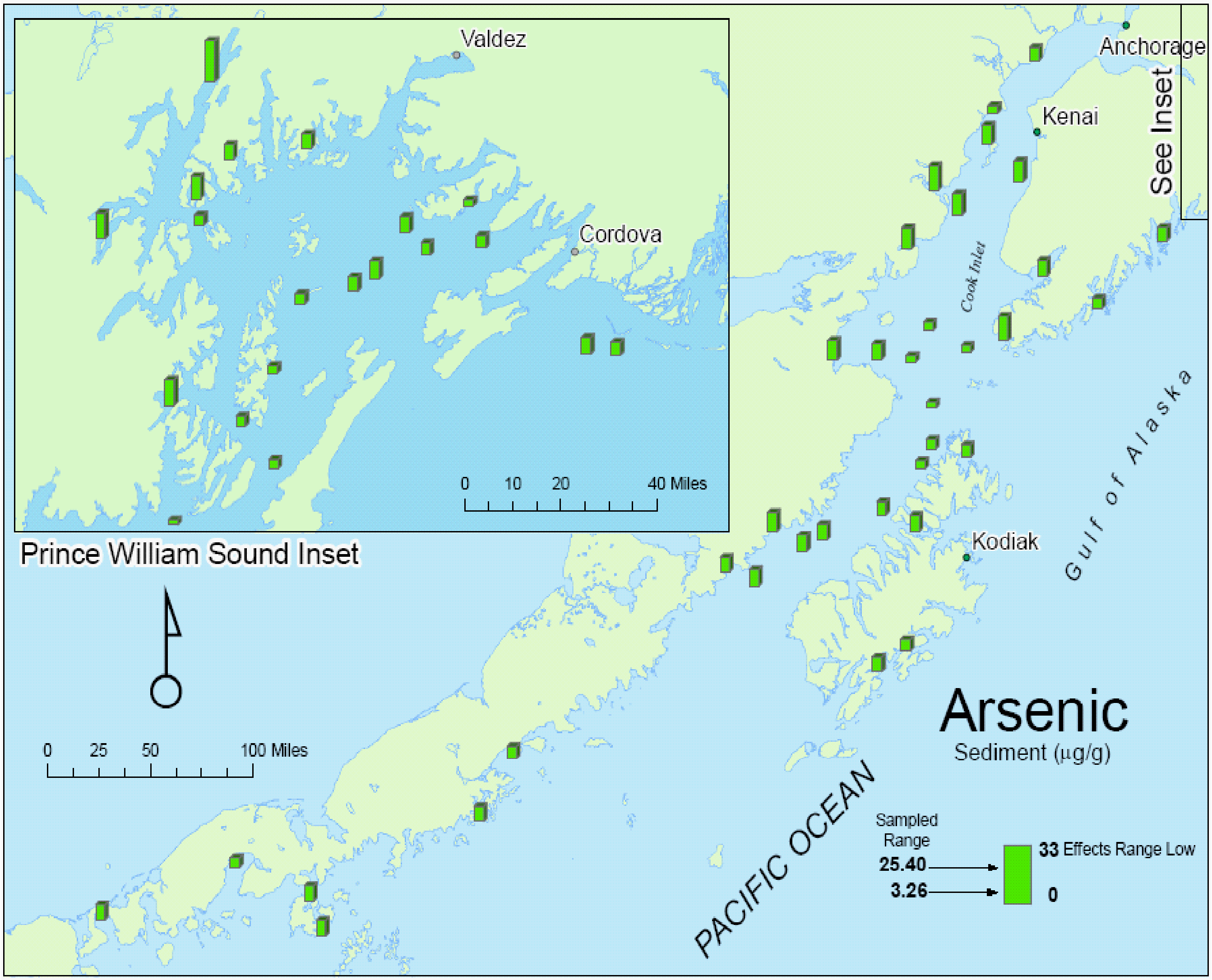


Figure 56. Sediment arsenic concentrations (µ g/g) at sampled stations across the study area's geographic range. Note that Prince William Sound is an inset on the left instead of at its normal geographical position at the eastern edge of the study area. Legend shows range of concentrations measured for all sites relative to Effects Range Low concentration.

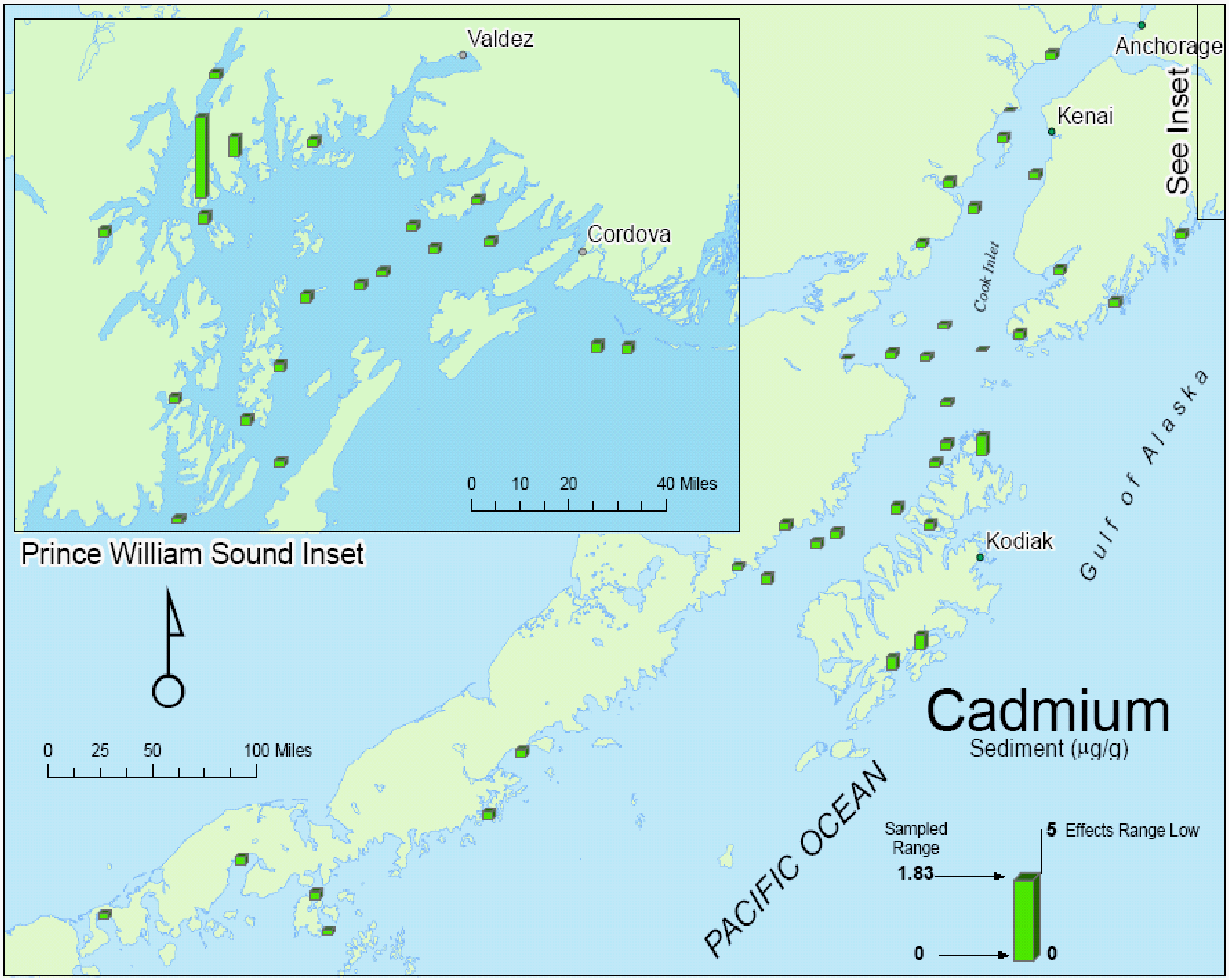


Figure 57. Sediment cadmium concentrations (µ g/g) at sampled stations across the study area's geographic range. Note that Prince William Sound is an inset on the left instead of at its normal geographical position at the eastern edge of the study area. Legend shows range of concentrations measured for all sites relative to Effects Range Low concentration.

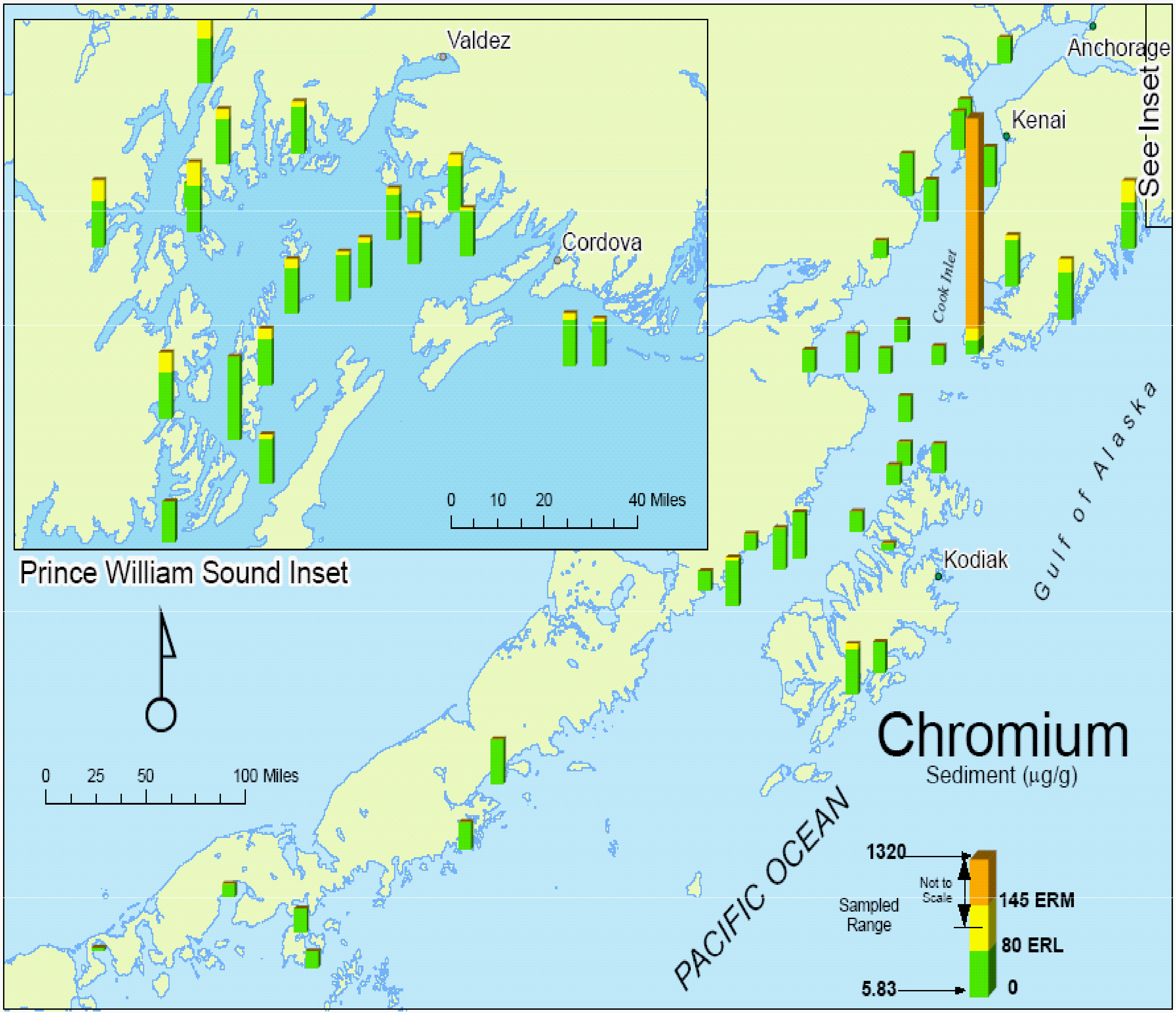


Figure 58. Sediment chromium concentrations (μ g/g) at sampled stations across the study area's geographic range. Note that Prince William Sound is an inset on the left instead of at its normal geographical position at the eastern edge of the study area. Legend shows range of concentrations measured for all sites relative to Effects Range Low (ERL) and Effects Range Median (ERM) concentrations.

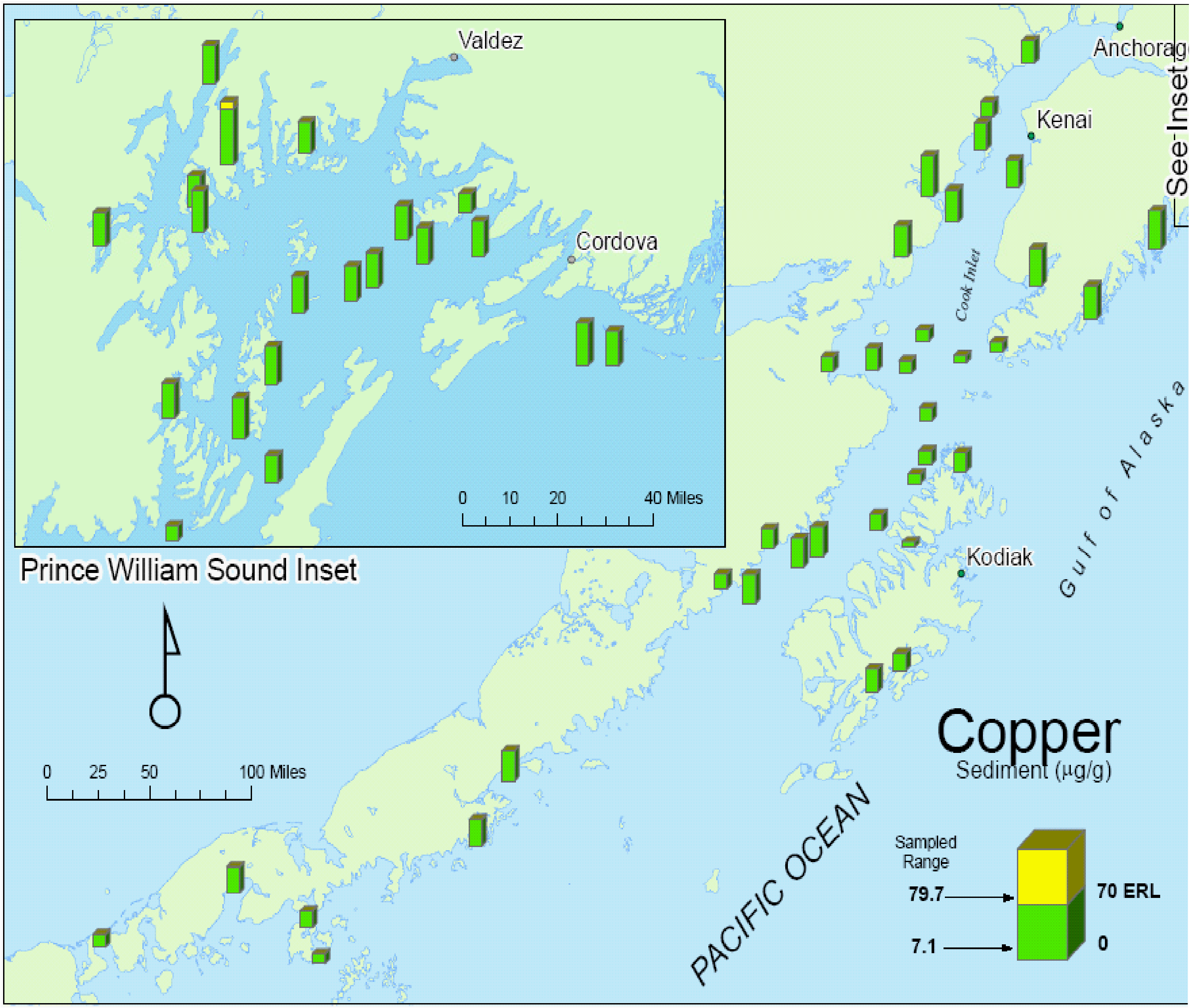


Figure 59. Sediment copper concentrations (µ g/g) at sampled stations across the study area's geographic range. Note that Prince William Sound is an inset on the left instead of at its normal geographical position at the eastern edge of the study area. Legend shows range of concentrations measured for all sites relative to concentrations above (yellow) and below (green) Effects Range Low (ERL).

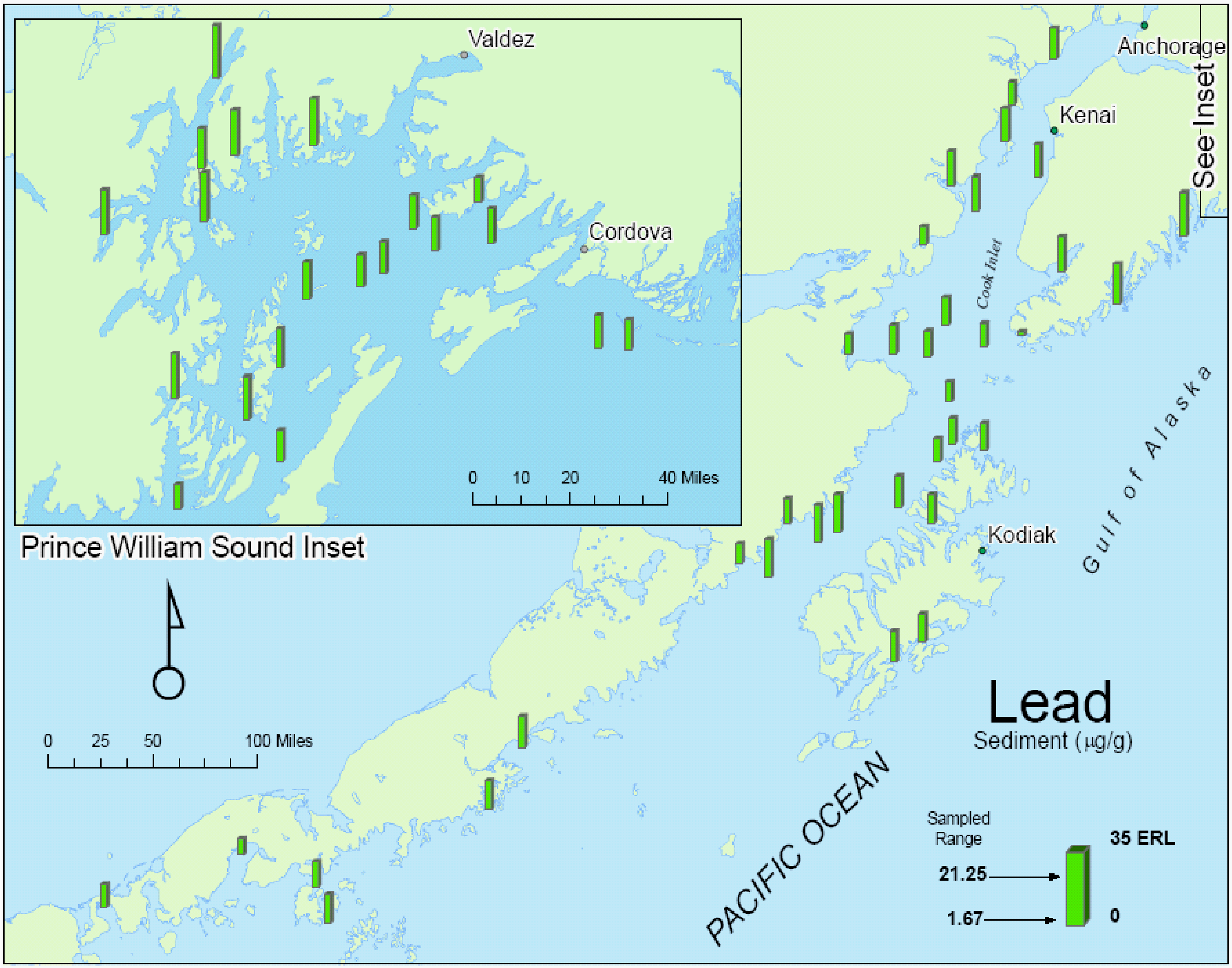


Figure 60. Sediment lead concentrations (µg/g) at sampled stations across the study area's geographic range. Note that Prince William Sound is an inset on the left instead of at its normal geographical position at the eastern edge of the study area. Legend shows range of concentrations measured for all sites relative to Effects Range Low (ERL) concentration.

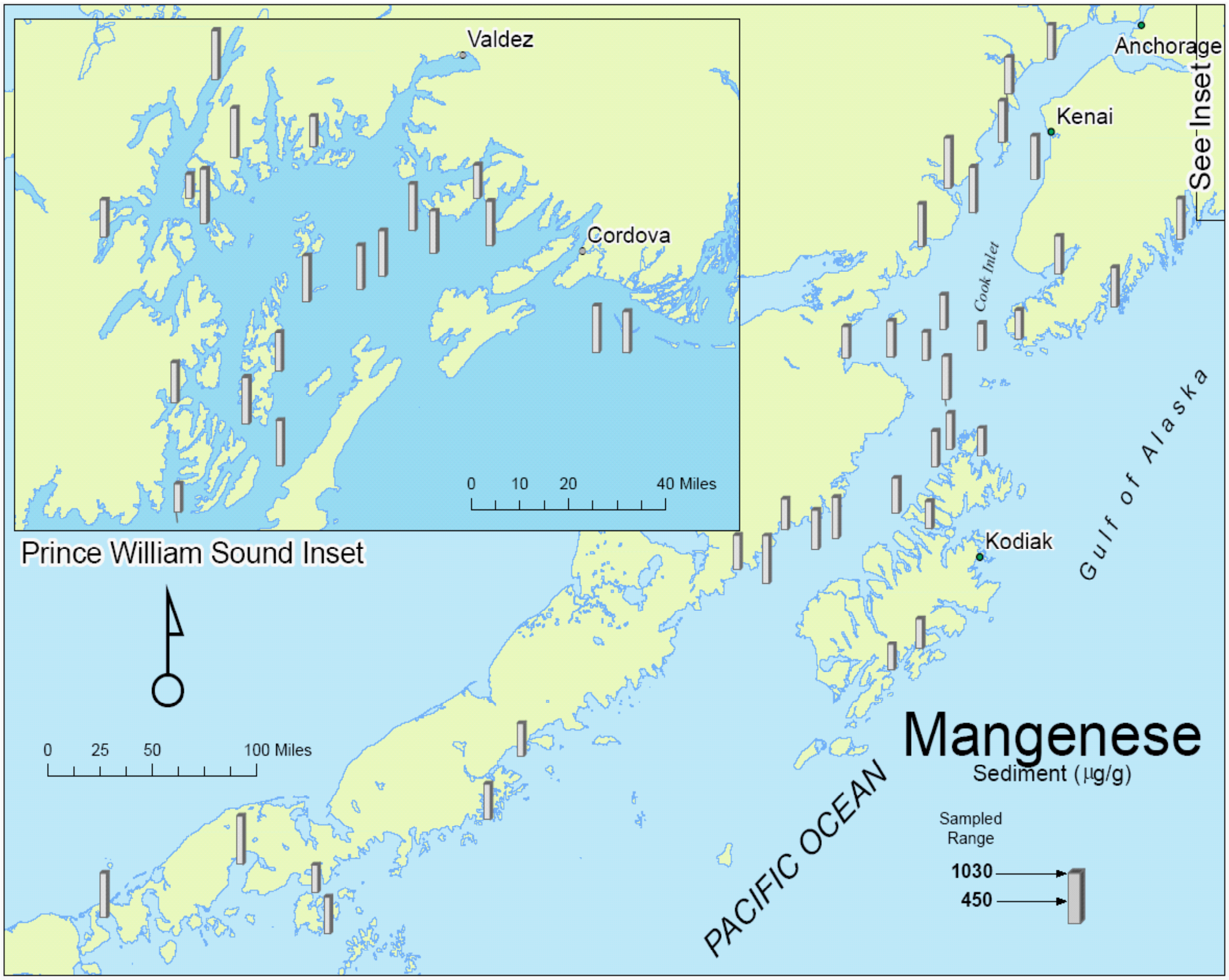


Figure 61. Sediment manganese concentrations (µ g/g) at sampled stations across the study area's geographic range. Note that Prince William Sound is an inset on the left instead of at its normal geographical position at the eastern edge of the study area.

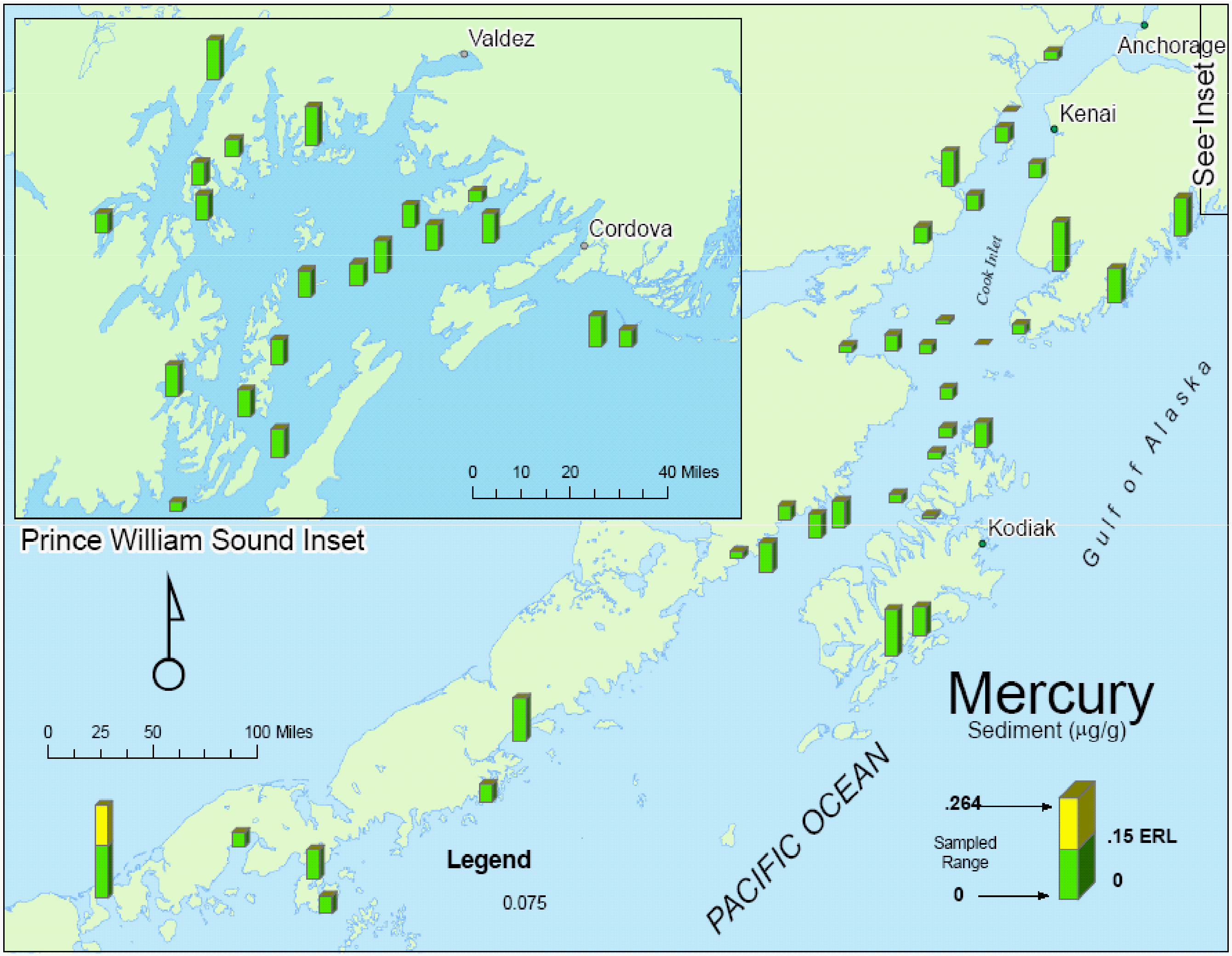


Figure 62. Sediment mercury concentrations (µ g/g) at sampled stations across the study area's geographic range. Note that Prince William Sound is an inset on the left instead of at its normal geographical position at the eastern edge of the study area. Legend shows range of concentrations measured for all sites relative to concentrations above (yellow) and below (green) Effects Range Low (ERL).

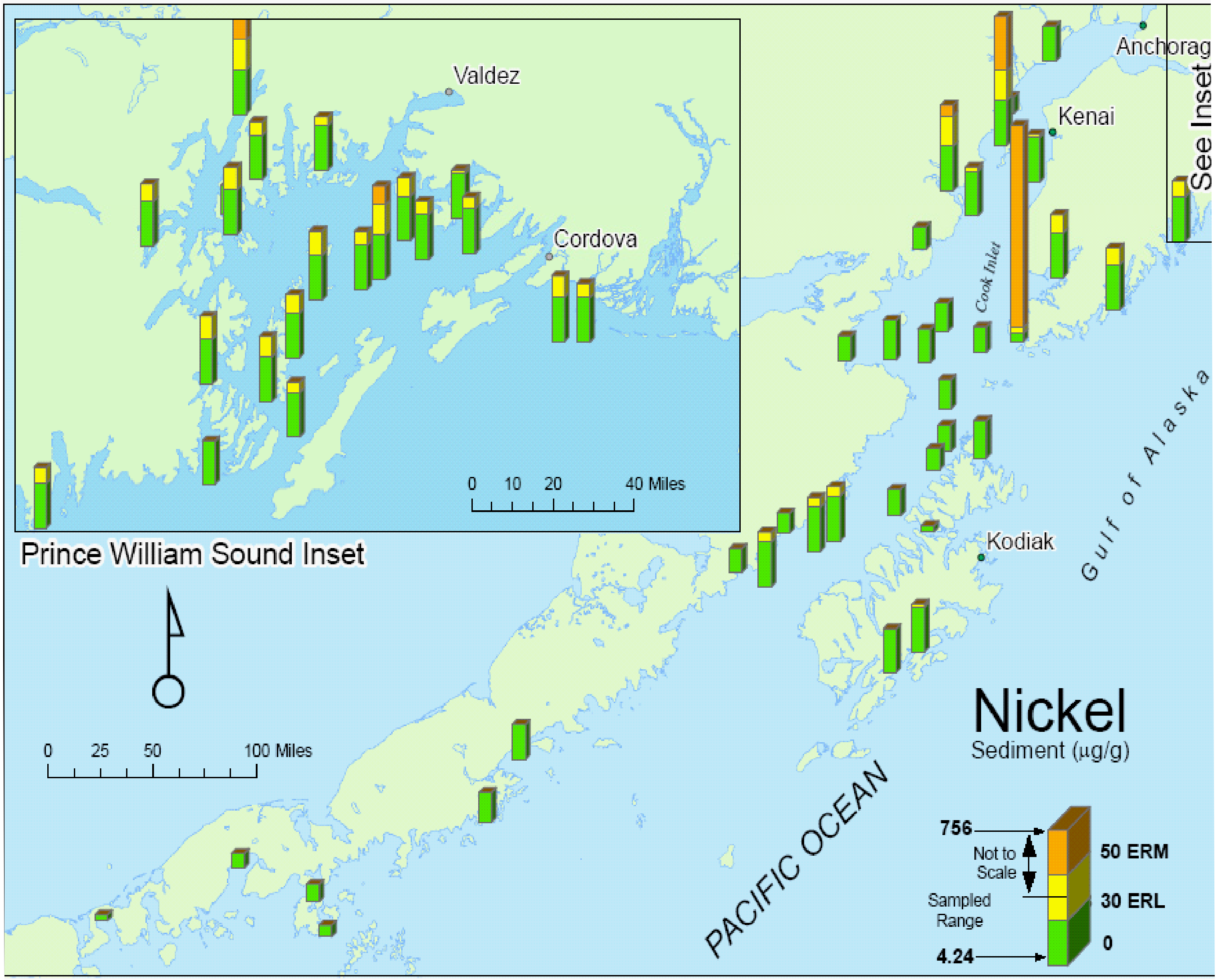


Figure 63. Sediment Nickel concentrations (µ g/g) at sampled stations across the study area's geographic range. Note that Prince William Sound is an inset on the left instead of at its normal geographical position at the eastern edge of the study area. Legend shows range of concentrations measured for all sites relative to Effects Range Low (ERL) and Effects Range Median (ERM) concentrations.

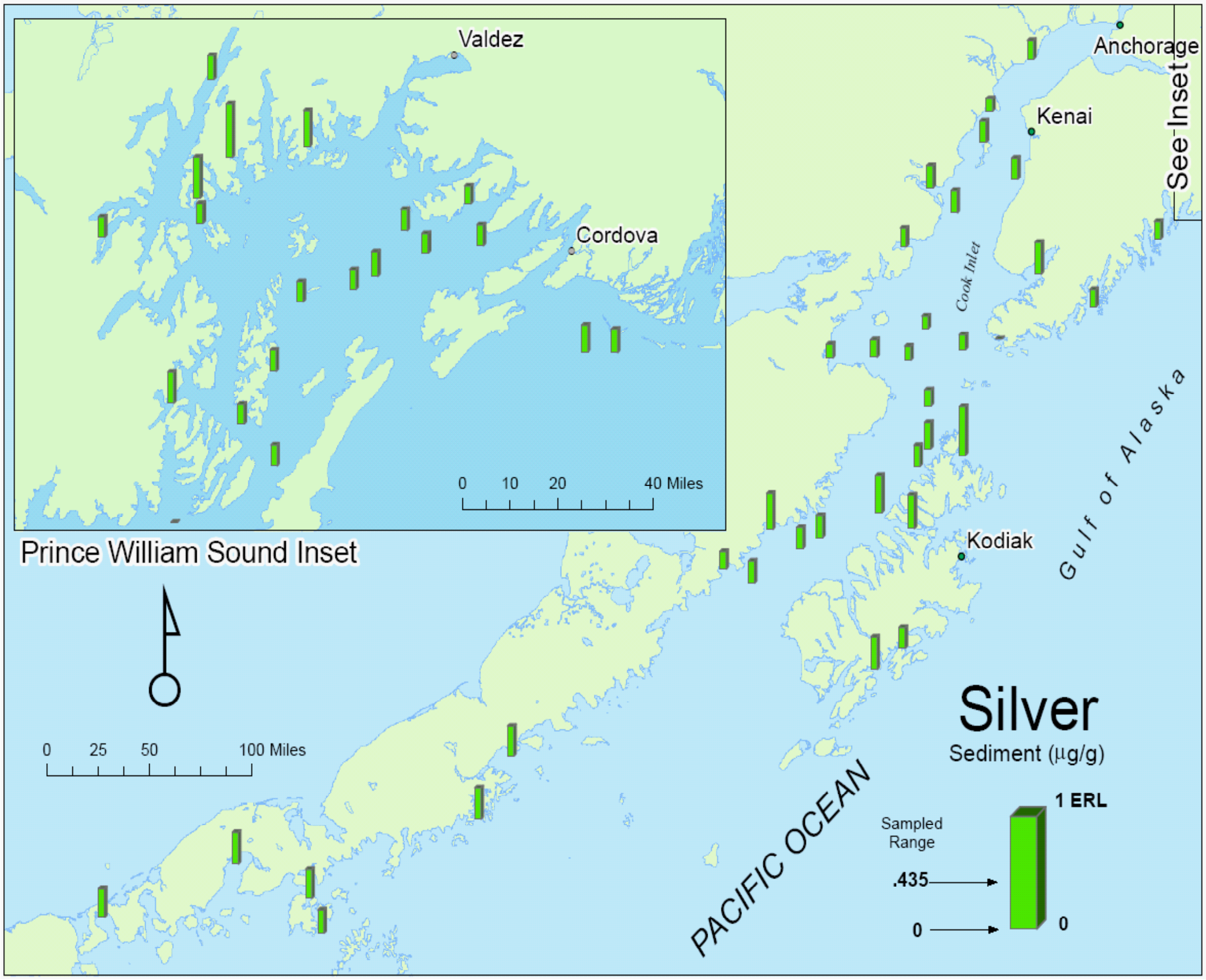


Figure 64. Sediment Silver concentrations (µ g/g) at sampled stations across the study area's geographic range. Note that Prince William Sound is an inset on the left instead of at its normal geographical position at the eastern edge of the study area. Legend shows range of concentrations measured for all sites relative to Effects Range Low (ERL) concentration.

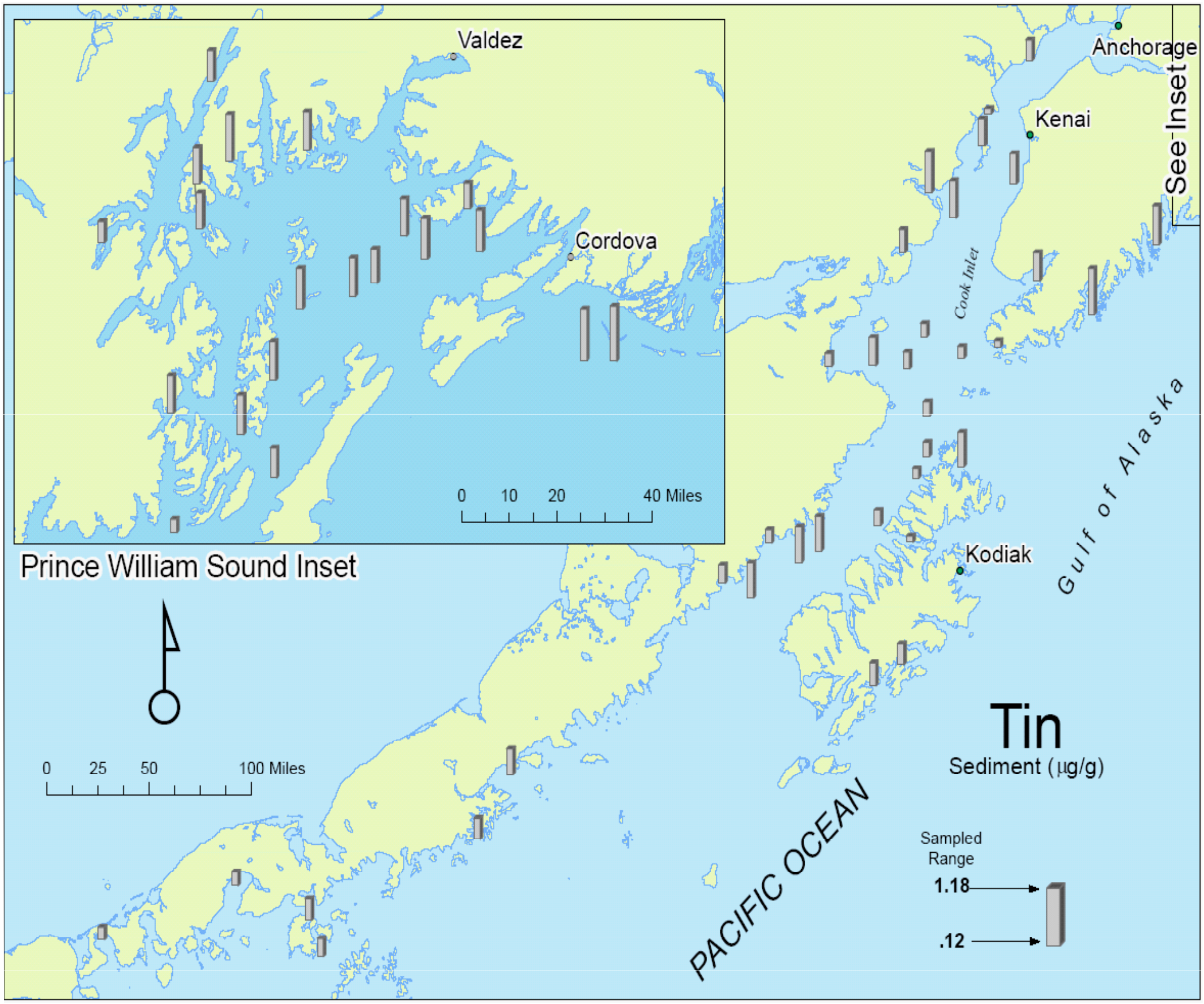


Figure 65. Sediment Tin concentrations (µ g/g) at sampled stations across the study area's geographic range. Note that Prince William Sound is an inset on the left instead of at its normal geographical position at the eastern edge of the study area.

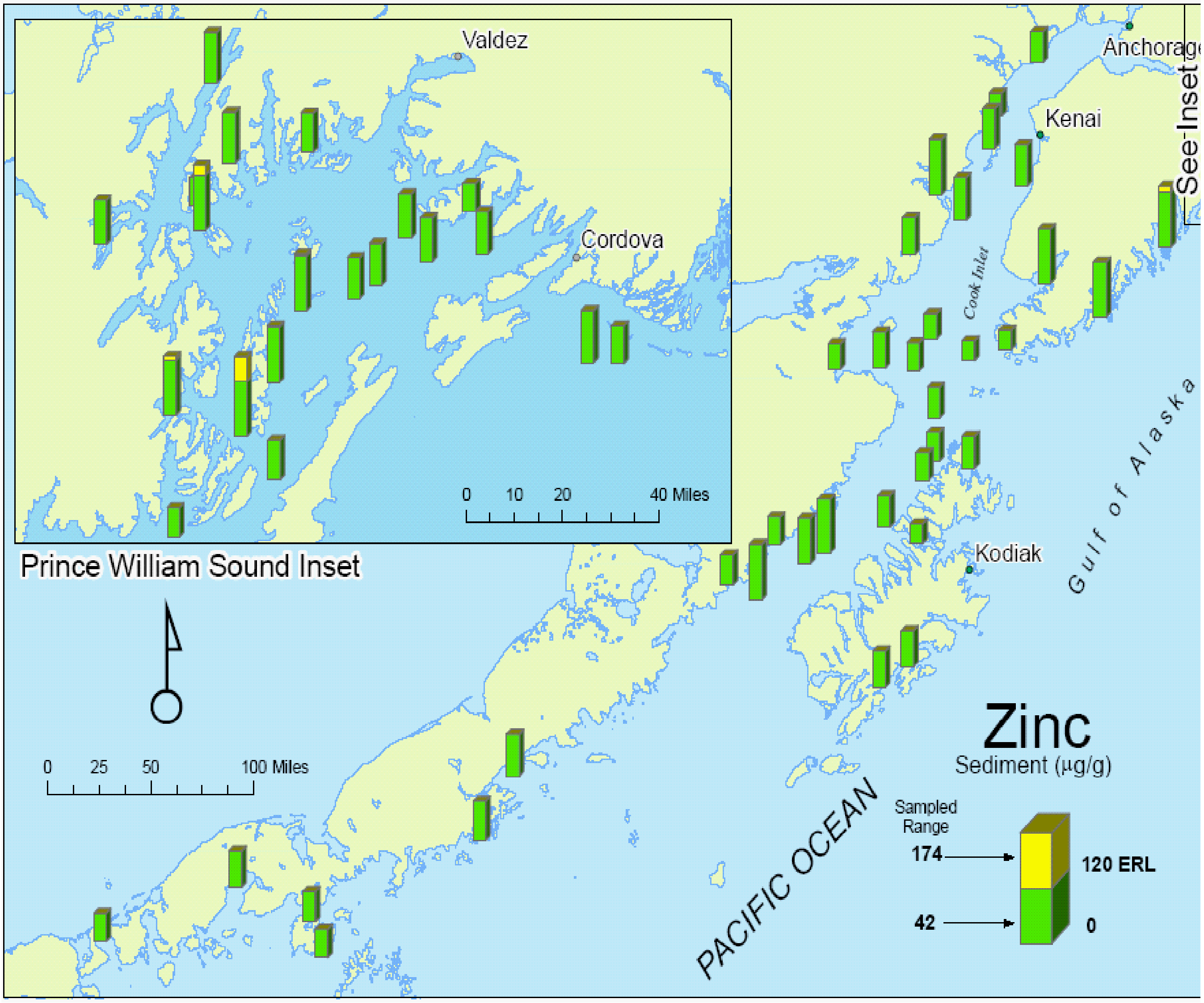


Figure 66. Sediment Zinc concentrations (µ g/g) at sampled stations across the study area's geographic range. Note that Prince William Sound is an inset on the left instead of at its normal geographical position at the eastern edge of the study area. Legend shows range of concentrations measured for all sites relative to concentrations above (yellow) and below (green) Effects Range Low (ERL).

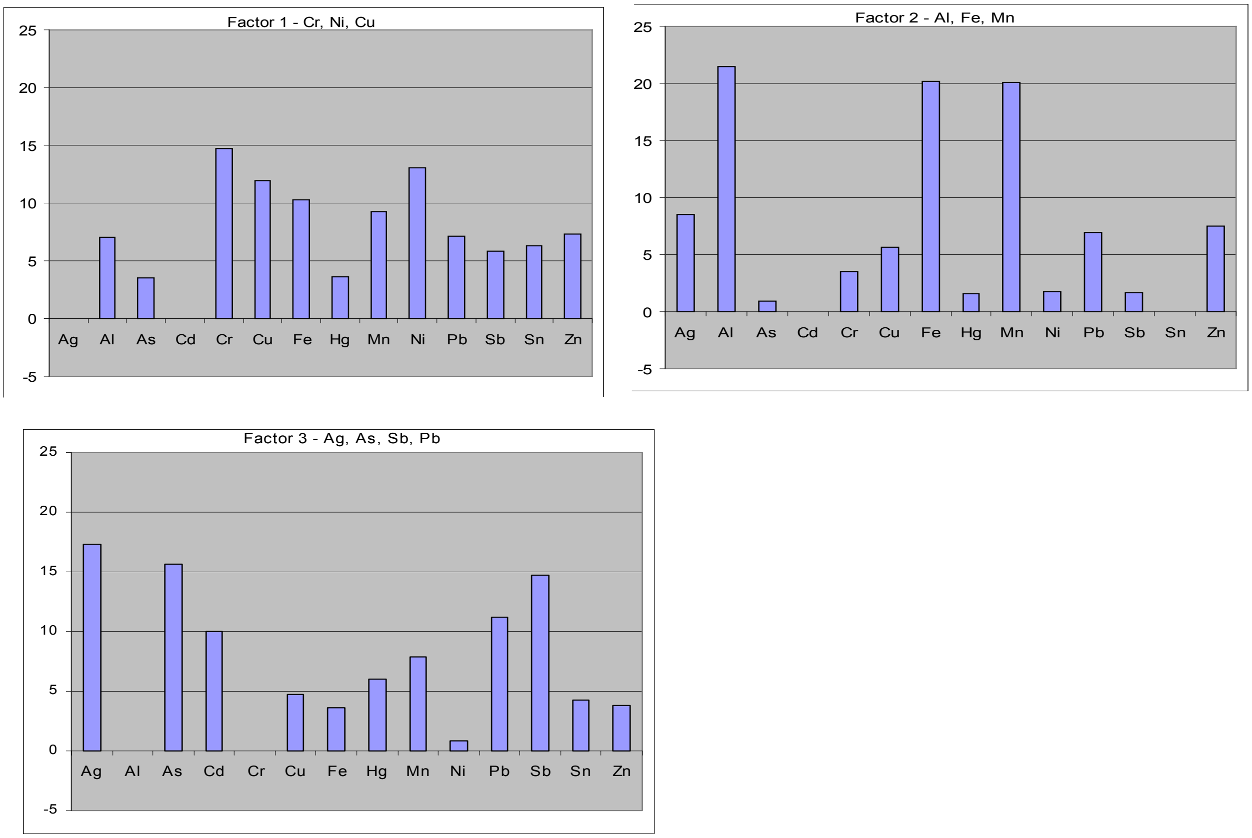


Figure 67. Histograms of the oblique factor scores for southcentral Alaska EMAP sediment metals for Factor 1 (upper), Factor 2 (middle), and Factor 3

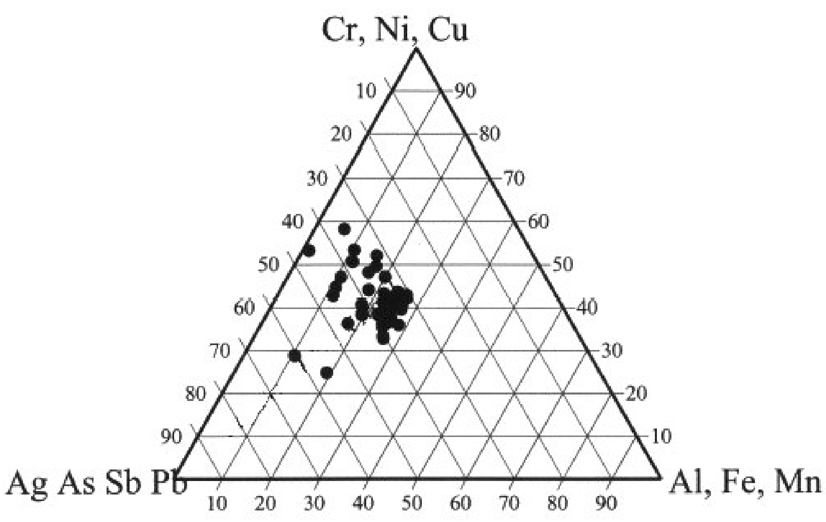


Figure 68. Ternary plot of the southcentral Alaska EMAP surficial sediment factors identified in Figure 67.

Sediment Hydrocarbon Contaminants

As with metals, hydrocarbons can also be concentrated in benthic sediments and can also have both anthropogenic and natural sources. Some natural sources that have been reported in the Southcentral Alaska coastal environment include oil seeps, eroded petroleum source sedimentary rocks, coal, terrestrial and marine plants and animals, peat, and the deposition of forest fire particulates. Anthropogenic sources of hydrocarbons to the area include discharges from petroleum industry in Cook Inlet and Prince William Sound through the National Pollutant Discharge Elimination System (NPDES) permitting program, municipal wastewater-treatment discharges, non-point source runoff from urban areas, small spills from marinas and boats, as well as large spills such as the 1989 T/V Exxon Valdez oil spill in Prince William Sound.

The hydrocarbons reported in this study are polynuclear aromatic hydrocarbons (PAH), a suite of two- to six-ring aromatic hydrocarbons that are of environmental concern because they are known to be toxic, mutagenic, and carcinogenic constituents of petroleum. By focusing on the 21 priority EMAP PAH analytes listed in Table 4, thirteen of which have ERM and ERL Guidance Values associated with them (Long et. al. 1995), comparisons can be made with the national database and results from the various regions will be comparable. Data are reported for total PAH (TPAH) for the 21 priority EMAP compounds, the 2- and 3-ring low molecular weight (LMW) PAH, and the 4- to 6-ring high molecular weight (HMW) PAH. An additional suite of PAH analytes, mainly alkylated congeners of the parent compounds, were analyzed to allow for fingerprinting of the compounds which are discussed briefly below.

Table 15 and Figure 70 show summary statistics for the study area PAHs and Figure 69 is the CDF for total hydrocarbons concentrations as percent of study area. When compared to the values reported in Table 10 for Total PAH, 100% of the study area values below the 4020 ng/g concentration reported for ERL, and almost 90% of the study area is an order of magnitude lower than ERL.

For individual PAH analytes that have associated ERM and ERL guidelines (Long et. al. 1995), none exceeded ERM values. These analytes with associated ERL and ERM guideline concentrations include Acenapthene, Acenaphylene, Anthracene, Fluorene, 2-Methyl naphthalene, Napththalene, Phenanthrene, Benz(a)pyrene, Benzo(a)pyrene, Chrysene, Dibenzo(a.h)anthracene, Fluoranthene, and Pyrene. For these analytes, sediment concentrations above ERL occurred for Fluorene at Sites AK02-0041, -0045, -0050, -0055, -0058, and -0059 (all within deep stations within Prince William Sound) and for 1-Methyl naphthalene at sites AK02-0003, -0041, -0045, -0050, -0059, and -0070 (including site AK02-0003, the sites with the highest total PAH values).

For each station, LMW and HMW PAH as a fraction of total PAH are shown as a histogram (Figure 71) and plotted geographically on a map (Figure 72). The site with the highest PAH concentration is AK02-0003, in Chinitna Bay on the west side of Cook Inlet. As shown previously in Figure 41, sediment grain sizes at this site indicate that it is not a depositional area for the glacial fines that are associated with depositional areas from upper Cook Inlet, so it is unlikely that these concentrations reflect the downstream transport of dissolved or particulate oil from upper Cook Inlet, either from oil industry operations or from the urban run-off or discharges near Anchorage. Natural oil seeps have been documented have been documented seeping within the Chinitna Bay watershed, as well as several other locations on the west side of Cook Inlet (Becker and Manen 1988), which could potentially account for these higher numbers.

Low molecular weight PAH hydrocarbons dominate total PAHs, indicating higher proportions of lower-ringed PAHs. The larger ringed compounds are often associated with combustion byproducts from either forest fires or anthropogenic sources. Data results from PAH analyses in coastal sediments from urban across the U.S. have shown that PAHs are dominated by 4-6-ring PAH (i.e. high molecular weight PAH) (Stout et. al. 2003). In addition, the homologue series from the urban sediments exhibited decreasing abundance with increasing degree of alkylation - which is a characteristic typical of pyrogenic compounds. The authors concluded on those bases that the PAH in urban background arises from pyrogenic sources, in spite of evidence for the presence of petroleum sources. For all stations sampled in the Southcentral Alaska EMAP study area, total PAH were dominated by LMW compounds and thus do not reflect an "urban background."

Figure 73 is a regression analysis between sediment total PAH and sediment silt + clay fraction. After removing the data from site AK02-0003, an exponential curve fitted through the line has an R2 value of 0.593. This is the typical trend expected for fine grained sediments, as their increased surface to volume ration typically increases the surface area available for adsorption of hydrocarbons.

PAH data can also be interpreted by comparing their relative ratios to evaluate potential sources. Individual site histograms can be created for each site to look at the distribution of each analyte to its parent compound (e.g. C1-napthalene relative to the parent naphthalene and to the other PAH groups). This requires the analysis of the alkylated homologues, which were not part of the priority EMAP PAH compounds and are not included in the summed PAH values presented above. However, these compounds were measured so that histograms, or "fingerprints," that include these alkylated compounds can provide information about potential sources of those hydrocarbons. The dominant shape of the histogram profile is the same across most sites, including both the higher and lower concentration ranges, reflecting a Gulf of Alaska background hydrocarbon signature of mixed sources (Venkatesan and Kaplan 1982, Boehm 1998, Short and Heinz 1998, Short et. al. 1999, Lees et. al. 2002, Henrichs et. al. 2003). Figure 74 shows this background signature for a few sites representing the geographic range from the western Alaska Peninsula (Pavlov Bay) to the eastern study area (Copper River); from downstream of urban areas (Chinitna Bay) to "upcurrent" of any urban areas (Copper River); to areas within the path of the Exxon Valdez Oil Spill (Prince William Sound) to an area upstream of any oiling (Copper River); and from the lower (Pavlov Bay) and higher (Chinitna Bay) end of the concentration ranges within the study. The ubiquitous signature is similar for all of these sites reflecting a mixed source of hydrocarbons, dominated by LMW PAH, yet including some HMW, that reflects potential contributions for coal, pyrogenic sources, petrogenic sources, and biogenic sources. Recent work by Short (2004) suggests that the stable naphthalene component means the complex is not weathering in transit and likely is enclosed within a stable matrix such as particulates of oil shale and that, furthermore, the PAHs do not appear to be bioavailable.

Several stations had relatively high levels of perylene compared to the other PAHs, which has been shown to be significant in several Gulf of Alaska source peat samples and is typically derived from terrestrial or natural organic carbon sources such as marshes and from the early diagenesis of plant pigments. It is often associated with finer-grained particles; however, the sites with relatively high levels of perylene were those with few % fines (silt + clay) and often represented the most mixed sediments (Sites AK02-0017, -0016, -0015, -0011, -0008, -0004, -0067, -0074, -0046, and -0040.

<u>Sediment Persistent Organic Pollutants</u>

For the suite of persistent organic pollutants analyzed for this study (Table 4), no detects were found for sediments at any station. These included most of what is known as "the dirty dozen" persistent organic pollutants and included a suite of PCBs – 21 congeners), DDTs (total and 7 congeners), Cyclopentadienes (three pesticides), Chlordanes (four compounds), and 6 additional herbices and pesticides. 100% of the study area fell below any guidance levels such as ERL.

Combined Contaminant Concentration Indicator

An indicator value that has been used by other coastal assessments while evaluating sediment condition is derived from the combined concentrations of all contaminants present at a site relative to bioeffects guidelines (Hyland et. al. 1999). The combined measure is calculated by dividing the measured concentrations of the 24 contaminants with ER-M guidelines by their respective ER-M guideline values and averaging the resulting values. The resulting average value is the ERM-Quotient (ERM-Q) and is described to represent a low risk of observing degraded benthic communities at ERM-Q ≤ 0.02, a moderate risk for values > 0.02 and ≤ 0.058, and a high risk at values > 0.058. ERM-Q values were calculated for the Southcentral Alaska EMAP stations using the measured metals, PAH, and persistent organic pollutant concentrations. The results shown in Figure 76 imply that if the ERM-Q bioindicator were applied to the Southcentral Alaska EMAP study area, almost 99% of the study area would be expected to show a moderate to high risk of observing degraded benthic communities. These results clearly show that this indicator that has been applied successfully elsewhere (Hyland et. al. 1999, Van Dolah, et. al. 20002) is not an appropriate indicator for this study area, given the natural background signals

Sediment Toxicity

Sediment contaminant concentrations do not alone provide enough information to evaluate the potential biological effects to benthic communities. As discussed above, many of the naturally occurring concentrations of trace metals and some organic chemicals may be present in sediments, sometimes at levels exceeding those shown to cause toxic effects in some laboratory or field studies. Another important factor in determining potential effects of chemicals in the environment is whether or not they are bioavailable to the organisms present. There are several ways to begin addressing whether sediment contaminants can or are having negative effects on benthic organisms, two of which are toxicity testing and assessing the condition of the organisms that live in the sediments. We will discuss measures of benthic community condition in a later section. Here we will present results from sediment toxicity tests across the study area. These tests try to determine whether sediments are toxic to test animals that have known responses to specific contaminant levels and expose these organisms to the sediments under very specific conditions. Toxicity test results are evaluated as part of a "weight-of evidence approach," or sediment quality triad, where results of contaminant concentration measurements, sediment toxicity, and benthic condition of the resident species are all evaluated together.

The toxicity test, or bioassay, required for comparison across all of the nation's coastal bays and estuaries is the 10-day Ampelisca abdita amphipod survival test. This test was selected due to its long history of use for assessing benthic sediment condition, and thus has a robust dataset that can be used as background information. Sediments with toxic levels of contaminants do not always show toxicity during the bioassay, and vice versa, for various reasons such as toxic chemicals in the sediments may not be bioavailable or lethal and most studies cannot analyze for every possible toxic chemical. Also, other benthic organisms may be less or more tolerant than Ampelisca to chemicals in the sediments presenting difficulties in directly applying the results to actual field biological effects. The State of Alaska has not yet developed any specific benthic species for use in Alaska sediment toxicity studies, but considers the EMAP work useful in helping guide future studies to establish a suitable Alaska sediment toxicity test organism(s). However, in conjunction with measuring a large suite of chemical contaminant levels as well as measures of benthic community structure, this bioassay can be a powerful tool.

For the Southcentral Alaska EMAP program, results are available for the 10-day Ameplisca amphipod survival test, where sediments from each station were compared to control sediments in affecting amphipod survival rates. The results of the tests (Figure 75) show that two stations, AK02-0005 and

AK02-0038 had amphipod survival rates less than 80%. As discussed above, site AK02-0005 had an order of magnitude higher chromium values in the sediments than any other station and site AK02-0038 had a very high sediment %TOC. Both of these factors, high metals concentrations and high TOC are known to have detrimental effects on benthic community assemblages. High TOC is known to cause detrimental effects to some individual organisms, such as standard toxicity test organisms, but Tagliapeietra et. al. (2004) caution that total sediment organic content alone cannot be used to evaluate a bioindicator, since the degree of liability to resident organisms may differ depending on the source of the carbon.

Sediment toxicity as a percent of the study area is shown in Figure 77. Based on their weighted distribution within the study area, the two sites that showed sediment toxicity represent 1.1% of the study area.

Metal	Units	Mean	std	median	max	min	N
Aluminum	mg/g	4714	15.47	44.60	70.30	9.44	
Antimony	μ g/g	0.91	0.45	0.82	2.80	0.32	55
Arsenic	μ g/g	8.94	3.97	9.03	25.40	3.26	55
Cadmium	μ g/g	0.22	0.25	0.16	1.96	0.00	55
Chromium	μ g/g	74.95	171.82	73.70	1320.00	5.83	55
Copper	μ g/g	35.51	14.60	35.00	79.70	7.10	55
Iron	mg/g	47.78	10.30	41.70	56.50	16.70	55
Lead	μ g/g	13.23	3.62	12.50	21.25	1.67	55
Manganese	μ g/g	738.61	145.64	747.00	1030.00	426.00	55
Mercury	μ g/g	0.07	0.04	0.06	0.26	0.00	55
Nickel	μ g/g	32.35	99.03	32.60	756.00	4.24	55
Selenium	μ g/g	0.14	0.30	0.00	1.45	0.00	55
Silver	μ g/g	0.20	0.08	0.17	0.44	0.00	55
Tin	μ g/g	0.64	0.27	0.61	1.18	0.12	55
Zinc	μ g/g	90.98	28.11	83.80	174.00	42.00	55

Table 11. Summary statistics for sediment metals analyzed at each station.

Table 12. Percent of the study area that falls within NOAA's sediment quality guidelines for Effects Range Low (ERL) and Effects Range Median (ERM).

Metal	% Area < ERL	% Area >ERL and <ERM	% Area > ERM
Arsenic	40.2	59.8	0.0
Cadmium	99.5	0.5	0.0
Chromium	68.4	31.0	0.6
Copper	55.5	44.5	0.0
Lead	100.0	0.0	0.0
Mercury	98.2	1.8	0.0
Nickel	36.8	57.0	6.2
Silver	100.0	0.0	0.0
Zinc	99.5	0.5	0.0

Metal	Copper River ADL (1999)	Susitna/Knik/Matanuska Rivers ADL (1999)	Alaskan Rock	Average Continental Crust
Al (mg/g)	76.1-81.4	66.1-101.3	26.7-78.1	79.6
Ag (µg/g)	0.07-0.10	0.10-0.66	---	0.07
As (µg/g)	11.9-18.0	23.1-38.5	8-39	1.7
Cd (µg/g)	0.19-0.24	0.19-0.58	---	0.10
Cr (µg/g)	80-98	103-163	47-84	126
Cu (µg/g)	5303-63.5	46.4-77.9	16-75	25
Fe (µg/g)	44.0-54.3	51.5-70.1	15.9-66.6	43.2
Hg (µg/g)	0.183-.206	0.111-0.428	---	0.040
Mn (µg/g)	961-1000	995-1240	351-1710	716
Ni (µg/g)	38.5-41.4	38.85-76.7	19-47	56
Pb (µg/g)	12.9-15.0	16.2-32.5	6-25	14.8
Sb (µg/g)	2.00-2.74	1.22-3.59	---	0.30
Zn (µg/g)	81.9-109	84.3-267	96-288	65

Table 13. Ranges of metal concentrations in known or potential sources of sediments to southcentral Alaska coastal bays and estuaries (data from ADL 2001). Shaded yellow reflects concentrations above ERL and shaded orange reflects concentrations above

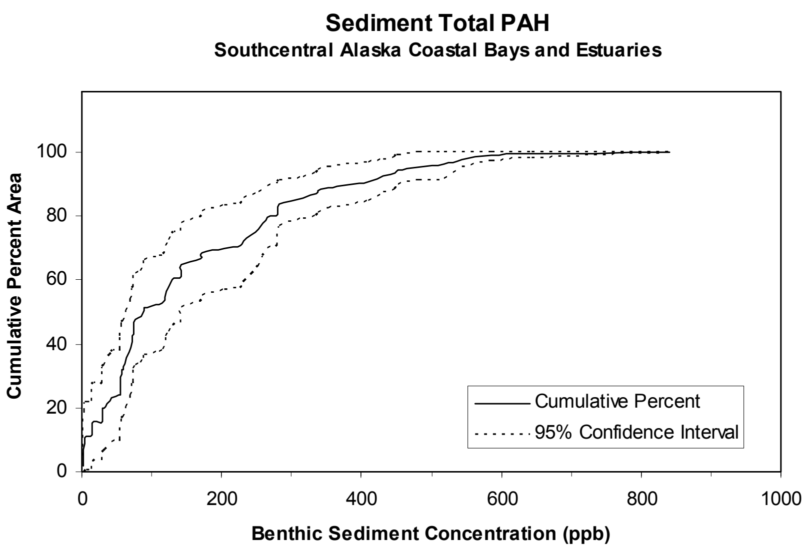
	Al	Sb	As	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Sn	Zn	% Fines	% TOC
Al							R=.430 P=.001		R=.284 P=.038							R=.284 P=.037	
Sb			R=0.725 P=.000		R=.515 P=.000	R=.386 P=.004		R=.684 P=.000	R=.320 P=.018	R=.294 P=.034	R=.495 P=.000				R=.511 P=.000	R=.442 P=.001	
As						R=.344 P=.011		R=.449 P=.001			R=.358 P=.008	R=.893 P=.007				R=.269 P=.049	
Cd									R=-.309 P=.027			R=.949 P=.001	R=.447 P=.001				R=.851 P=.000
Cr						R=.764 P=.000	R=.584 P=.000	R=.7990 P=.000	R=.467 P=.000		R=.768 P=.000			R=.724 P=.000	R=.833 P=.000	R=.793 P=.000	
Cu							R=.678 P=.000	R=.725 P=.000	R=.6368 P=.000	R=.295 P=.033	R=.674 P=.000			R=.838 P=.000	R=.817 P=.000	R=.7932 P=.000	R=.308 P=.025
Fe								R=.343 P=.011	R=.684 P=.000	R=.365 P=.008	R=.351 P=.009	R=-.766 P=.045		R=.584 P=.000	R=.685 P=.000	R=.562 P=.000	
Pb									R=.362 P=.007	R=.314 P=.024	R=.655 P=.000			R=.648 P=.000	R=.744 P=.000	R=.713 P=.000	
Mn											R=.512 P=.000			R=.488 P=.000	R=.656 P=.000	R=.514 P=.000	
Hg														R=.275 P=.048	R=.356 P=.009	R=.340 P=.014	
Ni														R=.658 P=.000	R=.668 P=.000	R=.730 P=.000	
Se																	R=.838 P=.019
Ag																	R=.593 P=.000
Sn															R=.721 P=.000	R=.796 P=.000	R=.272 P=.049
Zn																R=.816 P=.000	

Table 14. Correlations between sediment parameters. Black indicates a p < 0.05 and red indicates an R > 0.7071 (R2>0.5) and a p <0.05.

Table 15. Summary statistics for Polynuclear Aromatic Hydrocarbons (ng/g, PAH) as Total PAH, High Molecular Weight PAH, and Low Molecular Weight PAH.

Parameter	Units	Mean	std	median	max	min	N
Total PAH	ng/g	224.45	193.62	121.32	840.3	1.66	55
High Molecular Weight PAH	ng/g	60.18	48.75	35.15	187.7	0	55
Low Molecular Weight PAH	ng/g	164.27	85.51	85.51	652.6	1.32	55

hydrocarbon (PAH, ng/g) concentrations as a percent of area in the southcentral Alaska EMAP study area.



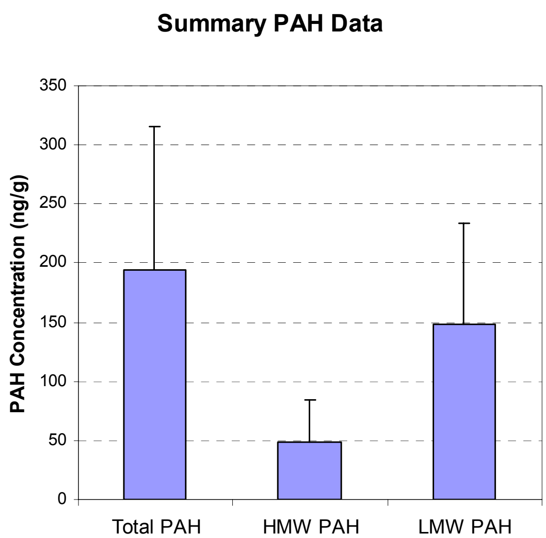


Figure 70. Average (error bar is one standard deviation) polynuclear aromatic hydrocarbons (PAH) concentrations (ng/g) across all sites. Data presented include Total PAH, High Molecular Weight (HMW, 4 and 5-ringed compounds) and Low Molecular Weight (LMW, 2 and 3 – ringed compounds). concentrations (ng/g) across all stations.

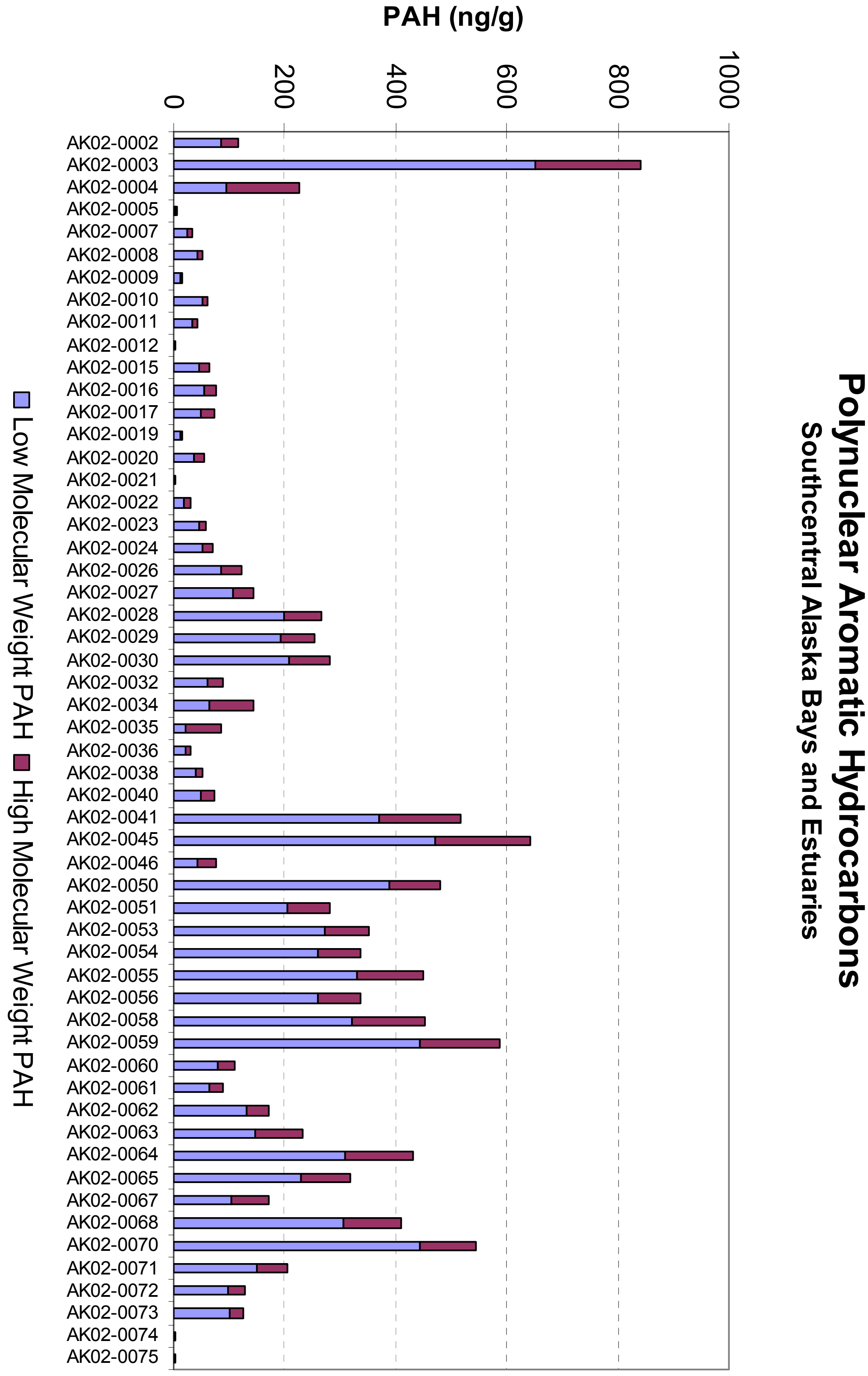


Figure 71. Polynuclear Aromatic Hydrocarbon Concentrations for all sites sampled for southcentral Alaska coastal bays and estuaries EMAP. Total PAH values are divided into low molecular weight (2 – 3 ringed) and high molecular weight (4-6-ring) PAHs.

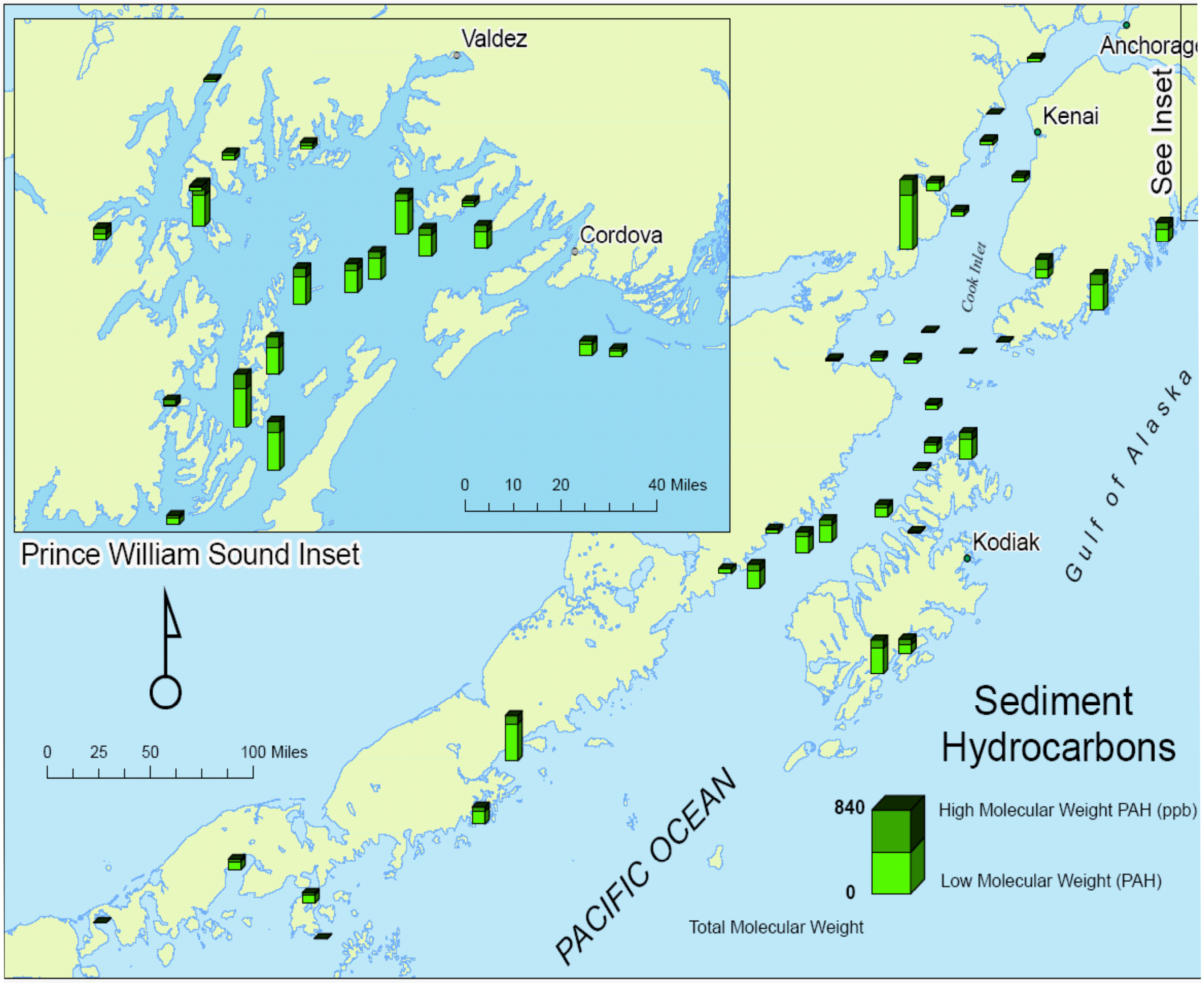


Figure 72. Sediment polynuclear aromatic hydrocarbon (PAH) concentrations (μ g/g) at sampled stations across the study area's geographic range, with low and high molecular weight PAHs shown as a fraction of total PAH. Note that Prince William Sound is an inset on the left instead of at its normal geographical position at the eastern edge of the study area.

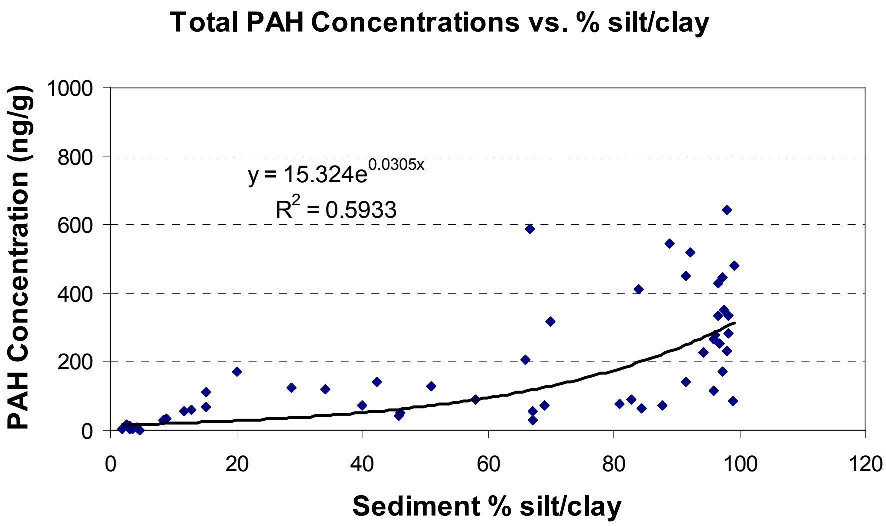


Figure 73. PAH concentration plotted against sediment % silt + clay. Line is an exponential curve fitted through the data. R2 = 0.593. The outlier from station AK02-0003 was not included in the regression.

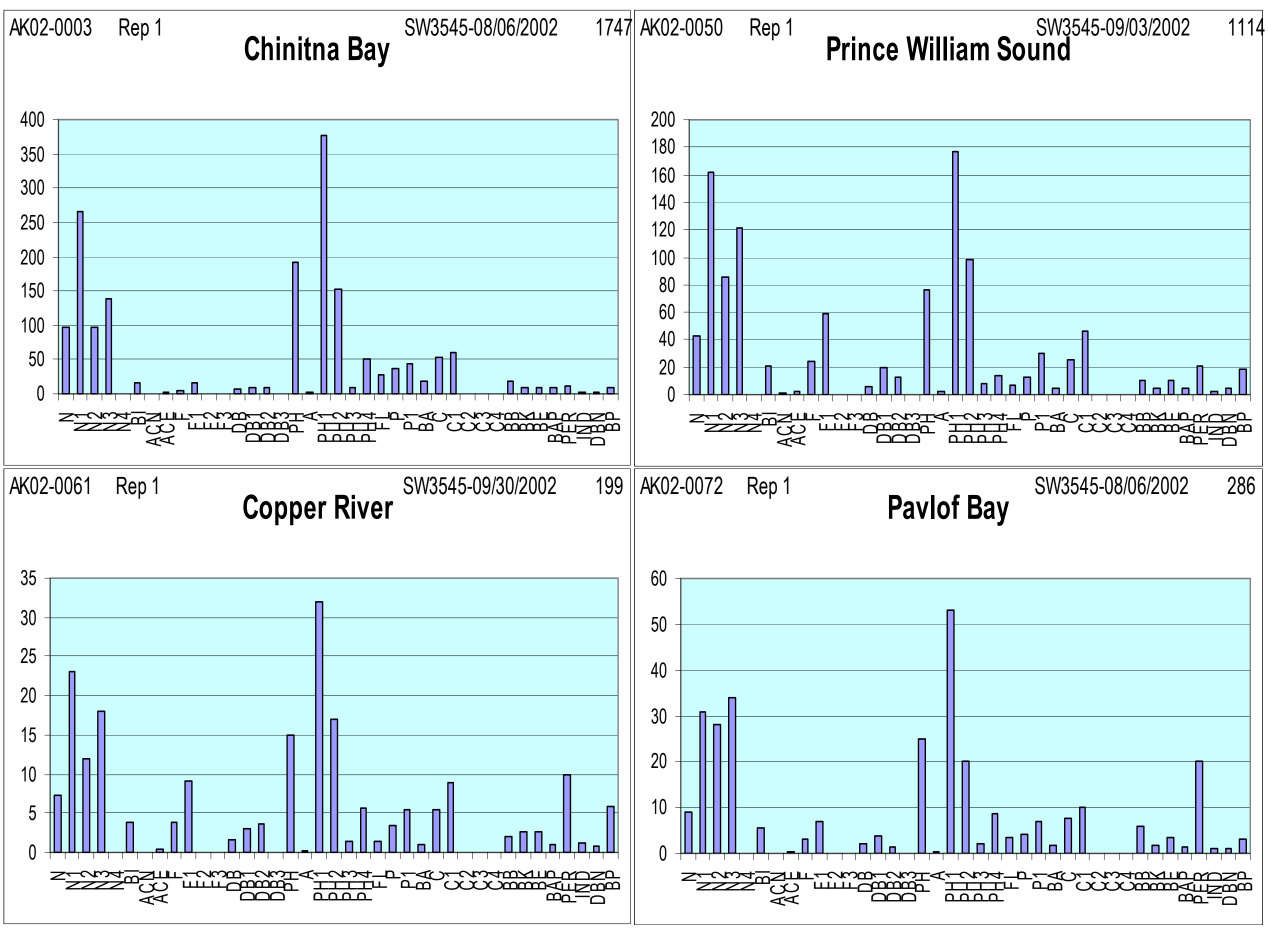


Figure 74. PAH histogram "fingerprints" for four stations from the Southcentral Alaska study area, including sites from across the entire geographic range and whose total PAH concentrations ranged from the highest to the low range. For definitions of the individual codes, see Appendix XXX.

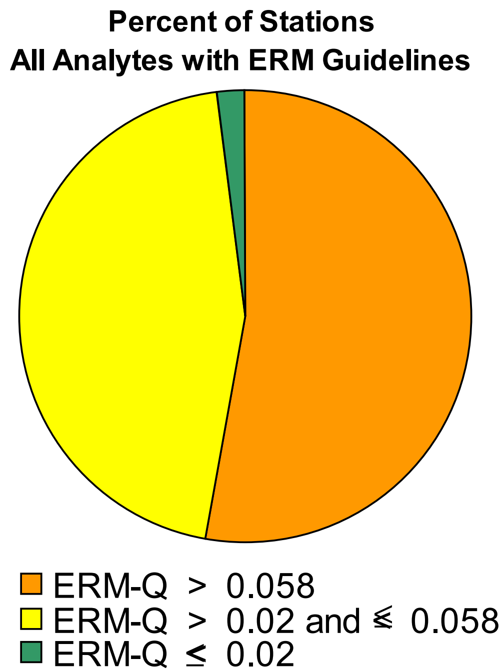


Figure 76 Estimates of the proportion of stations that would be considered having a low (≤ 0.02), moderate (<0.02 and ≤ 0.058), or high (> 0.058) risk of observing stress in benthic communities if the bioindicator ERM-Q were used as an indicator for the Southcentral Alaska EMAP study area.

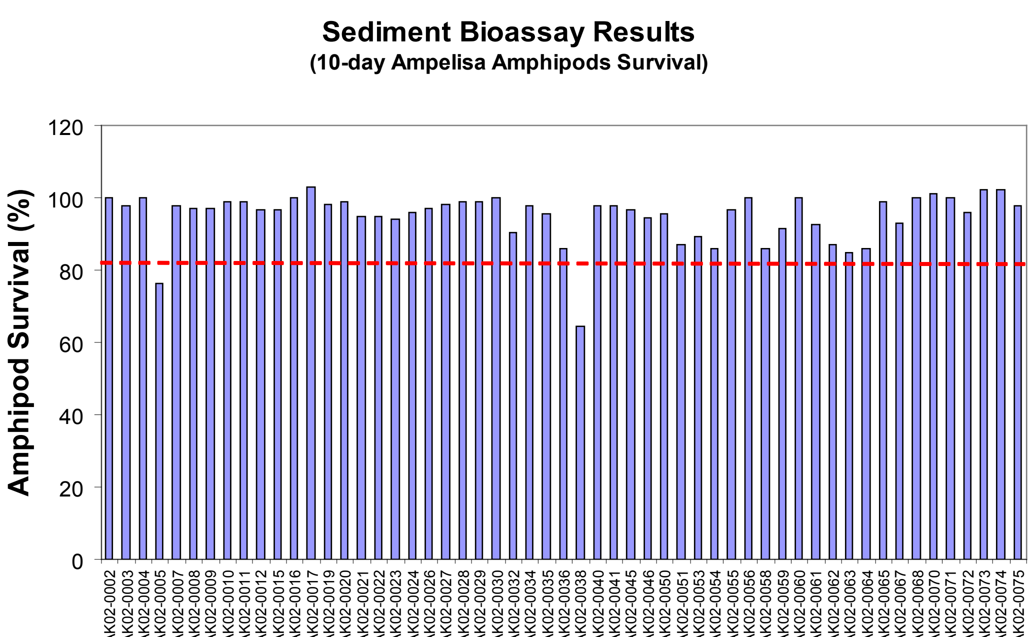
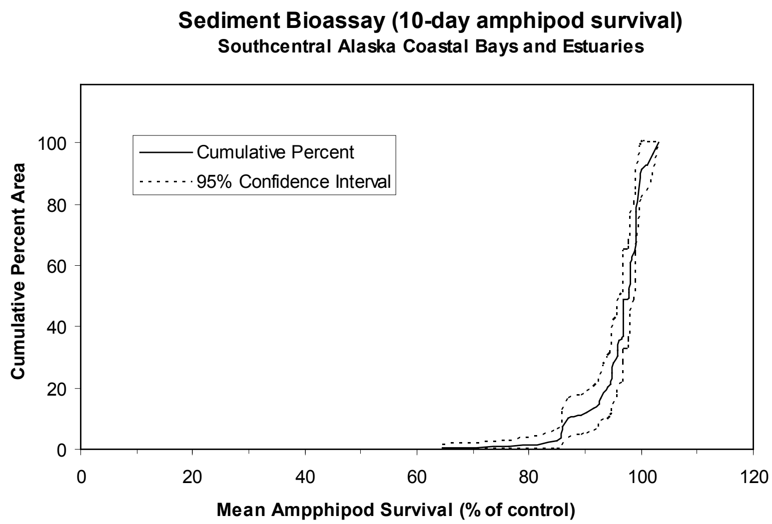


Figure 75. Amphipod Survival Rate (%) of station sediments compared to control sediments for 10-day Ampelisa abdita amphipod survival. Red dotted line indicates 80% survival for control-corrected tests as the criteria for determining toxicity.



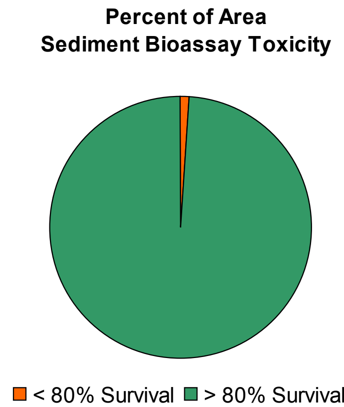


Figure 77. Cumulative distribution of mean amphipod survival in a 10-day laboratory toxicity test expressed as a percent of control survival (left). Dashed lines are the 95% confidence intervals. Summary of bioassay results expressed as percent area showing toxicity is shown at right.

3.6 Benthic Communities – Biological Condition

Benthic organisms that live in close association with benthic sediments are considered good indicators of sediment habitat condition as they are often the primary consumers and are in direct contact with sediment and porewater contaminants. Most benthic infaunal invertebrates are sessile making them better integrators of longer-term sediment condition than mobile organisms.

In general, exposed but healthy benthic environments contain balanced populations of species, where abundance, richness, and diversity are similar to undisturbed habitats. Determining these balanced populations for undisturbed habitats is difficult without an extensive database for various habitats that take into consideration natural variability such as depth, sediment grain size, overlying water column parameters, nutrient availability, predation and other variables.

Benthic indices can be developed using measures of the benthic community to evaluate condition for specific areas or habitats. Several different benthic indices have been developed for other regions during the National Coastal Assessment program for coastal bays and estuaries but only after extensive evaluation of known species assemblages for various habitats and in the context of known undisturbed habitat. When appropriate data were available, some indices have incorporated knowledge of whether species are indigenous, non-indigenous, or cryptogenic, as well as the known sensitivity of particular species to evnrionmental conditions and contaminants. Alaska currently does not have any established benthic indicies or guidelines in the DEC AWQS to evaluate freshwater or marine water ecological health. The Alaska EMAP program is one of the first large scale efforts to begin to gather data that will be useful in helping develop appropriate benthic indicies in the future.

For now, relative comparisons across the study area will be made for benthic invertebrate and fish abundance, richness, and Shannon-Weaver Diversity (H'). It should be stressed that since community composition is strongly influenced by factors other than environmental "health," (e.g. sediment grain size, available organic carbon, overlying water salinity and temperature, natural suspended sediment loads influence light penetration and ambient primary production, local currents that affect the sediment grain size and food availability for filter feeders, as well as other factors), the results of the abundance, richness, and diversity data alone cannot be used to infer whether the community is disturbed or not. However, these data can show the extremes and comparisons of data can be made to the overall study area as well as other water and sediment quality indicators.

Benthic invertebrate communities were collected from benthic sediment grabs and all organisms greater than or equal to 1.0 mm were sorted to the lowest possible taxa. Data are presented per grab sample and have not been normalized per square meter. The grab area was 0.1 m2, so numbers can be multipled by 10 to obtain a meter square value. Across the entire study area, there were 17,063 individual invertebrates represented by 441 taxa and 176 families.

Benthic invertebrates were found at all 54 sites where benthic grab samples were analyzed. At site AK02-0067, a grab sample was collected but the sample was lost before benthic sorting and taxonomy could be conducted. Benthic invertebrate data are shown as a function of percent area in the southcentral Alaska coastal bays and estuaries for organism abundance (Figure 78), total taxa richness (Figure 79), and Shannon-Weaver Diversity (H', Figure 80). These data represent the lowest taxa to which the organisms were identified. The abundance of specific benthic organisms ranged from 0 to 2892 individuals per station and the number of taxa identified ranged from 0 to 106 total taxonomic levels. Shannon-Weaver Diversity (H') ranged from 0.91 to 5.64. The two sites with the lowest benthic invertebrate abundance, richness, and diversity were sites AK02-0011 and AK02-0012, the two sites with the highest total suspended sediment loads measured in the study area, as well as some of the lowest TOC values measures (AK02-0012 had 0% TOC). The site with the highest abundance was site AK02-0008 on the west side of Shelikof Strait and site AK02-0059 in Prince William Sound had the highest tax richness and diversity.

Benthic invertebrates were lumped to the the family level (or higher if organisms was not identified to the family level) and are shown on a map reflecting relative abundance and species richness (Figure 81). This display gives a station comparison of total abundance (size of the pies) and total number of family or higher taxa (number of pie slices). When both measures (abundance and richness) are combined into a diversity index at this level, the sites with the largest symbols do not, always reflect the highest diversity (Figure 82) since diversity also incorporates taxa richness.

To evaluate the general taxonomic composition of the study area, the data were lumped into higher taxonomic levels and are shown in Figure 83 and Table 16 for summed abundance for the entire study area. Table 17 lists the breakdown of organisms to the family or higher within the larger taxonomic groups.

Polychaete worms were by far the dominant taxonomic group, representing over 63% of all individual invertebrates from 41 different families. Polychaetes from the family Spionidae dominate and were found at 45 of the 54 stations. Some families had higher abundances than others, but represented fewer stations, and vice versa. For instance, Nephtyidae were found at 46 stations, the most sites for any other polychaete worms, but had only 298 total individuals. Bivalvia (clams) were represented by 23 different families and were present at the most sites and in the highest total abundances by Thyasiridae, Tellinidae, and Nuculanidae. For crustacea, 40 families were represented. The most dominant family in terms of total abundance was Balanidae (barnacles), which was found at only 11 sites. Leuconidae (cumaceans) were found at 37 sites showing a greater geographic range, but represented less than half the total individuals. Gastropoda (snails) were represented by 27 different families, with a high number of individuals (99 out of 410) being unidentifiable to a taxonomic level below Gastropoda. Echinodermata (sea stars, sea urchins, sea cucumbers) were represented at 30 sites by 15 families, with Amphiuridae being the most abundant and occuring at the most sites.

Figure 84. Total abundance (size of pie) and fraction of major taxonomic groups (pie slices) for benthic invertebrates at sampled stations across the study area's geographic range. Data are from family level or higher. Note that Prince William Sound is an inset on the left instead of at its normal geographical position at the eastern edge of the study area. shows the relative fraction of major taxonomic groups compared to total abundance at each station across the study area. Note that those stations that have relatively lot total abundance and only a few of these larger taxonomic groups represented, do not necessarily have the lowest diversity when Figure 84 is compared to Figure 82 for data at lower taxonomic levels (family level data). For example, the sites in central Shelikof Strait and central Prince William Sound have relatively low abundances and few of the large taxonomic groups, yet they have diverse taxa within the larger taxonomic groups. These locations represented some of the deepest sites sampled, however when depth was compared with species abundance, richness, and diversity, there was no significant correlation, nor was there any significant correlation between benthic indices and sediment silt + clay fraction.

Interestingly, site AK02-0005, which had high chromium and nickel sediment concentrations and was one of only two sites showing sediment toxicity, had abundance, richness, and diversity indices that were in mid-range. This site was one of only two where oligochaetes, which are often considered to be able to tolerate stressful environmental conditions better than many other annelids, were identified. The only other site where oligochaetes were identified was site AK02-0003, the site with the second lowest TOC, but highest concentration of PAHs found in the study area. Although these concentrations are well below ERL, oligochaetes are known to colonize oiled sediments at high densities. Site AK02-0003, is located in Chinitna Bay where there are known petroleum seeps and where sediments introduced by the Chinitna River deposit. Site AK02-0038, which also showed sediment toxicity to the laboratory test organisms, Ampelisa abdida and had a sediment organic total carbon content (TOC) at a level known to reflect poor conditions for benthic organisms, had benthic invertebrate indices that were mid-range. Very high or very low TOC levels have been shown to have negative effects on benthic organisms (Hyland et. al. 2000). The high organic content of the sediments at this site were derived mainly from decaying eelgrass. The waters were well oxygenated from tidal mixing and showed no indication of hypoxia from microbial degradation of this organic matter. These data suggest that, although the high organic content was toxic to laboratory organisms, it was not a liability to the resident organisms. It has been shown in other areas that high organic loads do not necessarily affect species diversity when the source is considered (Tagliapietra et. al. 2004).

It is important to again stress that the results for the benthic community measures of abundance, richness, and diversity described above for the Soutcentral Alaska EMAP cannot be used to define benthic community disturbance or stress from anthropogenic sources. The stations ranged from shallow transitional areas to continental shelf to deep "holes" within Prince William Sound; the benthos live in radically different habitats. The shallow areas, especially, are influenced by numerous factors on a daily, and even hourly basis from changing tides, currents, salinity, and associated factors. Although the deeper or offshore stations are not exposed to such dramatic changes with time, there are differences among them, depending on their position relative to riverine source material and the presence or absence of strong currents that could facilitate or preclude settling of the glacial flour. These factors must all be taken into consideration when defining typology of habitat (Silvestri et. al. 2004) subsequent to identifying appropriate reference conditions for developing classification schemes of benthic community condition. Hence, there must be considerably more data before benthic community assemblages can be categorized and generalized to define benthic health for the study area.

Fish Tissue Contaminants

In addition to causing direct effects on benthic biota, sediment contaminants can enter the food chain and accumulate into the tissues of higher trophic level consumers. Many contaminants can be stored in tissues with very slow metabolic breakdown and will, in effect, accumulate at higher concnetrations in the consumer than in its prey; this is called bioaccumulation. Concerns for bioaccumulation of contaminants in aquatic species are driven by concerns for potential effects on the populations from effects such as reduced growth, reproduction and survival, or behavioral anomalies.

For the Southcentral Alaska EMAP study, target fish were collected from all sites where fish were available including many sites at which more than one fish species was collected. At the 55 stations, a total of 95 fish tissue analyses were conducted on station/species combinations of the target species; Up to 5 fish were composited per sample. For the summary statistics for this report, all fish were considered within the analyses.

Comparisons are made between the concentrations measured in this study to guidelines prepared by the USEPA as "Risk Guidelines for Recreational Fishers (USEPA 2000) or the U.S. Food and Drug Administration's "Action Limits" for commercial fish (or for crustaceans when limits are not available for fish). No contaminant index other than those mentioned above, are applied to these data.

Table 18 and Figure 85 show summary statistics for fish tissue metal concentrations for all fish sampled and analyzed for the study area and Table 19 and Figure 86 show similar data for persistent organic pollutants. 100% of all fish and study area fall below either of the guidelines presented in Table 20.

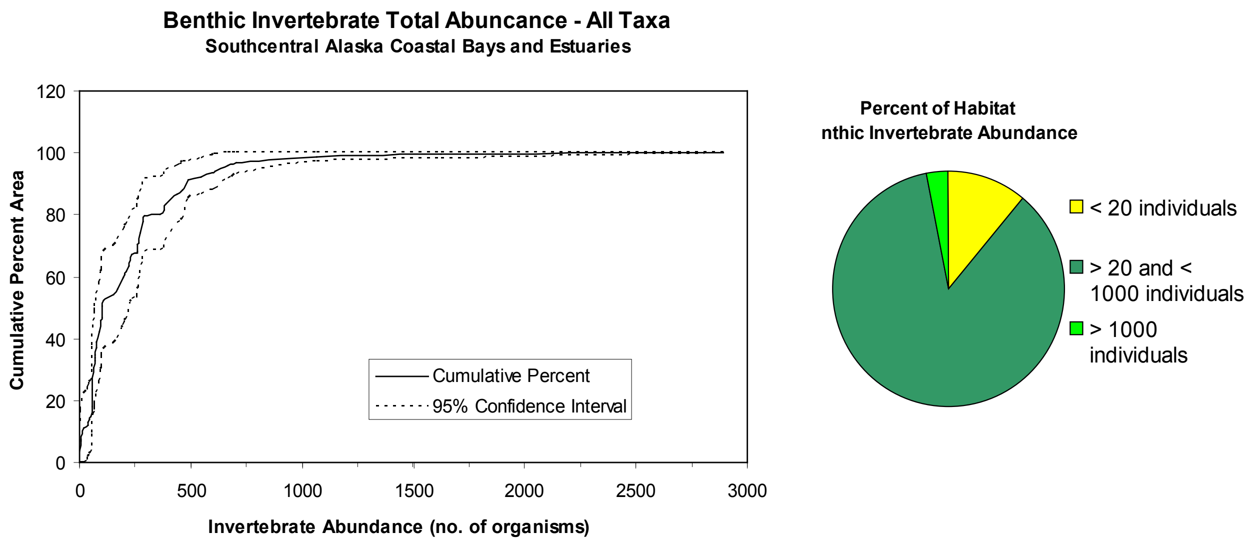


Figure 78. Cumulative distribution of the total number of benthic organisms per sediment grab (0.1m2).

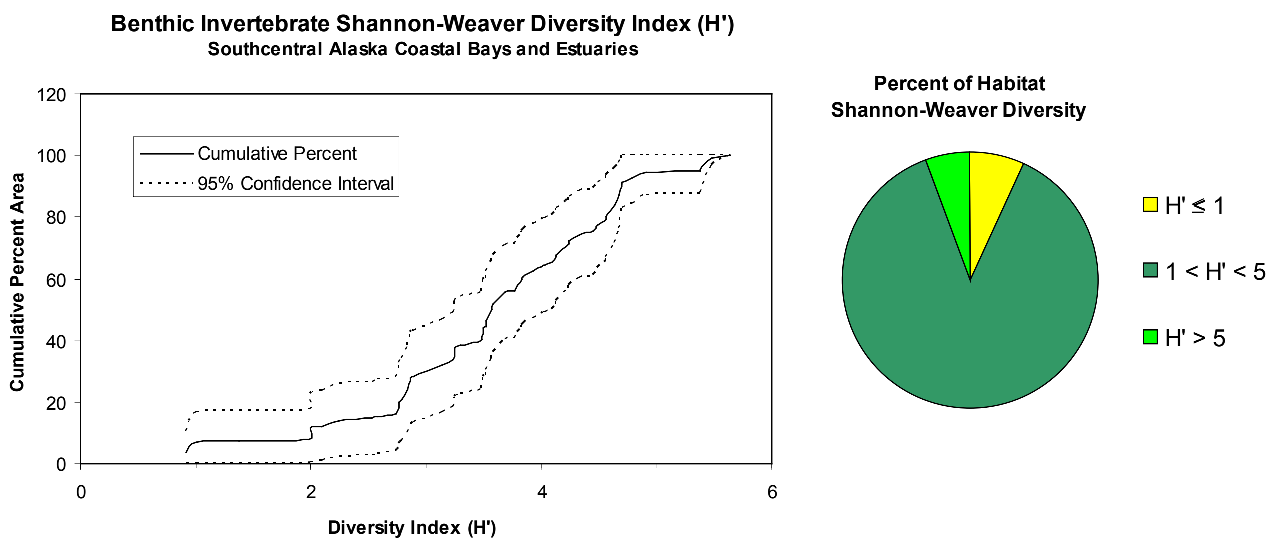
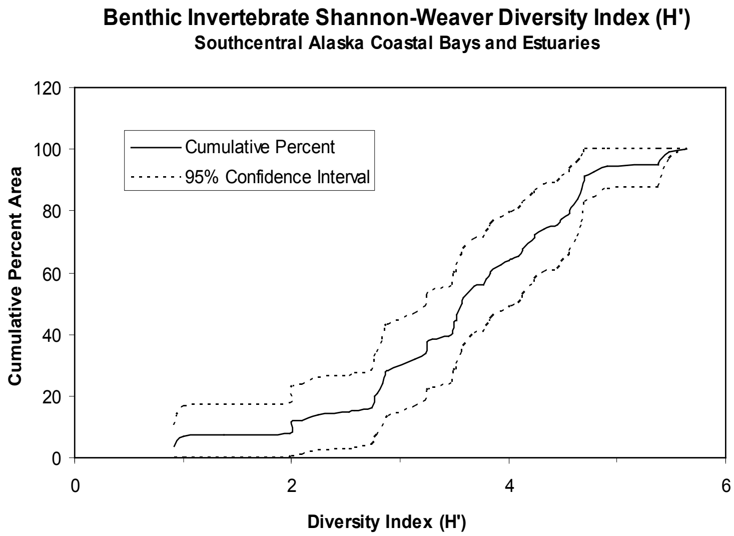


Figure 79. Cumulative distribution of the total number of benthic organism taxa per sediment grab (0.1m2).



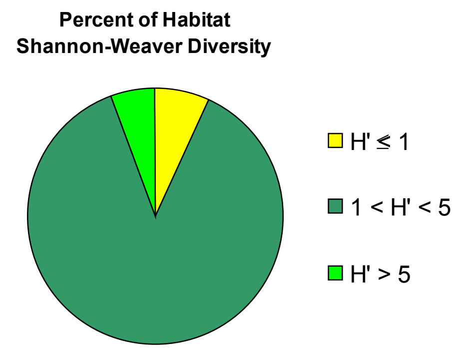


Figure 80. Cumulative distribution of the Shannon-Weaver Diversity Index (H') for benthic organisms per sediment grab (0.1m2).

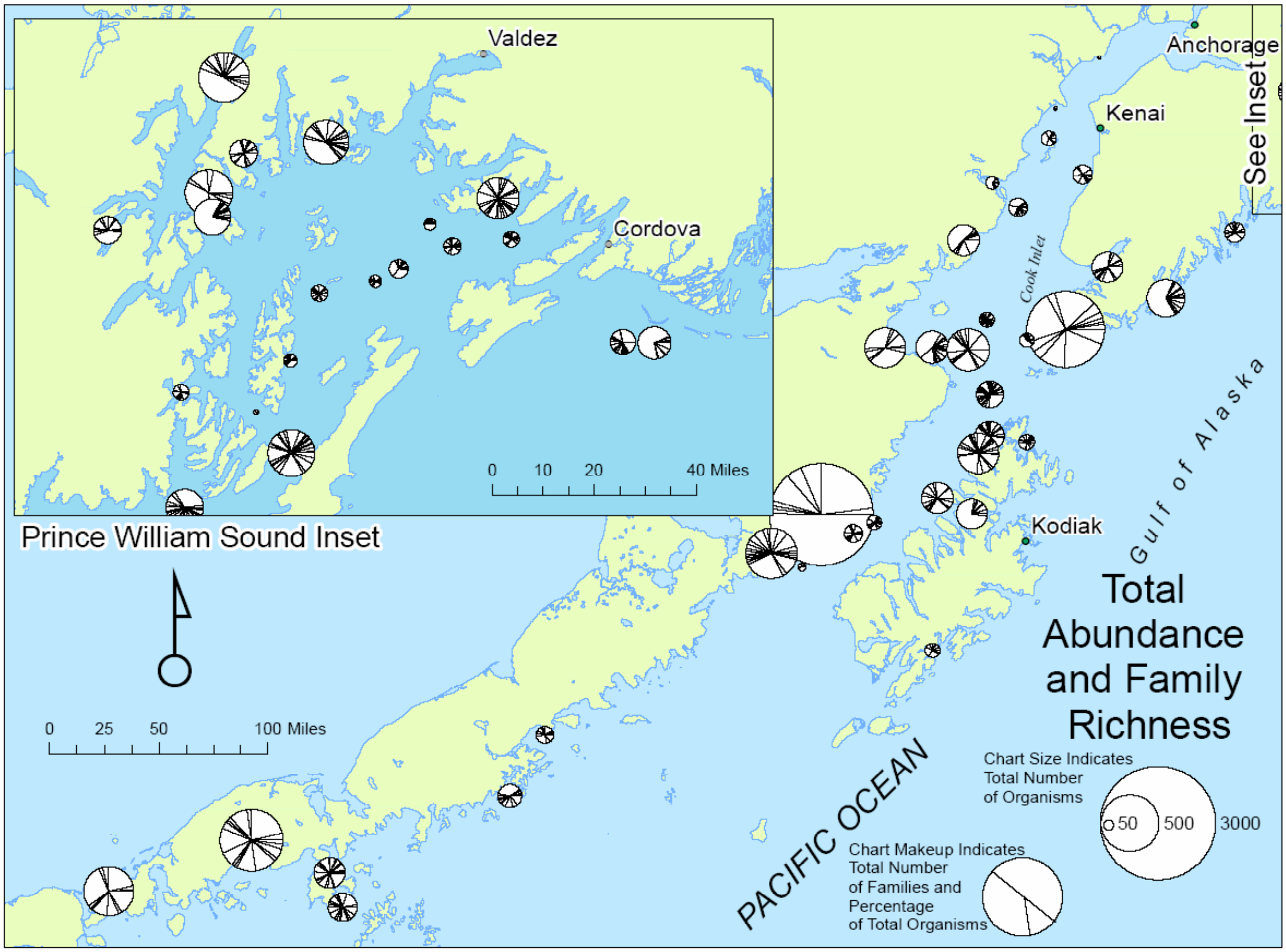


Figure 81. Benthic invertebrate abundance (size of circles) and richness (number of pie divisions) at sampled stations across the study area's geographic range. Data are from family level or higher. The fraction of each pie to the total pie represents the number of individuals in that taxa relative to total individuals of all taxa (total abundance). Note that Prince William Sound is an inset on the left instead of at its normal geographical position at the eastern edge of the study area.

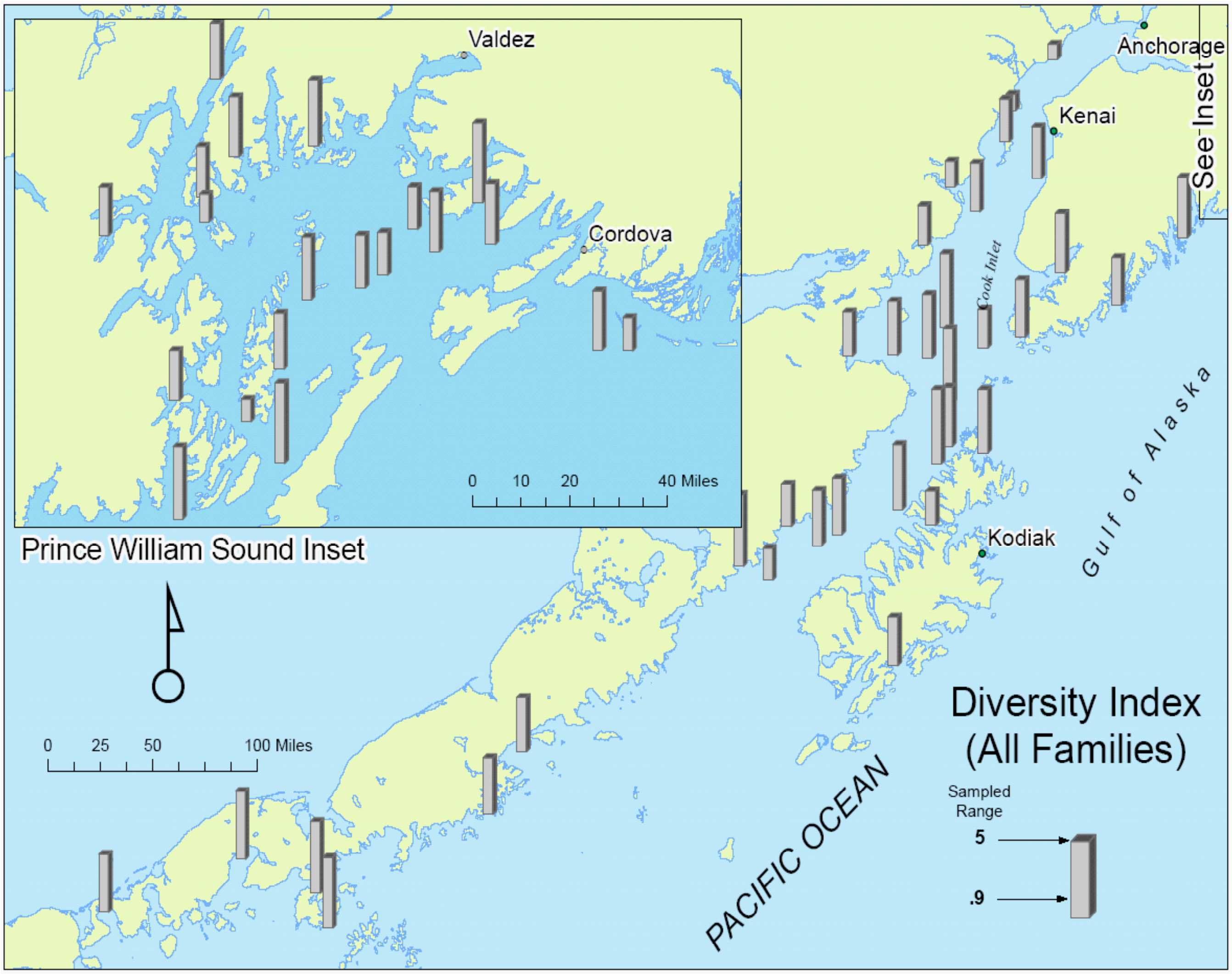


Figure 82. Benthic invertebrate Shannon-Weaver Diversity (H') at sampled stations across the study area's geographic range. Data are from family level or higher. Note that Prince William Sound is an inset on the left instead of at its normal geographical position at the eastern edge of the study area.

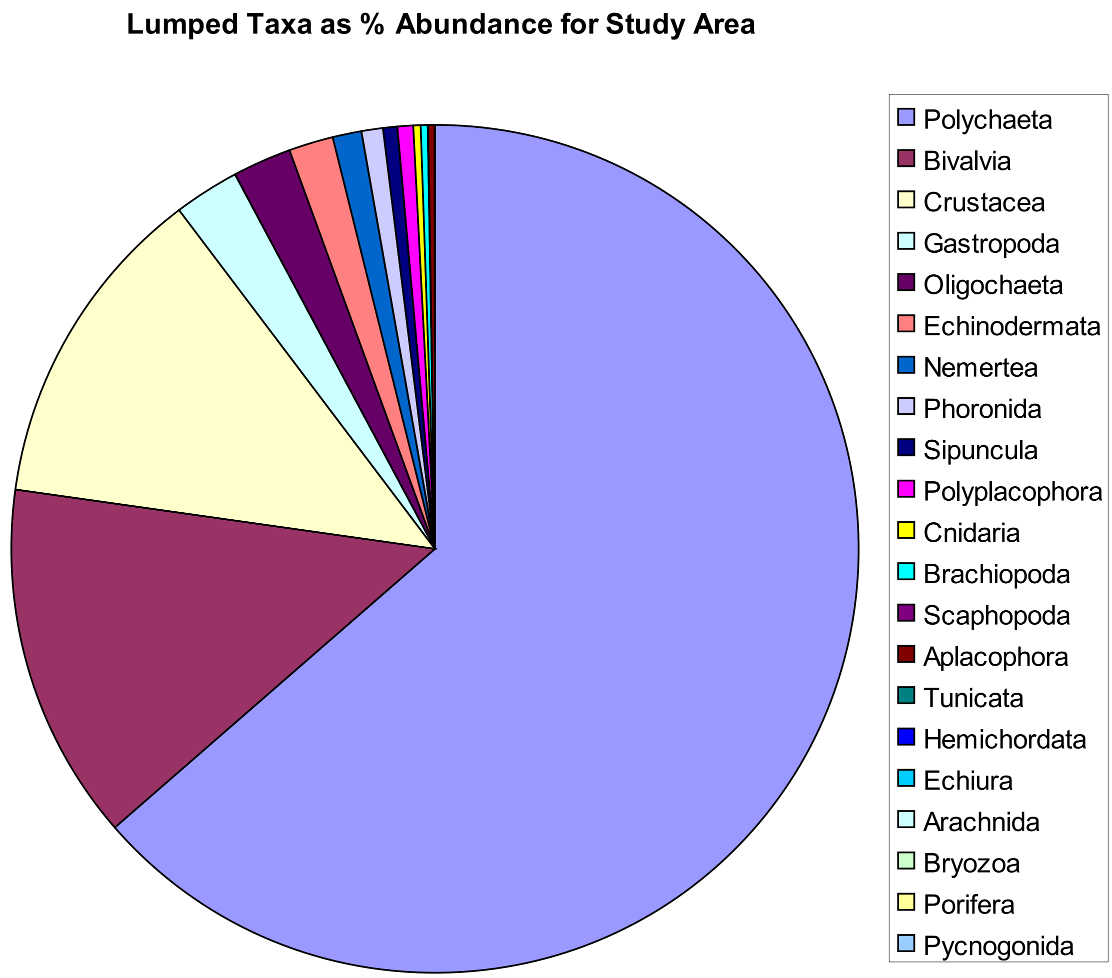


Figure 83. Percent of total benthic invertebrates representing general taxonomic groups collected in benthic grabs, summed for all stations.

Taxon	Total Abundance	% Abundance
Polychaeta	10834	63.494
Bivalva	2322	13.608
Crustacea	2167	12.700
Gastropoda	410	2.403
Oligochaeta	397	2.327
Echinodermata	286	1.676
Nermertea	150	0.879
Phoronida	147	0.862
Sipuncula	107	0.627
Polyplacophora	81	0.475
Cnidaria	54	0.316
Brachiopoda	39	0.229
Scaphopoda	35	0.205
Aplacophora	11	0.064
Tunicata	8	0.047
Hemichordata	6	0.035
Echiura	3	0.018
Arachnida	2	0.012
Byozoa	1	0.006
Porifera	1	0.006
Pycnogonida	1	0.006

Table 16. Total abundance and % fraction of all benthic invertebrate individuals collected across the entire study area.

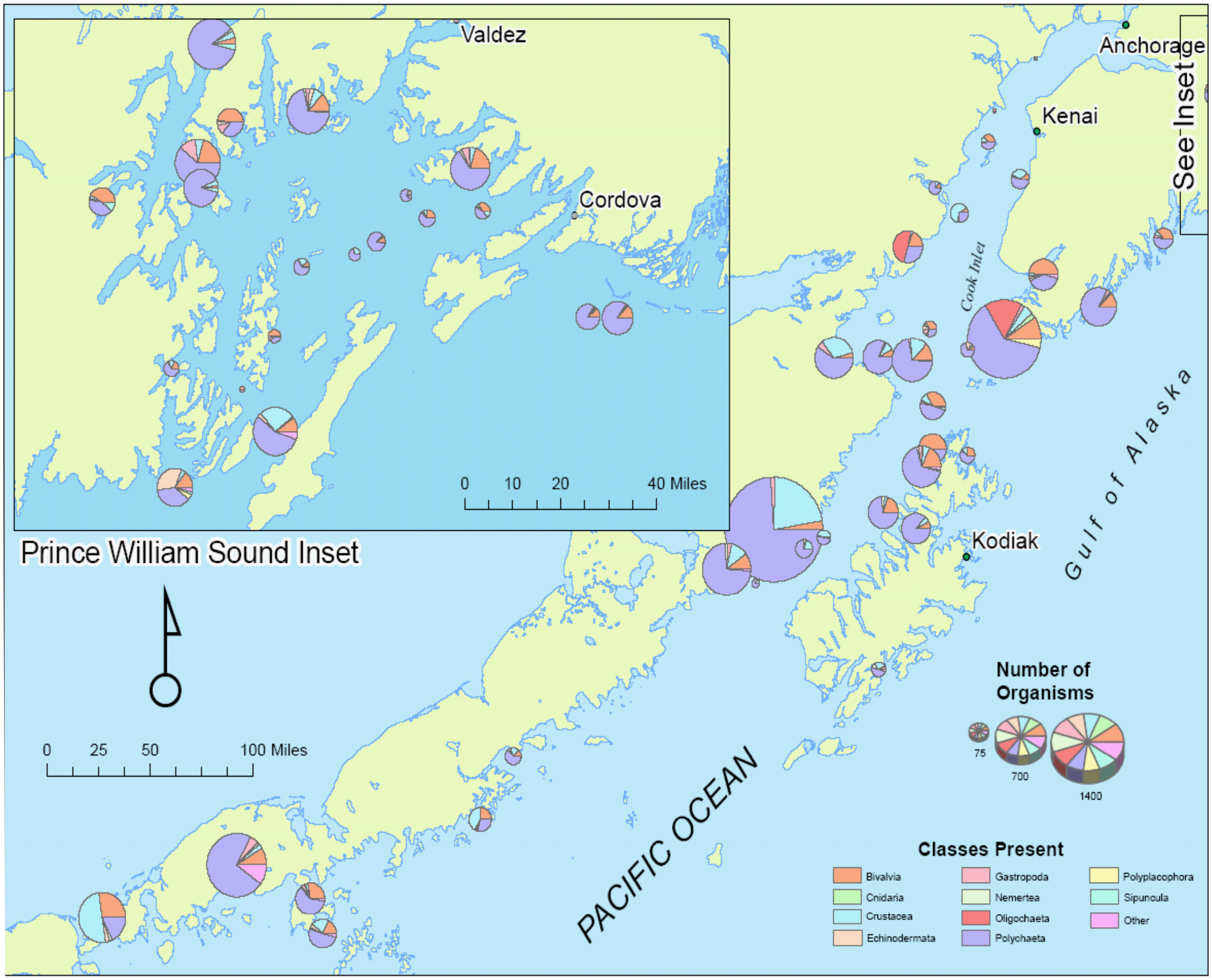


Figure 84. Total abundance (size of pie) and fraction of major taxonomic groups (pie slices) for benthic invertebrates at sampled stations across the study area's geographic range. Data are from family level or higher. Note that Prince William Sound is an inset on the left instead of at its normal geographical position at the eastern edge of the study area.

Table 17. Abundance, occurrence, and fraction of all invertebrates for major taxonomic groups and for family (or higher) subgroups summed for all stations. The lighter shaded rows indicate the contributions for each major taxonomic group and are presented in order of % abundance to total in vertebrate abundance at all sites. Within each major taxonomic group, families (or higher) contributions are listed.

Family or Higher Taxonomic Level	Number of stations where occurred	total abundance at all stations	% abundance of all invertebrates
Annelids	**54**	**11231**	**65.821**
Polychaeta	**54**	**10834**	**63.494**
Spionidae	45	3169	18.573
Lumbrineridae	41	953	5.586
Oweniidae	39	879	5.152
Capitellidae	33	770	4.513
Cirratulidae	41	581	3.405
Polynoidae	21	497	2.913
Maldanidae	33	474	2.778
Sabellidae	23	416	2.438
Syllidae	16	408	2.391
Nephtyidae	46	298	1.747
Ampharetidae	29	276	1.618
Magelonidae	20	232	1.360
Paraonidae	32	228	1.336
Orbiniidae	31	209	1.225
Hesionidae	8	187	1.096
Trichobranchidae	30	178	1.043
Sternaspidae	18	156	0.914
Sigalionidae	25	144	0.844
Terebellidae	25	139	0.815
Nereidae	10	95	0.557
Phyllodocidae	20	85	0.498
Goniadidae	20	66	0.387
Chaetopteridae	16	61	0.358
Onuphidae	16	55	0.322
Cossuridae	14	48	0.281
Glyceridae	15	45	0.264
Serpulidae	3	33	0.193
Pectinariidae	13	32	0.188
Opheliidae	14	28	0.164
Scalibregmidae	10	20	0.117
Apistobranchidae	3	10	0.059
Flabelligeridae	6	10	0.059
Pholoididae	2	10	0.059
Polychaeta	6	10	0.059
Spirorbidae	4	9	0.053
Sphaerodoridae	3	8	0.047
Arabellidae	4	5	0.029
Dorvilleidae	3	4	0.023
Chrysopetalidae	3	3	0.018
Sabellariidae	3	3	0.018
Euphrosinidae	1	1	0.006

Family or Higher Taxonomic Level	Number of stations where occured	total abundance at all stations	% abundance of all invertebrates
Oligochaeta	2	397	2327
Bivalva	**50**	**2322**	**2.327**
Thyasiridae	33	784	13.608
Tellinidae	35	326	4.595
Nuculanidae	30	225	1.911
Unidentified Bivalvia	24	221	1.319
Nuculidae	24	142	1.295
Mytilidae	12	120	0.832
Montacutidae	13	112	0.703
Turtoniidae	2	98	0.656
Lucinidae	5	71	0.574
Veneridae	13	30	0.416
Carditidae	9	26	0.152
Hiatellidae	3	26	0.152
Myidae	7	24	0.141
Astartidae	4	19	0.111
Cardiidae	10	19	0.111
Solenidae	3	18	0.105
Thraciidae	4	17	0.100
Lyonsiidae	5	16	0.094
Mactridae	6	13	0.076
Pandoridae	4	8	0.047
Pectinidae	2	2	0.012
Ungulinidae	2	2	0.012
Kelliidae	1	1	0.006
Limidae	1	1	0.006
Crustacea	**52**	**2167**	**12.700**
Balanidae	11	679	3.980
Lysianassidae	9	305	1.788
Leuconidae	37	284	1.665
Corophiidae	3	191	1.119
Ampeliscidae	22	139	0.815
Isaeidae	11	100	0.586
Pinnotheridae	14	57	0.334
Haustoriidae	5	46	0.270
Janiridae	1	46	0.270
Phoxocephalidae	16	46	0.270
Amphipoda	13	41	0.240
Oedicerotidae	16	38	0.223
Diastylidae	20	36	0.211
Caprellidea	2	27	0.158
Gnathiidae	4	17	0.100
Stenothoidae	3	14	0.082
Eusiridae	3	11	0.064
Gammaridae	3	11	0.064
Lampropidae	5	10	0.059
Munnidae	4	9	0.053
Pardaliscidae	3	8	0.047
Podoceridae	2	8	0.047

Family or Higher Taxonomic Level	Number of stations where occured	total abundance at all stations	% abundance of all invertebrates
Atelecyclidae	1	5	0.029
Dexaminidae	**1**	**4**	0.023
Ischyroceridae	3	5	0.023
Microcerberidae	1	5	0.023
Paguridae	4	5	0.023
Crangonidae	3	3	0.018
Hippolytidae	1	3	0.018
Ampithoidae	1	2	0.012
Campylaspidae	2	2	0.012
Cirripedia	1	2	0.012
Cumacea	2	2	0.012
Pleustidae	2	2	0.012
Synopiidae	2	2	0.012
Atylidae	1	1	0.006
Cancridae	1	1	0.006
Decapoda	1	1	0.006
Majidae	1	1	0.006
Sphaeromatidae	1	1	0.006
Gastropada	**36**	**410**	**2.403**
Unidentified Gastropoda	14	99	0.058
Pyramidellidae	16	87	0.510
Rissoidae	9	32	0.188
Columbellidae	7	28	0.164
Diaphanidae	2	25	0.147
Retusidae	5	24	0.141
Cephalaspidea	2	22	0.129
Turridae	11	19	0.111
Cylichnidae	9	18	0.105
Trochidae	9	15	0.088
Naticidae	5	7	0.041
Calyptraeidae	1	5	0.029
Olividae	2	5	0.029
Cancellariidae	2	3	0.018
Nassariidae	1	3	0.012
Lacunidae	1	2	0.012
Lepetidae	1	2	0.012
Onchidorididae	1	2	0.012
Scaphandridae	1	2	0.012
Turritellidae	2	2	0.116
Aglajidae	1	1	0.006
Conidae	1	1	0.006
Dendronotidae	1	1	0.006
Eulimidae	1	1	0.006
Gastropteridae	1	1	0.006
Haminoeidae	1	1	0.006
Muricidae	1	1	0.006
Neptuneidae	1	1	0.006
Echinodermata	**30**	**286**	**1.676**
Amphiuridae	11	161	0.944

Family or Higher Taxonomic Level	Number of stations where occured	total abundance at all stations	% abundance of all invertebrates
Echinarachniidae	5	30	0.176
Ophiuroidea	11	27	0.158
Ophiuridae	5	22	0.129
Holothuroidea	6	12	0.070
Echinoidea	2	7	0.041
Molpadiidae	4	7	0.014
Ophiacanthidae	1	4	0.023
Porcellanasteridae	3	4	0.023
Strongylocentrotidae	1	4	0.023
Asteroidea	2	2	0.012
Cucumariidae	2	1	0.012
Ophiactidae	1	1	0.012
Unidentified Echinodermata	1	1	0.006
Schizasteridae	1	1	0.006
Nemertea	**39**	**150**	**0.879**
Phoronida	**11**	**147**	**0.862**
Sipuncula	**14**	**107**	**0.627**
Golfingiidae	8	85	0.498
Unidentified Sipuncula	6	**21**	**0.123**
Sipunculidae	1	1	0.006
Polyplacophora	**5**	**81**	**0.475**
Schizoplacidae	1	60	0.352
Lepidopleuridae	2	19	0.111
Polyplacophora	2	2	0.012
Cnidaria	**12**	**54**	**0.316**
Actiniaria	1	34	0.199
Cerianthidae	4	9	0.053
Anthozoa	4	6	0.035
Pennatulidae	4	4	0.023
Virgulariidae	1	1	0.006
Brachiopoda	**3**	**39**	**0.229**
Laqueidae	2	20	0.117
Cancellothyrididae	2	19	0.111
Scaphopoda	**13**	**35**	**0.205**
Dentaliidae	9	24	0.141
Siphonodentaliidae	3	10	0.059
Scaphopoda	1	1	0.006
Aplacophora	**6**	**11**	**0.064**
Chaetodermatidae	6	11	0.064
Tunicata	**6**	**8**	**0.047**
Ascidiacea	4	5	0.029
Molgulidae	2	3	0.018
Hemichordata	**4**	**6**	**0.035**
Enteropneusta	4	6	0.035
Echiura	**3**	**3**	**0.018**
Echiuridae	3	3	0.018
Arachnida	**2**	**2**	**0.012**
Acarina	2	2	0.012

Family or Higher Taxonomic Level	Number of stations where occured	total abundance at all stations	% abundance of all invertebrates
Bryozoa	**1**	**1**	**0.006**
Porifera	**1**	**1**	**0.006**
Hyalospongia	1	1	0.006
Pycnogonida	**1**	**1**	**0.006**

Metal	Units	Mean	Stdev	Median	Max	Min	N
Arsenic	ug/g	3.706	3.140	2.540	15.200	0.670	95
Cadmium	ug/g	0.003	0.018	0.000	0.140	0.000	95
Chromium	ug/g	0.219	0.372	0.000	2.300	0.000	95
Copper	ug/g	0.975	1.080	0.7000	10.400	0.360	95
Lead	ug/g	0.022	0.100	0.000	0.860	0.000	95
Mercury	ug/g	0.024	0.024	0.017	0.186	0.000	95
Nickel	ug/g	3.429	4.628	2.500	39.600	0.300	95
Selenium	ug/g	0.217	0.652	0.000	5.740	0.000	95
Silver	ug/g	0.000	0.000	0.000	0.000	0.000	95
Tin	ug/g	8.475	8.698	4.510	35.900	0.740	95
Zinc	ug/g	11.327	2.432	11.000	18.000	6.600	95
Arsenic	ug/g	3.706	3.140	2.540	15.200	0.670	95

Table 18. Summary statistics for fish tissue metal concentrations (ug/g, wet weight) of whole fish analyses at all EMAP stations. More than one fish species was analyzed at several stations.

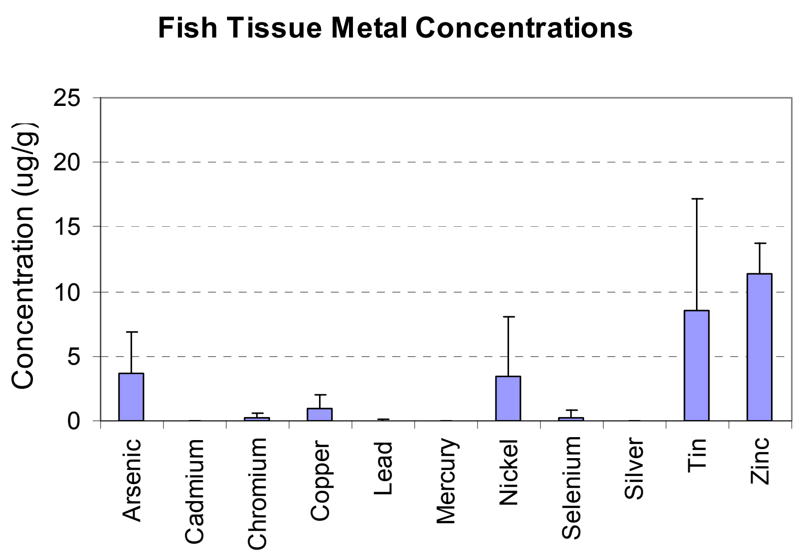


Figure 85. Summary statistics for fish tissue metal concentrations (ug/g wet weight) of whole fish analyses at all Southcentral Alaska EMAP stations. Data are means and standard deviations for all fish. More than one fish species was analyzed from several stations.

Contaminant	Units	Mean	Stdev	Median	Max	Min	N
Cyclopentadienes							
Aldrin	ng/g	0.005	0.048	0.000	0.470	0	95
Dieldrin	ng/g	0.010	0.098	0.000	0.940	0	95
Endrin	ng/g	0.000	0.000	0.000	0.000	0	95
Chlordanes							
Alpha-Chlordane	ng/g	0.025	0.064	0.000	0.320	0	95
Heptachlor	ng/g	0.005	0.048	0.000	0.470	0	95
Heptachlor Epoxide	ng/g	0.000	0.000	0.000	0.000	0	95
Hexachlorobenzene	ng/g	0.098	0.257	0.000	2.100	0	95
Trans-Nonachlor	ng/g	0.134	0.219	0.000	1.000	0	95
Other Herbicides/ Pesticides							
Endosulfan I	ng/g	0.000	0.000	0.000	0.000	0	95
Endosulfan II	ng/g	0.000	0.000	0.000	0.000	0	95
Endosulfan Sulfate	ng/g	0.000	0.000	0.000	0.000	0	95
Lindane	ng/g	0.025	0.089	0.000	0.480	0	95
Mirex	ng/g	0.000	0.000	0.000	0.000	0	95
Toxaphene	ng/g	0.000	0.000	0.000	0.000	0	95
Other Pollutants							
Total PCB	ng/g	0.235	0.413	0.000	2.040	0	95
p,p'-DDE	ng/g	0.279	0.377	0.180	1.800	0	95

Table 19. Summary statistics for fish tissue persistent organic pollutant concentrations (ng/g, wet weight) of whole fish analyses at all EMAP stations. More than one fish species was analyzed at several stations.

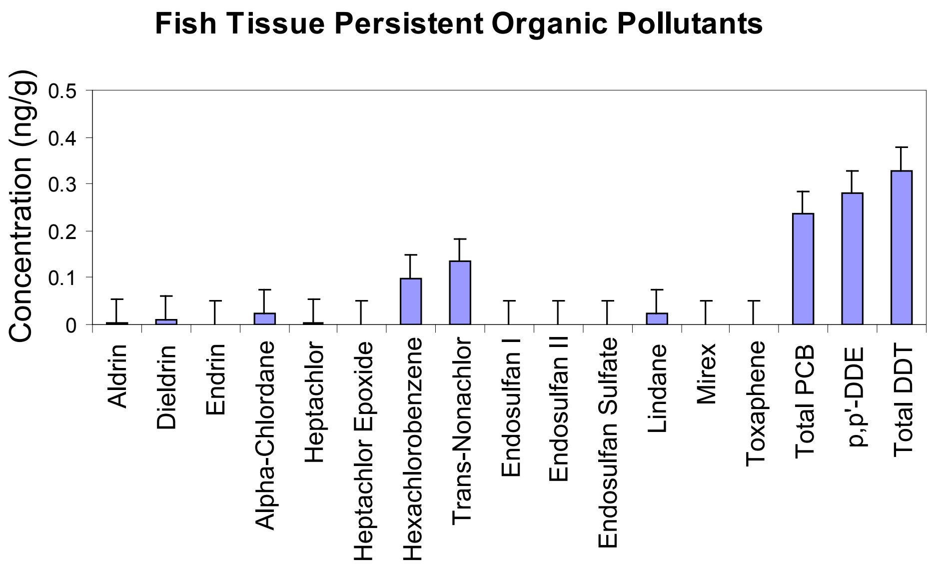


Figure 86. Summary statistics for fish tissue persistent organic pollutant concentrations (ug/g wet weight) of whole fish analyses at all Southcentral Alaska EMAP stations. Data are means and standard deviations for all fish. More than one fish species was analyzed from several stations.

Analyte	Units	EPA Risk Guidelines for Consumption Limits for Issuing Fish Advisories-risk to humans	FDA Action Limit	Maximum Value Found This Study
Arsenic (inorganic)	(μg/g)	1.2	76[a]	0.304*
Cadmium	(μg/g)	4.0	3[a]	0.140
Chromium	(μg/g)		12[a]	2.300
Lead	(μg/g)		1.5[a]	0.860
Mercury	(μg/g)	0.4	1	0.186
Nickel	(μg/g)		70[a]	39.600
Selenium	(μg/g)	20		5.740
Total Chlordane	(μg/g)	110	300	0.320
Aldrin	(μg/g)		300	0.470
Dieldrin	(μg/g)	2.5	300	0.940
Endosulfan	(μg/g)	24000		0
Endrin	(μg/g)	1200	300	0
Heptachlor epoxide	(μg/g)	4.0	300	0
Heptachlor	(μg/g)			0.470
Lindane	(μg/g)	30.7	100	0.480
Mirex	(μg/g)	800		0
Toxaphene	(μg/g)	36.3	500	0
Total DDT	(μg/g)	117	200	1.800
Total PCB	(μg/g)	20		2.040
*Inorganic arsenic estimated as 2% of total aresenic				
[a]Action limits for curstacea				

Table 20. Risk Guidelines for Issuing Fish Advisories (USEPA) and FDA Action Limits for Fish and Shellfish compared to maximum concentration measured for any fish during the Southcentral Alaska EMAP.

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