EPA/620-R-07/001
February 2007

Condition of Estuaries and Bays of Hawaii for 2002: A Statistical Summary

Office of Research and Development
U.S. Environmental Protection Agency
Washington, DC 20460

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Preface

This document is one of a series of statistical summaries for the U.S. Environmental Protection Agency (EPA), National Coastal Assessment Western regional component (NCA-West). The program is the coastal component of the nationwide Environmental Monitoring and Assessment Program (EMAP). This document is the first statistical summary for the program for the state of Hawaii estuaries and bays. The NCA in the western region is a collaborative effort between EPA and the states of Hawaii, Alaska, California, Oregon and Washington, the territories of Guam and American Samoa, and the National Oceanic and Atmospheric Administration (NOAA). The program is administered through the EPA and implemented through partnerships with a combination of federal and state agencies, universities and the private sector.

The appropriate citation for this report is:

Nelson, Walter G.; Brock, Richard; Lee II, Henry; Lamberson, Janet O.; Cole, Faith. 2007. Condition of Estuaries and Bays of Hawaii for 2002: A Statistical Summary. Office of Research and Development, National Health and Environmental Effects Research Laboratory, EPA/620-R-07/001.

Disclaimer

The information in this document has been funded wholly or in part by the U.S. Environmental Protection Agency under a Cooperative Agreement with the University of Hawaii (CR-832114). It has been subjected to review by the National Health and Environmental Effects Research Laboratory and approved for publication. Approval does not signify that the contents reflect the views of the agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

Acknowledgments

The NCA-West involves the cooperation of a significant number of federal, state, and local agencies. The project has been principally funded by the U.S. Environmental Protection Agency, Office of Research and Development. Moss Landing Marine Laboratory provided training for the Hawaii field crews.

Project wide information management support during initial phases of the Hawaii sampling effort was provided by SCCWRP as part of their cooperative agreement.

Many individuals within EPA made important contributions to Western Coastal EMAP. Critical guidance and vision in establishing this program was provided by Kevin Summers of Gulf Ecology Division. Virginia Engle and Linda Harwell of Gulf Ecology Division were extremely helpful with issues on data analysis. Tony Olsen of Western Ecology Division has made numerous comments which have helped to improve the quality of this document. Terrence Fleming of the Region 9 Office of EPA ably served as the regional liaison with the state participants. Robert Ozretich of WED performed a detailed review of the database contents used for this analysis, and we additionally thank him for his extensive quality assurance review of this document.

We thank Pam Tsai and Terrence Fleming of EPA Region 9, and Terence Teruya of the Hawaii Department of Health for their reviews of the draft report.

The success of the Western Coastal pilot has depended on the contributions and dedication of many individuals. Special recognition for their efforts is due the following participants:

University of Hawaii
- Julie Bailey Brock
- Bill Cooke
- Christine Frazier
- Alan Kam
- Andrea Messer
- Brian Paavo

Southern California Water Resources Research Project (SCCWRP)
- Larry Cooper
- Steve Weisberg

Moss Landing Marine Laboratory
- Russell Fairey
- Cassandra Roberts

Hawaii Department of Health
- Terence Teruya
- Denis Lau

U.S. Environmental Protection Agency
- Office of Research and Development
  - Tony Olsen
  - Steve Hale
  - John Macauley
  - Craig McFarlane
- Region 9
  - Terrence Fleming
  - Janet Hashimoto
  - Cindy Lin

Indus Corporation
- Patrick Clinton

CSC Corporation
- Dan Guzman

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List of Acronyms

BEST	Biomonitoring of Environmental Status and Trends Program
CDF	Cumulative distribution function
CEB	Coastal Ecology Branch, Western Ecology Division (EPA)
CFU	Colony Forming Units
CRM	Certified Reference Material
CVAA	Cold Vapor Atomic Adsorption
CWA	Clean Water Act
DO	Dissolved Oxygen Concentration
DQO	Data Quality Objectives
EMAP	Environmental Monitoring and Assessment Program
EPA	U.S. Environmental Protection Agency
ERI	Environmental Research Institute, Univ. of Conn
ERM	Effects Range Median
GAO	U. S. General Accounting Office
GCECD	Gas Chromatography and Electron Capture Detection
GCMS	Gas Chromatography/Mass Spectroscopy
GFAAS	Graphite Furnace Atomic Absorption Spectrometry
GIS	Geographic Information System
GPL	GPL Laboratories
HDOH	Hawaii Department of Health
ICPAES	Inductively-Coupled Plasma Atomic Emission Spectrometer
ICPMS	Inductively Coupled Plasma-Mass Spectrometry
ICPOES	Inductively Coupled Plasma Optical Emission Spectroscopy
IM	Information Manager
LCM	Laboratory Control Material
LCS	Laboratory Control Standard
MDL	Method Detection Limit
MQO	Methods Quality Objectives
MS	Matrix Spike
NCA	National Coastal Assessment
NCA-West	National Coastal Assessment - Western regional component
NCL	EPA’s National Contract Laboratory
NOAA	National Oceanic and Atmospheric Administration
N/P	Nitrogen to Phosphorus
NTU	Turbidity
ORD	EPA Office of Research and Development
PAH	Polyaromatic Hydrocarbons
PCB	Polychlorinated Biphenyls
QA/QC	Quality Assurance/Quality Control
QAC	Quality Assurance Coordinator
RL	Reporting Limit

RPD	Relative Percent Difference
RSG	Random Sampling Generator
RTS	Random Tessellation Stratified
SCCWRP	Southern California Water Resources Research Project
SDTP	Standardized Data Transfer Protocols
SRM	Standard Reference Material
TOC	Total Organic Carbon
TSS	Total Suspended Solids
WED	Western Ecology Division

Executive Summary

As a part of the National Coastal Assessment (NCA), the Environmental Monitoring and Assessment Program (EMAP) of US EPA initiated a pilot study of the estuarine resources of the main islands of Hawaii in 2002. This study provides the first probabilistic assessment of the condition of the estuaries and bays of Hawaii. The objectives of the program were: to assess the condition of estuarine resources of Hawaii based on a range of indicators of environmental quality using an integrated survey design; to establish a baseline for evaluating how the condition of the estuarine resources of Hawaii changes with time; to develop and validate improved methods for use in future coastal monitoring and assessment efforts in Hawaii; and to transfer the technical approaches and methods for designing, conducting and analyzing data from probability based environmental assessments to the state of Hawaii.

For Hawaii, the focus of the study during 2002 was all estuaries and the semienclosed coastal embayments of the state. The study utilized a stratified, random sampling design, with the base study consisting of 50 sites probabilistically assigned across the estuaries and bays of Hawaii. Additionally, an intensification study was conducted that consisted of 30 sites distributed among the urbanized estuaries located within the city of Honolulu on the south shore of the island of Oahu. The two data sets were analyzed separately. Cumulative distribution functions (CDFs) were produced using appropriate sampling area weightings to represent the areal extent associated with given values of an indicator variable for both the Hawaii estuaries and bays study and the Oahu urbanized estuary study.

The environmental condition indicators used in this study included measures of: 1) general habitat condition (depth, salinity, temperature, pH, sediment characteristics), 2) water quality indicators (chlorophyll *a*, nutrients, turbidity), 3) pollutant exposure indicators (dissolved oxygen concentration, sediment contaminants, invertebrate tissue contaminants, sediment toxicity), and 4) benthic condition indicators (diversity and abundance of benthic infauna and fishes).

In contrast to the mainland west coast, the indicators of general habitat condition (temperature, salinity, pH) showed relatively narrow ranges of values, e.g. water temperatures ranged only from 24 to 28 °C, with a maximum surface to bottom difference of 2.5 °C. About 73% of the area of the Hawaii estuaries and bays had sediments composed of sands, about 21% was composed of intermediate muddy sands, and about 6% was composed of muds. The Oahu urbanized estuaries (29 stations) had a greater proportion of area characterized by muds (62%), and less area characterized by sands (15%) or intermediate muddy sands (23%). The 90th percentile of area of the Hawaii estuaries and bays had a sediment TOC level of <1 %. The 90th percentile of area of the Oahu urbanized estuaries had a sediment TOC level of 2.1 %, which is expected given the more depositional character of these harbors.

The ranges of values of chlorophyll *a* were very similar between the Hawaii estuaries and bays and the Oahu urbanized estuaries. Maximum values were several orders of magnitude lower that those typical of coastal sites on the mainland west coast. Total nitrogen and phosphorus indicators generally showed similar patterns in their CDFs, with high values being observed in a very small percentage of area, thus generating extensive right hand tails to CDF distributions. For example, the average water column concentration of total nitrogen of Hawaii estuaries and bays ranged from 2.5 to 284 μg L^{-1}, but only 10% of estuarine area had nitrate values that exceeded concentrations of 67 μg L^{-1}. Approximately 40% of area of Hawaii estuaries and bays, and 74% of area in Oahu urbanized estuaries, had molar ratios of average water column total nitrogen to total phosphorus (N/P) values $\leq$ 16, suggesting nitrogen limitation.

Turbidity at the surface was below 3.4 ntu, representing 90% of area of both the Hawaii estuaries and bays and the Oahu urbanized estuaries. Valid Secchi depth readings were obtained at too few stations to provide a useful indicator of water clarity. In most cases this was due to the high degree of water clarity, such that the Secchi disk was still visible at the bottom. There was little indication of water column stratification within either the Hawaii estuaries and bays or the Oahu urbanized estuaries sampled, suggesting well mixed water columns are typical during the sampling period.

Among pollutant exposure indicators, approximately 7% of estuarine area for the Hawaii estuaries and bays and 8% in the Oahu urbanized estuaries had bottom water dissolved oxygen concentrations slightly $\leq$ 5 mg/L.

High values of potentially toxic metals generally occurred in a very small percentage of the area of Hawaii estuaries and bays sampled. With the exception of nickel for which the Effects Range Median concentration (ERM) is unreliable, chromium and mercury exceeded the ERM in $\leq$ 1% of the area. While concentrations of metals were generally higher in the Oahu urbanized estuaries, only copper and mercury exceeded the ERM values, and only in 4% and 5% of area, respectively. Eighty-seven percent of area of Hawaii estuaries and bays had undetectable concentrations of PAHs, as compared to only 8% of the area of the Oahu urbanized estuaries. Thirty-nine percent of the area of the Hawaii estuaries and bays had undetectable concentrations of PCBs, as compared to only 12% of the area of the Oahu urbanized estuaries. Thirty-four percent of the area of the Hawaii estuaries and bays had undetectable levels of DDT, as compared to 36% of the area of the Oahu urbanized estuaries. There were no exceedances of the ERM for any organic compound analyzed at any station.

Sediment toxicity tests with the amphipod *Ampelisca abdita* found no instances of elevated sediment toxicity (control corrected survivorship $\leq$ 80 %) in Oahu urbanized estuaries, but in approximately 10% of the area of Hawaii estuaries and bays amphipod survivorship was less than 80%.

Samples of two species of holothurians (sea cucumbers) were analyzed for tissue contaminants in pilot method development effort. Mercury, cadmium, and silver were undetected in holothurian tissue samples. PCBs and DDT were detected in some tissue samples at low levels, while PAHs and other pesticides were not detected. Total sample size was small and analytical issues were present with the tissue matrix, so that these results have high uncertainty.

Sampling for three bacterial indicators (enterococci, *Clostridium perfringens*, fecal coliforms) showed that in most cases the density of colony forming units was low in the waters of Hawaii. Approximately 4% of the area of Hawaii estuaries and bays and 13% of Oahu urbanized areas exceeded the Hawaii criterion for enterococci. The state enterococci criterion requires multiple samples, and the EMAP samples are single events, so results should not be interpreted to mean that locations with values above the criterion would technically violate water quality standards for bacteria.

Sediments were encountered at all but five stations in the 79 sites sampled. A total of 214 soft sediment benthic taxa were recorded. Benthic species richness on a per sample basis ranged from 4 to 52 species per sample in the samples from Hawaii estuaries and bays, and from 3 to 43 species per sample from the Oahu urbanized estuaries. On an areal basis, 50% of the area of the Hawaii estuaries and bays had a species richness less than 22 species per sample, and 90% had a richness less than 38.5 species per sample. The Oahu urbanized estuaries had a lower richness, with 50% of the area of these estuaries having fewer than 8 species per sample and 90% of the area having less than 21 species per sample.

Benthic infaunal density in samples from Hawaii estuaries and bays ranged from 5 to 1927 individuals per sample, and had a similar range of 8 to 1872 individuals per sample in samples from Oahu urbanized estuaries. On an areal basis, 50% of the area of the Hawaii estuaries and bays had a benthic density less than 270 individuals per sample, while in the Oahu urbanized estuaries, 50% of the area had benthic densities less than 76 individuals. Abundance was dominated by nematodes, oligochaetes, and polychaetes. Fully 57 % of the polychaete taxa are classified as nonindigenous in origin.

Underwater biological surveys to assess condition of hard substrata were carried out by SCUBA divers at 38 of the 79 (48%) completed survey sites, only three of which were located in the Oahu urbanized estuaries. Mean algal percent cover ranged between 0 and 70%, with 90% of the area of Hawaii estuaries and bays having an algal percent coverage less than approximately 14%. Corals were found at 26 of 38 (68%) stations surveyed. At sites with corals present, the number of coral species ranged from 1 to 9 per transect, with a mean of 4 species per transect. Coral coverage at the 26 sites with corals present ranged from 0.2% to 99.7% with a mean of 16.4%.

Visual censuses of fishes were carried out at 38 of the 79 Hawaiian stations and fishes were encountered at 34 of the 38 sites. In total, 110 species/taxa were encountered. The mean number of fish taxa per transect was 9, mean number of fishes/transect was 56 and mean estimated biomass was 19 g/m^2 per transect. Fish species richness on a per sample basis ranged from 0 to 31 species per transect in the samples from Hawaii estuaries and bays, and on an areal basis, approximately 50% of the area had less than 8 species per transect. Fish abundance per transect ranged from 0 to 278 individuals, and on an areal basis, 50% of the area had less than 48 individuals per transect. Estimated fish biomass per transect in samples from Hawaii estuaries and bays ranged from 0 to 18.6 kg per transect, and on an areal basis, 50% of the area had less than 0.6 kg per transect.

The NCA assessment of condition of Hawaiian waters represents the first quantitative estimates of condition across the Hawaiian Islands for many parameters. The project also successfully demonstrated the application of techniques, such as underwater visual surveys of hard substrates, which are new to the NCA program.

1.0 Introduction

1.1 Program background

Safeguarding the natural environment is fundamental to the mission of the US Environmental Protection Agency (EPA). The legislative mandate to undertake this part of the Agency's mission is embodied, in part, in the Clean Water Act (CWA). Sections of this Act require the states to report the condition of their aquatic resources and list those not meeting their designated use (Section 305b and 303d respectively). Calls for improvements in environmental monitoring date back to the late 1970's, and have been recently reiterated by the U. S. General Accounting Office (U.S. GAO, 2000). The GAO report shows that problems with monitoring of aquatic resources continue to limit states' abilities to carry out several key management and regulatory activities on water quality. At the national level, there is a clear need for coordinated monitoring of the nation's ecological resources. As a response to these needs at state and national levels, the EPA Office of Research and Development (ORD) has undertaken research to support the Agency's Regional Offices and the states in their efforts to meet the CWA reporting requirements. The Environmental Monitoring and Assessment Program (EMAP) is one of the key components of that research and EMAP-West is the newest regional research effort in EMAP. From 1999 through 2005, EMAP-West has worked to develop and demonstrate the tools needed to measure ecological condition of the aquatic resources in the 14 western states in EPA's Regions 8, 9, and 10.

The Coastal Component of EMAP-West began as a partnership with the states of California, Oregon and Washington, the National Oceanic and Atmospheric Administration, and the Biomonitoring of Environmental Status and Trends Program (BEST) of the U.S. Geological Survey to measure the condition of the estuaries of these three states. Sampling began during the summer of 1999 and the initial phase of estuarine sampling was completed in 2000. Data from this program is the basis for individual reports of condition for each state, as well as to providing data to the National Coastal Assessment.

The US EPA's National Coastal Assessment (NCA) is a five-year effort led by EPA's Office of Research and Development to evaluate the assessment methods it has developed to advance the science of ecosystem condition monitoring. This program has surveyed the condition of the Nation's coastal resources (estuaries and offshore waters) by creating an integrated, comprehensive coastal monitoring program among the coastal states to assess coastal ecological condition. The NCA is accomplished through strategic partnerships with all 24 U.S. coastal states. Using a compatible, probabilistic design and a common set of survey indicators, each state conducts the survey and assesses the condition of their coastal resources independently. Because of the compatible design, these estimates can be aggregated to assess conditions at the EPA Regional, biogeographical, and national levels.

This report provides a statistical summary of the data from 2002 for the estuarine systems of the state of Hawaii. A second assessment of condition of coastal resources of the Hawaiian Islands is planned for the summer of 2006.

1.2 The Hawaii Context for a Coastal Condition Assessment

The Hawaiian Islands are the most isolated archipelago in the world. This isolation has resulted in Hawaii's flora and fauna having the highest percentage of endemic species of anywhere in the world. This singular distinction has a downside: over the last 200 years with development and westernization, Hawaii has suffered the greatest number of known extinctions for any fauna and flora. There are many reasons for this great loss of native species; habitat destruction, pollution, human over use and the introduction of alien species have all played key roles.

The population of Hawaii has fluctuated through time. Following contact with the West, disease took its toll on the native population such that by the 1870's there were less than 60,000 individuals. In 1900 the population had grown to 154,000 people primarily through the importation of labor for agriculture. Today, Hawaii's population exceeds 1.2 million people and more than 90% live in urban centers. Because of the relatively small land area of the islands, development, population and economic growth have all exacerbated the impacts to native ecosystems. Human population growth in Hawaii is a principal driver for many ecological stressors such as habitat loss, pollution, and nutrient enhancement which alter coastal ecosystems and affect the sustainability of coastal ecological resources. Increased globalization of the economy is a major driver influencing the introduction of exotic species into port and harbors.

Estuaries represent less than 1% of the coastal ocean area around the Hawaiian Islands and these are best developed on the older islands (Kauai and Oahu). Most of these estuaries are small occupying less than a square kilometer. Pearl Harbor which is the largest remaining Hawaiian estuary has a water surface area of approximately 58 km^2 and is the country's largest naval port. However, historically, estuarine waters were once more important. In the Moiliili-Waikiki-Kewalo districts of Honolulu on Oahu, approximately 48% of the land area was formerly occupied by wetland/estuarine habitat in 1887. Today these aquatic features are absent and remaining estuarine waters are all channelized conduits that rapidly transport storm water runoff directly to the sea. Sedimentation problems associated with land use changes may be especially acute in coastal areas of Hawaii because of the combination of steep coastal watersheds, high seasonal rainfall, and agricultural and other land development.

Estuaries serve as important nursery habitat for a number of commercial and recreational Hawaiian fishery resources. These aquatic features also serve as natural biofilters sequestering sediment and pollutants adsorbed to particulate materials thus lessening the impact of storm water runoff to adjacent coral reefs. The development

of the hinterland surrounding most of Hawaii's largest estuaries with concurrent pollution and alien species introductions has resulted in tremendous changes to the abundance and species composition of important estuarine species. Causal mechanisms responsible for these changes have not been quantitatively defined and the rate of these changes has not been measured.

Within estuaries and coastal embayments, benthic environments are areas where many types of impacts from the stressors described above will tend to accumulate. Deposition of toxic materials, accumulation of sediment organics, and oxygen deficiency of bottom waters typically have a greater impact on benthic organisms than on planktonic and nektonic organisms because of their more sedentary nature. Long-term studies of the macrobenthos (Reish, 1986, Holland and Shaughnessey, 1986) demonstrate that macrobenthos is a sensitive indicator of pollutant effects. Benthic assemblages are also closely linked to both lower and higher trophic levels, as well as to processes influencing water and sediment quality, and therefore appear to integrate responses of the entire estuarine system (Leppakoski, 1979; Holland and Shaughnessey, 1986).

Quantitative baseline information and establishment of long-term comprehensive monitoring programs are needed as a first step for any rational program of pollution abatement and habitat restoration. Not only should the impacted areas be studied but parallel studies must be undertaken in remaining high quality habitats to ascertain if mitigation programs are being successful.

The principal population and commercial center for Hawaii is on the south shore of Oahu, in an area encompassing Pearl Harbor, the Port of Honolulu, and several other estuaries or embayments that are highly altered and surrounded by a high density urban setting. The rest of the Hawaiian Islands has a much lower population density. While it may be presumed that the magnitude of anthropogenic impacts will be highest in the urbanized estuaries of Oahu, this hypothesis has not yet been tested. Therefore, in addition to the assessment of condition for the Hawaiian Islands as a whole, an intensified level of sampling was conducted within the Oahu urbanized estuaries.

1.3 Objectives

The EMAP sampling program conducted in Hawaii in 2002 was a pilot program to determine the feasibility of conducting condition assessments of coastal resources throughout the island group and had the following objectives:

1. To assess the condition of estuarine and coastal embayment resources of Hawaii based on a range of indicators of environmental quality using an integrated survey design;

2. To establish a baseline for evaluating how the conditions of the estuarine resources of Hawaii may change with time;

3. To develop and validate improved methods for use in future coastal monitoring and assessment efforts in Hawaii and U.S. Pacific Island territories;

4. To transfer the technical approaches and methods for designing, conducting and analyzing data from probability based environmental assessments to the state of Hawaii.

2.0 Methods

2.1 Sampling Design and Statistical Analysis Methods

2.1.1 Background

The EMAP approach to evaluating the condition of ecological resources is described in reports such as Diaz-Ramos et al. (1996), Stevens (1997), Stevens and Olsen (1999) and is also presented in summaries provided on the internet at the URL:

http://www.epa.gov/nheerl/arm/index.htm

A brief summary from these documents follows.

Given the fact that it is generally impossible to completely census an extensive resource, such as the set of all estuaries and bays in Hawaii, a more practical approach to evaluating resource condition is to sample selected portions of the resource using probability based sampling. Studies based on random samples of the resource rather than on a complete census are termed sample surveys. 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 inventory, consumer price index, labor surveys, and such activities as voter opinion surveys.

A 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 scrips (Bourgeois et al., 1998) was 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 Hawaii. 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 (see Section 2.2) 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 estuarine resource class. Because of the area weights, estimates provided in this report of the percentage of estuarine area associated with given values of the indicators are not the same as simple proportions based on the number of stations in a condition category.

2.1.2 2002 Hawaii Sampling Design

The assessment of the condition of Hawaiian estuaries and coastal embayments included two design elements. The base study was an assessment of these water bodies for the main Hawaiian Island chain. An intensification study was also conducted to assess the condition of the urbanized ports and harbors of the south shore of the Island of Oahu adjacent to Mamala Bay. The complete Hawaii assessment combines data from all stations in both design elements for analysis, using the inclusion probabilities, defined as the total estuarine area in km^2 within a given design stratum
(= estuarine size class), to weight the representation of samples in the combined analysis.

The Hawaii sampling frame was constructed as a GIS coverage that included the total area of the polygons representing the estuaries and coastal bays in the state. Available GIS coverages were not perfect representations of the estuarine resource, and so the coverages were defined to ensure that they included the resource, but may have possibly included some nearby land or inland water. The inland boundary of the sampling frame was defined as the head of salt water influence, while the seaward boundary was defined by the confluence with the ocean. Sample locations could fall within any water depth contained within the estuarine resource which was bounded by the shoreline. Emergent salt marsh areas, if present, were not included in the sampling frame. For coastal bays, the offshore boundary was constrained to a depth of 60 ft in order to be conservative in terms of safety for the SCUBA divers used to obtain bottom samples. There was also considerable uncertainty associated with the bathymetry used to define this offshore boundary.

The sampling design for the 2002 Hawaii base study included all estuaries and coastal bays of the main Hawaiian Island chain, and consisted of a total of 50 sites (Sites 1-50, Table 2.1-1, Figures 2.1-1, 2.1-2, 2.1-3, 2.1-4). Sample site selection utilized four hexagonal grid sizes reflecting these four estuary size classes: 0.55, 2.5, 4.98 and

6.78 km^2 (see Table 2.1-1 for association of grid size with estuary stratum). Approximately equal sampling effort was placed in each of four design strata to ensure that there was at least some level of sampling across the entire range of sizes of estuaries and bays. No alternate or oversample sites were selected during the design, and thus any sites which could not be sampled were not replaced. Improvements to subsequent versions of the RSG produced after this study allow incorporation of alternate sample sites if future assessment studies for Hawaii.

The sampling design for the 2002 Hawaii intensification study included Pearl Harbor, Honolulu Harbor, and the other ports, harbors, marinas and canals located along the waterfront of the city of Honolulu, with Mamala Bay, and consisted of a total of 30 sites (Sites 51-80, Table 2.1-1, Figure 2.1-5). The design for this intensification study incorporated 2 hexagonal grid sizes: 0.86 and 1.24 km^2. The hexagonal grid sizes were used to locate random sample sites within a total of two strata representing differing total areas of the estuarine resource in the Oahu urbanized estuaries (see Table 2.1-1 for association of grid size with estuary stratum). No alternate or oversample sites were selected during the design, and thus any sites which could not be sampled were not replaced.

2.1.3 Field Sampling

Field sampling began on April 1, 2002 and concluded on October 30, 2002. Samples from the Hawaii base study were completed by September 30, 2002. Sampling for the urbanized estuaries of Oahu began in April, but did not conclude until the end of October. Pearl Harbor was sampled between Oct. 7-11, 2002. The extended period required for field work resulted from the logistical issues associated with sampling the multiple islands of the Hawaiian Island chain, and from delays in receiving permission to sample within military areas on Oahu.

Sampling methods are described in detail in the following sections. Water column measurements and samples were obtained from small boats using standard NCA methods following guidance provided in the NCA Quality Assurance Project Plan document (US EPA, 2001). One exception to the use of small boats was a “walk-in” station located in Halekou Pond on Oahu. Bottom samples and other biotic measurements were obtained by divers using either snorkel or SCUBA gear. Boats used in sampling included a kayak to reach a shallow site in Pearl Harbor, a 22 ft. boat with outboard motor used for much of the sampling on the island of Oahu, and a 43 ft. chartered vessel used for sampling stations located on the other islands. Because of the predominant use of small boats, weather conditions were generally moderate, with maximum wind speeds estimated at 10 mph. Drizzle was encountered only in sampling station HI02-006 at Wahiawa Bay, Kauai.

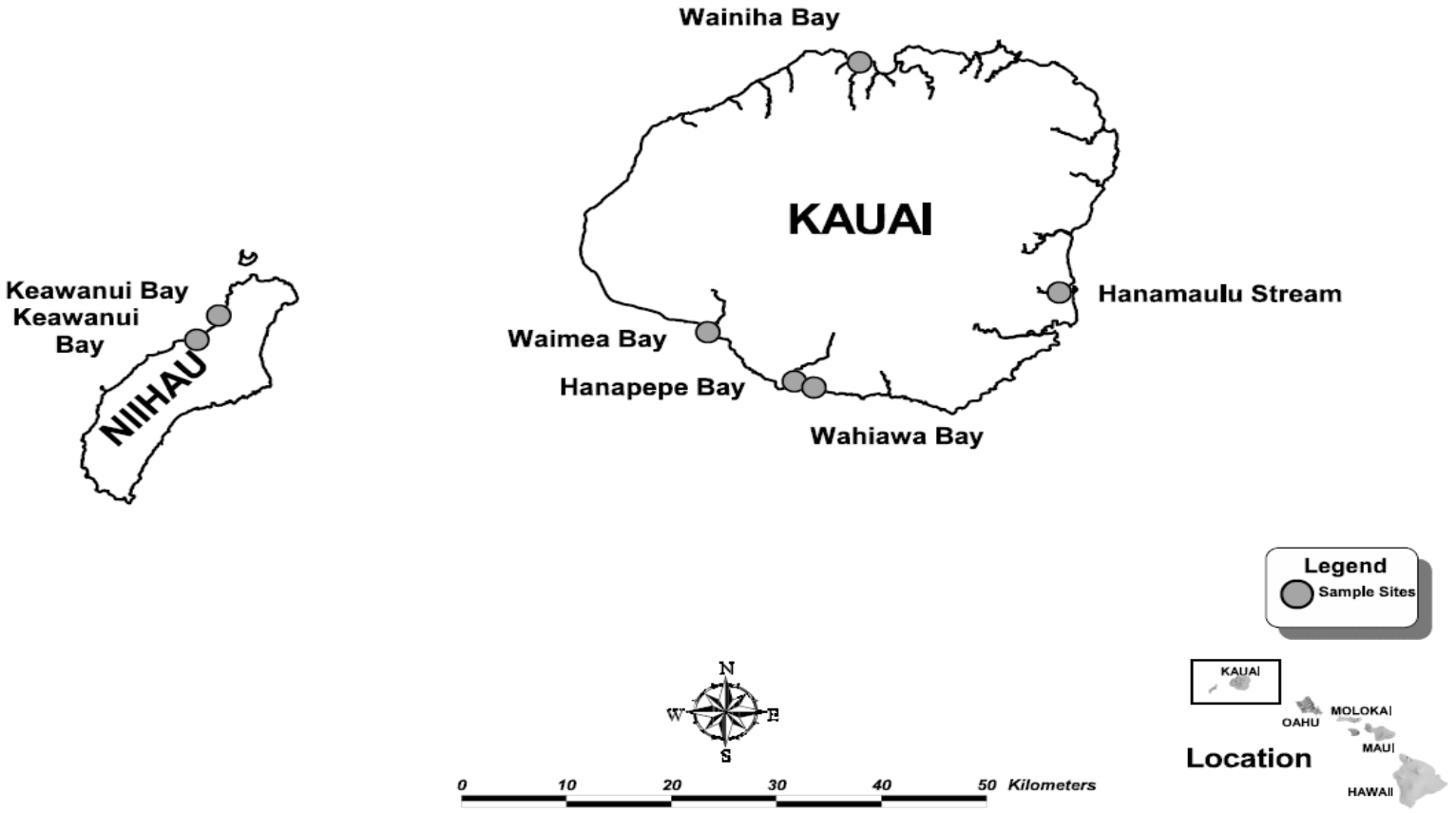

Figure 2.1-1. Location of Hawaii EMAP survey sites on the islands of Kauai and Niihau.

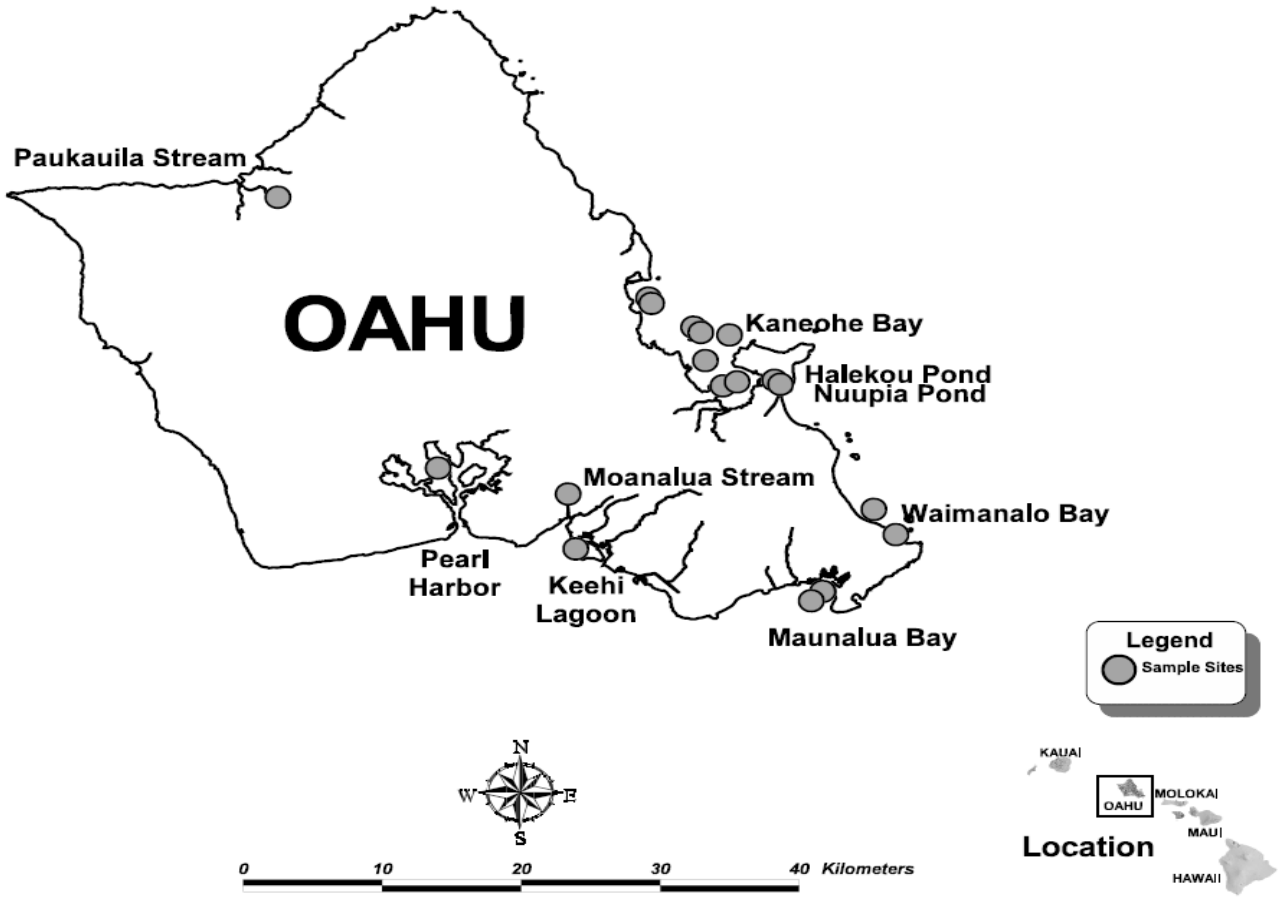

Figure 2.1- 2. Location of Hawaii EMAP survey sites on the island of Oahu, excluding the Oahu urbanized estuary study sites.

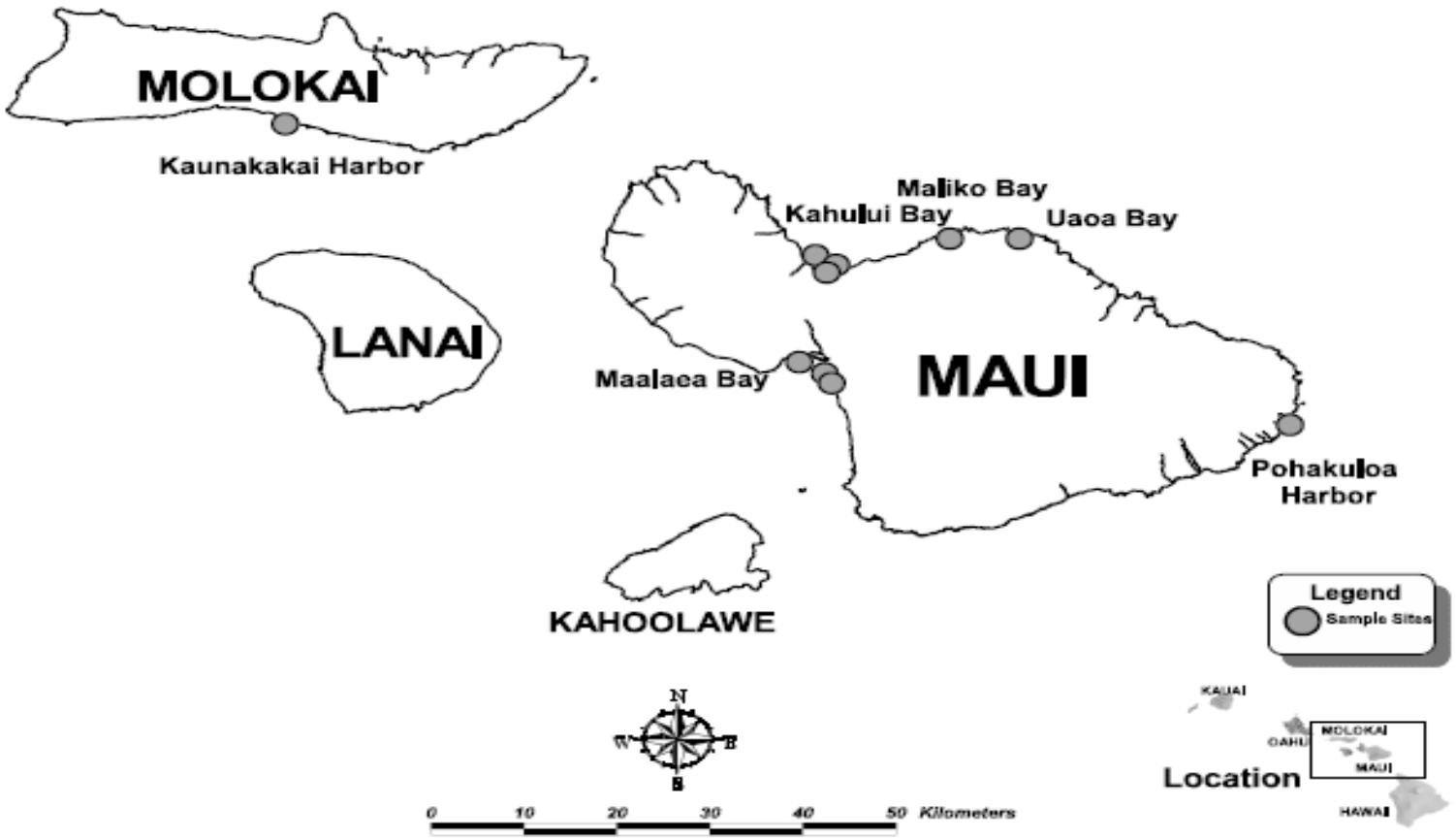

Figure 2.1-3. Location of Hawaii EMAP survey sites on the islands of Maui and Molokai.

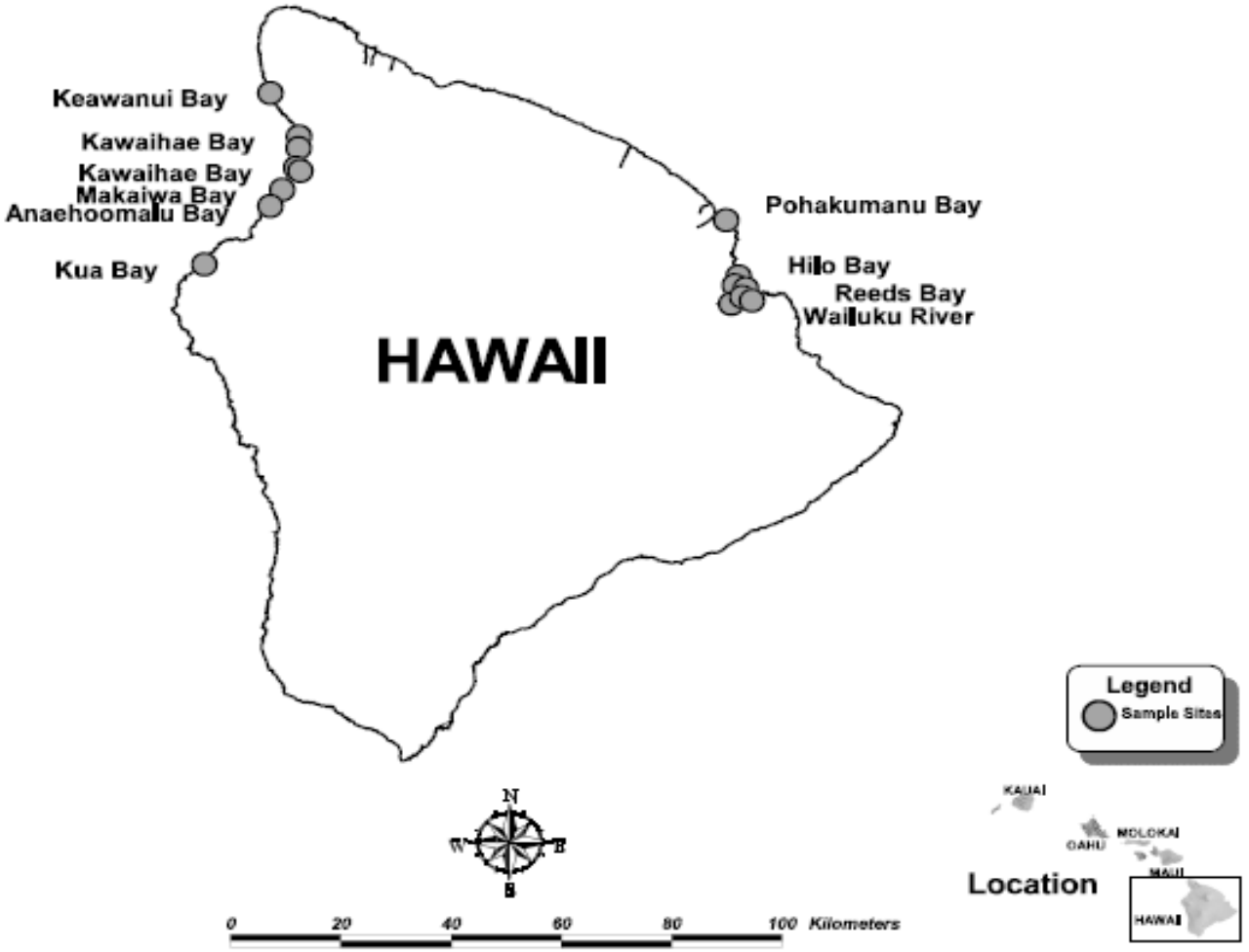

Figure 2.1-4. Location of Hawaii EMAP survey sites on the island of Hawaii.

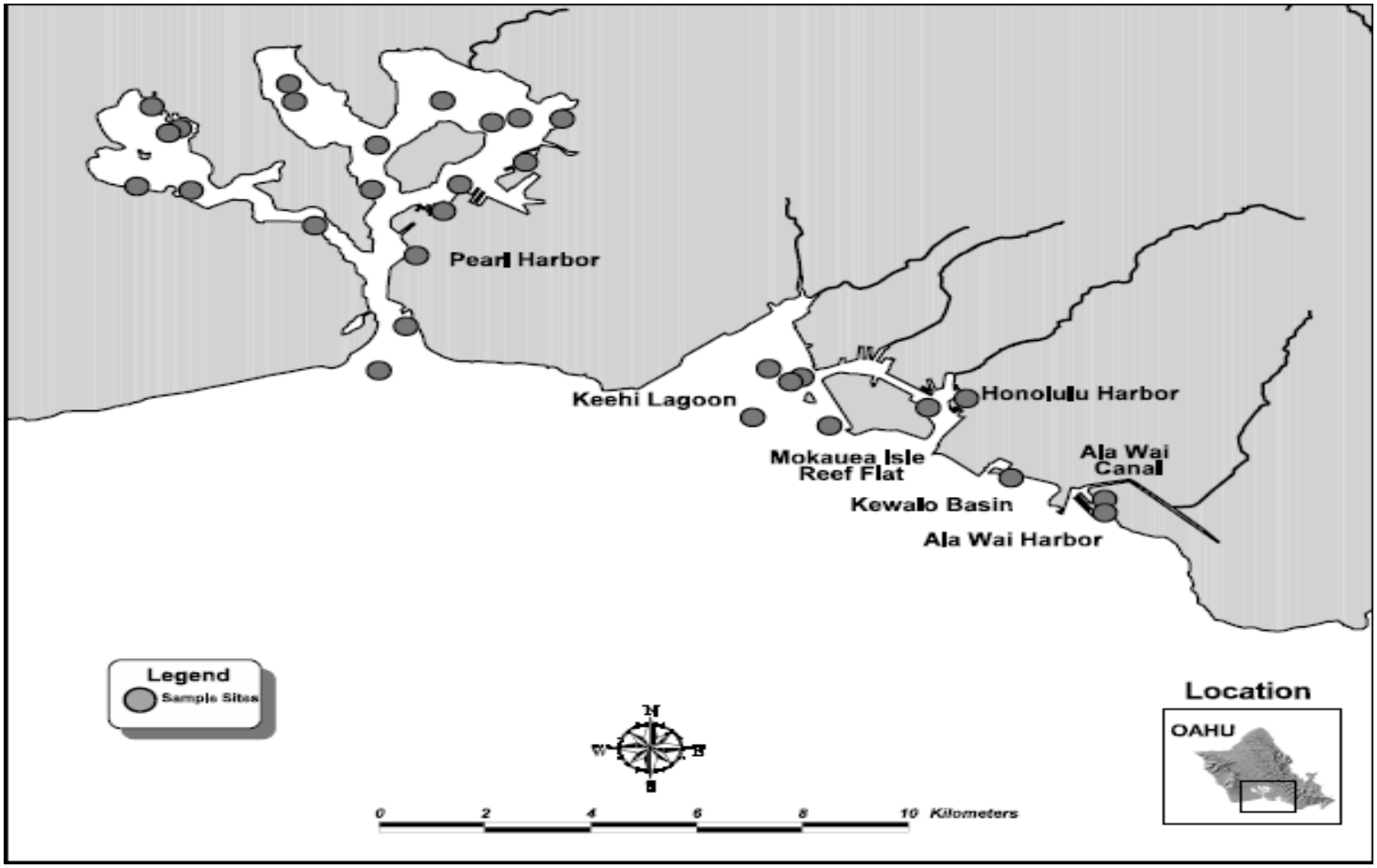

Figure 2.1-5. Location of Hawaii EMAP survey sites for the intensification study within the urbanized estuaries on the island of Oahu.

Table 2.1-1. Hawaii sampling sites with station coordinates of locations sampled. Station numbers 51-80 constitute the Oahu urban estuaries intensive study. The Frame Area represents the total estuarine area within a stratum.

EMAP Sta. No.	Latitude	Longitude	Estuary or Coastal Bay	Hex Size	Frame Area km^2	Stratum
HI02-0001	21.965	-160.124	Keawanui Bay (Niihau)	4.98	72.873	HI00-003
HI02-0002	21.941	-160.144	Keawanui Bay (Niihau)	4.98	72.873	HI00-003
HI02-0003	22.217	-159.534	Wainiha Bay	2.5	26.160	HI00-002
HI02-0004	21.951	-159.673	Waimea Bay	4.98	72.873	HI00-003
HI02-0005	21.903	-159.593	Hanapepe Bay	2.5	26.160	HI00-002
HI02-0006	21.897	-159.575	Wahiawa Bay	0.55	5.168	HI00-001
HI02-0007	21.991	-159.349	Hanamaulu Stream	2.5	26.160	HI00-002
HI02-0008	21.575	-158.096	Paukauila Stream	0.55	5.168	HI00-001
HI02-0009	21.498	-157.839	Kaneohe Bay	6.78	120.848	HI00-004
HI02-0010	21.494	-157.837	Kaneohe Bay	6.78	120.848	HI00-004
HI02-0011	21.372	-157.986	Pearl Harbor	6.78	120.848	HI00-004
HI02-0012	21.476	-157.808	Kaneohe Bay	6.78	120.848	HI00-004
HI02-0013	21.472	-157.803	Kaneohe Bay	6.78	120.848	HI00-004
HI02-0014	21.470	-157.783	Kaneohe Bay	6.78	120.848	HI00-004
HI02-0015	21.451	-157.800	Kaneohe Bay	6.78	120.848	HI00-004
HI02-0016	21.352	-157.896	Moanalua Stream	0.55	5.168	HI00-001
HI02-0017	21.432	-157.788	Kaneohe Bay	6.78	120.848	HI00-004
HI02-0018	21.435	-157.778	Kaneohe Bay	6.78	120.848	HI00-004
HI02-0019	21.436	-157.752	Halekou Pond	0.55	5.168	HI00-001
HI02-0020	21.433	-157.748	Nuupia Pond	2.5	26.160	HI00-002
HI02-0021	21.311	-157.891	Keehi Lagoon	4.98	72.873	HI00-003
HI02-0022	21.339	-157.684	Waimanalo Bay	4.98	72.873	HI00-003
HI02-0023	21.320	-157.669	Waimanalo Bay	4.98	72.873	HI00-003
HI02-0024	21.278	-157.720	Maunalua Bay	4.98	72.873	HI00-003
HI02-0025	21.271	-157.728	Maunalua Bay	4.98	72.873	HI00-003
HI02-0026	21.085	-157.026	Kaunakakai Harbor	2.5	26.160	HI00-002
HI02-0027	20.919	-156.480	Kahului Bay	4.98	72.873	HI00-003
HI02-0028	20.907	-156.459	Kahului Bay	4.98	72.873	HI00-003
HI02-0029	20.898	-156.469	Kahului Harbor	2.5	26.160	HI00-002
HI02-0030	20.937	-156.341	Maliko Bay	0.55	5.168	HI00-001
HI02-0031	20.790	-156.499	Maalaea Bay	6.78	120.848	HI00-004
HI02-0032	20.936	-156.269	Uaoa Bay	2.5	26.160	HI00-002
HI02-0033	20.776	-156.473	Maalaea Bay	6.78	120.848	HI00-004
HI02-0034	20.764	-156.466	Maalaea Bay	6.78	120.848	HI00-004
HI02-0035	20.706	-155.994	Pohakuloa Harbor	0.55	5.168	HI00-001
HI02-0036	20.117	-155.887	Keawanui Bay (Hawaii)	0.55	5.168	HI00-001
HI02-0037	20.038	-155.839	Kawaihae Bay	6.78	120.848	HI00-004
HI02-0038	20.017	-155.840	Kawaihae Bay	6.78	120.848	HI00-004
HI02-0039	19.982	-155.845	Kawaihae Bay	6.78	120.848	HI00-004
HI02-0040	19.976	-155.838	Kawaihae Bay	6.78	120.848	HI00-004
HI02-0041	19.943	-155.870	Makaiwa Bay	0.55	5.168	HI00-001
HI02-0042	19.914	-155.891	Anaehoomalu Bay	2.5	26.160	HI00-002
HI02-0043	19.811	-156.007	Kua Bay	2.5	26.160	HI00-002
HI02-0044	19.873	-155.103	Pohakumanu Bay	2.5	26.160	HI00-002
HI02-0045	19.772	-155.084	Hilo Bay	6.78	120.848	HI00-004
HI02-0046	19.756	-155.091	Hilo Bay	6.78	120.848	HI00-004
HI02-0047	19.750	-155.072	Hilo Bay	6.78	120.848	HI00-004
HI02-0048	19.723	-155.098	Wailuku River	0.55	5.168	HI00-001
HI02-0049	19.735	-155.079	Hilo Bay	6.78	120.848	HI00-004

EMAP Sta. No.	Latitude	Longitude	Estuary or Coastal Bay	Hex Size	Frame Area km^2	Stratum
HI02-0050	19.728	-155.062	Reeds Bay	0.55	5.168	HI00-001
HI02-0051	21.378	-158.014	Pearl Harbor	0.13	0.210	Pearl00-010
HI02-0052	21.373	-158.009	Pearl Harbor	0.13	0.210	Pearl00-010
HI02-0053	21.383	-157.989	Pearl Harbor	0.07	0.011	Pearl00-011
HI02-0054	21.372	-158.011	Pearl Harbor	0.86	7.492	Pearl00-012
HI02-0055	21.359	-158.017	Pearl Harbor	0.86	7.492	Pearl00-012
HI02-0056	21.379	-157.988	Pearl Harbor	0.86	7.492	Pearl00-012
HI02-0057	21.359	-158.007	Pearl Harbor	0.86	7.492	Pearl00-012
HI02-0058	21.369	-157.973	Pearl Harbor	0.86	7.492	Pearl00-012
HI02-0059	21.379	-157.961	Pearl Harbor	0.86	7.492	Pearl00-012
HI02-0060	21.349	-157.987	Pearl Harbor	0.86	7.492	Pearl00-012
HI02-0061	21.359	-157.974	Pearl Harbor	1.24	20.341	Pearl00-013
HI02-0062	21.374	-157.952	Pearl Harbor	1.24	20.341	Pearl00-013
HI02-0063	21.360	-157.958	Pearl Harbor	1.24	20.341	Pearl00-013
HI02-0064	21.375	-157.947	Pearl Harbor	1.24	20.341	Pearl00-013
HI02-0065	21.354	-157.961	Pearl Harbor	1.24	20.341	Pearl00-013
HI02-0066	21.365	-157.946	Pearl Harbor	1.24	20.341	Pearl00-013
HI02-0067	21.373	-157.936	Pearl Harbor	1.24	20.341	Pearl00-013
HI02-0068	21.344	-157.966	Pearl Harbor	1.24	20.341	Pearl00-013
HI02-0069	21.318	-157.973	Pearl Harbor	1.24	20.341	Pearl00-013
HI02-0070	21.328	-157.968	Pearl Harbor	1.24	20.341	Pearl00-013
HI02-0071	21.288	-157.841	Ala Wai Canal	1.24	20.341	Pearl00-013
HI02-0072	21.285	-157.841	Ala Wai Harbor	1.24	20.341	Pearl00-013
HI02-0073	21.293	-157.858	Kewalo Basin	1.24	20.341	Pearl00-013
HI02-0074	21.318	-157.902	Keehi Lagoon Borrow Pit	1.24	20.341	Pearl00-013
HI02-0075	21.307	-157.905	Keehi Lagoon	1.24	20.341	Pearl00-013
HI02-0076	21.316	-157.896	Keehi Lagoon Reef Flat	1.24	20.341	Pearl00-013
HI02-0077	21.315	-157.898	Keehi Lagoon Reef Flat	1.24	20.341	Pearl00-013
HI02-0078	21.305	-157.891	Mokauea Isle Reef Flat	1.24	20.341	Pearl00-013
HI02-0079	21.311	-157.866	Honolulu Harbor	1.24	20.341	Pearl00-013
HI02-0080	21.309	-157.873	Honolulu Harbor	1.24	20.341	Pearl00-013

2.2 Data Analysis

Analysis of indicator data was conducted by calculation of cumulative distribution functions (CDFs), an analysis approach that has been used extensively in other EMAP coastal studies (Summers et al. 1993, Strobel et al. 1994, Hyland et al. 1996). The CDFs describe the full distribution of indicator values in relation to their areal extent across the sampling region of interest. The approximate 95% confidence intervals for the CDFs also were computed based on estimates of variance. A detailed discussion of methods for calculation of the CDF's used in EMAP analyses is provided in Diaz-Ramos et al. (1996).

The Horvitz-Thompson ratio estimate of the CDF is given by the formula:

$$\hat{F}(x_k) = \frac{\sum_{i=1}^{n} \frac{1}{\pi_i} I(y_i \le x_k)}{\hat{N}} \quad ; \quad \hat{N} = \sum_{i=1}^{n} \frac{1}{\pi_i}$$

$\hat{F}(x_k)$ = estimated CDF (proportion) for indicator value x_k

n = number of samples

y_i = the sample response for site i

x_k = the k th CDF response indicator

$$I(y_i \le x_k) = \begin{cases} 1, y_i \le x_k \\ 0, otherwise \end{cases}$$

π_i = selection probability for site i

$\hat{N}$ = the estimated population size

The selection probability for a site is 1/area of the hexagon, e.g. the hexagon area used for Hawaii estuaries and bays in the base study in the size class 4.98 km^2 (see Table 2.1-1). When calculating the mean for a variable, the same equation is used, with Y_i replacing the indicator function.

The Horvitz-Thompson unbiased estimate of the variance for the ratio estimate is given by the formula:

$$\hat{V}[\hat{F}(x_k)] = \frac{\sum_{i=1}^{n} \frac{d_i^2}{\pi_i^2} + \sum_{i=1}^{n}\sum_{j\neq 1}^{n} d_i d_j \left(\frac{1}{\pi_i}\frac{1}{\pi_j} - \frac{1}{\pi_{ij}} \right)}{\hat{N}^2} \quad ;$$

$$\hat{N} = \sum_{i=1}^{n} \frac{1}{\pi_i}, \quad d_i = I(y_i \le x_k) - \hat{F}(x_k), \quad d_j = I(y_j \le x_k) - \hat{F}(x_k)$$

$\hat{F}(x_k)$ = estimated CDF (proportion) for indicator value x_k

$$I(y_i \le x_k) = \begin{cases} 1, y_i \le x_k \\ 0, otherwise \end{cases}$$

x_k = the kth indicator level of interest

y_i = value of indicator for the ith unit sampled

π_i = inclusion density evaluated at the location of the ith sample point

π_{ij} = joint inclusion density evaluated at the locations of the ith and jthsample points

n = number of units sampled

The joint inclusion probabilities are given by

$$\pi_{ij} = \frac{(n-1) * \pi_i \pi_j}{n}$$

When estimating the CDF across several strata, the above estimates for each stratum must be combined. The equations are

$$\hat{F}(x_k) = \sum_{i=1}^{s} \left(\frac{A_i}{A} \right) \hat{F}_i(x_k)$$

$\hat{F}(x_k)$ = estimated CDF

$\hat{F}_i(x_k)$ = estimated CDF for stratum i

A_i = area for stratum i

S = number of strata

A = total area of all strata

and the variance estimate across strata is

$$\hat{V} = \sum_{i=1}^{s} \left(\frac{A_i}{A} \right)^2 \hat{V}_i$$

$\hat{V}$ = estimated variance for all strata

$\hat{V}_i$ = estimated variance for stratum i

A_i = area for stratum i

S = number of strata

A = total area of all strata

2.3 Indicators

The condition of Hawaii estuarine resources was evaluated by collecting data for a standard set of core environmental parameters at all stations within the survey (Table 2.3-1). Field procedures followed methods outlined in the US EPA National Coastal Assessment Field Operations Manual (US EPA, 2001b). The environmental indicators were similar to those used in previous EMAP estuarine surveys in other regions of the country (Weisberg et al., 1992; Macauley et al., 1994, 1995; Strobel et al., 1994, 1995; Hyland et al., 1996, 1998). Indicators were divided into classes representing general habitat condition (Habitat Indicators), condition of benthic and demersal faunal resources (Biotic Condition Indicators), and exposure to pollutants (Exposure Indicators). Habitat indicators describe the general physical and chemical conditions at the study site, and are often important in providing information used to interpret the results of biotic condition indicators (e.g., salinity and sediment grain size with regard to benthic community composition). Biotic condition indicators are measures of the status of the benthic biological resources in response to site environmental conditions. The exposure indicators used in this survey quantify the amounts and types of pollutant materials (metals, hydrocarbons, pesticides) that may be harmful to the biological resources present. Some indicators may overlap the above categories. For example, dissolved oxygen is clearly an indicator of habitat condition, but may also be considered an exposure indicator because of the potentially harmful effects of low dissolved oxygen levels to many members of the benthic community.

The Hawaii NCA program added several indicators to the NCA core group of parameters. Dissolved silicate was added because of its importance as a conservative tracer of groundwater input. Because of the extensive presence of hard bottom habitat in Hawaiian waters, indicators derived from quadrat and transect assessments of hard bottom communities were added, such as percent macroalgal and coral cover. In contrast to other states in the NCA program, bottom trawling was not feasible in Hawaii, and visual surveys of the entire fish community, rather than measurement of demersal fishes only, was carried out. Fish biomass estimates were added because they are a measure of importance in understanding the trophic structure of sample locations. Three bacterial indicators were also measured in the Hawaii NCA assessment.

Table 2.3-1. Core environmental indicators for the National Coastal Assessment survey. Supplemental indicators measured in Hawaii but not in other states participating in the National Coastal Assessment are indicated by *****. All fish visible in the water column were censussed visually in Hawaii, as contrasting with trawl samples of demersal species only for other states.

Habitat Indicators	**Benthic Condition Indicators**
Salinity	Infaunal species composition
Water depth	Infaunal abundance
pH	Infaunal species richness and diversity
Water temperature	(Demersal) fish species composition
Total suspended solids (TSS)	(Demersal) fish abundance, biomass*****
Chlorophyll *a* concentration	(Demersal) fish species richness and diversity
Nutrient concentrations (nitrate, nitrite, ammonium, orthophosphate, silicate*****)	External pathological anomalies in fish (not assessed)
Percent light transmission (not assessed)	Percent cover of dominants on hard bottom*****
Secchi depth	**Exposure Indicators**
Percent silt-clay of sediments	Dissolved oxygen concentration (DO)
Percent total organic carbon (TOC) in sediments	Sediment contaminants
	Holothurian tissue contaminants*****
	Sediment toxicity (*Ampelisca abdita* acute toxicity test)
	Bacteria*****

2.3.1 Water Measurements

2.3.1.1 Hydrographic Profile

Once a station was located and the vessel was anchored on station, a continuous, vertical water column profile was carried out using a Hydrolab® H_2O Datasonde coupled to a field display and lap top computer. The instrument measured temperature, depth, dissolved oxygen, pH and turbidity (NTU). The time of day and tide state were noted for each station. Methods and procedures used for hydrographic profiling followed guidance provided in the NCA Quality Assurance Project Plan document (US EPA, 2001).

Secchi depth was determined by using a standard 20-cm diameter black and white Secchi disc. The disc was lowered to the depth at which it could no longer be discerned, then was slowly retrieved until it just reappeared. The depth of reappearance was recorded as Secchi depth (rounded to the nearest 0.1 m). Water clarity at many stations in the Hawaii base study was such that Secchi depth was equal to the bottom. In such cases, the true value of the Secchi depth can not be determined, and such values were set to missing in the analysis of this parameter. Valid data for Secchi depth were obtained from only 14 of 50 stations in the base study, although 23 of 30 sites from the more turbid Oahu estuaries produced valid Secchi depth readings.

Salinity was determined using an AGE laboratory salinometer (limit of detection = 0.0001 ppt, accuracy = 0.003 ppt). Standard seawater (Copenhagen Water) was used to calibrate the instrument. Turbidity samples were collected as unfiltered water, and stored on ice in 125-ml polyethylene bottles until measurements were made. Turbidity was measured on a Monitek Model 21 nephelometer following procedures as described in Standard Methods (1985) and data were recorded in NTU.

2.3.1.2 Water Quality Indicators

Once the physical measurements were completed at a station, water samples were collected at three depths for each station: within 20 cm of the surface, mid-depth in the water column, and at approximately 1-m above the sea floor, using a 2.2 liter Niskin sample bottle. Subsamples were withdrawn for nutrients (orthophosphate, nitrate, nitrite, ammonia), dissolved silica and a bacteria sample. The nutrient samples were collected in acid-rinsed polyethylene bottles that were triple-rinsed with the sample water. These samples were held on ice for transportation to the laboratory. The nutrient samples were filtered through Whatman glass fiber filters (GF/F, 0.7- µm particle retention) into 125-ml acid-washed, triple-rinsed polyethylene bottles and immediately placed on ice. Samples were air shipped to the NCA national contract laboratory for analysis.

All laboratory methods used in processing water column samples followed standard accepted protocols including those as given in Standard Methods (1985), Strickland and

Parsons (1972), Grasshoff (1983). Analyses for the various nutrients were be carried out by national contract laboratories following standard procedures, protocols and QA/QC. Water samples were held on ice for no more than 24 hours prior to sample processing. If a holding time greater than 24 hours was required, nutrient samples were frozen. The exception was for the silica sample which was refrigerated

Dissolved oxygen was measured with a Hydrolab® DO sensor on the Hydrolab® H_2O datasonde.

2.3.2 Sediment Toxicity Testing

2.3.2.1 Sediment Collection for Toxicity Testing, Chemical Analysis and Grain Size

Composite samples of sediment were collected and analyzed for organic and inorganic contaminants (i.e., those elements and compounds as given in Table 2.3-3), toxicity bioassays and determination of physical characteristics. At sample sites that were within diving depths, the sediment samples were hand-collected by divers in pre-cleaned one-liter Teflon® lined jars with Teflon lined lids, pushing the jar into the substratum, digging alongside of the jar in the sediment and using the lid to cover the jar mouth so it could be extracted. At stations where a grab was used the jar was handled the same way to sample sediment from the grab. Samples for various analyses were taken within a one-square meter area of substratum and included the sediment from the surface through the upper 10 cm of material. Samples were chilled and sent within 48 hours of collection by overnight carrier to EPA-approved contract laboratories for appropriate sample processing and sediment toxicity testing. Holding times for sample measurements are given in Table 2.3-4.

2.3.2.2 Amphipod Toxicity Tests

The 10-day, solid-phase toxicity test with the marine amphipod *Ampelisca abdita* was used to evaluate potential toxicity of sediments from all sites. Procedures followed the general guidelines provided in ASTM Protocol E1367-92 (ASTM 1991), the EPA amphipod sediment toxicity testing manual (US EPA, 1994a), and the EMAP Laboratory Methods Manual (US EPA 1994b). The *Ampelisca* test is a 10-d acute toxicity test which measures the effect of sediment exposure on amphipod survival under static beaker conditions with aeration. Toxicity tests were conducted with sediment collected from a one-square meter area within which the sediment for analysis of organic and trace metal contaminants and other sediment characteristics was also collected. Some toxicity test sediment was collected several months later than sediment for contaminants due to problems with the handling of the sediment for toxicity testing.

Ampelisca tests were conducted by an EPA contract laboratory in Pensacola, FL using amphipods collected from San Pablo Bay in the San Francisco Bay Estuary, CA. All

tests were monitored daily during the test for water quality (temperature, salinity, dissolved oxygen, pH, and total ammonia in the overlying water). Test temperature for *A. abdita* ranged from 19 to 21 ˚C and salinity ranged from 29 to 34 ‰. Test pH at test initiation ranged from 8 to 8.4 and maximum total ammonia concentration was 1.47 mg/L. The general health of each batch of amphipods was evaluated in a reference toxicity test ("positive control") with the reference toxicant cadmium chloride or sodium dodecyl sulfate (SDS). LC_{50} values were computed for comparison with other reported toxicity ranges for the same reference toxicant and test species.

Treatments for the definitive tests with field samples consisted of five replicates of each sediment sample (100% sediment) and a negative control consisting of sediment from the amphipod collection site. A negative control was run with each batch of field samples. The negative controls provided a basis for comparison to determine statistical differences in survival in the field sediments and also provided a measure of the acceptability of final test results. Test results with *A. abdita* were considered valid if mean control survival (among the 5 replicates) was $\geq$ 90% and survival in no single control replicate was less than 80%. Test results are reported as control-corrected values. Mean control survival for *A. abdita* ranged from 90 to 98% throughout the various tests, but three control batches had minimum replicate survival < 80%. Test batches where negative control QA requirements were not met were included in the CDF analysis. This situation occurred with 24% of the sediments tested.

A variety of quality control procedures were incorporated to assure acceptability of amphipod test results and comparability of the data with other studies. As described above, these provisions included the use of standard ASTM and EMAP protocols, negative "performance" controls run with reference sediment from the amphipod collection site, positive controls with reference chemicals to determine the health of the amphipods, and routine monitoring of water quality variables to identify any departures from optimum tolerance ranges.

2.3.3 Biotic Condition Indicators

2.3.3.1 Benthic Community Structure

A single sample of approximately 500 cm^3 was collected at each station by SCUBA divers using jars of 11.2 cm in diameter inserted into the sediment to a depth of approximately 5 cm. Samples of this volume are adequate because the soft bottom infauna are both small in size and usually very abundant (Nelson 1986, Swartz et al. 2000). These samples were fixed in their labeled collection containers with buffered formalin (15%).

All benthic sample processing was carried out at the University of Hawaii. The protocol for sample handling/processing was as follows: in the laboratory each sediment sample was handled in a manner identical to the protocol used in the EPA-approved monitoring program for Honolulu deep ocean sewer outfalls (Swartz et al. 2000). The fixed

samples were elutriated using the technique of Sanders et al. (1965). This method successfully removes from the sediment all organisms that are not heavily calcified. The samples were washed several times, and the water from each was poured through 0.5-mm mesh sieves. Polychaetes and other invertebrates retained on the sieve were transferred to alcohol, stained with rose bengal solution, and stored in 70% ethanol. When large carbonate rubble fragments were collected in the sediment samples, the rubble fragments were carefully washed and visually examined to ensure that any organisms on the external surfaces were removed. The fragments were then placed in a nitric acid bath for 24 hours or longer to dissolve the carbonate and to recover organisms living in burrows. The acid dissolution technique used was modified from the methods of Brock and Brock (1977), as described in Nelson (1986).

All specimens were identified to the lowest taxonomic level possible. As a QA/QC check, all specimens were double checked by a second individual to ascertain that sorting was complete and identifications were accurate. Any disparity between the identifications of the two taxonomists was discussed, and discrepancies were resolved by a sequential process. Additional specimens were examined to compare to the specimen in question, the literature was searched for additional information, and finally international specialists of the genus or family were contacted. Voucher specimens were submitted to taxonomic specialists for verification when necessary. All specimens will be archived and maintained for six years by the University of Hawaii.

Duplicate field collections of benthic samples were conducted at 10 percent of the sample sites. This sampling strategy is identical to that employed in the ongoing studies in Mamala Bay carried out as part of the monitoring requirements for Honolulu's deep ocean outfalls (Swartz *et al*. 2000). Comparisons were made between the duplicate samples. In the case of sites with coralline rubble substratum, two replicate samples were taken for analysis and served the same purpose.

Many of the EMAP stations in Hawaii estuaries and bays are located in areas occupied by coral reefs. The diversity of life forms on coral reefs dictates that a number of techniques be used to quantify the larger, diurnally active species present.

Following a visual transect census for fish (Section 2.3.3.2), an enumeration of epibenthic invertebrates (excluding corals) was undertaken using the same 25 m transect line as established for fishes. Exposed invertebrates, usually greater than 2 cm in some dimension, are censussed in the 4 m x 25 m area. This sampling methodology is quantitative for a few invertebrate groups, e.g., some of the echinoderms (some echinoids and holothurians), mollusks, and crustaceans. Most coral reef invertebrates (other than corals) are cryptic or nocturnal in their habits making accurate assessment of them in areas of topographical complexity very difficult. These factors, coupled with the fact that the majority of these cryptic invertebrates are small, necessitates the use of techniques as described for the infaunal component of this study (see also Brock and Brock 1977). Recognizing these constraints, the macroinvertebrate censusing technique used here attempts to assess those few species that are diurnally exposed.

Exposed sessile benthic forms such as corals and macrothalloid algae were quantitatively surveyed by use of quadrats and photographic techniques. Quadrat sampling consisted of recording benthic organisms, algae and substratum type present as a percent cover in six, one-meter square frames placed at five-meter intervals along the transect line established for fish censusing (at 0, 5, 10, 15, 20, and 25 m). At these same locations a camera mounted on a 0.67 x 1 m frame was also placed and the substratum was photographed. Photographs provided a permanent record from which additional coverage estimates of corals and other sessile forms can be made. All sessile forms were recorded as percent cover. With the macrothalloid algae, emphasis was placed on those species that are visually dominant, and no attempt was made to quantitatively assess the multitude of microalgal species that constitute the "algal turf" so characteristic of many coral reef habitats.

The benthic infaunal data were used to compute total numbers of individuals and total number of species per 0.0985 m^2 sample. The Shannon-Weaver information diversity index H′ was calculated (log base 2) per 0.0985 m^2 sample.

Species collected in the infaunal sampling were classified as to origin, using the following categories: native species, nonindigenous species, cryptogenic species, indeterminate origin, and unclassified. These assignments were made by the taxonomic specialists in Hawaii based on their knowledge of components of the fauna, supported by a variety of publications (Englund et al., 2000; Preskitt et al., 2001).

2.3.3.2 Fish Community Structure

Once a station was located and the vessel appropriately anchored, two SCUBA equipped divers entered the water. The lead diver was equipped with a slate and pencil and the assistant carried a 25 m transect line. Fish abundance and diversity is often related to small-scale topographical relief over short linear distances. A long transect may bisect a number of topographical features (e.g., cross coral mounds, sand flats, and algal beds), thus sampling more than one community and increasing the variance in the resulting data. To alleviate this problem, a short transect (25 m in length) has proven adequate in sampling many Hawaiian benthic communities (Brock and Norris 1989) and was approved by US EPA Region IX for survey work assessing Hawaiian ocean sewer outfalls (Brock 1998a, 1999a). Studies have demonstrated that the visual census technique probably provides the most accurate, nondestructive method available for the assessment of diurnally-active coral reef fishes (Brock 1982).

The lead diver located the sample site and commenced to visually enumerate all fishes present in a 4 x 25 m corridor from the bottom to the surface. Directly behind the lead diver, the second diver payed out the 25-m transect line. This strategy avoided underwater activity in the area which could frighten wary fishes. All individuals of all species were counted and estimates were made on the standard length of each fish seen. The length was converted to standing crop estimates using linear regression

techniques (Richer 1975). The regression coefficients have been developed over 40 years of study in the Hawaiian Islands by a number of authors (Brock 1954, Evans 1974, Brock and Norris 1989) from weight and body length measurements of captured fishes; for many species, the coefficients have been developed using sample sizes in excess of a hundred individuals.

2.3.3.3 Holothurian Contaminant Sampling and Chemistry Analyses

Residues of a suite of metals, PCBs, and pesticides were measured in the whole-body tissues of two species of holothurians (*Holothuria atra and H. whitmaei*) at 11 stations in the Hawaii estuaries and bays and 2 stations in the Oahu urbanized estuaries (Table 2.3-2). At each station, the sample team looked for the presence of holothurians in the immediate vicinity of the sample site (within 10 m). If either of these two species of holothurians was seen, they were collected. While underwater, holothurians were placed in zip top plastic bags for transport to the surface. Once on the surface, they were immediately individually wrapped in tin foil, labeled, placed in a plastic bag with a second label, sealed and frozen. All samples were sent in a frozen state to the NCA national contract laboratory for analysis. Guts were not cleared, and thus may have contained some level of sediments which may have contributed to observed contaminant levels.

Table 2.3-2. List of stations with collection of holothurians for tissue analysis.

EMAP Station	Date	Number Collected	Species
HI02-0001	18-Jun-02	1	*Holothuria whitmaei*
HI02-0003	16-Jun-02	1	*Holothuria atra*
HI02-0012	10-May-02	3	*Holothuria atra*
HI02-0013	21-May-02	3	*Holothuria atra*
HI02-0024	1-Apr-02	3	*Holothuria atra*
HI02-0030	3-Apr-02	2	*Holothuria atra*
HI02-0033	9-Jun-02	1	*Holothuria whitmaei*
HI02-0037	7-Jun-02	2	*Holothuria atra*
HI02-0038	7-Jun-02	2	*Holothuria atra*
HI02-0040	7-Jun-02	1	*Holothuria atra*
HI02-0041	8-Jun-02	3	*Holothuria whitmaei*
HI02-0069	11-Oct-02	2	*Holothuria atra*
HI02-0078	16-Apr-02	1	*Holothuria whitmaei*

A total of 13 inorganic metals, 23 polyaromatic hydrocarbons (PAHs), 20 polychlorinated biphenyls (PCBs,), DDT and its primary metabolites, and an additional 14 pesticides (Table 2.3-3) were measured in the holothurian samples. PCB congener 110 was not reported, but the values for PCB77 are likely to actually represent PCB110/77. Table 2.3-4 summarizes the sample collection, preservation, and holding

time requirements for tissue samples. Table 2.4-2 summarizes the analytical methods used for tissues. The analytical QA/QC procedures for tissue chemistry analysis are described in Section 2.4.

2.3.3.4 Bacterial Indicators

Water samples for bacterial analysis, collected at three depths (section 2.3.1.2) were transferred to sterile 125-ml polyethylene bottles and placed on ice for transport to the laboratory. Because of the time-sensitive nature of the bacterial samples, upon return of the survey crew to land (generally within 6 hours), these samples were given to personnel from the Hawaii Department of Health for immediate on-island sample processing. On return to the laboratory, enterococci samples were filtered through 0.4 u sterile membrane filters. Enterococci were measured using techniques described in "Test Methods for *Escherichia coli* and Enterococci in Water by the membrane filter procedure" (EPA 600/4-85/076). Fecal coliforms were measured by the method 9222D, Fecal Coliform Membrane Filter Procedure (Standard Methods, 1998). *Clostridium perfringens* was analyzed by the membrane filtration enumeration method (Bisson and Cabelli, 1979).

2.3.4 Sediment Chemistry

A total of 15 metals, 20 PCB congeners (PCBs), DDT and its primary metabolites, 13 pesticides, 23 polyaromatic hydrocarbons (PAHs), and total organic carbon (TOC) were measured in sediments (Table 2.3-3). PCB congener 110 was not reported, but the values for PCB77 are likely to actually represent PCB110/77. With a few additions, this suite of compounds is the same as measured in the NOAA NS&T Program.

Sediment for chemical analysis was collected from the top 15 centimeters by hand and stored in pre-cleaned glass containers with Teflon® lids (see Table 2.3-4). Sediment samples for chemical analysis were taken from a one-square meter area within which the sediment for toxicity testing and analysis of other sediment characteristics was also collected. Approximately 250-300 ml of sediment were collected from each station for analysis of organic pollutants and another 250-300 ml for analysis of metals and TOC (Table 2.3-4). Once collected, samples were held in coolers and chilled and once ashore were sent by overnight carrier to the EPA-approved contract laboratories for processing.

Analysis for sediment contaminants was conducted by EPA's National Contract Laboratory (NCL). Table 2.4-1 lists the analytical methods used for each compound. The analytical QA/QC procedures for sediment chemistry analysis are described in Section 2.4.

Table 2.3-3. Compounds analyzed in sediments and holothurian tissues. TOC, antimony, and manganese were analyzed only in sediments. Toxaphene was analyzed only in tissues.

Polyaromatic Hydrocarbons (PAHs)	PCB Congeners (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 Phenanthrene High Molecular Weight PAHs Benz(a)anthracene Benzo(a)pyrene Benzo(b)fluoranthene Benzo(k)fluoranthene Benzo(g,h,i)perylene Chrysene Dibenzothiophene Dibenz(a,h)anthracene Fluoranthene Indeno(1,2,3-c,d)pyrene Pyrene	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 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 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 Others Endosulfan I Endosulfan II Endosulfan Sulfate Hexachlorobenzene Lindane (gamma-BHC) Mirex Toxaphene (tissue only)	Metals Aluminum Antimony (sediment only) Arsenic Cadmium Chromium Copper Iron Lead Manganese (sediment only) Mercury Nickel Selenium Silver Tin Zinc Miscellaneous Total organic carbon (sediment only)

Table 2.3-4. Summary of NCA chemistry sample collection, preservation, and holding time requirements for sediment and tissue samples. Modified from Table 5-3 of the *Quality Assurance Project Plan 2001-2004* (U.S. EPA, 2001a).

Parameter	**Container**	**Volume**	**Sample Size**	**Sample Preservation**	**Max. Sampling Holding Time**	**Max. Extract Holding Time**
Sediment - Organics	500-ml pre-cleaned glass	250 - 300 ml	300 g (approx.)	Freeze (-18^{o} C)	1 year	40 days
Sediment - Metals	125-ml HDPE wide-mouth bottle	100 - 150 ml	75 - 100 g (approx.)	Freeze (-18^{o} C)	1 year	a
Sediment - TOC	Glass jar	100 - 150 ml	30 - 50 ml (approx.)	Cool (4^{o} C)	6 months	a
Tissue	Whole holothurian individually wrapped in Al foil, then placed in water-tight plastic bag.	NA	NA	Freeze (-18^{o} C)	1 year	40 days

a - No EPA criterion exists. Every effort should be made to analyze the sample as soon as possible following extraction, or in the case of metals, digestion.

2.4 Quality Assurance/ Quality Control of Chemical Analyses

The goals of the NCA QA/QC procedures are to promote the generation of analytical results achieving the stated objectives and to provide levels of uncertainty in terms of accuracy and precision of the results. The quality assurance/quality control (QA/QC) program for the National Coastal Assessment - West program is defined by the "Environmental Monitoring and Assessment Program (EMAP): National Coastal Assessment Quality Assurance Project Plan 2001-2004" (US EPA, 2001a), which established both Methods Quality Objectives (MQOs) and Data Quality Objectives (DQO). The specific DQOs for the NCA for estimates of current status for indicators of condition are: "For each indicator of condition, estimate the portion of the resource in degraded condition within ±10% for the overall system and ±10% for subregions (i.e., states) with 90% confidence based on a completed sampling regime." Measurement quality objectives (MQO) for all NCA field and laboratory parameters are expressed in terms of accuracy, precision, and completeness goals in the NCA QA Project Plan (US EPA, 2001a, Table A7-1). These MQOs were established from considerations of instrument manufacturers' specifications, scientific experience, and/or historical data. However, accuracy and precision goals may not be definable for all parameters due to the nature of the measurement type (e.g., fish pathology, no expected value). In general, the quality assurance elements for the National Contract Laboratory (NCL) included communication of sampling and analytical requirements to the NCL, initial laboratory capability exercises, program-wide audits of laboratory operations, documentation of chain-of-custody, and maintaining open lines of communication and information exchange.

Details of the general quality assurance procedures to generate sediment and tissue chemical concentrations with acceptable levels of precision and accuracy are given in U.S. EPA (2001a). Briefly, a performance-based approach was used, which depending upon the compound included 1) continuous laboratory evaluation through the use of Certified Reference Materials (CRMs), Laboratory Control Materials (LCMs), or Standard Reference Material (SRM); 2) laboratory spiked sample matrices, 3) laboratory reagent blanks, 4) calibration standards, 5) analytical surrogates, and 6) laboratory and field replicates.

One measure of the accuracy of the analytical results is control limit criteria for "relative accuracy" based on comparing the laboratory's value to the true or "accepted" values in CRMs or LCMs (see U.S. EPA, 2001a for details). The requirements for PAHs, PCBs, and pesticides are that the "Lab's value should be within ±30% of true value on average for all analytes; not to exceed ±35% of true value for more than 30% of individual analytes." (U.S. EPA 2001a). For metals and other inorganic compounds, the laboratory's value for each analyte should be within ±20% of the true value of the CRM, LCM, or SRM. Another measure of accuracy is the percent recovery from matrix spikes, where a known quantity of the analyte is added to sediment or tissue before analysis. High percent recoveries indicate that the analytical method and instruments can adequately quantify the analyte. However, matrix spikes do not evaluate the ability

of the extraction method to actually extract the compound bound to the tissue or sediment. A measure of precision is the “relative percent differences” (RPD) of duplicate samples, with the objective that the RPD should be <30%. RPDs were determined from sample replication (if done), matrix spike duplicates, and SRM/CRM/LCM replicates.

Measures of whether the analytical procedure is sufficient to detect the analytes at environmental levels of concern are the Method Detection Limits (MDLs). An MDL is “the minimum concentration of a substance that can be measured and reported with 99% confidence that the analyte concentration is greater than zero and is determined from analysis of a sample in a given matrix containing the analyte." (Code of Federal Regulations 40 CFR Part 136). Approved laboratories were expected to perform in general accord with the target MDLs presented for NCA analytes (US EPA, 2001a, Table A7-2). Because of analytical uncertainties close to the MDL, there is greater confidence with concentrations above the Reporting Limit (RL), which is the concentration of a substance in a matrix that can be reliably quantified during routine laboratory operations. Typically, RLs are 3 to 5 times the MDL. Concentrations between the MDL and the RL were used in generating the CDF and mean for the analyte. Any reported values below the MDL were set to 0 and this value was used in calculating both the CDFs and means.

A post-analysis assessment of the success of the analytical laboratories in meeting NCA QA/QC guidelines was conducted by the QA manager of the Western Ecology Division. The accuracy of results was assessed by determining whether the laboratory values for SRMs, CRMs, or LCMs were within the NCA guidelines for sediment and tissues, while precision was assessed by the RPDs. An overview of the QA/QC results is given below.

2.4.1 Metals in Sediments

Table 2.4-1 lists analytical method for each of the metals in the sediment samples. The analytical methods are those used in the NOAA NS&T Program (Lauenstein and Cantillo,1993) or documented in the EMAP Laboratory Methods Manual (U.S. EPA, 1994b). Table 2.4-1 also lists the units and method detection limits (MDL) for each metal. The laboratory MDL met or were below the target MDL for all the sediment metals. Reporting limits (RLs) were not reported for the metals, but as mentioned they are typically 3 to 5 times the MDL.

The percent recovery from certified/standard materials, recovery from matrix spikes, and the average RPD for non-zero sample duplicates and matrix spikes for the sediment metals are summarized in Table 2.4-3. No defined sediment certified/standard reference materials were reported for metals, and thus this aspect of the DQOs can not be directly assessed. However, the matrix spike samples had sufficiently low concentrations that the sediment samples were likely to have been sufficiently accurate for the project goals. One caveat is that the laboratory reported QC results from the batches containing only 26 of 85 stations. Averaged across all metals,

the recovery for sediment metals from matrix spikes met the DQO of being within ±50% of the true values. Exceptions were aluminum, which deviated by 157% from the matrix spike, and iron, which deviated by 79%. On average, the RPDs for metals were <30%. Manganese slightly exceeded the criterion (33%), while aluminum and iron failed the DQO with RPDs of 87% and 75%, respectively.

2.4.2 Organics in Sediments

Table 2.4-1 lists analytical method for each of the organic compounds in the sediment samples. The analytical methods are those used in the NOAA NS&T Program (Lauenstein and Cantillo, 1993) or documented in the EMAP Laboratory Methods Manual (U.S. EPA, 1994b). Table 2.4-1 also lists the units, method detection limit (MDL), and reporting limits (RL) for each organic compound. The laboratory MDLs met or were below the target MDL for all of the sediment organics.

The percent recovery from certified/standard materials, recovery from matrix spikes, and the average RPD for non-zero sample duplicates and matrix spikes are summarized in Table 2.4-3. No defined sediment reference materials were reported for organics, and thus this aspect of the DQOs can not be directly assessed. However, the matrix spike samples had sufficiently low concentrations that the sediment samples were likely to have been sufficiently accurate for the project goals. One caveat is that the laboratory reported QC results from the batches containing only 26 of 85 stations. Averaged across all compounds within a class, the matrix spikes were within ±50% of the true values for PAHs, PCBs, and pesticides. Individual compounds where the average percent difference among matrix spikes was >50% included pyrene (51%), PCB 18 (191%), Endosulfan I (61%), and Endosulfan II (94%). The average RPDs for all sediment analytes met the DQO of duplicates being within 30%. The individual compounds with >30% difference among matrix spike duplicates included 2-methylnaphthalene (43%), PCB 18 (138%), Endosulfan I (36%) and Endosulfan II (67%).

2.4.3 Chemical Residues in Tissues

Table 2.4-2 lists analytical method for each of the metals and organic compounds measured in tissue samples. The analytical methods are those used in the NOAA NS&T Program (Lauenstein and Cantillo, 1993) or documented in the EMAP Laboratory Methods Manual (U.S. EPA, 1994b). Table 2.4-2 also lists the units, method detection limit (MDL), and reporting limits (RL) for each metal or organic compound. The laboratory MDLs were met or were below the target MDL for all of the compounds except for tin.

The percent recovery from certified/standard materials, recovery from matrix spikes, and the average RPD for non-zero sample duplicates and matrix spikes for tissue metals and organics are summarized in Table 2.4-3. Spiked cod fillets from NSI were

used as a laboratory control material. The percent recovery for the metals in these cod fillets for the six metals analyzed were all within ±30% of the true value. The percent recovery for the metals in the matrix spikes with the cod tissue met the criterion of being with ±50% of the true value. No sample duplicates or matrix spike duplicates were reported, so it is not possible to assess the RPD for tissue metals.

Recovery of PAHs, PCBs, and the pesticides was poor in the cod laboratory control material, exceeding the DQO of being within ±30% of the true value for every individual compound. The matrix spikes for all PCBs met the DQO of being within ±50% of the true values, although PCB 126 exceeded the criterion. In comparison, the average for both PAHs and pesticides exceeded the DQO for matrix spikes, with most individual compounds exceeding ±50% criterion. No non-zero duplicate tissue results were reported, so it is not possible to assess the RPD for tissue organics. In summary, the organic tissue residue data are suspect, and the lack of detection of a compound does not necessarily mean that the compound was not present.

Table 2.4-1. Units, method detection limits (MDL), reporting limits (RL), analytical method, and responsible laboratory for sediment chemistry. Target MDLs are from the National Coastal Assessment (US EPA, 2001a). NR = not reported. NA = not applicable.

Analyte	Units (dry wt.)	Target MDL	MDL/RL	Method	Laboratory
Aluminum	µg/g	1500	28/NR	ICPOES	ERI
Antimony	µg/g	0.2	0.1/NR	ICPMS	ERI
Arsenic	µg/g	1.5	0.1/NR	GFAAS	ERI
Cadmium	µg/g	0.05	0.05/NR	ICPMS	ERI
Chromium	µg/g	5.0	0.7/NR	ICPOES	ERI
Copper	µg/g	5.0	0.7/NR	ICPOES	ERI
Iron	µg/g	500	14/NR	ICPOES	ERI
Lead	µg/g	1.0	0.1/NR	ICPMS	ERI
Manganese	µg/g	1.0	0.7/NR	ICPOES	ERI
Mercury	µg/g	0.01	0.01/NR	CVAA	ERI
Nickel	µg/g	1.0	0.7/NR	ICPOES	ERI
Selenium	µg/g	0.1	0.1/NR	ICPMS	ERI
Silver	µg/g	0.05	0.01/NR	ICPMS	ERI
Tin	µg/g	0.1	0.1/NR	ICPMS	ERI
Zinc	µg/g	2.0	1.4/NR	ICPOES	ERI
PAHs (23 compounds)	ng/g	10.0	4.97/16.79	GCMS	ERI
PCB (20 congeners)	ng/g	1.0	0.18/0.89	GCECD	ERI
DDT, DDD, and DDE	ng/g	1.0	0.18/0.89	GCECD	ERI
Aldrin	ng/g	1.0	0.18/0.89	GCECD	ERI
Alpha-Chlordane	ng/g	1.0	0.18/0.89	GCECD	ERI
Dieldrin	ng/g	1.0	0.18/0.89	GCECD	ERI
Endosulfan I	ng/g	1.0	0.18/0.89	GCECD	ERI
Endosulfan II	ng/g	1.0	0.18/0.89	GCECD	ERI
Endosulfan Sulfate	ng/g	1.0	0.18/0.89	GCECD	ERI
Endrin	ng/g	1.0	0.18/0.89	GCECD	ERI
Heptachlor	ng/g	1.0	0.18/0.89	GCECD	ERI

Analyte	Units (dry wt.)	Target MDL	MDL/RL	Method	Laboratory
Heptachlor Epoxide	ng/g	1.0	0.18/0.89	GCECD	ERI
Hexachlorobenzene	ng/g	1.0	0.18/0.89	GCECD	ERI
Lindane (gamma-BHC)	ng/g	1.0	0.18/0.89	GCECD	ERI
Mirex	ng/g	1.0	0.18/0.89	GCECD	ERI
Trans-Nonachlor	ng/g	1.0	0.18/0.89	GCECD	ERI
TOC	percent	NA	NR	SEDM-TC	ERI
Percent fines	percent	NA	NR	Gravimetric	ERI

Analytical Methods: GCMS = gas chromatography/mass spectroscopy; ICPOES = Inductively Coupled Plasma Optical Emission Spectroscopy; ICPMS = Inductively Coupled Plasma-Mass Spectrometry, GFAAS = graphite furnace atomic absorption spectrometry; CVAA = cold vapor atomic adsorption, GCECD = gas chromatography and electron capture detection, SEDM-TC = organic and inorganic analysis by EPA method 440.

Analytical Laboratories: ERI = Environmental Research Institute, Univ. of Connecticut.

Table 2.4-2. Units, method detection limits (MDL), reporting limits (RL), analytical method, and responsible laboratory for tissue chemistry. Target MDLs are from the National Coastal Assessment (US EPA, 2001a, Table A7-2). NA = not applicable.

Analyte	Units (wet wt.)	Target MDL	MDL/RL	Method	Laboratory
Aluminum	µg/g	10.0	0.41/9.3	ICPAES	GPL
Arsenic	µg/g	2.0	0.13/0.93	GFAA	GPL
Cadmium	µg/g	0.2	0.01/0.27	ICPMS	GPL
Chromium	µg/g	0.1	0.04/0.23	ICPAES	GPL
Copper	µg/g	5.0	0.05/0.36	ICPAES	GPL
Iron	µg/g	50.0	1.16/6.9	ICPAES	GPL
Lead	µg/g	0.1	0.04/0.46	ICPMS	GPL
Mercury	µg/g	0.01	0.009/0.018	CVAA	GPL
Nickel	µg/g	1.0	0.05/0.36	ICPAES	GPL
Selenium	µg/g	0.5	0.13/0.93	ICPMS	GPL
Silver	µg/g	0.05	0.04/0.14	ICPMS	GPL
Tin	µg/g	0.05	0.14/1.1	ICPMS	GPL
Zinc	µg/g	50.0	0.43/2.3	ICPAES	GPL
PAHs (average23 compounds)	ng/g	20.0	6.2/20	GCMS	GPL
PCB (20 congeners)	ng/g	2.0	0.1/2	GCMS	GPL
DDT, DDD, and DDE	ng/g	2.0	0.01/1	GCECD	GPL
Aldrin	ng/g	2.0	0.01/1	GCECD	GPL
Alpha-Chlordane	ng/g	2.0	0.01/1	GCECD	GPL
Dieldrin	ng/g	2.0	0.01/1	GCECD	GPL
Endosulfan I	ng/g	2.0	0.01/1	GCECD	GPL
Endosulfan II	ng/g	2.0	0.01/1	GCECD	GPL
Endosulfan Sulfate	ng/g	2.0	0.01/1	GCECD	GPL
Endrin	ng/g	2.0	0.01/1	GCECD	GPL
Heptachlor	ng/g	2.0	0.01/1	GCECD	GPL
Heptachlor Epoxide	ng/g	2.0	0.01/1	GCECD	GPL
Hexachlorobenzene	ng/g	2.0	0.01/1	GCECD	GPL
Lindane (gamma-BHC)	ng/g	2.0	0.01/1	GCECD	GPL

Analyte	Units (wet wt.)	Target MDL	MDL/RL	Method	Laboratory
Mirex	ng/g	2.0	0.01/1	GCECD	GPL
Toxaphene	ng/g	2.0	0.01/50	GCMS	GPL
Trans-Nonachlor	ng/g	2.0	0.01/1	GCECD	GPL

Analytical Methods: Analytical Methods: GCMS = gas chromatography/mass spectroscopy, ICPMS = Inductively Coupled Plasma-Mass Spectrometry, GFAA = graphite furnace atomic absorption spectrometry, ICPAES = Inductively-Coupled Plasma Atomic Emission Spectrometer, CVAA = cold vapor atomic adsorption, GCECD = gas chromatography and electron capture detection,

Analytical Laboratories: GPL = GPL Laboratories.

Table 2.4-3. Summary of performance of analytical laboratories for Hawaii samples with regard to data quality objectives (DQOs) for analysis of reference materials, matrix spike recoveries, and relative percent differences (RPD) of duplicates. MS = matrix spike, SRM = Standard Reference Material, CRM = Certified Reference Material, LCM = Laboratory Control Material, None = the QC material was not analyzed or QC activity not performed. NA = not applicable. DQOs for organics for recovery from reference materials is ±30% for organics and ±20% for metals.

Analyte (# analytes)	Material	Average met DQO for comparison to standard?	If No, % difference from true value / (# analytes reported) / type of reference material	Matrix spike recovery within 50%-150% and (% difference from matrix spike)	Average RFD of sample replicates and matrix spike duplicates <30%
Metals	**Sediment**	None	None	Yes (33%)	Yes
(15)	**Tissue**	Yes	NA / 7 / LCM	Yes (5%)	None
PAHs	**Sediment**	None	None	Yes (38%)	Yes
(23)	**Tissue**	No	73% / 16 / LCM	No (71%)	Yes
PCBs	**Sediment**	None	None	Yes (17%)	Yes
(21)	**Tissue**	No	72% / 8 / LCM	Yes (35%)	Yes
Pesticides	**Sediment**	None	None	Yes (20%)	Yes
(20)	**Tissue**	No	73% / 13 / LCM	No (71%)	Yes

2.5 Data management

Data management for the Hawaii stations sampled in 2002 is a component of the overall National Coastal Assessment - West Information Management Program. The Information Management System is based on a centralized data storage model using standardized data transfer protocols (SDTP) for data exchange among program participants. The data are submitted to the NCA - West Information Manager (IM) located at the U.S. EPA laboratory in Newport, Oregon, for entry into the relational database (Microsoft Access).

The data flow consists of interactions among four levels. Field crew leaders and laboratory supervisors are responsible for compiling data generated by their organizations and for entering the data into one or more of the SDTP tables. The State Information Management (IM) Coordinator is responsible for compiling all data generated within a state into a unified state database. The NCA - West IM Coordinator is responsible for working with State Coordinators to develop the SDTP, and for creation and management of the centralized West Coast EMAP database. The EMAP IM Coordinator, located at the Atlantic Ecology Division of EPA at Narragansett, Rhode Island, is responsible for accepting data from Western EMAP, for placing it in the national EMAP database, and for transferring it to other EPA databases, such as STORET.

Once all data tables of a particular data type (e.g. all tables containing fish data) were certified by the NCA - West IM Coordinator, integrated multi-state data tables were provided to the Western EMAP Quality Assurance Coordinator (QAC). The QAC reviewed the data with respect to scientific content. Necessary corrections resulting from this review process were returned to the NCA - West IM Coordinator who was responsible for working with the State IM Coordinator to make necessary changes.

Following certification of all portions of the data by the QAC, the NCA - West IM Coordinator submitted the integrated multi-state data set to the EMAP IM Coordinator who is the point of contact for data requests about the integrated data set.

Details of the Western EMAP Information Management process are provided in Cooper (2000). The structure of each of the relational data base tables and supporting database look-up tables used by the states to submit data to the NCA - West IM Coordinator are provided in this document.

2.6 Unsamplable Area

All stations in Hawaii were sampled except station HI02-0065. This station was located within the East Loch of the Pearl Harbor Naval base, and access to this location was denied by the U.S. Navy due to classified (military) activities occurring in the area during the period of time that the EMAP field survey team was present in the harbor. No sediment was obtained at stations HI02-0004, HI02-0012, HI02-0030, HI02-0032, and

HI02-0037. Underwater visual surveys could not be conducted at many stations due to poor water visibility, particularly those in the Oahu urbanized harbors.

2.7 Lessons Learned

The EMAP survey of the Hawaiian Islands utilized several approaches which were new to the National Coastal Assessment program. Some of the approaches proved useful, and others were less successful. The sampling of holothurian tissue was attempted as a substitute for the usual analysis of fish tissue for chemical contaminants. Specimens were obtained at only 13 stations, demonstrating that this taxon was much less widely distributed than anticipated. The analytical laboratory also had considerable difficulty with the tissue matrix, and the recovery of target analytes from the holothurian tissues was less than desired in some cases. Alternate approaches to collection of tissue for contaminant analysis should be explored.

Visual survey methods for fish community analyses were highly effective wherever water conditions permitted visual transects to be conducted. However, surveys could only be conducted at 38 of the 79 (48%) sites, and tended to be unsuccessful in the more turbid, estuarine conditions. Given the heterogeneous nature of the bottom types in Hawaii which precluded general use of trawls, this limitation on fish community assessment remains problematic.

The Hawaii field team did not collect PAR data in the water column, but did collect Secchi depth measurements. In many NCA assessments, Secchi depth has proved an acceptable indicator of water clarity. In Hawaii, Secchi depth was not a useful indicator for water quality because in the very clear waters typical of many areas, the Secchi disc was still visible at the bottom, and thus the true Secchi depth could not be measured. Secchi depth tended to be measurable at more turbid sites, thus introducing a bias into the data for Secchi depth as a measure of water clarity. It is therefore critical that PAR measurements be obtained in order to develop a useful indicator of water clarity for the Hawaiian Islands.

3.0 Indicator Results

Presentation of results for individual indicators utilizes cumulative distribution functions (CDFs) representing the percentage area of the sample frame associated with given values of the indicator. In the case of some parameters, area estimates associated with benchmark values of the indicator are presented, e.g. sediment contaminants are referred to values of the Effects Range Median (ERM) or Effects Range Low (ERL) if these values are available (see Section 3.2.2). In other cases where there are no relevant benchmarks, the area estimates associated with statistical percentiles (50^{th}, 90^{th}) are presented. The state of Hawaii has water quality criteria for marine waters for several indicators measured by EMAP (see (Section 11-54-8, Hawaii Department of Health, Amendment and Compilation of Chapter 11-54, Hawaii Administrative Rules, August 31, 2004). However, these criteria are expressed as geometric means of multiple sample events, and are different for specific estuaries, bays and coastal regions. The EMAP sampling frame was not designed with these specific water quality classes, and samples were taken at only one date per station. Therefore, we have chosen to present water quality indicators in reference to statistical percentiles.

3.1 Habitat Indicators

3.1.1 Water Depth at Sample Sites

Bottom depth for the 50 stations sampled in Hawaii estuaries and bays ranged from 0.25 m to 21.3 m. The 50^{th} percentile of area of the Hawaii estuaries and coastal bays sampled had a water depth of 6.1 m while the 90^{th} percentile had a depth of 14.8 m (Figure 3.1 -1). Bottom depth for sample sites in the Oahu urbanized estuaries ranged between 0.25 m and 16.5 m. The 50^{th} percentile of area of the Oahu urbanized estuaries had a bottom depth of 6.7 m while the 90^{th} percentile had a depth of approximately 13.2 m (Figure 3.1-2).

3.1.2 Salinity

Salinity in the bottom water for the 50 stations sampled in Hawaii estuaries and bays ranged only from 20.9 psu to 37.2 psu. The 50^{th} percentile of area of the Hawaii estuaries and coastal bays sampled had a bottom salinity of 35.2 psu, while the 90^{th} percentile had a salinity of 35.7 psu (Figure 3.1-3). Nearly the entire area (99.6%) of the Hawaii estuaries would be classified as euhaline ($\geq$30 psu) based on the EMAP sampling of bottom waters. The sites in the Oahu urbanized estuaries had bottom salinities in a similar range, 30.6 psu to 36.5 psu (Figure 3.1-4). The 50^{th} percentile of area of the Oahu urbanized estuaries had a bottom salinity of 35.7 psu while the 90^{th} percentile had a value of 36.2 psu. Only approximately 8% of the area of the Oahu urbanized estuaries had salinity less than or equal to 28.4 psu. In interpreting these results, it is important to recognize that salinity can vary both tidally and seasonally, as well as with depth in the water column, and that these single measurements are "snapshots" during the sampling events.

3.1.3 Water Temperature

Temperature in the bottom water for the 50 stations sampled in Hawaii estuaries and bays ranged from 23.9 °C to 27.5 °C (Figure 3.1-5). The range of surface water temperatures was virtually identical to that for bottom water temperatures (23.9 °C to 27.6 °C). Within a station, the maximum temperature difference between surface and bottom waters was 2.5 °C. The Oahu urbanized estuaries showed a similar range of bottom (25.4 °C to 27.9 °C) (Figure 3.1-6) and surface water temperatures (24.6 °C to 29.9 °C). These temperatures are representative of summer conditions in the region. The 50th percentile of area of the Hawaii estuaries and coastal bays sampled had a bottom temperature of 23.9 °C, while the 90th percentile had a salinity of 23.9 °C (Figure 3.1-5). The 50th percentile of area of the Oahu urbanized estuaries had a bottom temperature of 25.7 °C while the 90th percentile had a value of 26.7 °C.

3.1.4 pH

The pH of bottom waters for the 50 stations sampled in Hawaii estuaries and bays ranged from 7.7 to 8.2 (Figure 3.1-7). The Oahu urbanized estuaries showed a very similar range of bottom water pH from 7.4 to 8.1 (Figure 3.1-8). The range for pH in surface water samples was virtually identical to that for bottom waters (7.6 - 8.2). The 50th percentile of area of the Hawaii estuaries and coastal bays sampled had a pH of 8.07 while the 90th percentile had a pH of 8.1 (Figure 3.1-7). The 50th percentile of area of the Oahu urbanized estuaries had a bottom water pH of 7.97 while the 90th percentile had a pH of 8.1 (Figure 3.1-8).

3.1.5 Sediment Characteristics

The percent silt-clay of sediments ranged from 0% to 92.5% at the 45 stations sampled in Hawaii estuaries and bays from which soft sediment samples could be obtained (Figure 3.1-9). About 73% of the area of the Hawaii estuaries and bays had sediments composed of sands (<20% silt-clay), about 21% was composed of intermediate muddy sands (20-80% silt-clay), and about 6% was composed of muds (>80% silt-clay). The Oahu urbanized estuaries (29 stations) had a greater proportion of area characterized by muds (62%), and less area characterized by sands (15%) or intermediate muddy sands (23%) (Figure 3.1-10). The 50th percentile of area of the Hawaii estuaries and coastal bays sampled had a percent silt-clay of sediments of 3.1%, while the 90th percentile had a percent silt-clay of 53% (Figure 3.1-9). The 50th percentile of area of the Oahu urbanized estuaries had a percent silt-clay of 83.9%, while the 90th percentile had a percent silt-clay of 96.5% (Figure 3.1-10).

Percent total organic carbon (TOC) in sediments ranged from 0.05% to 2.47% at the 31 stations within the base study from which soft sediment samples for TOC analysis were obtained (Figure 3.1-11). The 50th percentile of area of the Hawaii estuaries and coastal bays sampled had a sediment TOC level of 0.19%, while the 90th percentile had a sediment TOC level of 0.96%. The range of TOC values was 0.19% to 3.86% at the 18

stations within Oahu urbanized estuaries for which TOC samples were analyzed (Figure 3.1-12). The 50th percentile of area of the Oahu urbanized estuaries had a sediment TOC level of 1.8%, while the 90th percentile had a sediment TOC level of 2.1%, which is expected given the more depositional character of these harbors.

3.1.6 Water Quality Parameters

Water quality parameters are presented as water column mean values based on the concentration averaged over the surface, mid-water, and bottom water samples.

Chlorophyll a

The average water column concentration of chlorophyll *a* for the 50 stations sampled in Hawaii estuaries and bays ranged from 0.1 to 8.7 µg L^{-1} (Figure 3.1-13) . The 50th percentile of area of the Hawaii estuaries and coastal bays sampled had a chlorophyll *a* concentration of 0.34 µg L^{-1}, while the 90th percentile had a chlorophyll *a* concentration of 1.2 µg L^{-1}. Chlorophyll a concentration within the Oahu urbanized estuaries ranged between 0.1 and 5.6 µg L^{-1}. The 50th percentile of area of the Oahu urbanized estuaries had a chlorophyll *a* concentration of 0.8 µg L^{-1}, while the 90th percentile of area had a chlorophyll *a* concentration of approximately 2.8 µg L^{-1} (Figure 3.1-14).

Nutrients

The average water column concentration of nitrate in Hawaii estuaries and bays ranged from 0 to 212 µg L^{-1} (Figure 3.1-15). The 50th percentile of area of the Hawaii estuaries and coastal bays sampled had a nitrate concentration of 2.5 µg L^{-1}, with the 90th percentile of area characterized by a nitrate concentration of 11 µg L^{-1}. Less than 5% of estuarine and coastal bay area exceeded concentrations of 14 µg L^{-1}. Nitrate concentration within the Oahu urbanized estuaries ranged between 0 and 68.7 µg L$^{-1.}$ The 50th percentile of area of the Oahu urbanized estuaries had a nitrate concentration of 3.2 µg L^{-1}, with the 90th percentile of area characterized by a nitrate concentration of 12 µg L^{-1} (Figure 3.1-16).

The average water column concentration of nitrite in Hawaii estuaries and bays ranged from 0 to 7 µg L^{-1} (Figure 3.1-17). The 50th percentile of area of the Hawaii estuaries and coastal bays sampled had a nitrite concentration of 0 µg L^{-1}, with the 90th percentile of total area characterized by a nitrite concentration of 3.6 µg L^{-1}. Nitrite concentration within the Oahu urbanized estuaries was within the similar range of 0 to 5 µg L^{-1}. The 50th percentile of area of the Oahu urbanized estuaries had a nitrite concentration of 0 µg L^{-1}, with the 90th percentile of total area characterized by a nitrite concentration of 3.4 µg L^{-1} (Figure 3.1-18).

The average water column concentration of ammonium in Hawaii estuaries and bays ranged from 2.5 to 77.6 µg L^{-1} (Figure 3.1-19). The 50th percentile of area of the Hawaii estuaries and coastal bays sampled had an ammonium concentration of 31.7 µg L^{-1},

with the 90th percentile of total estuarine area characterized by an ammonium concentration of 57 µg L^{-1}. Ammonium concentration within the Oahu urbanized estuaries ranged from 0 to 34 µg L^{-1}. The 50th percentile of area of the Oahu urbanized estuaries had an ammonium concentration of 10 µg L^{-1}, with the 90th percentile of total area characterized by an ammonium concentration of 25.7 µg L^{-1} (Figure 3.1-20).

The average water column concentration of total dissolved inorganic nitrogen (nitrogen as nitrate + nitrite + ammonium) in Hawaii estuaries and coastal bays ranged from 2.5 to 284 µg L^{-1} (Figure 3.1-21). The 50th percentile of area of the Hawaii estuaries and coastal bays sampled had a total nitrogen concentration of 36.5 µg L^{-1}, with the 90th percentile of total area characterized by a total nitrogen concentration of 66.5 µg L^{-1}. Total nitrogen concentration within the Oahu urbanized estuaries ranged from 0 to 97.7 µg L^{-1}. The 50th percentile of area of the Oahu urbanized estuaries had a total nitrogen concentration of 19 µg L^{-1}, with the 90th percentile characterized by a total nitrogen concentration of 35 µg L^{-1} (Figure 3.1-22).

The average water column concentration of orthophosphate in Hawaii estuaries and coastal bays ranged from 0 to 33 µg L^{-1} (Figure 3.1-23). The 50th percentile of area of the Hawaii estuaries and coastal bays sampled had an orthophosphate concentration of 4.4 µg L^{-1}, with the 90th percentile of total estuarine area characterized by a concentration of 7.1 µg L^{-1}. Orthophosphate concentration within the Oahu urbanized estuaries ranged between 0 and 396.7 µg L^{-1}. The 50th percentile of area of the Oahu urbanized estuaries had an orthophosphate concentration of 2.7 µg L^{-1}, with the 90th percentile of area characterized by a concentration of 6.4 µg L^{-1} (Figure 3.1-24).

The ratio of total dissolved inorganic nitrogen (nitrogen as nitrate + nitrite + ammonium) concentration to total orthophosphate concentration was calculated as an indicator of which nutrient may be controlling primary production. A ratio above 16 is generally considered indicative of phosphorus limitation, and a ratio below 16 is considered indicative of nitrogen limitation (Geider and La Roche, 2002). The N/P ratio ranged from 2.4 to 36.4, across the 49 stations in Hawaii estuaries and bays where sufficient measurements were collected to compute the ratio (Figure 3.1-25). Approximately 40% of estuarine area had N/P values $\leq$ 16. The 50th percentile of area of the Hawaii estuaries and coastal bays sampled had a ratio of 20.7, while the 90th percentile of area had a ratio of 27. The N/P ratio ranged from 0 to 64.6, across the 29 stations in Oahu urbanized estuaries where sufficient measurements were collected to compute the ratio (Figure 3.1-26). Approximately 74% of estuarine area in Oahu urbanized estuaries had N/P values $\leq$ 16. The 50th percentile of area of the Oahu urbanized estuaries had a ratio of 7.8, while the 90th percentile of area had a ratio of 25. The long right hand tail of the CDF was due to one station representing 8% of area with an N/P ratio of 64.6.

The average water column concentration of silicate in Hawaii estuaries and coastal bays ranged from 57.3 to 14,710 µg L^{-1} (Figure 3.1-27). The 50th percentile of area of the Hawaii estuaries and coastal bays sampled had a silicate concentration of 230 µg L^{-1}, with the 90th percentile of area characterized by a concentration of 1468 µg L^{-1} (Figure

3.1-27). Silicate concentration within the Oahu urbanized estuaries ranged between 70 and 10,090 µg L^{-1}. The 50th percentile of area of the Oahu urbanized estuaries had a silicate concentration of 839 µg L^{-1}, with the 90th percentile of area characterized by a concentration of 2988 µg L^{-1} (Figure 3.1-28).

Turbidity

The bottom turbidity in Hawaii estuaries and coastal bays ranged from 0 to 1423 NTU. The 50th percentile of area of the Hawaii estuaries and coastal bays sampled had a bottom turbidity of 0.8 NTU, with the 90th percentile of area characterized by a bottom turbidity of 204 NTU (Figure 3.1-29). Bottom turbidity within the Oahu urbanized estuaries ranged from 1.7 to 1746 NTU. The 50th percentile of area of the Oahu urbanized estuaries had a bottom turbidity of 340 NTU, with the 90th percentile of area characterized by a bottom turbidity of 1065 NTU (Figure 3.1-30).

The surface turbidity ranged from 0 to 355 NTU. The 50th percentile of area of the Hawaii estuaries and coastal bays sampled had a surface turbidity of 0.09 NTU, with the 90th percentile of area characterized by a turbidity level of only 3.4 NTU (Figure 3.1-31). The surface turbidity within the Oahu urbanized estuaries ranged from 0 to 970 NTU. The 50th percentile of area of the Oahu urbanized estuaries had a surface turbidity of 3.8 NTU, with the 90th percentile of area characterized by a turbidity level of 75 NTU (Figure 3.1-32).

Secchi Depth

The Secchi depth of the water column in Hawaii estuaries and bays ranged from 0.8 to 9.4 m at the 14 sites where measurements were obtained. Because the Secchi depth was equal to the bottom depth at many sites, information from this CDF should be interpreted cautiously (Figure 3.1-33), and percentiles are not presented. Sites with Secchi depths included in the analysis will tend to be either those that were deeper, or those that were more turbid. The Secchi depth within the Oahu urbanized estuaries ranged from 0.6 to 6.9 m at the 23 sites where measurements were obtained. The 50th percentile of area of the Oahu urbanized estuaries had a Secchi depth of 3.2 m, with the 90th percentile of area represented by a value of 5.5 m (Fig. 3.1-34).

3.1.7 Water Column Stratification

As an indicator of water column stratification, an index was calculated with temperature and salinity data. The index ($\Delta\sigma_t$) was the difference between the computed bottom and surface σ_t values, where σ_t is the density of a parcel of water with a given salinity and temperature relative to atmospheric pressure.

The $\Delta\sigma_t$ index for stations from Hawaii estuaries and bays had values ranging from -0.07 to +10.1. Approximately 4% of the area of Hawaii estuaries and bays showed $\Delta\sigma_t$ index values < 0, indicating bottom waters less dense than surface waters (Figure 3.1-

35). Approximately 18% of the area of Hawaii estuaries and bays had $\Delta\sigma_t$ index values $\geq$ 2, indicating strong stratification. The $\Delta\sigma_t$ index for stations from Hawaii estuaries and bays had values ranging from -1.1 to +21.2. Approximately 11% of the area of Oahu urbanized estuaries showed $\Delta\sigma_t$ index values < 0, indicating bottom waters less dense than surface waters (Figure 3.1-36). Approximately 65% of estuarine area had $\Delta\sigma_t$ index values $\geq$ 2, indicating strong vertical stratification.

The limited indication of strong water column stratification within the Hawaii estuaries and coastal bays indicates water bodies that are well mixed. The Oahu urbanized estuaries show a much higher indication of strong vertical stratification.

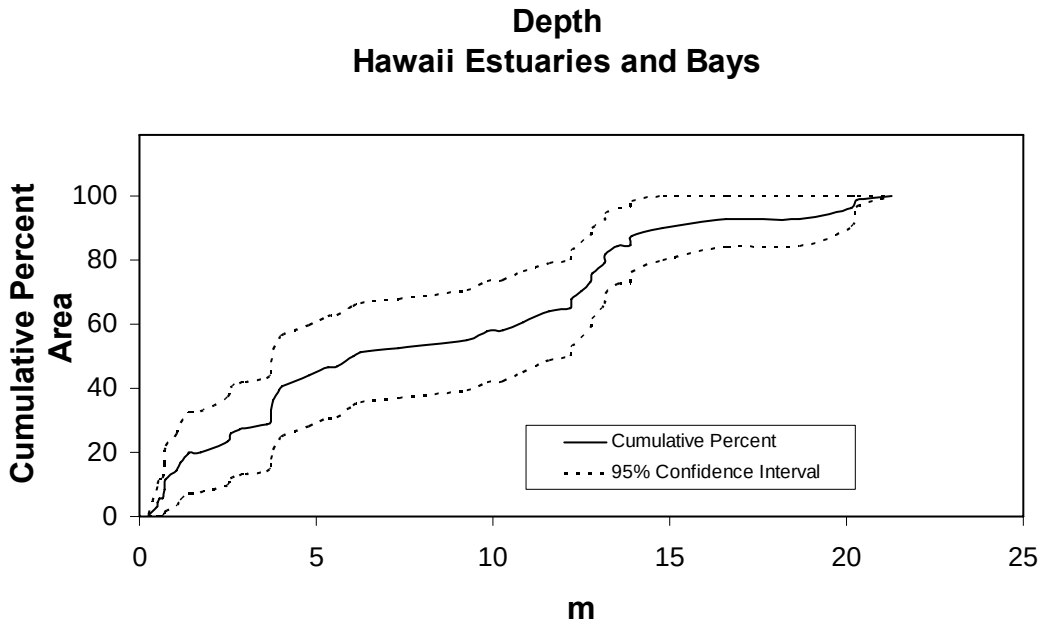

Figure 3.1-1. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. bottom depth.

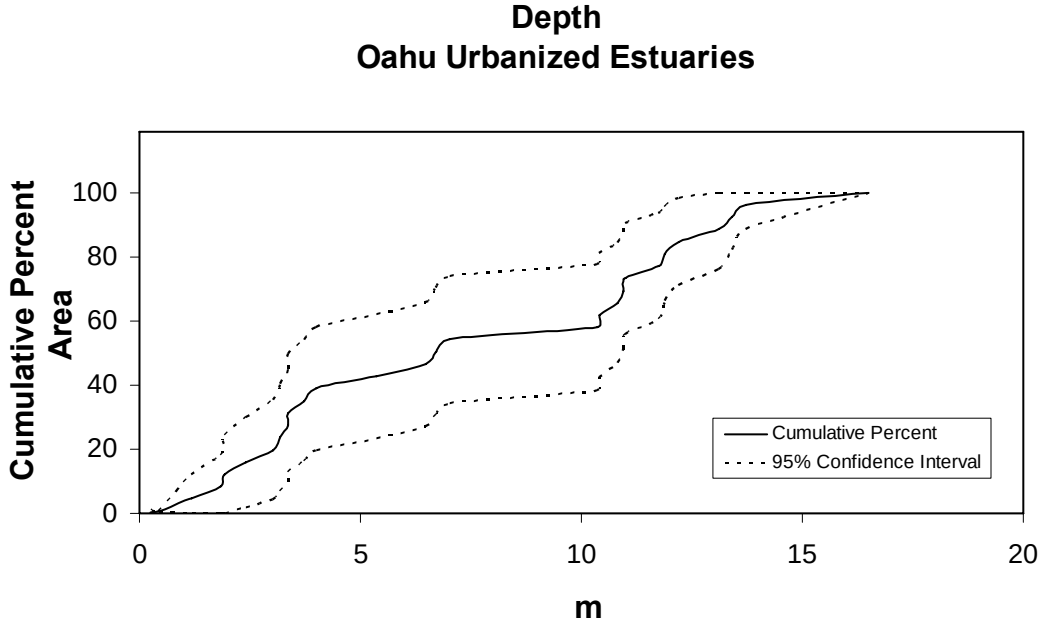

Figure 3.1-2. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. bottom depth.

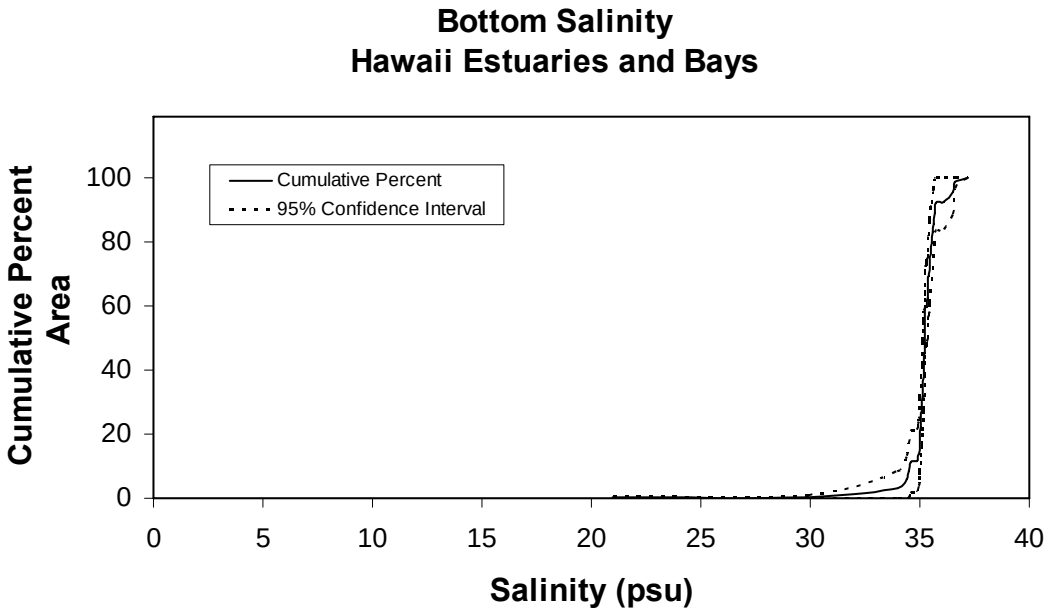

Figure 3.1-3. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. salinity of bottom waters.

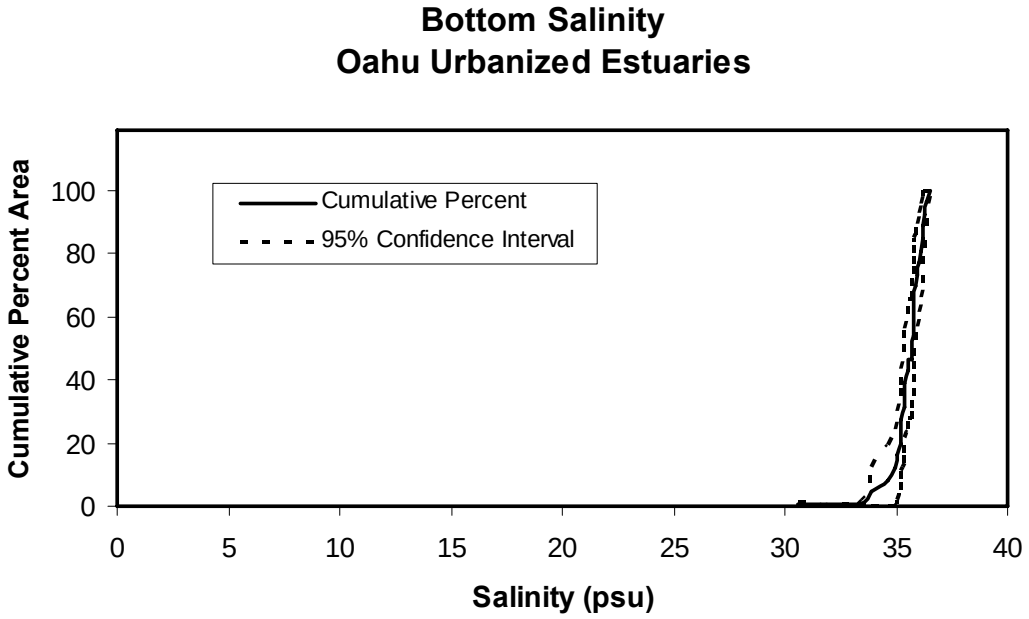

Figure 3.1-4. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. salinity of bottom waters.

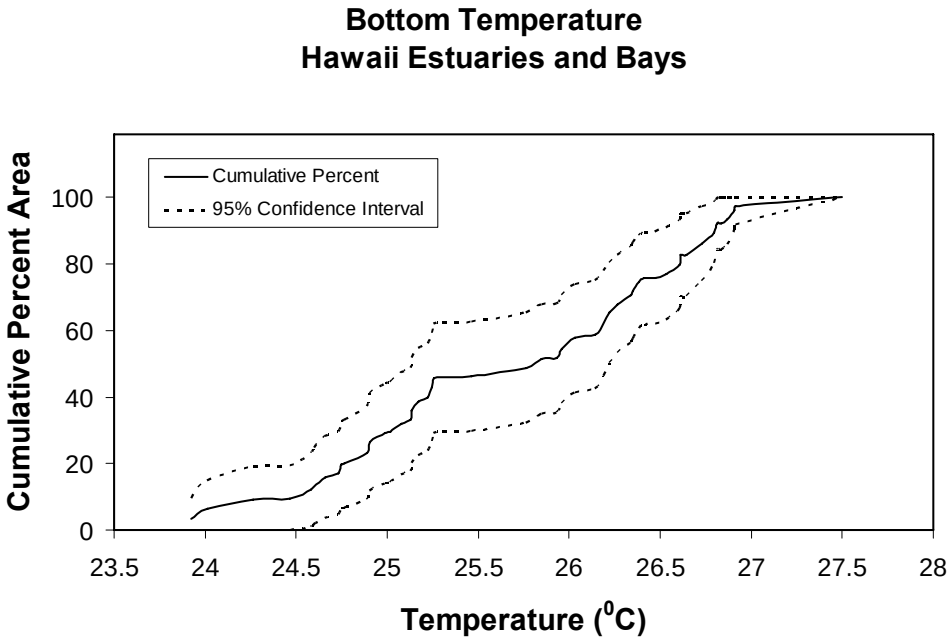

Figure 3.1-5. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. temperature of bottom waters.

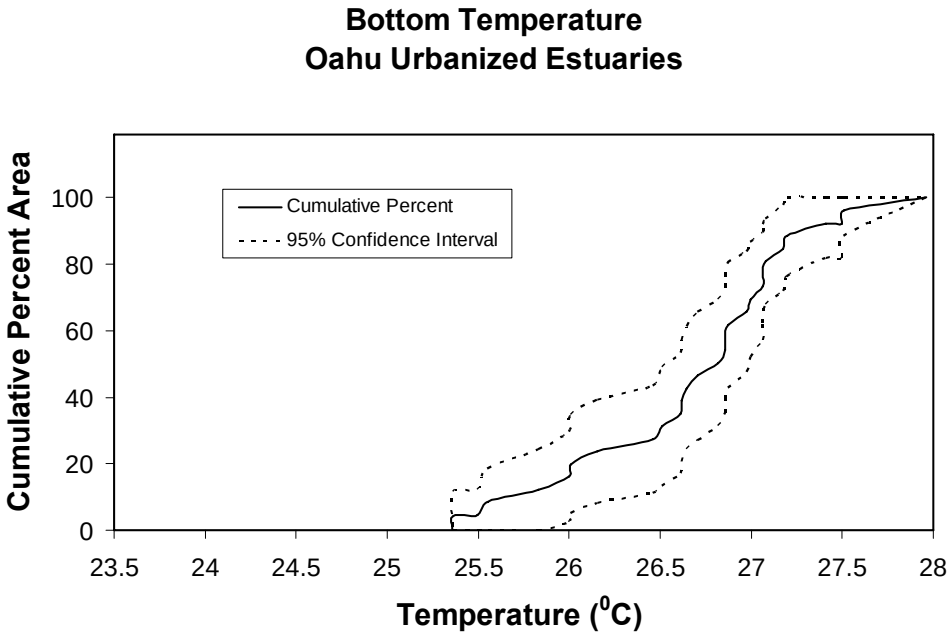

Figure 3.1-6. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. temperature in bottom waters.

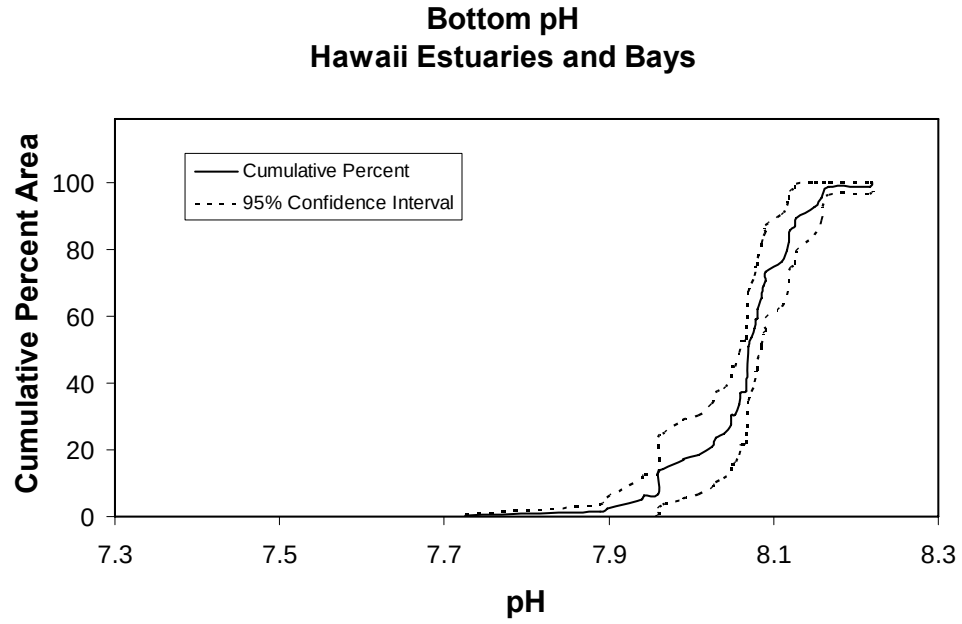

Figure 3.1-7. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. pH in bottom waters.

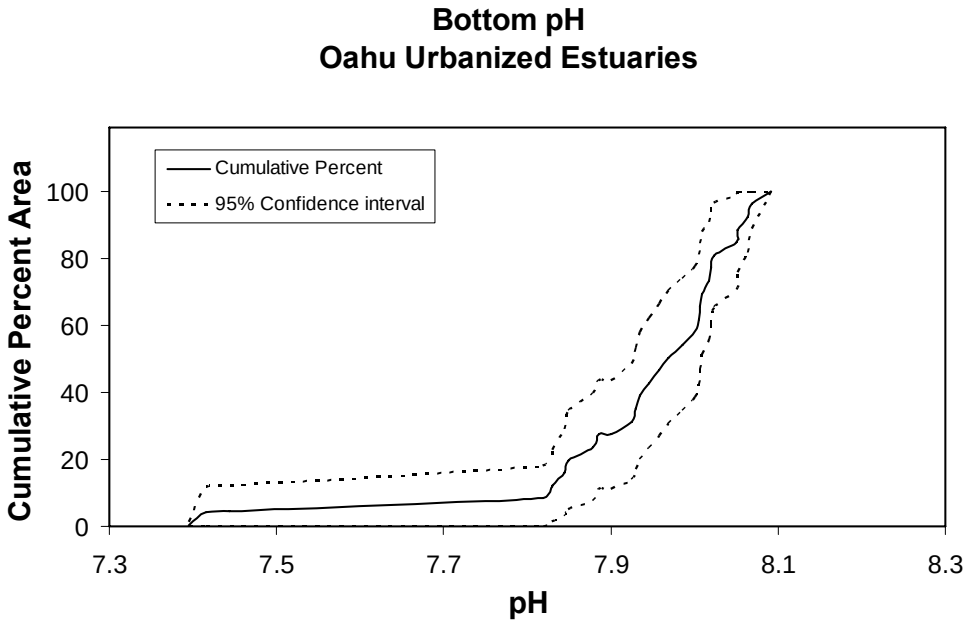

Figure 3.1-8. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. pH in bottom waters.

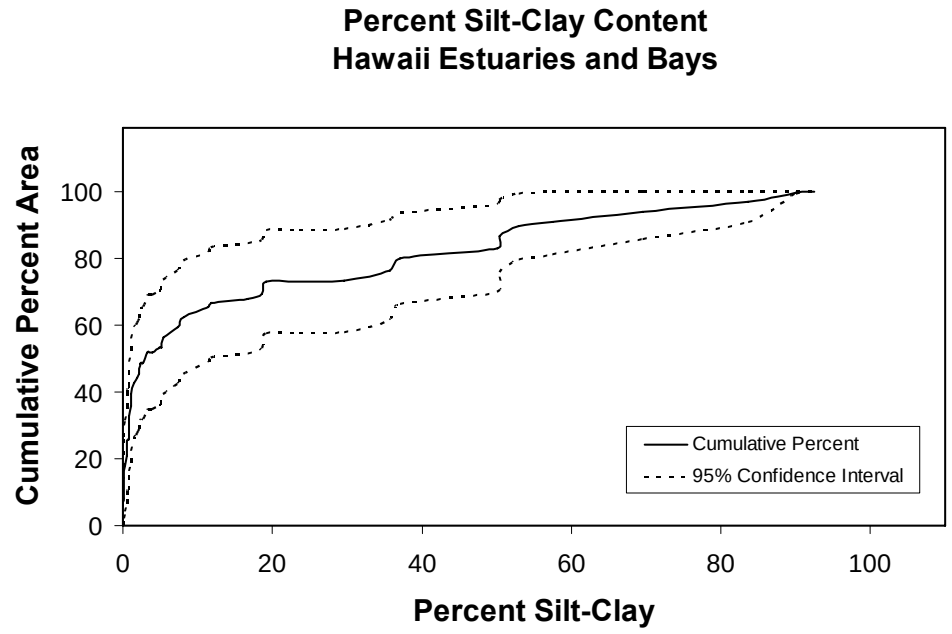

Figure 3.1-9. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. percent silt-clay of sediments.

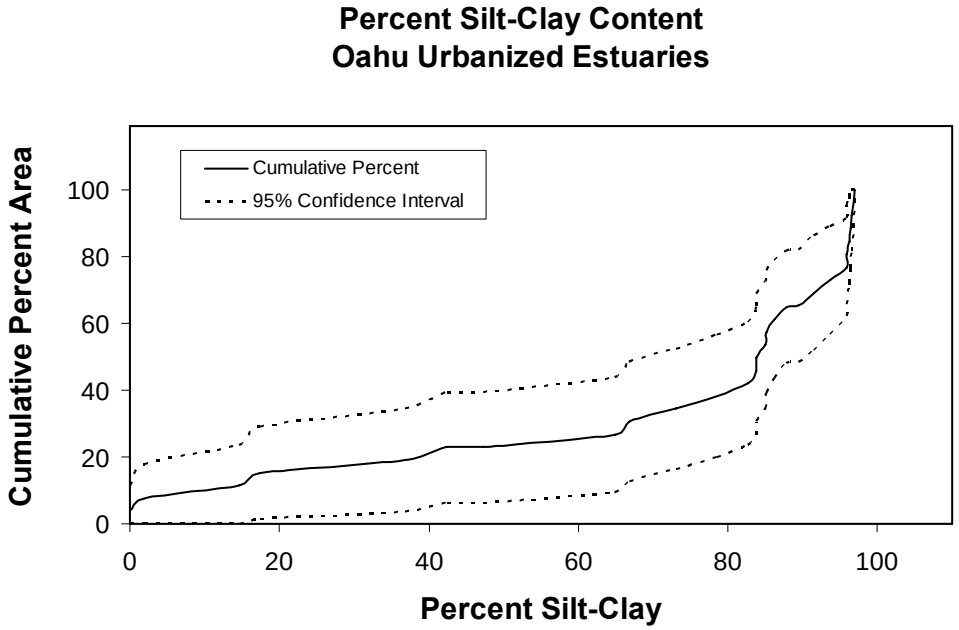

Figure 3.1-10. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. percent silt-clay of sediments.

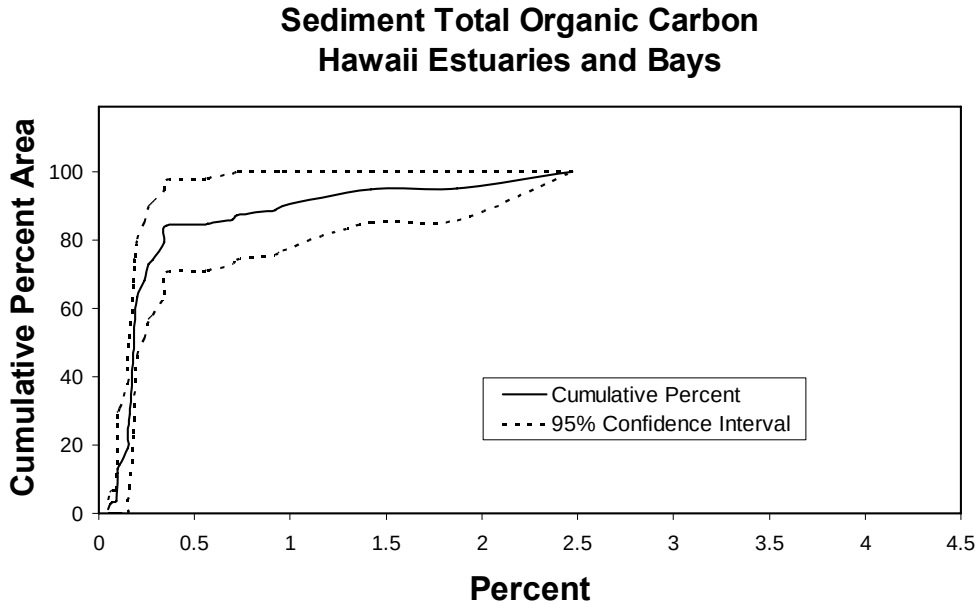

Figure 3.1-11. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. percent total organic carbon of sediments.

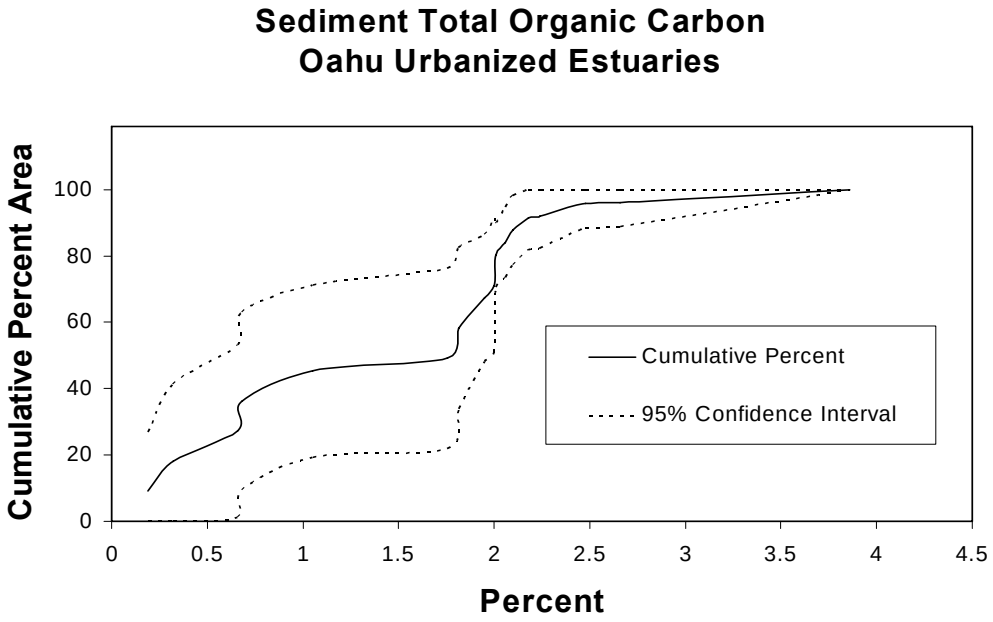

Figure 3.1-12. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. percent total organic carbon of sediments.

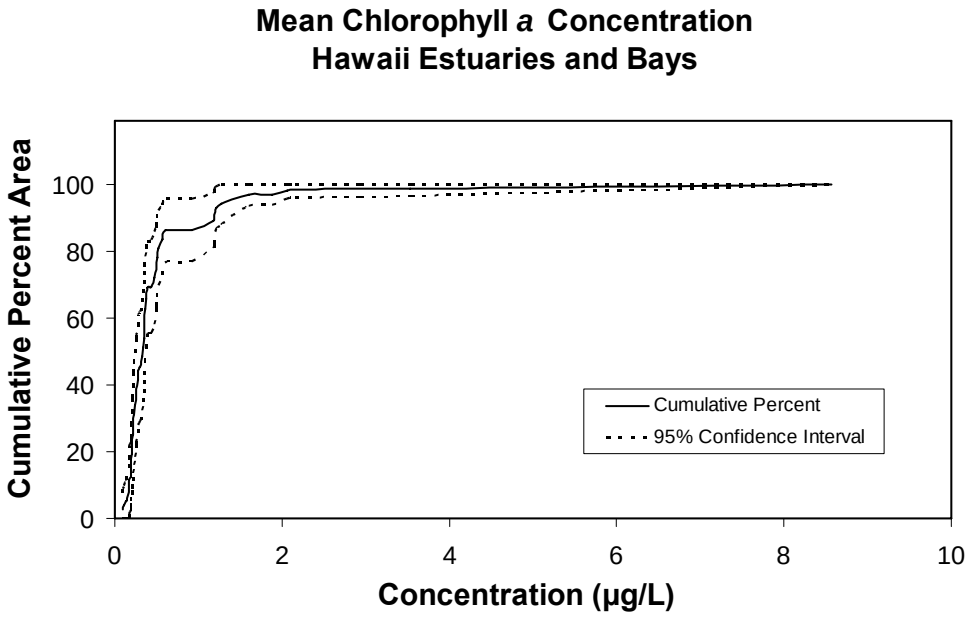

Figure 3.1-13. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. water column mean concentration of chlorophyll *a*.

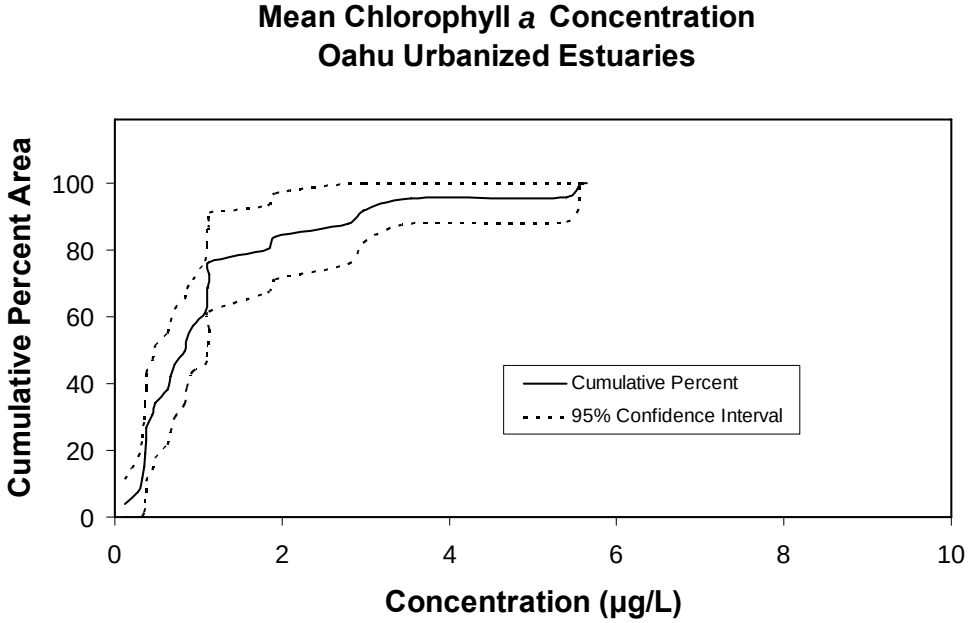

Figure 3.1-14. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. water column concentration of chlorophyll *a*.

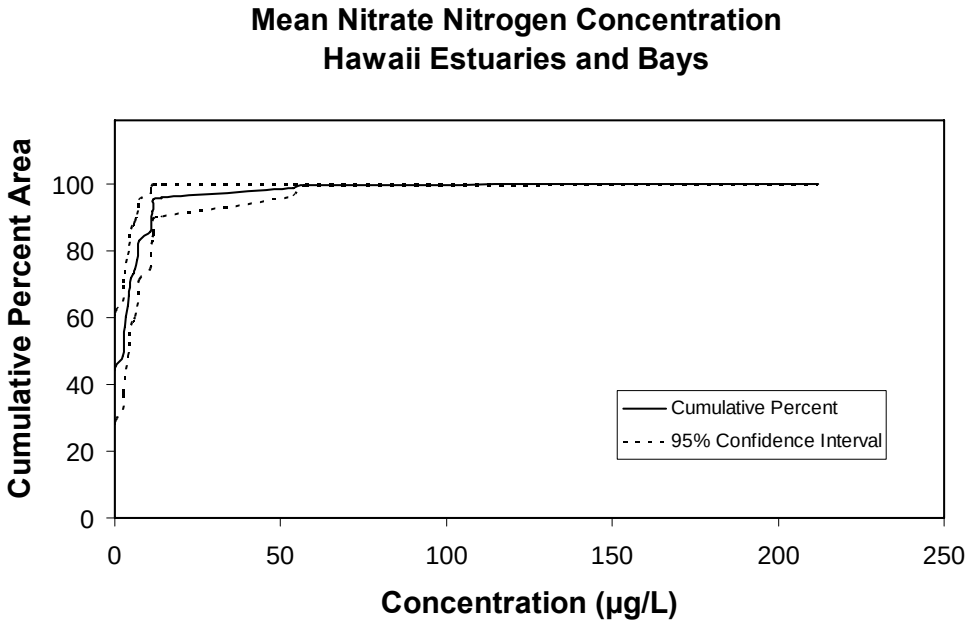

Figure 3.1-15. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. water column mean nitrate concentration.

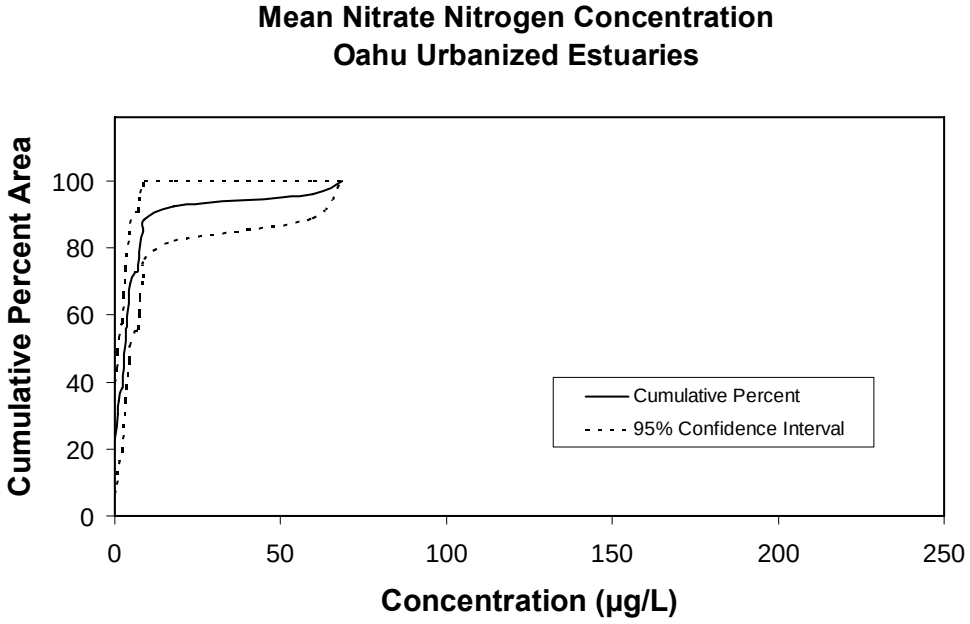

Figure 3.1-16. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. water column mean nitrate concentration.

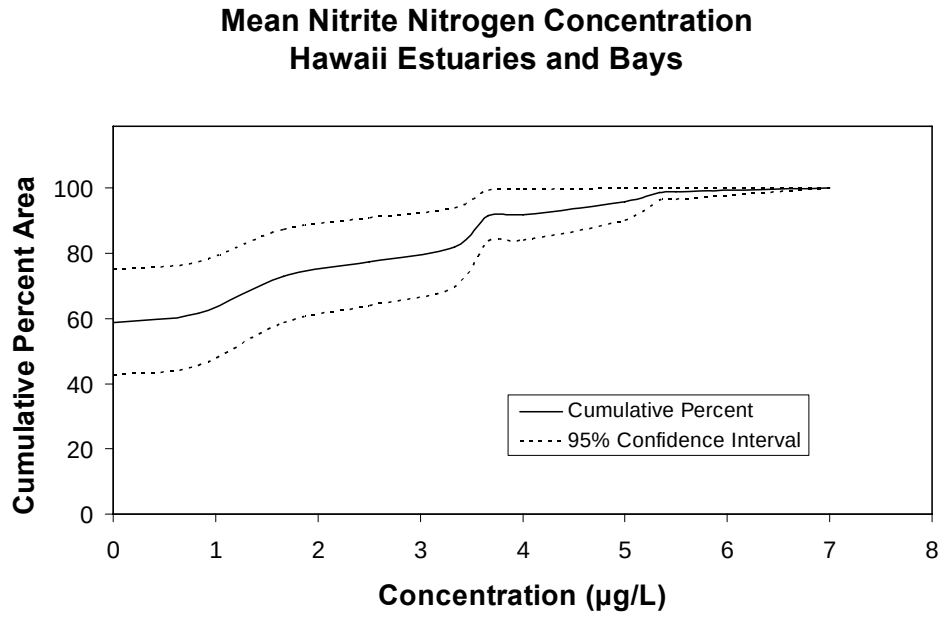

Figure 3.1-17. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. water column mean nitrite concentration.

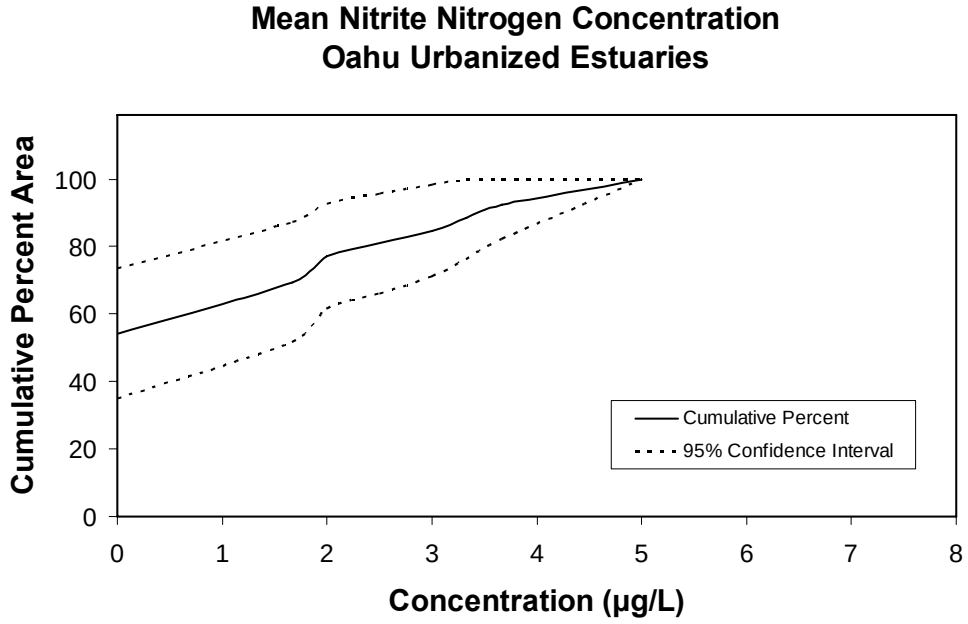

Figure 3.1-18. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. water column mean nitrite concentration.

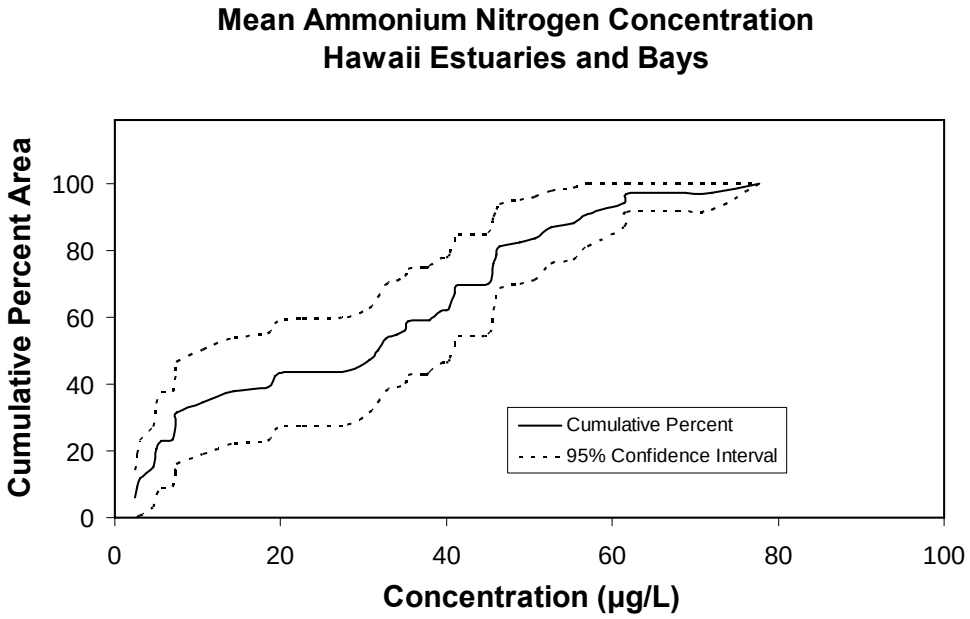

Figure 3.1-19. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. water column ammonium concentration.

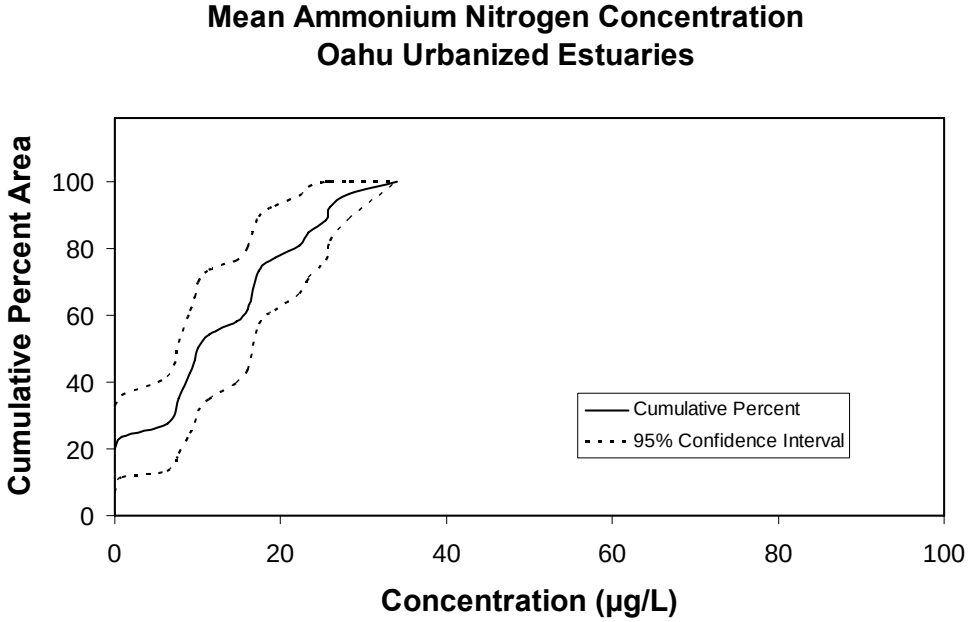

Figure 3.1-20. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. water column ammonium concentration.

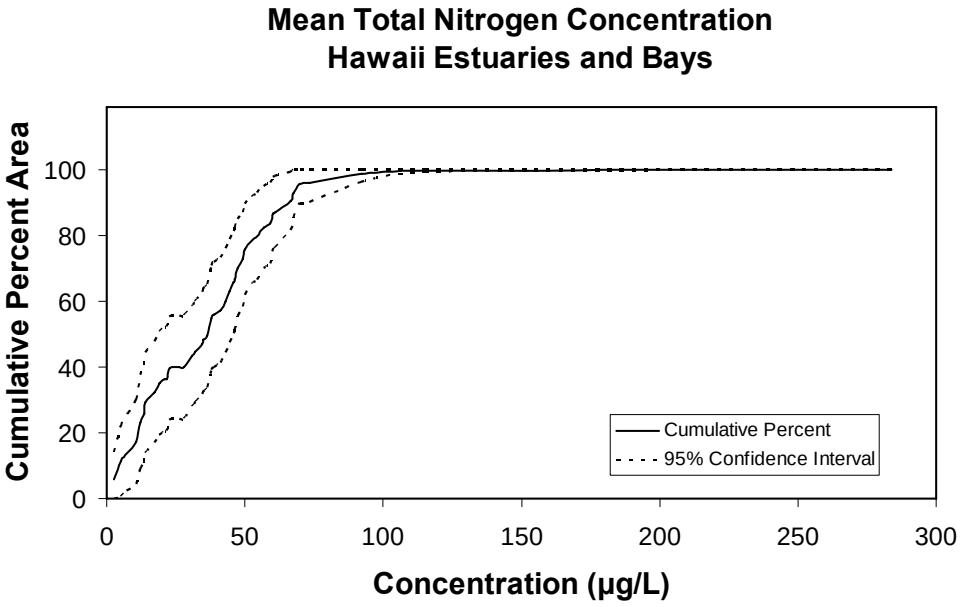

Figure 3.1-21. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. water column mean total nitrogen (nitrate + nitrite + ammonium) concentration.

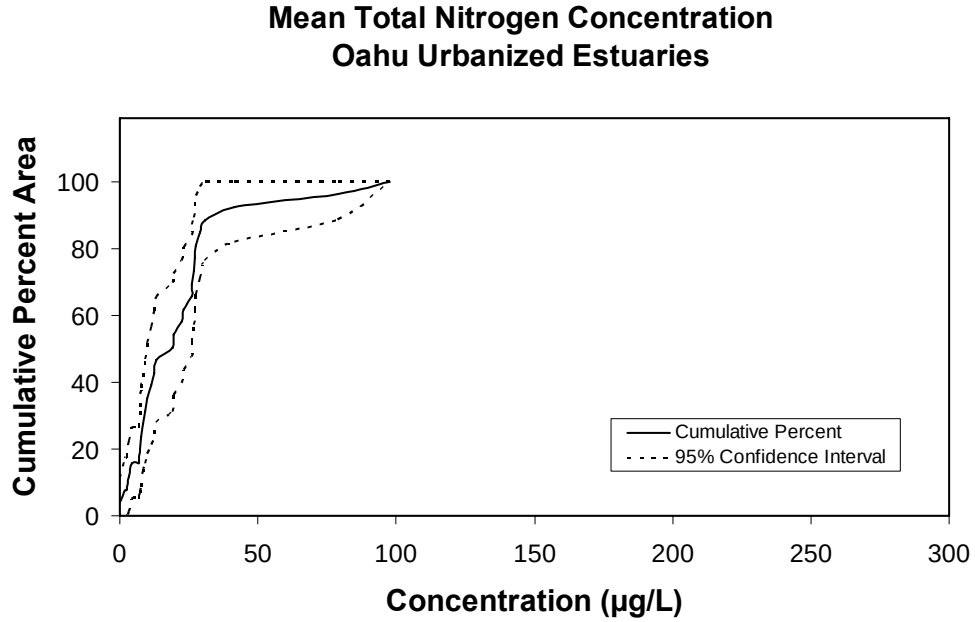

Figure 3.1-22. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. water column mean total nitrogen (nitrate + nitrite + ammonium) concentration.

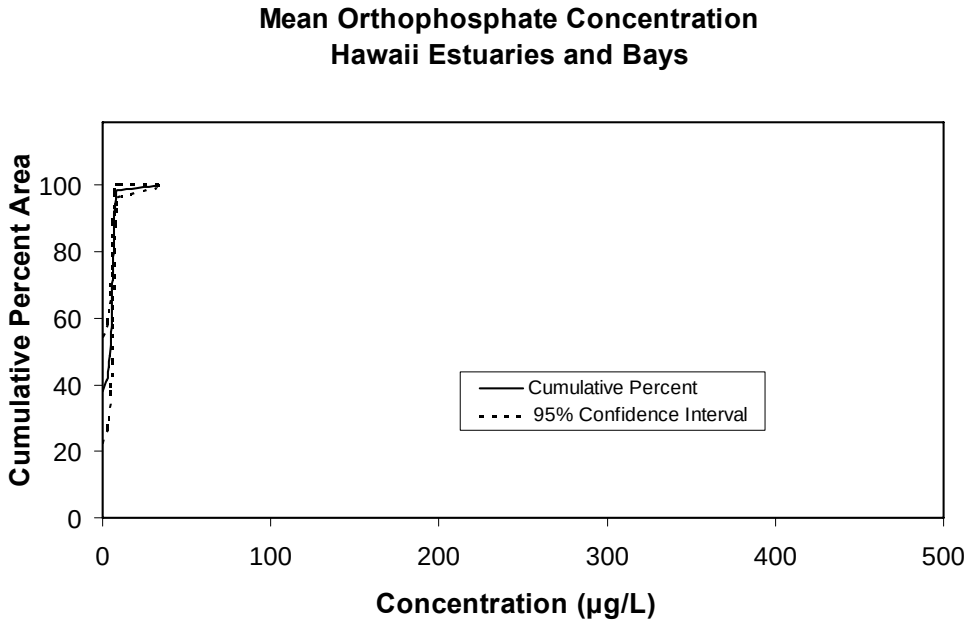

Figure 3.1-23. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. water column mean orthophosphate concentration.

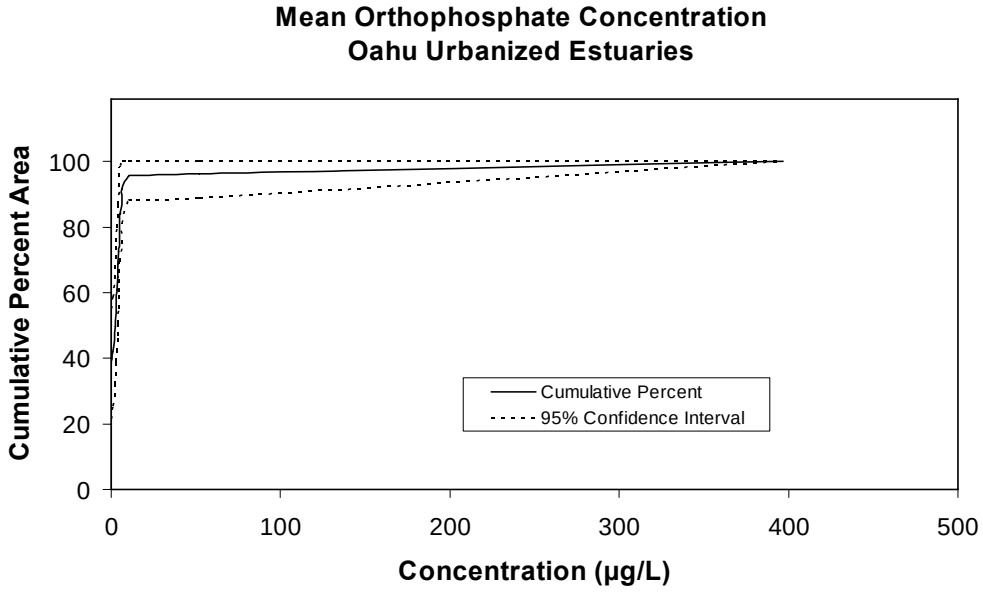

Figure 3.1-24. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. water column mean orthophosphate concentration.

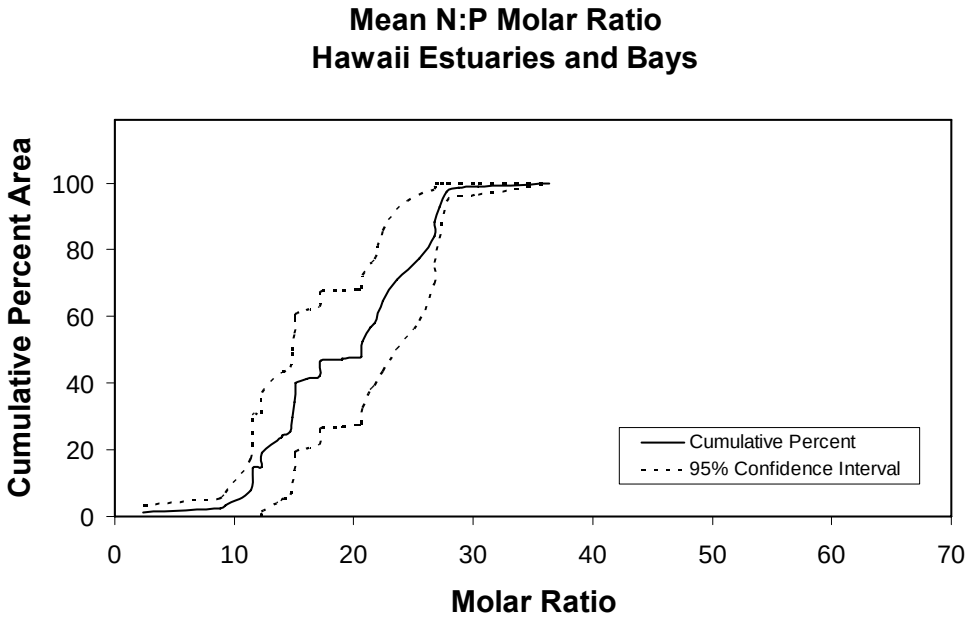

Figure 3.1-25. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. water column mean ratio of total nitrogen (nitrate + nitrite + ammonium) concentration to total orthophosphate concentration.

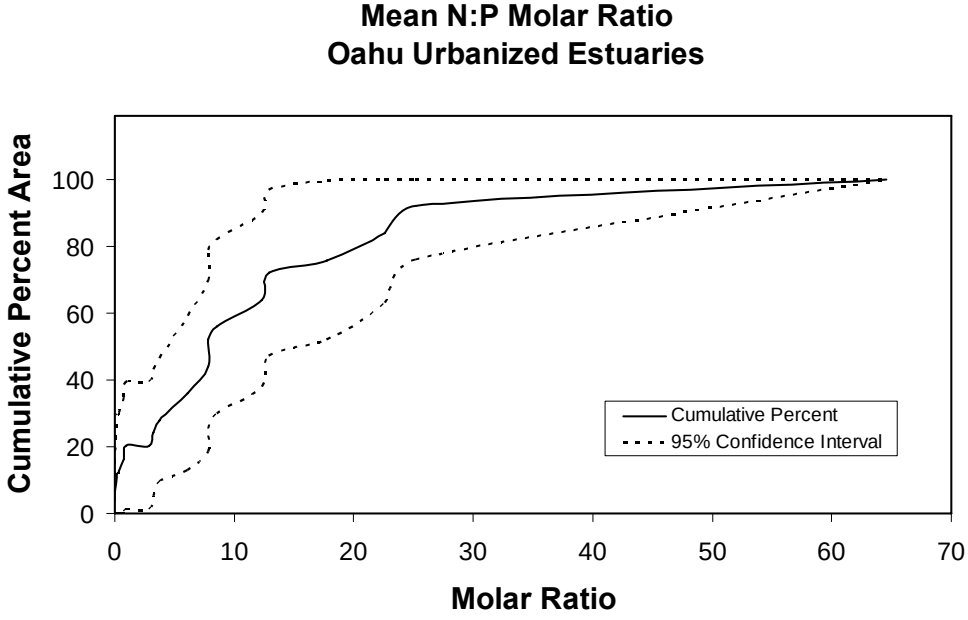

Figure 3.1-26. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. water column mean ratio of total nitrogen (nitrate + nitrite + ammonium) concentration to total orthophosphate concentration.

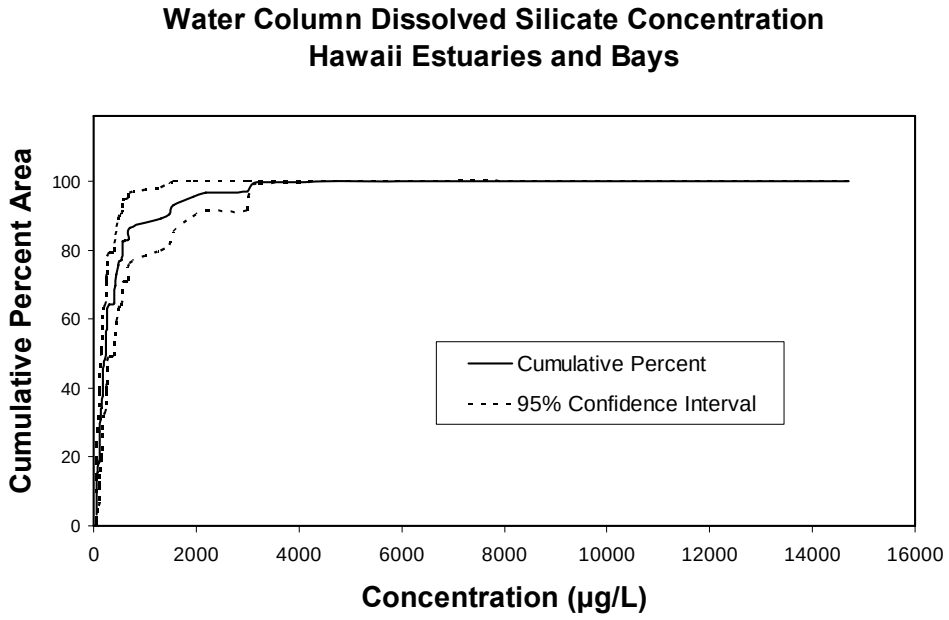

Figure 3.1-27. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. water column mean silicate concentration.

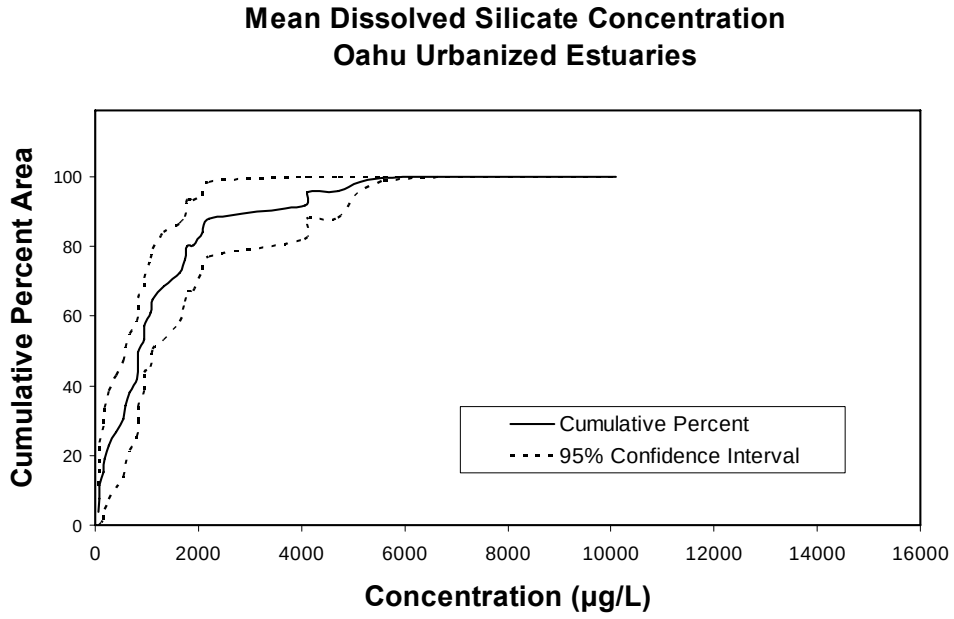

Figure 3.1-28. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. water column mean silicate concentration.

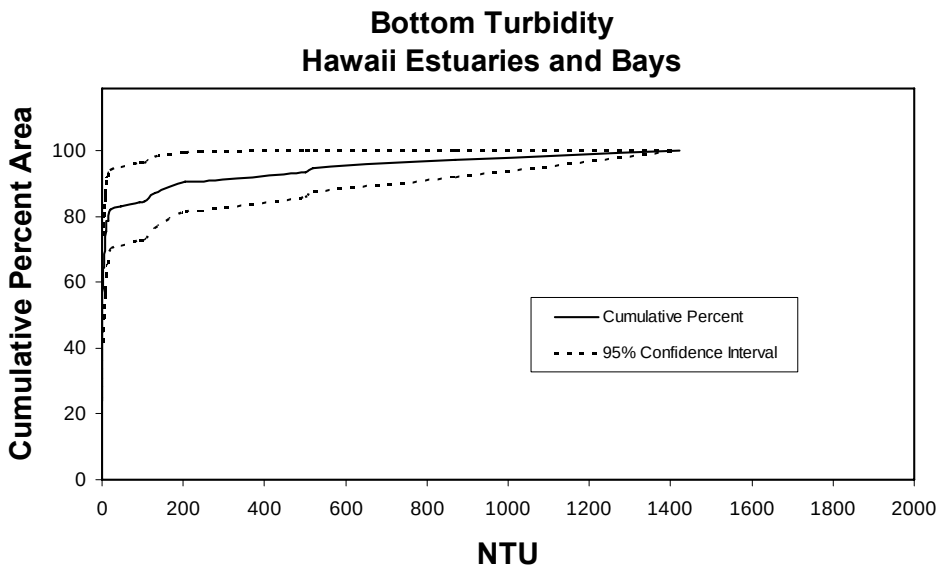

Figure 3.1-29. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. bottom water turbidity.

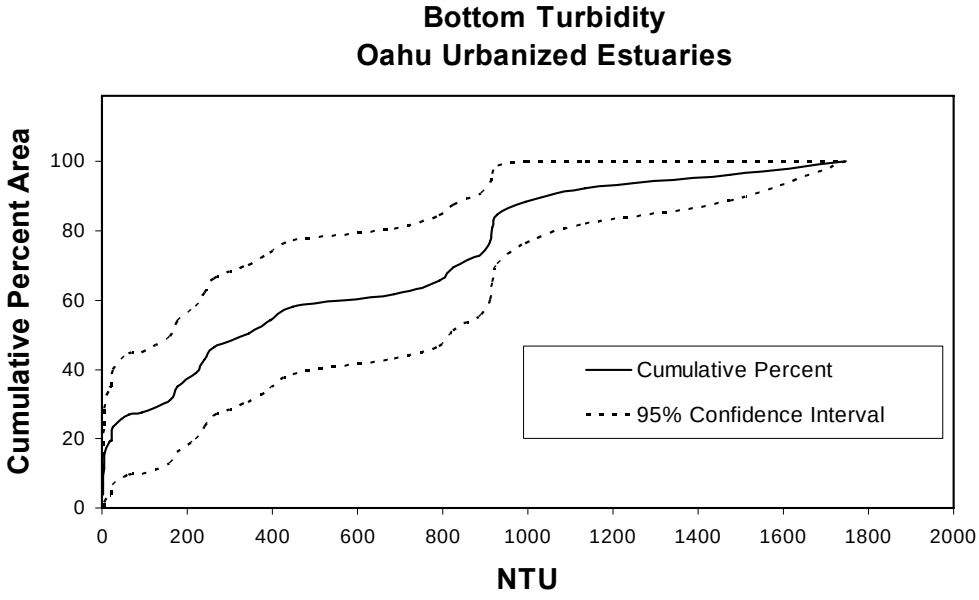

Figure 3.1-30. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. bottom water turbidity.

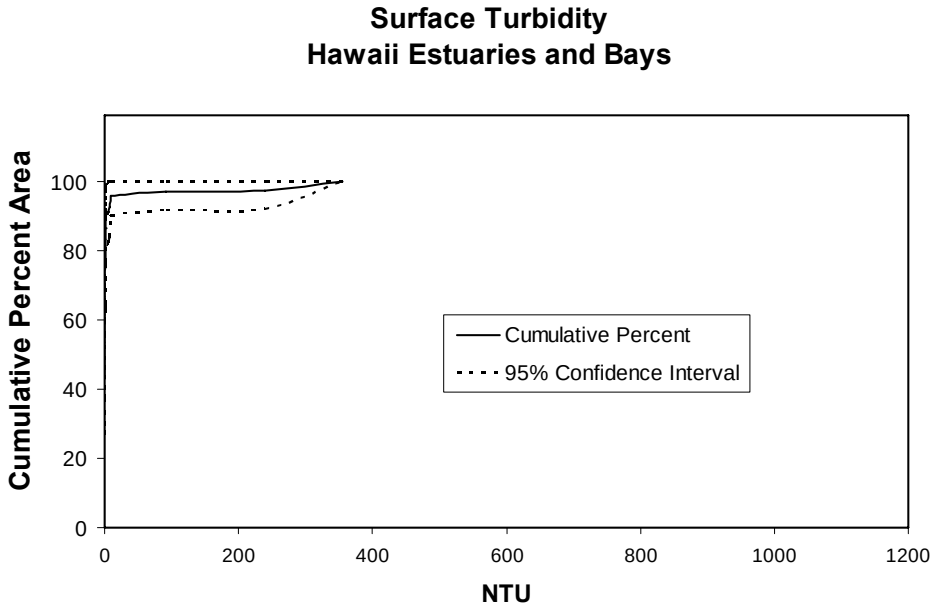

Figure 3.1-31. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. surface water turbidity.

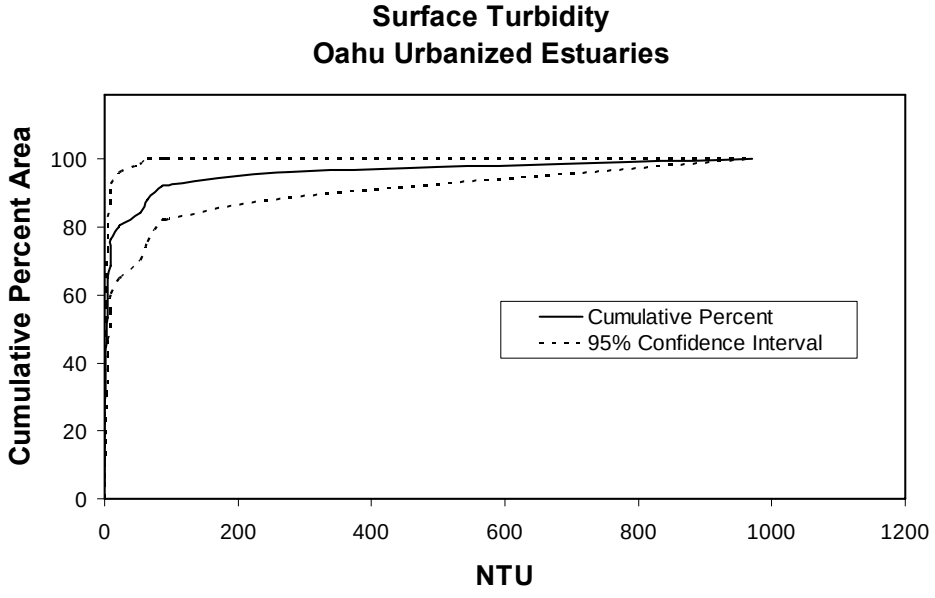

Figure 3.1-32. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. surface water turbidity.

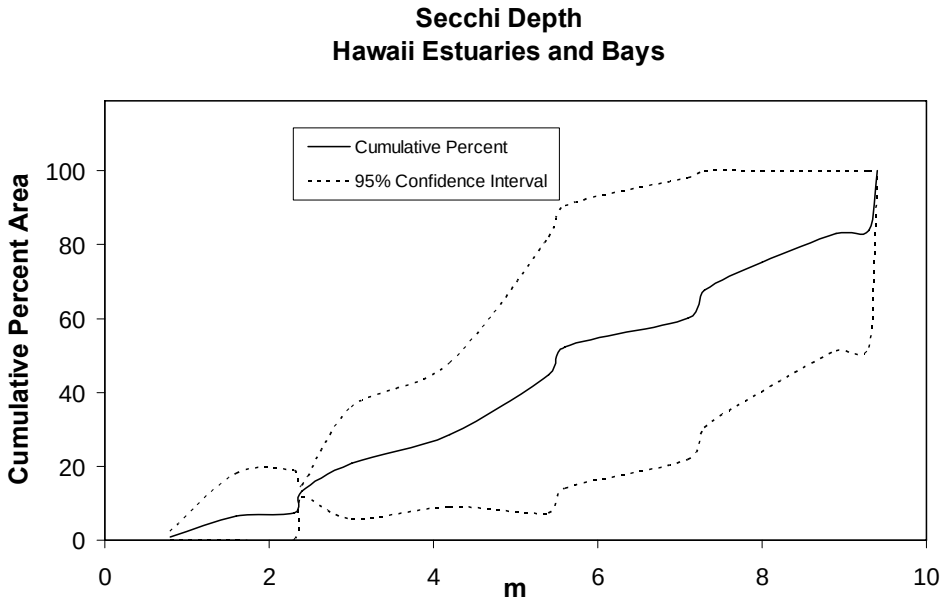

Figure 3.1-33. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. water column Secchi depth.

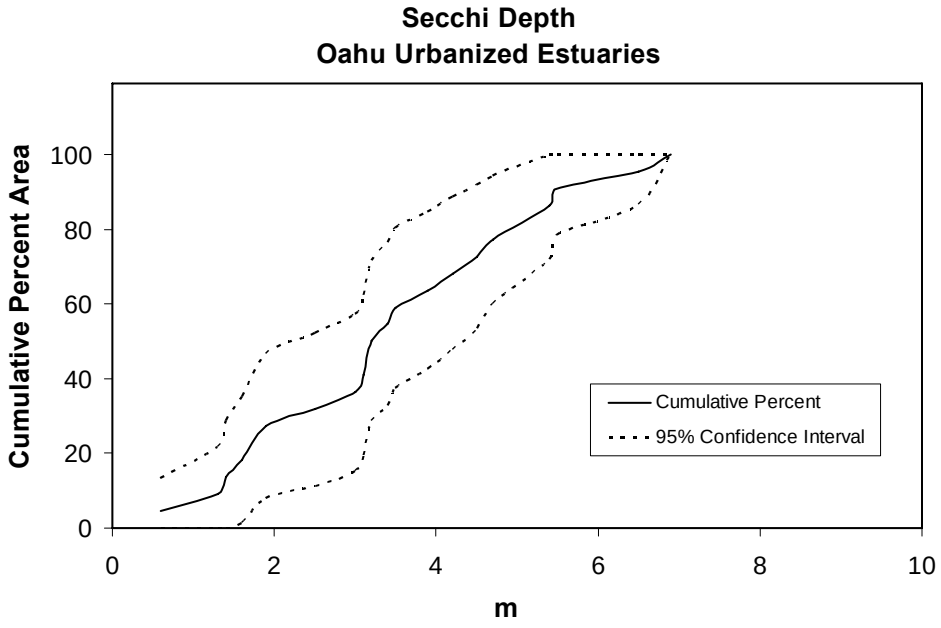

Figure 3.1-34. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. water column Secchi depth.

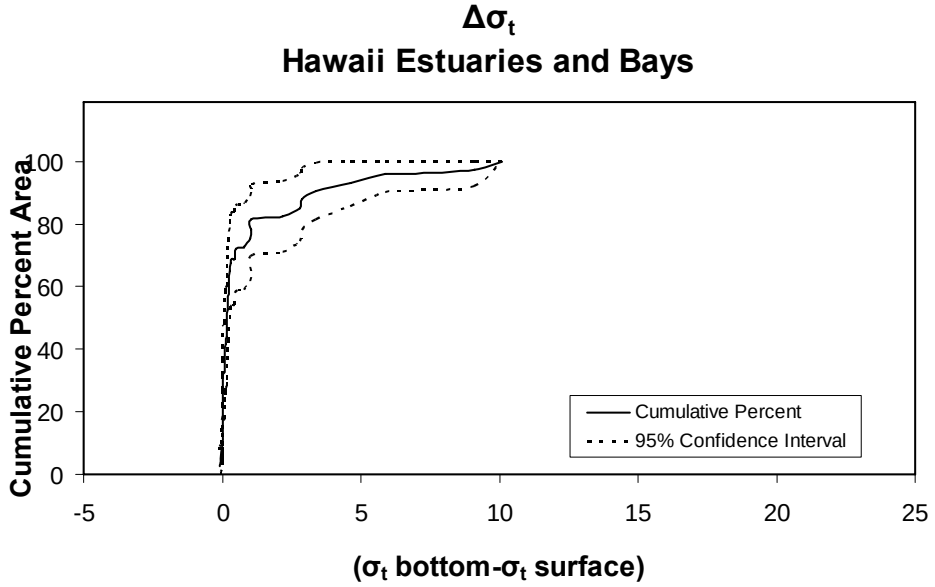

Figure 3.1-35. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. $\Delta\sigma_t$ stratification index.

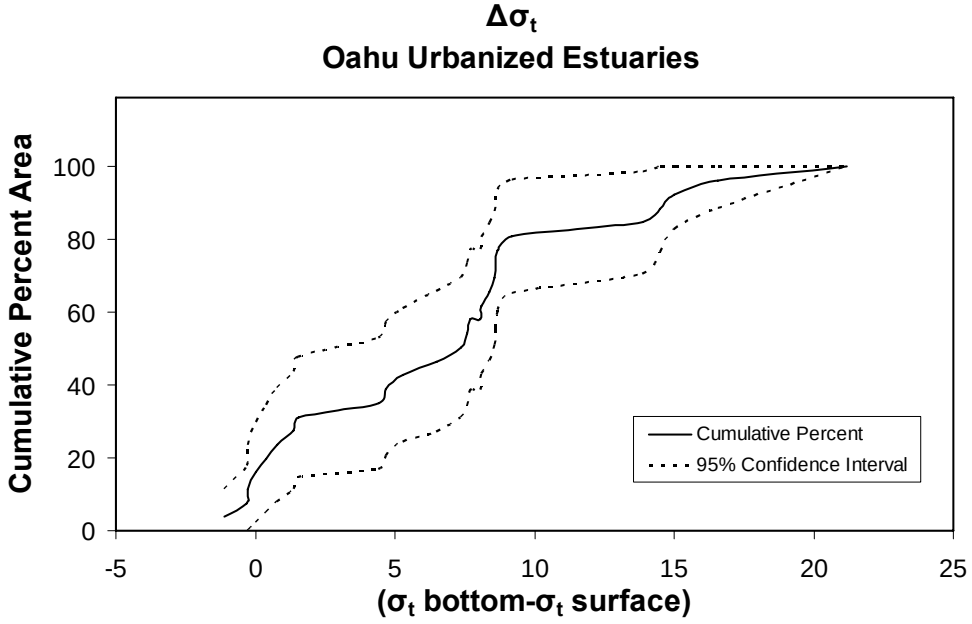

Figure 3.1-36. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. $\Delta\sigma_t$ stratification index.

3.2 Exposure Indicators

3.2.1 Dissolved Oxygen

Dissolved oxygen (DO) concentrations in the bottom water for the Hawaii estuaries and bays ranged from 4.4 mg/L to 8.4 mg/L, across the 50 stations where dissolved oxygen concentrations were measured. Approximately 7% of estuarine area had a bottom water DO concentration $\leq$ 5 mg/L (Fig. 3.2 -1). The range of dissolved oxygen (DO) concentrations in the surface waters of Hawaii estuaries and bays was very similar to that for bottom waters (4.6 mg/L to 8.5 mg/L; Fig. 3.2 -3). Only approximately 3.2 % of the area of Hawaii estuaries and bays had surface DO concentrations $\leq$ 5 mg/L.

Dissolved oxygen (DO) concentrations in both the surface and bottom water for the Oahu urbanized estuaries had a range from 4.2 mg/L to 8.8 mg/L, across the 29 stations where dissolved oxygen concentrations were measured. Approximately 92 percent of the area of Oahu urbanized estuaries had surface and bottom water DO concentrations > 5 mg/L (Fig. 3.2 -2, Fig. 3.2 -4).

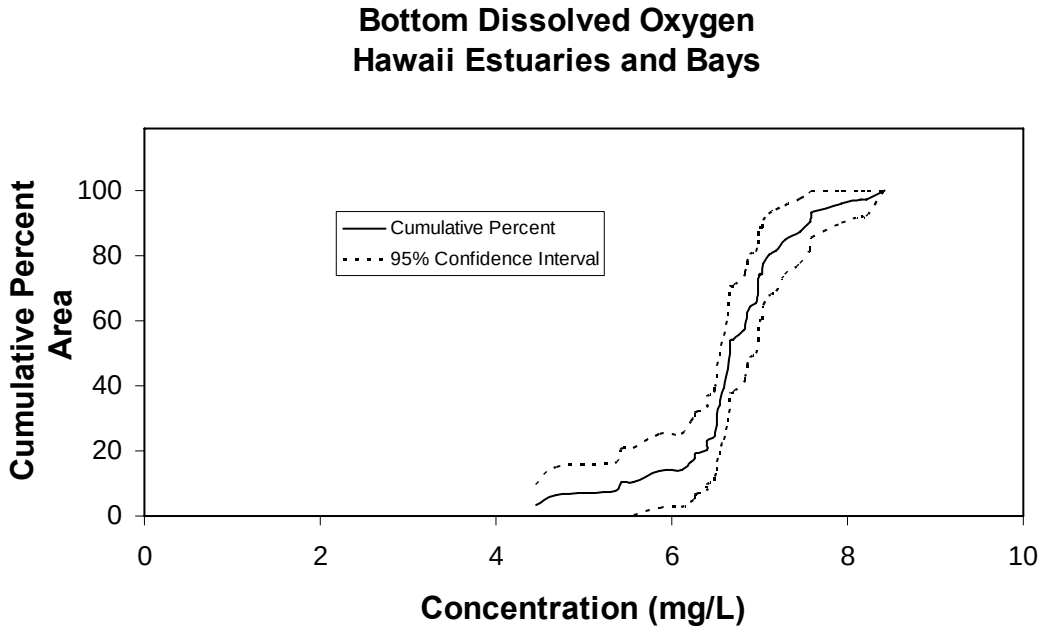

Figure 3.2 -1. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. dissolved oxygen of bottom waters.

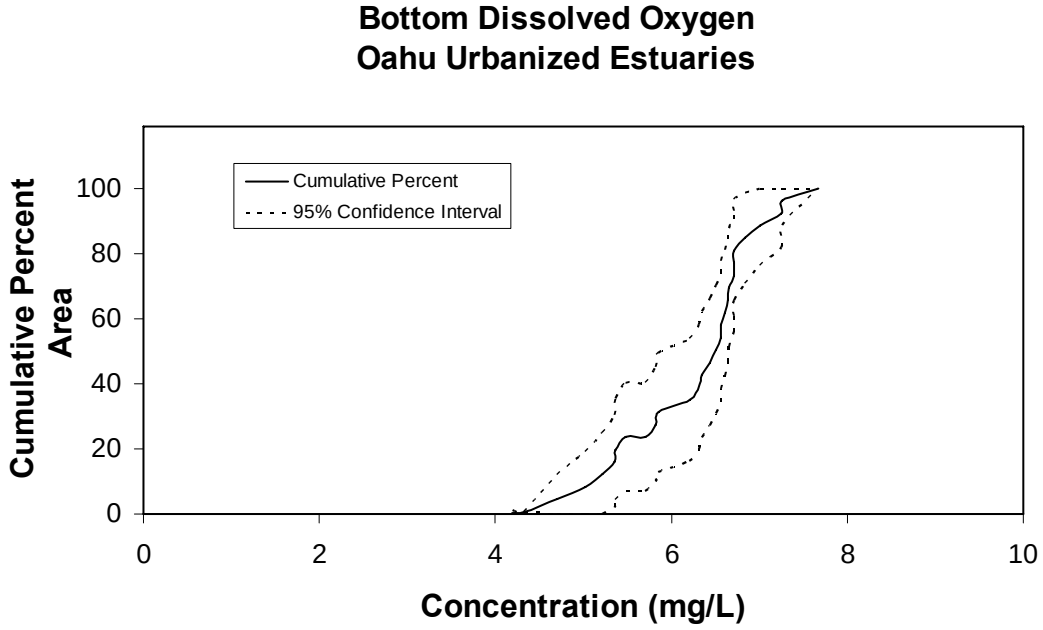

Figure 3.2 -2. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. dissolved oxygen of bottom waters.

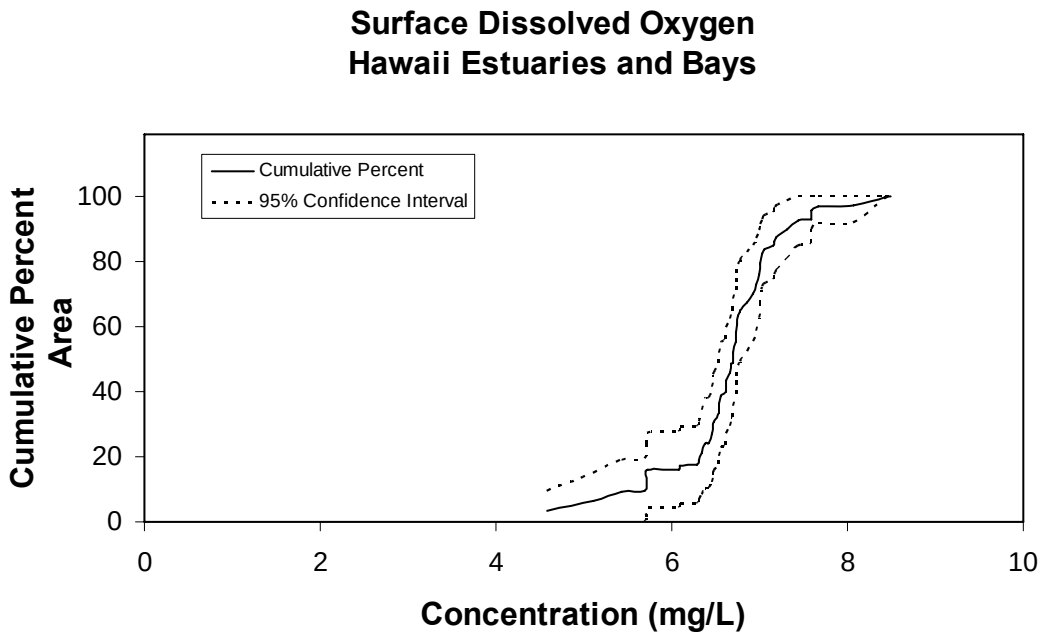

Figure 3.2 -3. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. dissolved oxygen of surface waters.

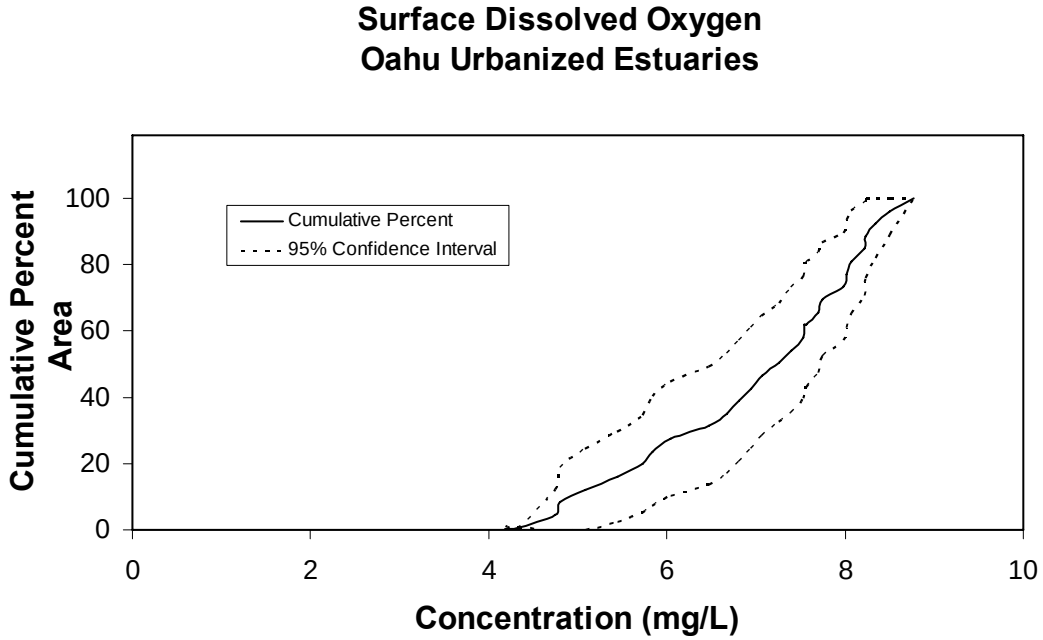

Figure 3.2 -4. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. dissolved oxygen of surface waters.

3.2.2 Sediment Contaminants

3.2.2.1 Sediment Metals

Concentrations of sediment metals were measured at 45 stations in the Hawaii estuaries and bays and at 28 stations in the Oahu urbanized estuaries. The mean concentration of each metal was calculated with the non-detects (i.e., less than the MDL) set to 0 (see Table 2.6 for the MDL's). Field replicates and laboratory replicates were averaged at stations where replicates were analyzed. For comparative purposes, mean concentrations of metals were also calculated using the subset of samples in which the metals were detected (Table 3.2 -1, 3.2-2).

Arsenic

Arsenic was detected at 41 of the 45 Hawaii estuaries and bays stations. Arsenic averaged 11.1 µg/g at these stations with a maximum concentration of 50.5 µg/g in Pohakumanu Bay (Table 3.2-1). Fifty percent of the area of the Hawaii estuaries and bays had an arsenic concentration less than 6.7 µg/g and 90% of the area had concentrations less than 25.8 µg/g (Figure 3.2-5). Arsenic was also detected at 27 of the 28 Oahu urbanized estuary stations. Arsenic averaged 12.1 µg/g at these stations with a maximum concentration of 27.8 µg/g in Keehi Lagoon Borrow Pit (Table 3.2-2). Fifty percent of the area of the Oahu urbanized estuaries had concentrations of 11.6 µg/g or less while 90% of the area had concentrations less than 21.7 µg/g (Figure 3.2-6). Arsenic concentrations exceeded the ERL at 23 Hawaii estuaries and bays stations (43% of area) and at 20 Oahu urbanized estuary stations (71% of area), while no stations had values exceeding the ERM (Table 3.2-1, 3.2-2).

Cadmium

Cadmium was detected at 6 of the 45 Hawaii estuaries and bays stations. Cadmium averaged 0.01 µg/g at these stations with a maximum concentration of 0.17 µg/g in the Paukauila Stream (Table 3.2-1). Approximately 90% of the area of Hawaii estuaries and bays had cadmium concentrations less than 0.01 µg/g (Figure 3.2-7). Cadmium was also detected at 20 of the 28 Oahu urbanized estuary stations. Cadmium averaged 0.16 µg/g at these stations with a maximum of 0.52 µg/g in Pearl Harbor (Table 3.2-2). Fifty percent of the area of the Oahu urbanized estuaries had cadmium concentrations less than 0.07 µg/g and 90% of the area had concentrations less than 0.40 µg/g (Figure 3.2-8). Cadmium concentrations did not exceed the ERL in any of the Hawaii estuaries and bays or in the Oahu urbanized estuaries (Tables 3.2-1, 3.2-2).

Chromium

Chromium was detected at all of the 45 Hawaii estuaries and bays stations. Chromium averaged 102.6 µg/g in these stations with a maximum concentration of 689 µg/g in the Paukauila Stream (Table 3.2-1). Fifty percent of the area of the Hawaii estuaries and bays had concentrations less than 18.4 µg/g and 90% of the area had concentrations less than 186 µg/g (Figure 3.2-9). Chromium was detected at 27 of the 28 Oahu

urbanized estuary stations. Chromium averaged 175.6 µg/g in the Oahu urbanized estuaries (Table 3.2-2) with a maximum concentration of 336 µg/g in Ala Wai Canal. Fifty percent of the area of the Oahu urbanized estuaries had chromium concentrations less than 166 µg/g and 90% had concentrations less than 288 µg/g (Figure 3.2-10). Chromium concentrations exceeded the ERL at 17 of the Hawaii estuaries and bays stations (27% of area), while one station in the Paukauila Stream (<1% of area) exceeded the ERM (Table 3.2-1). Chromium concentrations exceeded the ERL at 23 Oahu urbanized estuary stations (79% of area), with no stations exceeding the ERM (Table 3.2-2).

Copper

Copper was detected at 29 of the 45 Hawaii estuaries and bays stations. Copper averaged 23.3 µg/g in these stations with a maximum concentration of 201 µg/g in the Moanalua Stream (Table 3.2-1). Fifty percent of the area of the Hawaii estuaries and bays had concentrations less than 6.5 µg/g while 90% of the area had concentrations less than 48 µg/g (Figure 3.2-11). Copper was also detected at 27 of the 28 Oahu urbanized stations. Copper averaged 129 µg/g in the Oahu urbanized estuary stations with a maximum concentration of 405 µg/g in the Ala Wai Harbor (Table 3.2-2). Fifty percent of the area of the Oahu urbanized estuaries had concentrations less than 121 µg/g and 90% of the area had concentrations less than 208 µg/g (Figure 3.2-12). Copper concentrations exceeded the ERL at 9 Hawaii estuaries and bays stations (14% of area), with no stations exceeding the ERM (Table 3.2-1). Copper concentrations exceeded the ERL at 24 Oahu urbanized estuary stations (83% of area), with one station in the Ala Wai Harbor and one station in Pearl Harbor exceeding the ERM (4% of area; Table 3.2-2).

Lead

Lead was detected at 28 of the 45 Hawaii estuaries and bays stations. Lead averaged 3.6 µg/g in these stations with a maximum concentration of 46.5 µg/g in Moanalua Stream (Table 3.2-1). Fifty percent of the area of the Hawaii estuaries and bays had concentrations less than 1.0 µg/g and 90% of the area had concentrations less than 7.0 µg/g (Figure 3.2-13). Lead was also detected at 26 of the 28 Oahu urbanized estuary stations. Lead averaged 42.7 µg/g in the Oahu urbanized estuary stations with a maximum concentration of 216 µg/g in the Ala Wai Harbor (Table 3.2-2). Fifty percent of the area of the Oahu urbanized estuaries had concentrations less than 33.9 µg/g and 90% of the area had concentrations less than 78.8 µg/g (Figure 3.2-14). Lead concentrations did not exceed the ERL or ERM at any of the Hawaii estuaries and bays stations (Table 3.2-1). In comparison, lead exceeded the ERL concentration at 7 of the Oahu urbanized estuary stations (20% of area, Table 3.2-2), though no stations exceeded the ERM.

Mercury

Mercury was detected at 15 of the 45 Hawaii estuaries and bays stations. Mercury averaged 0.13 µg/g in the Hawaii estuaries and bays with a maximum concentration of 5.23 µg/g in the Moanalua Stream (Table 3.2-1). No other station in the Hawaii

estuaries and bays had a concentration >0.12 µg/g. Seventy-two percent of the area of the Hawaii estuaries and bays had undetectable concentrations of mercury while 90% of the area had concentrations less than 0.03 µg/g (Figure 3.2-15). Mercury was detected at 26 of the 28 Oahu urbanized estuary stations. Mercury averaged 0.29 µg/g in the Oahu urbanized estuaries with a maximum concentration of 1.24 µg/g in the Kewalo Basin (Table 3.2-2). Fifty percent of the area of the Oahu urbanized estuaries had concentrations less than 0.24 µg/g and 90% of the area had concentrations less than 0.51 µg/g (Figure 3.2-16). The Moanalua Stream site was the only station which exceeded the ERL or ERM in the Hawaii estuaries and bays stations (<1% of area) (Table 3.2-1). Mercury concentrations exceeded the ERL at 21 of the Oahu urbanized estuary stations (72% of area), while 2 stations (4% of area) had values exceeding the ERM (Table 3.2-2).

Nickel

Nickel was detected at 41 of the 45 Hawaii estuaries and bays stations. Nickel averaged 76.5 µg/g in these stations with a maximum concentration of 487 µg/g in Nuupia Pond (Table 3.2-1). Fifty percent of the area of the Hawaii estuaries and bays had concentrations less than 8.6 µg/g and 90% of the area had concentrations less than 152 µg/g (Figure 3.2-17). Nickel was detected at all 28 Oahu urbanized estuary stations. Nickel averaged 115.9 µg/g in the Oahu urbanized estuaries with maximum concentration of 252 ug/g at two stations in Pearl Harbor (Table 3.2-2). Fifty percent of the area of the Oahu urbanized estuaries had concentrations less than 92 µg/g and 90% of the area had concentrations less than 211 µg/g (Figure 3.2-18).

Nickel concentrations exceeded the ERL at 24 Hawaii estuaries and bays stations (40% of area), while 18 stations (32% of area) had values exceeding the ERM (Table 3.2-1). Nickel concentrations exceeded the ERL at 25 Oahu urbanized estuary stations (84% of area), while 21 stations (68% of area) had values exceeding the ERM (Table 3.2-2). Nickel concentrations in relation to the published ERM values should be interpreted cautiously since the ERM value has a low reliability (Long et al., 1995). Because of its unreliability, nickel was excluded from a recent evaluation of sediment quality in southern Puget Sound (Long et al., 2000). Additionally, a study of metal concentrations in cores on the West Coast determined an historical background concentration of nickel in the range of 35 - 70 ppm (Lauenstein et al., 2000), which brackets the value of the ERM (51.6 ppm).

Selenium

Selenium was detected at 23 of the 45 Hawaii estuaries and bays stations. Selenium averaged 0.38 µg/g in the Hawaii estuaries and bays stations with a maximum concentration of 2.3 µg/g in the Kahului Harbor (Table 3.2-1). Fifty-eight percent of the area of the Hawaii estuaries and bays had undetectable concentrations of selenium concentrations and 90% of the area had concentrations less than 1.1 µg/g (Figure 3.2-19). Selenium was detected in 19 of the 28 Oahu urbanized estuary stations. Selenium averaged 1.03 µg/g in the Oahu urbanized estuary stations with a maximum concentration of 3.9 µg/g in Pearl Harbor (Table 3.2-2). Fifty percent of the area of the

Oahu urbanized estuaries had concentrations less than 0.6 µg/g and 90% of the area had concentrations less than 2.5 µg/g (Figure 3.2-20). Selenium concentrations exceeded the ERL at one of the Hawaii estuaries and bays stations (1% of area), with no stations exceeding the ERM (Table 3.2-1). Selenium concentrations exceeded the ERL at 7 Oahu urbanized estuary stations (23% of area), with no stations exceeding the ERM (Table 3.2-2).

Silver

Silver was detected at 27 of the 45 Hawaii estuaries and bays stations. Silver averaged 0.11 µg/g in these stations with a maximum concentration of 0.77 µg/g in Kaunakakai Harbor (Table 3.2-1). Fifty percent of the area of the Hawaii estuaries and bays had silver concentrations less than 0.01 µg/g and 90% of the area had concentrations less than 0.23 µg/g (Figure 3.2-21). Silver was detected at all 28 Oahu urbanized estuary stations. Silver averaged 0.66 µg/g in the Oahu urbanized estuaries with a maximum concentration of 1.93 µg/g in Pearl Harbor (Table 3.2-2). Fifty percent of the area of the Oahu urbanized estuaries had silver concentrations less than 0.58 µg/g and 90% of the area had concentrations less than 1.06 µg/g (Figure 3.2-22). Silver concentrations did not exceed the ERL or ERM at any of the Hawaii estuaries and bays station (Tables 3.2-1). Silver exceeded the ERL at 4 Oahu urbanized estuary stations (12% area), with no stations exceeding the ERM (Table 3.2-2).

Tin

Tin was detected at 34 of the 45 Hawaii estuaries and bays stations. Tin averaged 1.1 µg/g in these stations with a maximum concentration of 7.1 µg/g in Maunalua Bay (Table 3.2-1). Fifty percent of the area of the Hawaii estuaries and bays had tin concentrations less than 0.59 µg/g and 90% had concentrations less than 2.89 µg/g (Figure 3.2-23). Tin was detected at all 28 Oahu urbanized estuary stations. Tin averaged 6.0 ug/g in the Oahu urbanized estuaries with a maximum of 14 ug/g in the Ala Wai Harbor (Table 3.2-2). Fifty percent of the area of the Oahu urbanized estuaries had tin concentrations less than 5.65 µg/g and 90% of the area had concentrations less than 11.43 µg/g (Figure 3.2-24). There are no ERL or ERM values for tin.

Zinc

Zinc was detected at 41 of the 45 Hawaii estuaries and bays stations. Zinc averaged 47.7 µg/g in these stations with a maximum concentration of 214 µg/g in the Moanalua Stream (Table 3.2-1). Fifty percent of the area of the Hawaii estuaries and bays had zinc concentrations less than 19.3 µg/g and 90% of the area had concentrations less than 86.7 µg/g (Figure 3.2-25). Zinc was detected at all 28 Oahu urbanized estuary stations. Zinc averaged 189.2 µg/g in the Oahu urbanized estuaries with a maximum concentration of 362 µg/g in the Ala Wai Harbor (Table 3.2-2). Fifty percent of the area of the Oahu urbanized estuaries had zinc concentrations less than 181 µg/g and 90% of the area had concentrations less than 268 µg/g (Figure 3.2-26). Zinc concentrations exceeded the ERL at 3 Hawaii estuaries and bays stations (<1% of area), with no stations exceeding the ERM (Table 3.2-1). Twenty-one of the Oahu urbanized estuary stations exceeded the ERL (68% of area), with no stations exceeding the ERM for zinc

(Table 3.2-2).

Additional Metals

In addition to the 11 metals discussed above, aluminum, antimony, iron, and manganese were measured in the sediments. The mean concentration and frequency of detection for each of these metals in the Hawaii estuaries and bays are given in Table 3.2-1 and the corresponding values for the Oahu urbanized estuaries are given in Table 3.2-2. Not unexpectedly, aluminum and iron were the two most abundant metals, with mean concentrations ranging from about 11,000 µg/g to 57,000 µg/g. Antimony was detected in sediments from only 2 samples from Hawaii estuaries and bays, and in 6 samples from Oahu urbanized estuaries.

Table 3.2-1. Summary statistics for sediment metal concentrations (µg/g, dry weight) for the Hawaii estuaries and bays stations (N=45). The mean and standard deviation (SD) were calculated using all the data, including the non-detects which were set to 0. Field duplicates and laboratory duplicates for a station were averaged. The "mean when present" was calculated using the samples which had detectable concentrations of the compound. ERL and ERM values are from Long et al. (1995), with NV = no value. NA = not applicable.

Metal	Overall Mean Concen-tration	Overall SD	Mean Concen-tration when Present	Min	Max	Frequency of detection	ERL	ERM	>ERL No. Sites	>ERM No. Sites	>ERL % Area	>ERM % Area
Aluminum	11260	14310	16890	0	48050	30	NV	NV	NA	NA	NA	NA
Antimony	0.024	0.12	0.55	0	0.6	2	NV	NV	NA	NA	NA	NA
Arsenic	11.1	10.5	12.2	0	50.5	41	8.2	70.0	23	0	43%	0
Cadmium	0.01	0.04	0.11	0	0.17	6	1.2	9.6	0	0	0	0
Chromium	102.6	140.5	102.6	5.3	689	45	81	370	17	1	27%	<1%
Copper	23.3	42.3	36.2	0	201	29	34	270	9	0	14%	0
Iron	22680	28930	23190	0	96200	44	NV	NV	NA	NA	NA	NA
Lead	3.6	7.8	5.9	0	46.5	28	46.7	218	0	0	0	0
Manganese	399	466	399	21.3	2438	45	NV	NV	NA	NA	NA	NA
Mercury	0.13	0.78	0.39	0	5.23	15	0.15	0.71	1	1	<1%	<1%
Nickel	76.5	111.5	83.9	0	487	41	20.9*	51.6*	24	18	40%	32%
Selenium	0.38	0.56	0.74	0	2.3	23	2.0	25.0	1	0	<1%	0
Silver	0.11	0.18	0.18	0	0.77	27	1.0	3.7	0	0	0	0
Tin	1.1	1.7	1.45	0	7.1	34	NV	NV	NA	NA	NA	NA
Zinc	47.7	53.4	52.3	0	214	41	150	410	3	0	<1%	0

* The ERL and ERM for nickel have low reliability for the West Coast. See text for discussion.

Table 3.2 -2. Summary statistics for sediment metal concentrations (µg/g, dry weight) for the Oahu urbanized estuary stations (N=28). The mean and the standard deviation (SD) were calculated using all the data, including the non-detects which were set to 0. The "mean when present" was calculated using the samples which had detectable concentrations of the compound. ERL and ERM values are from Long et al. (1995), with NV = no value. NA = not applicable.

Metal	Overall Mean Concen-tration	Overall SD	Mean Concen-tration when Present	Min	Max	Frequency of detection	ERL	ERM	>ERL No. Sites	>ERM No. Sites	>ERL % Area	>ERM % Area
Aluminum	47150	35450	52810	0	111000	25	NV	NV	NA	NA	NA	NA
Antimony	0.07	0.15	0.34	0	0.5	6	NV	NV	NA	NA	NA	NA
Arsenic	12.1	6.76	12.5	0	27.8	27	8.2	70.0	20	0	71%	0
Cadmium	0.16	0.17	0.22	0	0.52	20	1.2	9.6	0	0	0	0
Chromium	175.6	97.8	182.1	0	336	27	81	370	23	0	79%	0
Copper	128.6	86.4	133.3	0	405	27	34	270	24	2	83%	4%
Iron	56530	34620	56530	570	117000	28	NV	NV	NA	NA	NA	NA
Lead	42.7	41.3	46.0	0	216	26	46.7	218	7	0	20%	0
Manganese	779	533	779	43.8	2648	28	NV	NV	NA	NA	NA	NA
Mercury	0.29	0.25	0.31	0	1.24	26	0.15	0.71	21	2	72%	4%
Nickel	115.9	78.7	115.9	1.1	252	28	20.9*	51.6*	25	21	84%	68%
Selenium	1.03	1.16	1.52	0	3.9	19	2.0	25.0	7	0	23%	0
Silver	0.66	0.43	0.66	0.02	1.93	28	1.0	3.7	4	0	12%	0
Tin	5.99	3.45	5.99	0.1	14	28	NV	NV	NA	NA	NA	NA
Zinc	189.2	79.0	189.2	10.7	362	28	150	410	21	0	68%	0

* The ERL and ERM for nickel have low reliability for the West Coast. See text for discussion.

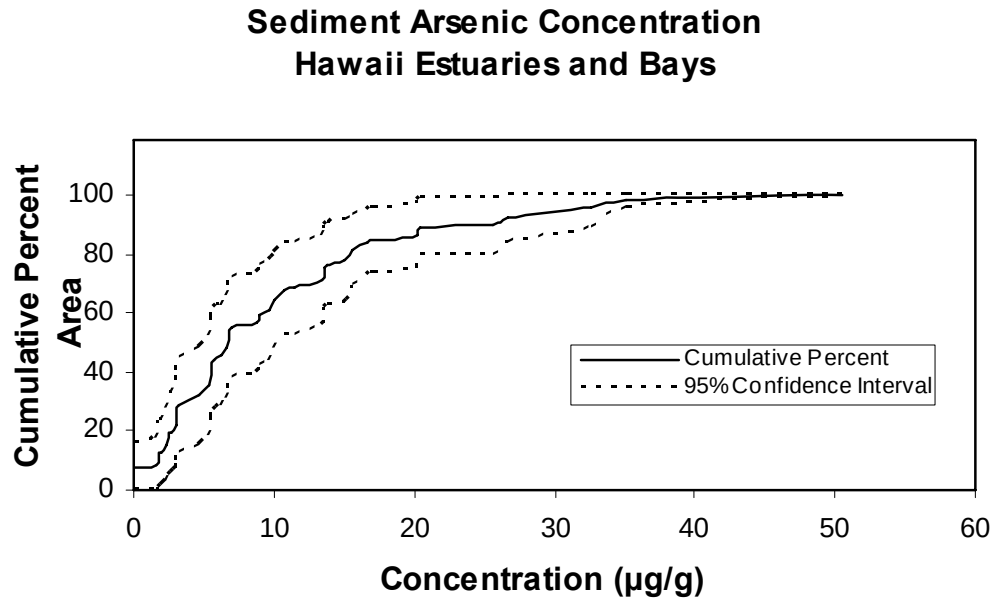

Figure 3.2-5. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. sediment concentration of arsenic.

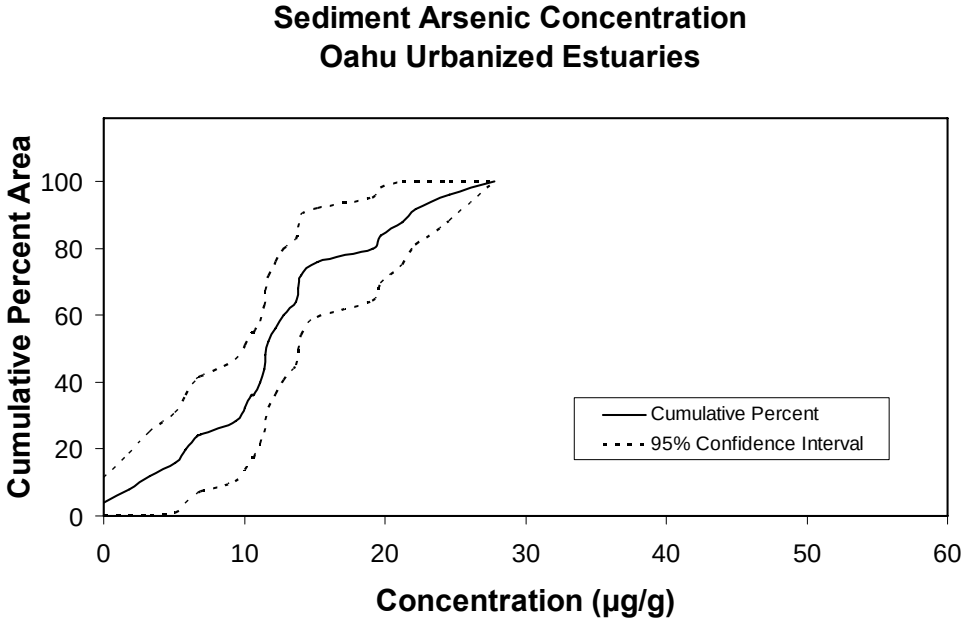

Figure 3.2-6. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. sediment concentration of arsenic.

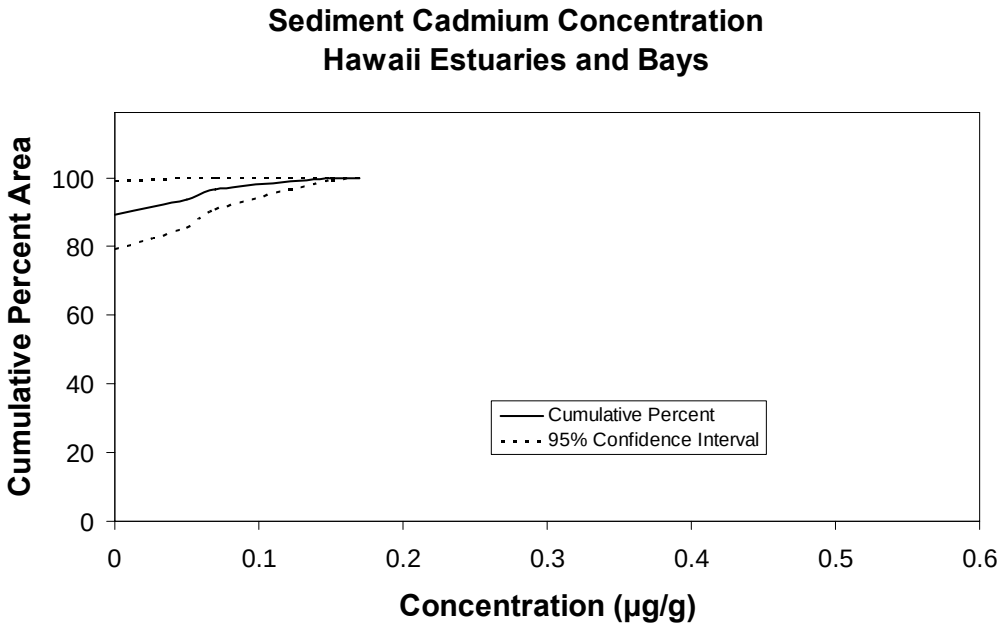

Figure 3.2-7. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. sediment concentration of cadmium.

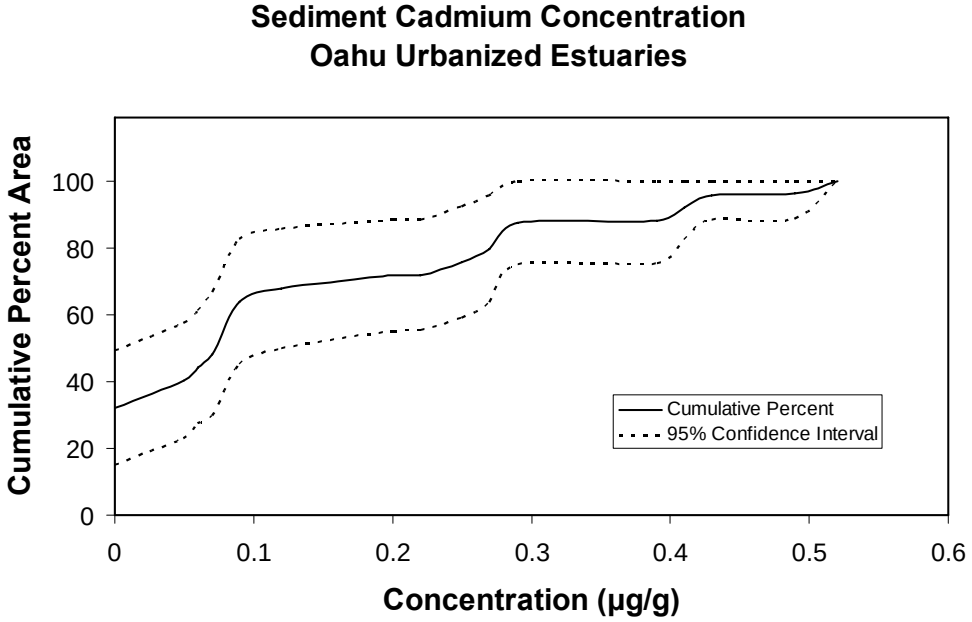

Figure 3.2-8. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. sediment concentration of cadmium.

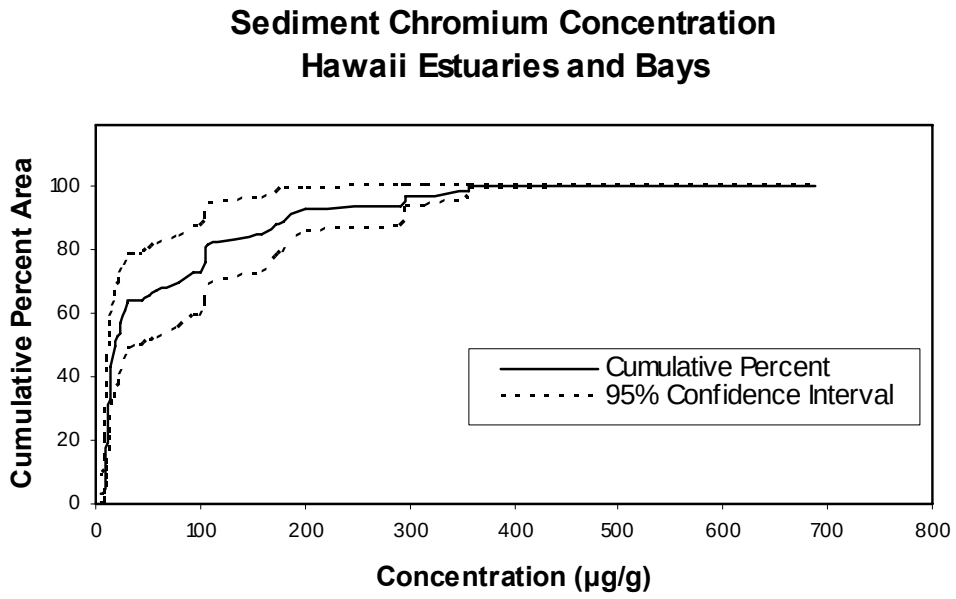

Figure 3.2-9. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. sediment concentration of chromium.

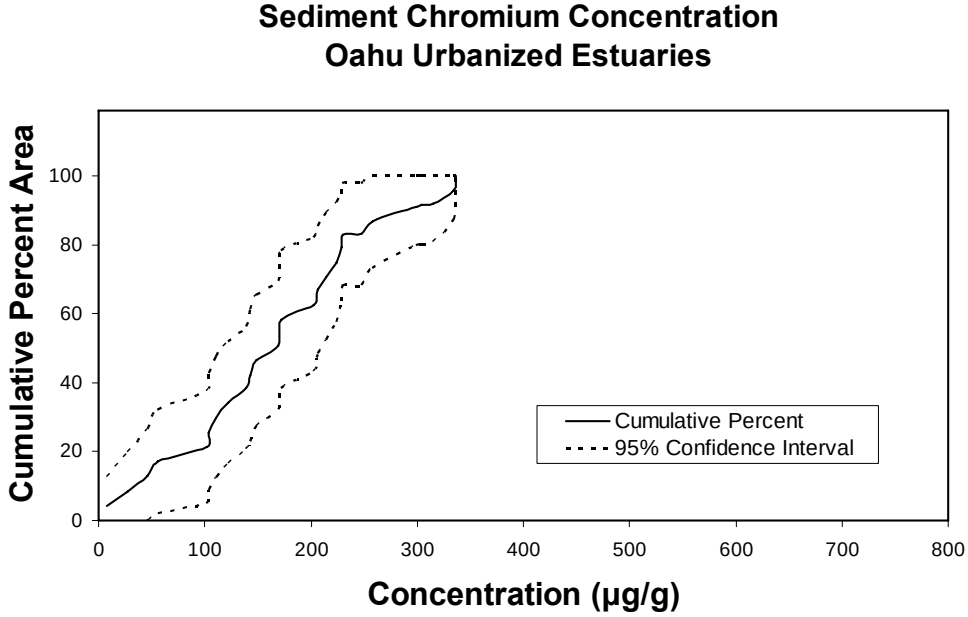

Figure 3.2-10. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. sediment concentration of chromium.

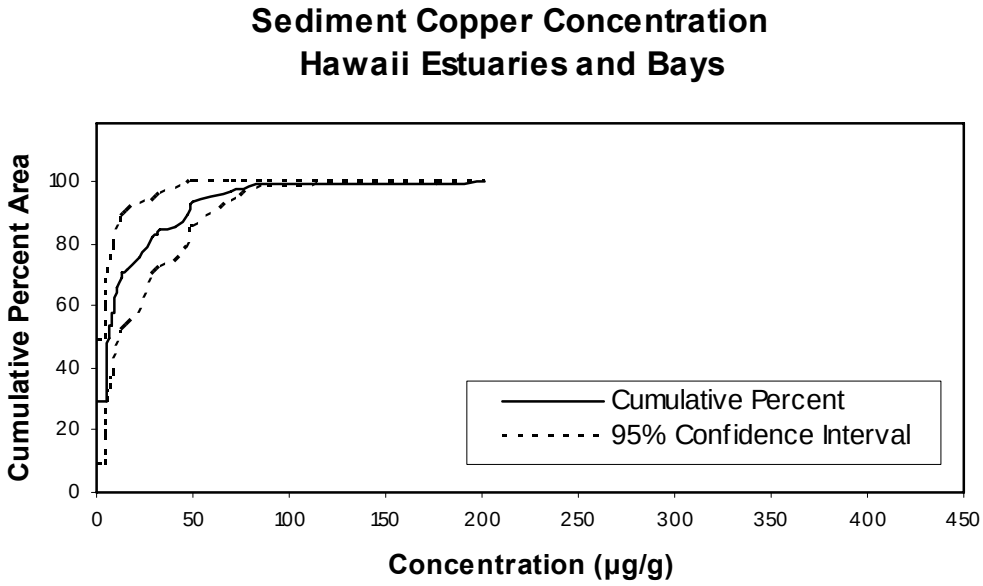

Figure 3.2-11. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. sediment concentration of copper.

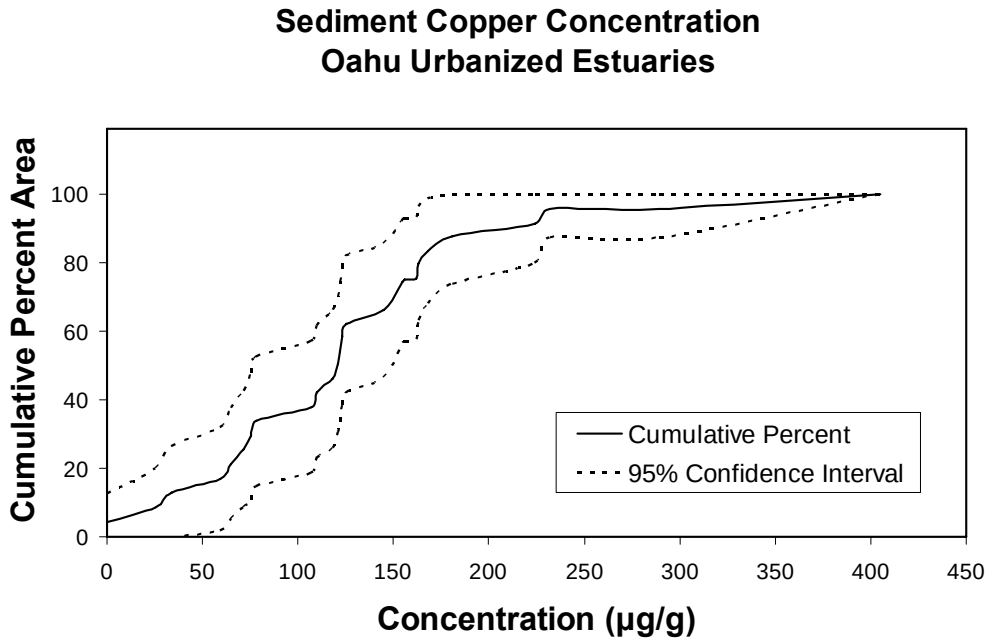

Figure 3.2-12. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. sediment concentration of copper.

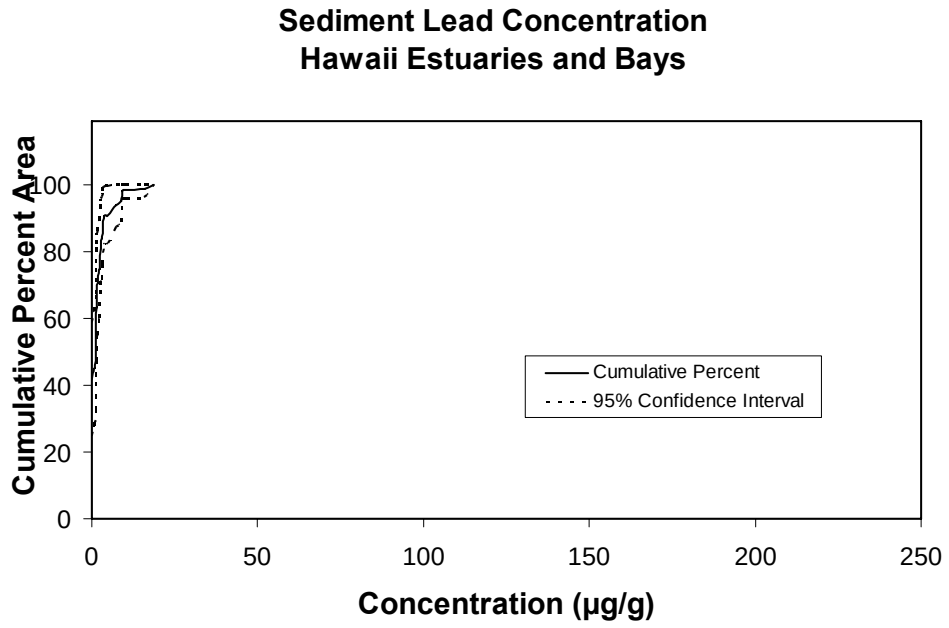

Figure 3.2-13. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. sediment concentration of lead.

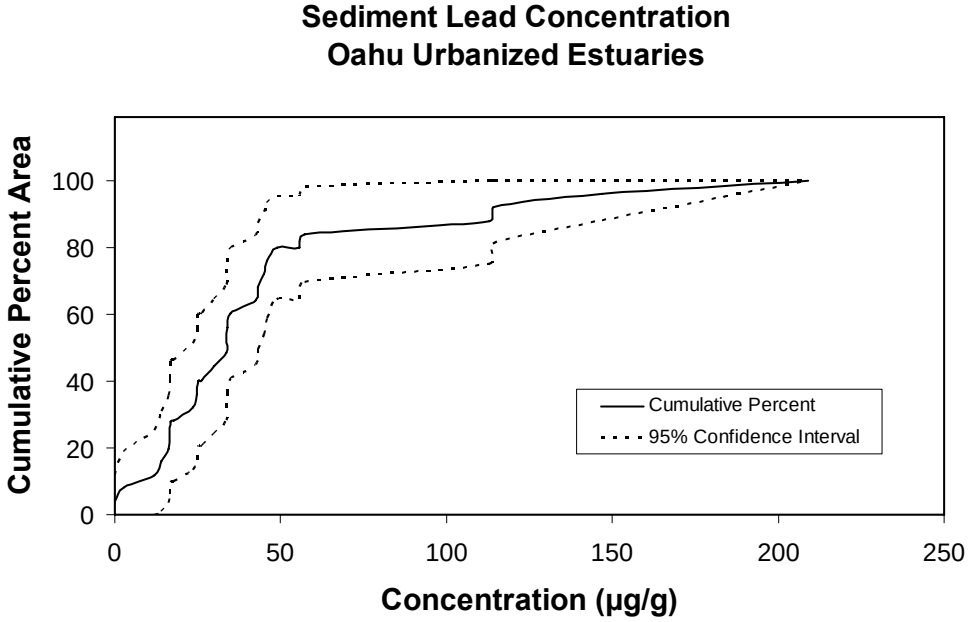

Figure 3.2-14. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. sediment concentration of lead.

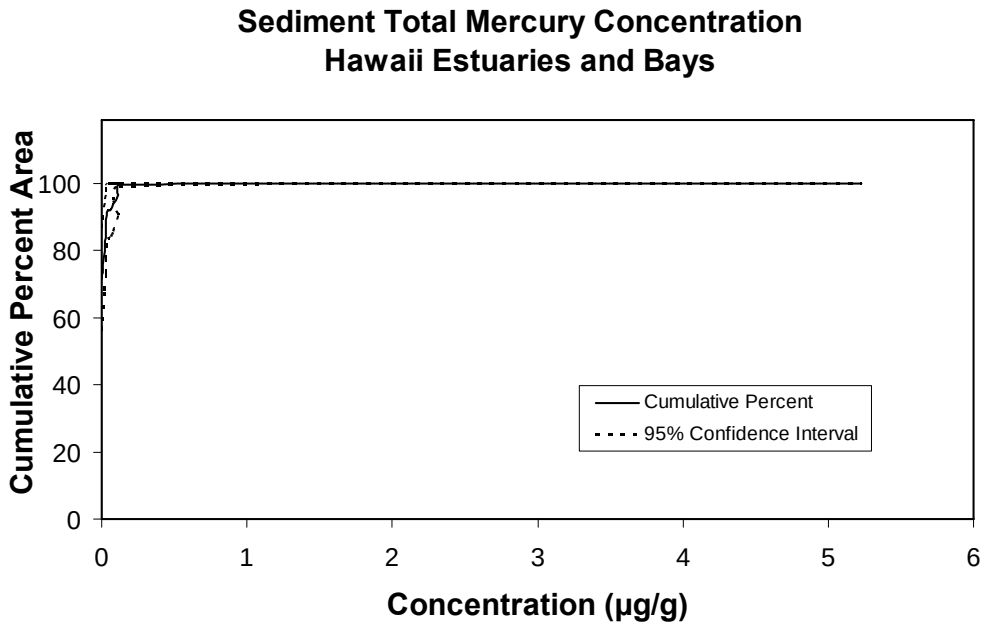

Figure 3.2-15. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. sediment concentration of mercury.

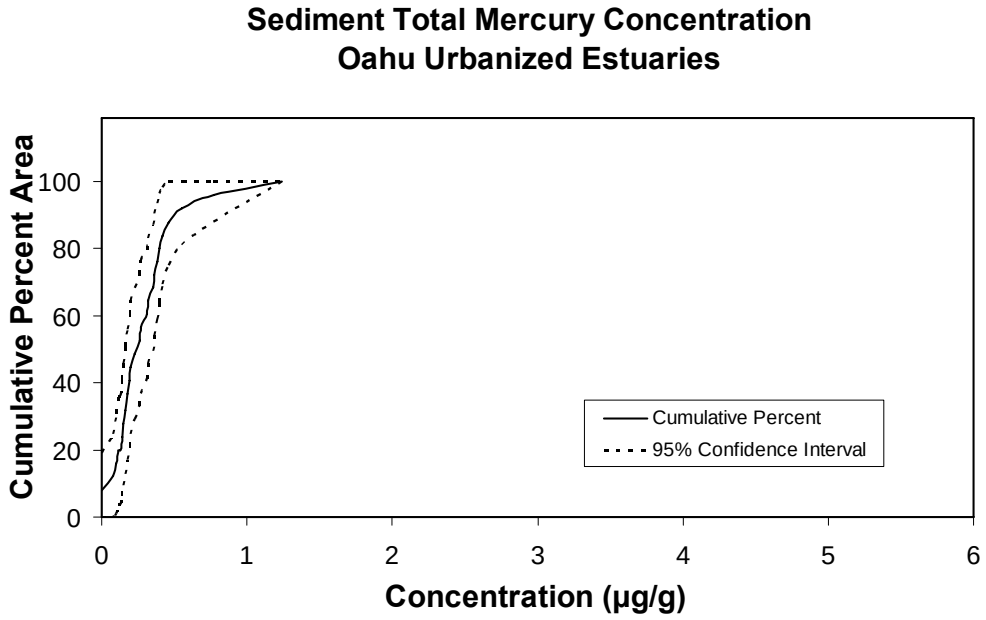

Figure 3.2-16. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. sediment concentration of mercury.

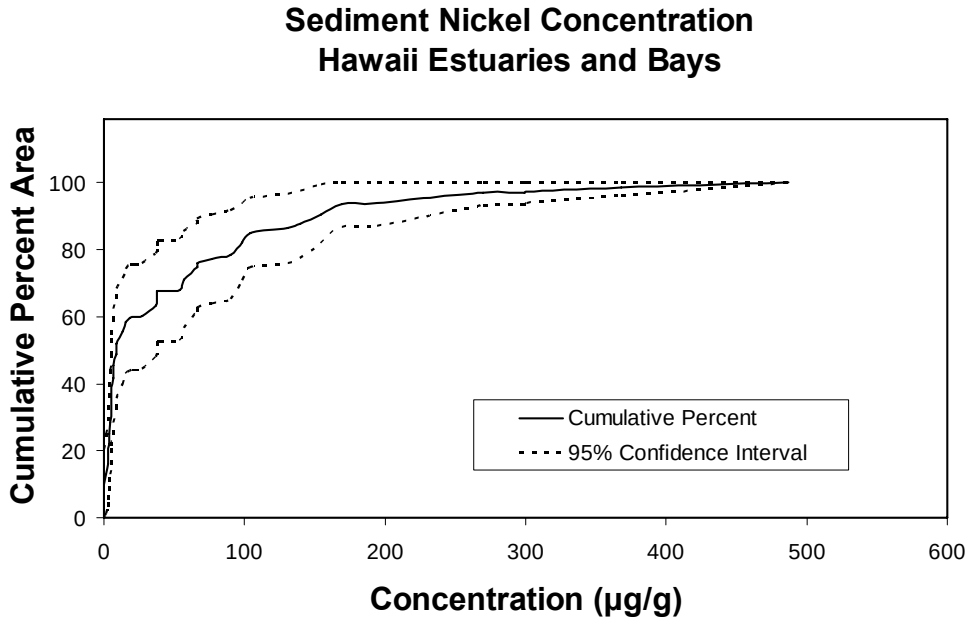

Figure 3.2-17. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. sediment concentration of nickel.

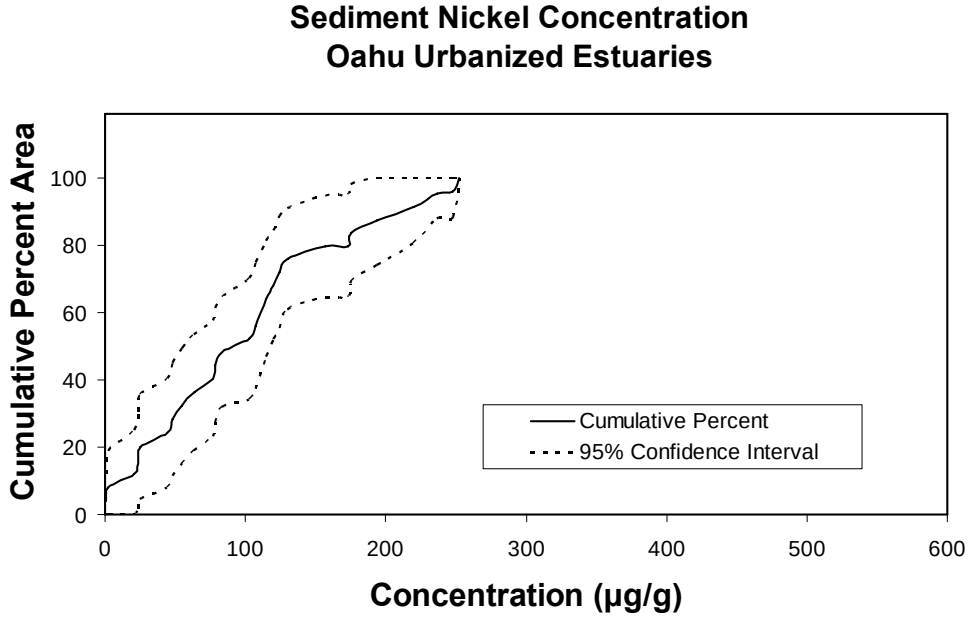

Figure 3.2-18. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. sediment concentration of nickel.

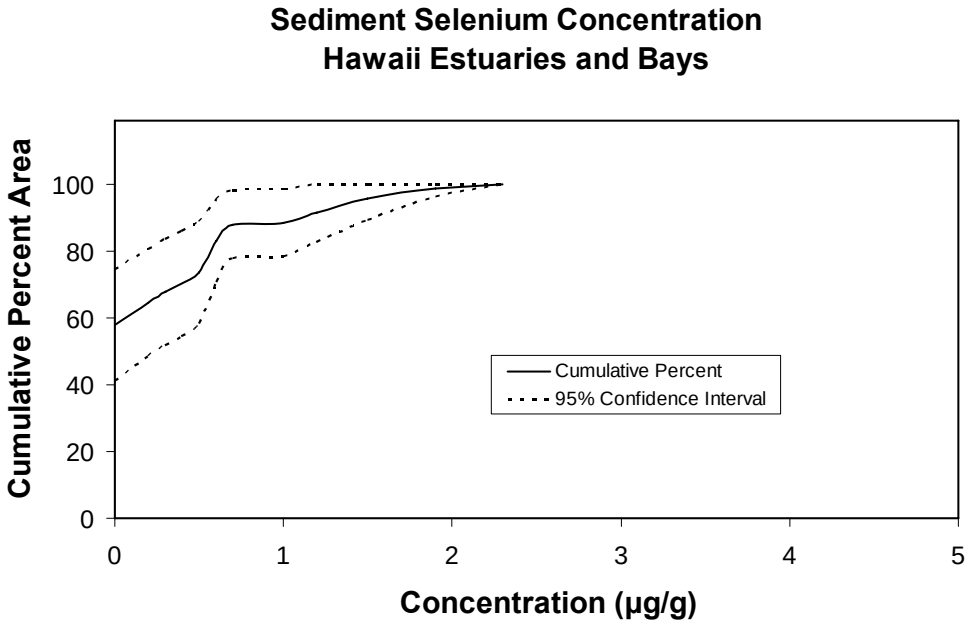

Figure 3.2-19. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. sediment concentration of selenium.

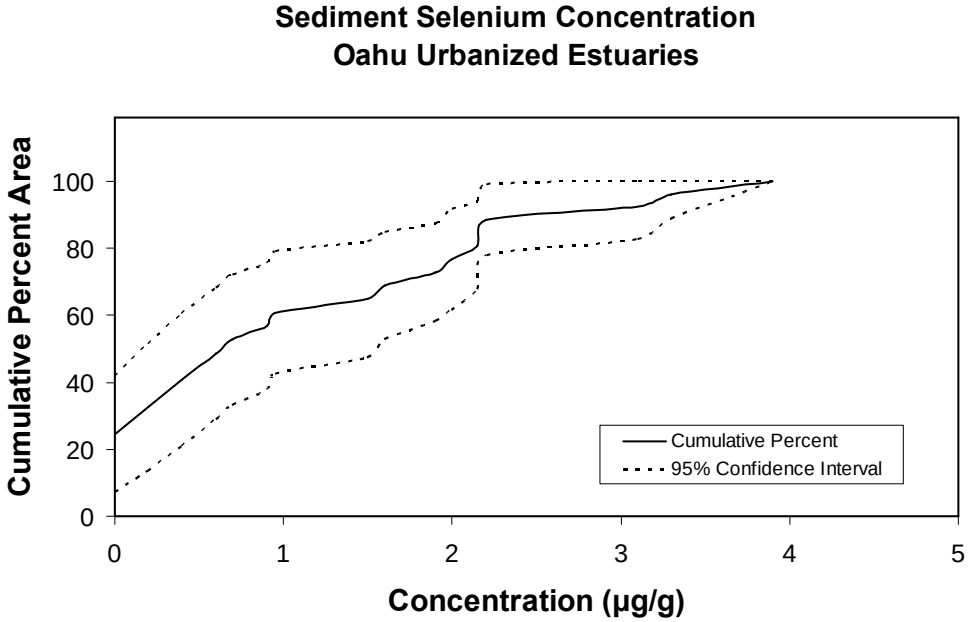

Figure 3.2-20. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. sediment concentration of selenium.

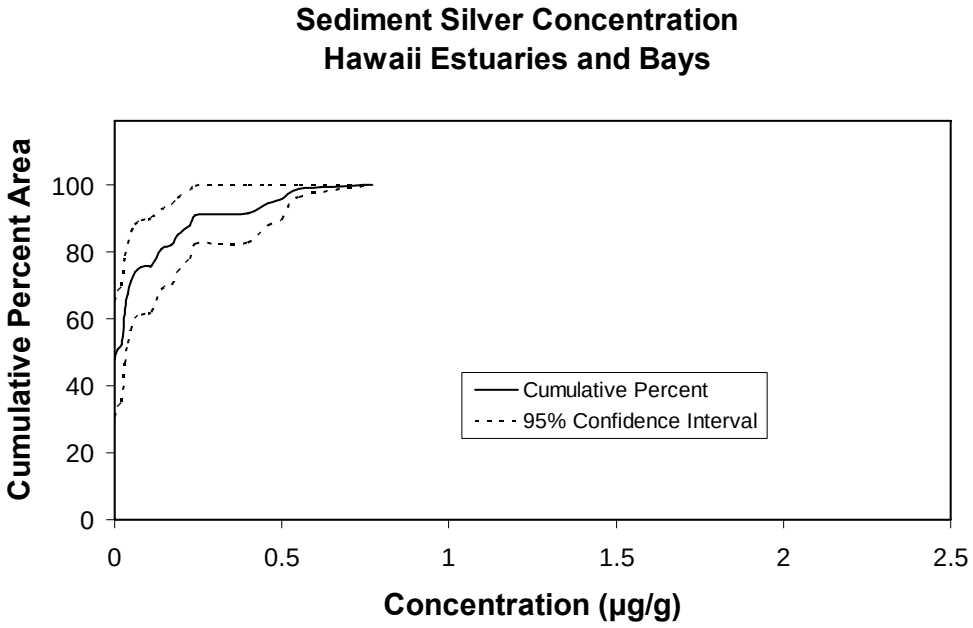

Figure 3.2-21. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. sediment concentration of silver.

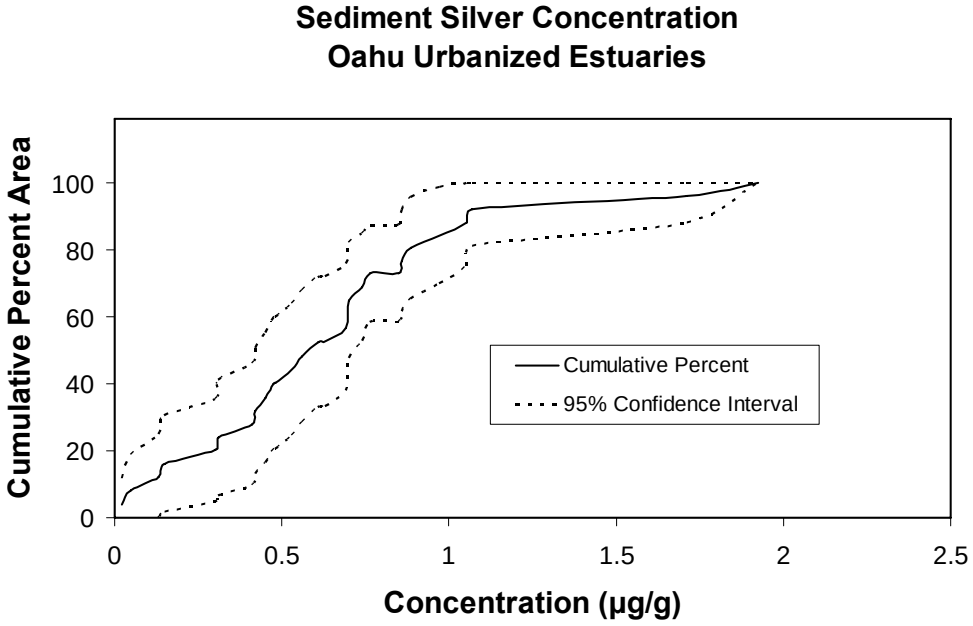

Figure 3.2-22. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. sediment concentration of silver.

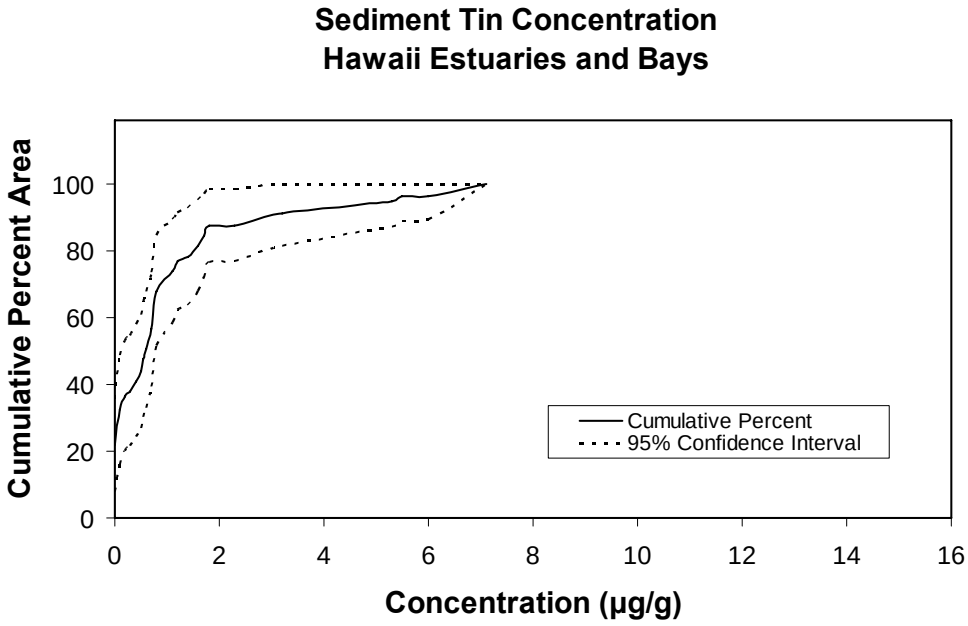

Figure 3.2-23. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. sediment concentration of tin.

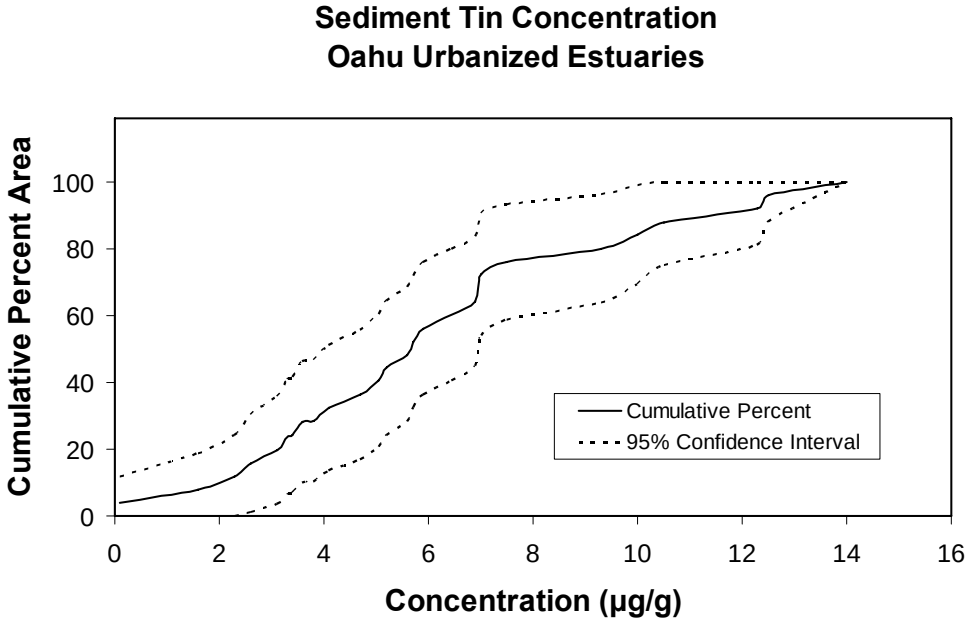

Figure 3.2-24. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. sediment concentration of tin.

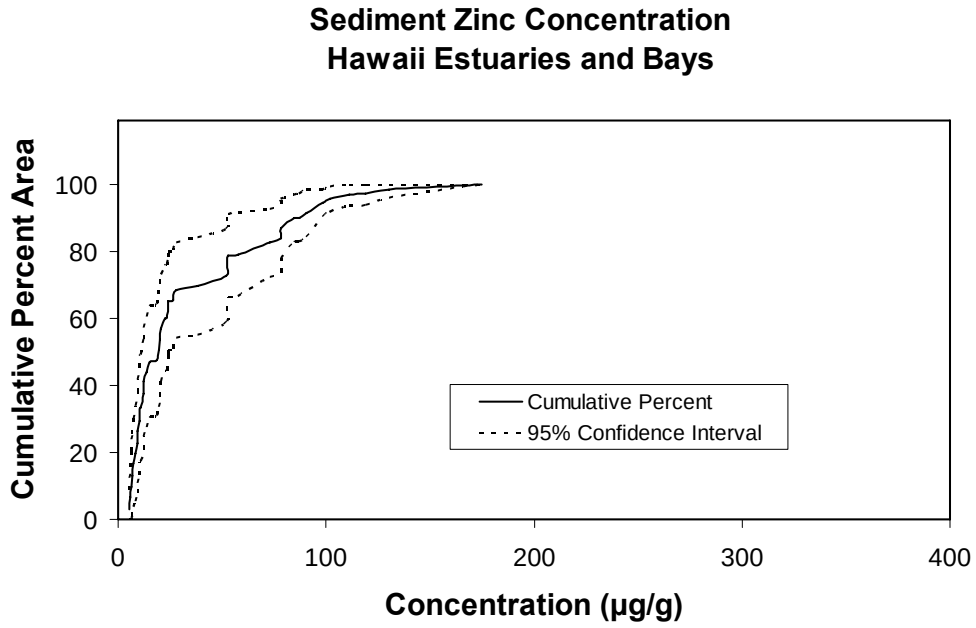

Figure 3.2-25. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. sediment concentration of zinc.

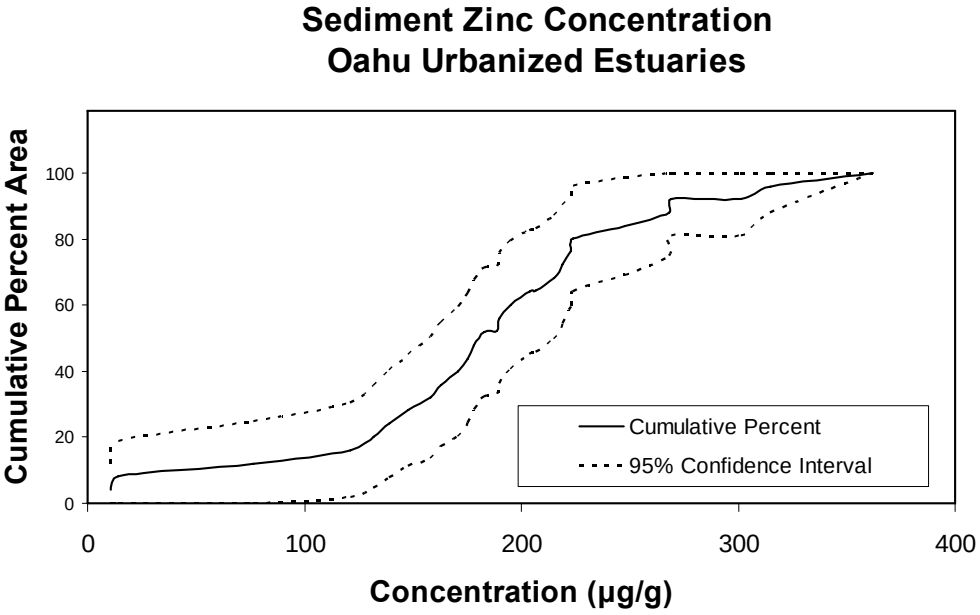

Figure 3.2-26. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. sediment concentration of zinc.

3.2.2.2 Sediment Organics

Sediment Organics

Concentrations of sediment organic pollutants were measured at 42 stations in the Hawaii estuaries and bays and in 28 stations in the Oahu urbanized estuaries. The mean concentration of each organic compound was calculated with the non-detects (i.e., less than the MDL) set to 0 (see Table 2.6 for the MDLs). For comparative purposes, mean concentrations of the organic compounds were also calculated using the subset of samples in which the compounds were detected.

Total PAHs

PAHs were detected at 8 of the 42 Hawaii estuary and coastal bay stations. Total PAHs averaged 15.9 ng/g in the Hawaii estuary and bay stations with a maximum concentration of 336 ng/g in the Moanalua Stream (Table 3.2-3). Eighty-seven percent of area of Hawaii estuaries and bays had undetectable concentrations of PAHs and 90% of the area had concentrations less than 13.1 ng/g (Figure 3.2-27). No stations exceeded the ERLs or ERMs for total PAHs, low molecular weight PAHs, or high molecular weight PAHs. On the average, 89% of the total PAHs in the Hawaii estuary and bay stations were composed of high molecular weight compounds.

PAHs were detected at 26 of the 28 Oahu urbanized estuary stations. Total PAHs averaged 1016 ng/g in the Oahu urbanized estuary stations with a maximum concentration of 9292 ng/g in the Honolulu Harbor (Table 3.2-4). Eight percent of the area of the Oahu urbanized estuaries had undetectable concentrations of PAHs while 50% of the area had concentrations less than 262 ng/g and 90% of the area had concentrations less than 3457 ng/g (Figure 3.2-28). Two stations exceeded the ERL for total PAHs, constituting 4% of the area of the Oahu urbanized estuaries. The ERL for high molecular weight PAHs was exceeded at four stations, constituting 12% of the area. No stations exceeded the ERL for low molecular weight PAHs. On the average, 96% of the total PAHs were composed of high molecular weight compounds.

Total PCBs

PCBs were detected at 30 of the 42 Hawaii estuary and bay stations. Total PCBs averaged 0.95 ng/g in the Hawaii estuary and bay stations with a maximum concentration of 6.8 ng/g in the Moanalua Stream (Table 3.2-3). Thirty-nine percent of the area of the Hawaii estuaries and bays had undetectable concentrations of PCBs while 50% of the area had concentrations less than 0.32 ng/g and 90% of the area had concentrations less than 1.66 ng/g (Figure 3.2-29). The ERL was not exceeded at any station (Table 3.2-3).

PCBs were detected at 24 of the 28 Oahu urbanized estuary stations. Total PCBs averaged 7.2 ng/g in the Oahu urbanized estuary stations with a maximum of 47.3 ng/g in Pearl Harbor (Table 3.2-4). Twelve percent of the area of the Oahu urbanized estuaries had undetectable levels of PCBs while 50% of the area had concentrations less than 3.2 ng/g and 90% of the area had concentrations less than 23.9 ng/g (Figure

3.2-30). The ERL was exceeded at four stations, representing 12.1 % of the area (Table 3.2-4). No stations exceeded the ERM.

Total DDT

DDT or one of its metabolites was detected at 32 of the 42 of the Hawaii estuary and bay stations. Total DDT averaged 0.79 ng/g in the Hawaii estuaries and bays with a maximum concentration of 10.2 ng/g in the Paukauila Stream (Table 3.2-3). The compound 4,4'-DDT was the most frequently detected DDT compound and had the highest mean concentration in the Hawaii estuaries and bays. Thirty-four percent of the area of the Hawaii estuaries and bays had undetectable levels of DDT and its metabolites while 50% of the area had concentrations less than 0.21 ng/g and 90% of the area had concentrations less than 1.18 ng/g (Figure 3.2-31). The ERL for total DDT was exceeded at four stations representing 3.9% of the area. The ERL for 4,4'-DDE was exceeded at one station, representing <0.3% of the area. The ERMs were not exceeded at any stations.

DDT or one of its metabolites was detected at 19 of the 28 Oahu urbanized estuary stations. Total DDT averaged 2.74 ng/g in the Oahu urbanized estuary stations with a maximum concentration of 11.9 ng/g in Pearl Harbor. The compound 4,4'-DDT was the most frequently detected DDT compound in the Oahu urbanized estuary stations, but 4,4'-DDE had a higher average concentration (Table 3.2-4). Thirty-six percent of the area of the Oahu urbanized estuaries had undetectable levels of DDT and its metabolites, while 50% of the area had concentrations less than 0.77 ng/g, and 90% of the area had concentrations less than 5.07 ng/g (Figure 3.2-32). The ERL for total DDT was exceeded at 13 stations, representing 36% of the area. The ERL for 4,4'-DDE was exceeded at 6 stations, representing 12% of the area. The ERMs were not exceeded at any station.

Additional Pesticides

Besides DDT, an additional 13 pesticides were measured in the sediments in the Hawaii estuaries and bays (Table 3.2-3) and in the Oahu urbanized estuaries (Table 3.2-4). Of these, Aldrin, Endosulfan I, Endosulfan Sulfate, Heptachlor, Lindane (gamma-BHC) and Mirex were never detected at any of the stations. Of the remaining pesticides, Alpha-chlordane had the highest average concentration in both the Hawaii estuaries and bays and in the Oahu urbanized estuaries. Alpha-chlordane was detected at 26 stations in the Hawaii estuaries and bays, with 50% of the area having concentrations less than 0.17 ng/g and 90% of the area having concentrations less than 0.70 ng/g. (Figure 3.2-33). In the Oahu urbanized estuaries, alpha-chlordane was detected at 20 stations, with 50% of the area having a concentration less than 0.55 ng/g and 90% of the area having a concentration less than 1.99 ng/g (Figure 3.2-34). Among the remaining pesticides, hexachlorobenzene and trans-nonachlor had the next highest concentrations in the Hawaii estuaries and bays while hexachlorobenzene, trans-nonachlor, and Endosulfan II had the next highest concentrations in the Oahu urbanized estuaries. Endrin was detected at one site in Honolulu Harbor. The concentration at this site exceeded the ERL, representing 4% of the area of the Oahu urbanized estuaries. Other than for alpha-chlordane, there were an insufficient number of detects to calculate CDFs for any of these additional pesticides.

Table 3.2-3. Summary statistics for sediment organic pollutants (ng/g, dry weight) for the Hawaii estuary and bay stations (N=42). The mean and standard deviation (SD) were calculated using all the data, including the non-detects which were set to 0. The "mean when present" was calculated using the samples which had detectable concentrations of the compound. ERL and ERM values are from Long et al. (1995), with NV = no value. NA = not applicable.

Analyte	Overall mean concentration ng/g dry wt	Overall SD	Mean concentration when present	Min	Max	Frequency of detection	ERL	ERM	>ERL No. Sites	>ERM No. Sites	>ERL Area %	>ERM Area %
HMW PAHs	14.14	54.01	84.86	0.00	298	7	1700	9600	0	0	0	0
LMW PAHs	1.81	7.57	19.00	0.00	38	4	552	3160	0	0	0	0
Total PAHs	15.95	61.45	83.75	0.00	336	8	4022	44792	0	0	0	0
Total PCBs	0.95	1.37	1.33	0.00	6.80	30	22.7	180	0	0	0	0
2,4'-DDD	0.03	0.22	0.03	0.00	0.03	1	NV	NV	NA	NA	NA	NA
2,4'-DDE	0.00	0.00	0.00	0.00	0.00	0	NV	NV	NA	NA	NA	NA
2,4'-DDT	0.00	0.00	0.00	0.00	0.00	0	NV	NV	NA	NA	NA	NA
4,4'-DDD	0.04	0.26	1.71	0.00	1.71	1	NV	NV	NA	NA	NA	NA
4,4'-DDE	0.15	0.72	2.09	0.00	4.53	3	2.2	27.0	1	0	<0.3	0
4,4'-DDT	0.57	0.86	0.74	0.00	3.99	32	NV	NV	NA	NA	NA	NA
Total DDT	0.79	1.74	1.04	0.00	10.23	32	1.58	46.1	4	0	3.9	0
Aldrin	0.00	0.00	0.00	0.00	0.00	0	NV	NV	NA	NA	NA	NA
Alpha-chlordane	0.31	0.32	0.50	0.00	1.30	26	NV	NV	NA	NA	NA	NA
Dieldrin	0.06	0.39	2.50	0.00	2.50	1	0.02	8	1	0	<0.3	0
Endosulfan I	0.00	0.00	0.00	0.00	0.00	0	NV	NV	NA	NA	NA	NA
Endosulfan II	0.00	0.00	0.00	0.00	0.00	0	NV	NV	NA	NA	NA	NA
Endosulfan Sulfate	0.00	0.00	0.00	0.00	0.00	0	NV	NV	NA	NA	NA	NA
Endrin	0.00	0.00	0.00	0.00	0.00	0	0.02	45	0	0	0	0
Heptachlor	0.00	0.00	0.00	0.00	0.00	0	NV	NV	NA	NA	NA	NA
Heptachlor Epoxide	0.01	0.03	0.16	0.00	0.16	2	NV	NV	NA	NA	NA	NA
Hexachloro-benzene	0.18	0.42	0.92	0.00	1.93	8	NV	NV	NA	NA	NA	NA
Lindane (gamma-BHC)	0.00	0.00	0.00	0.00	0.00	0	NV	NV	NA	NA	NA	NA
Mirex	0.00	0.00	0.00	0.00	0.00	0	NV	NV	NA	NA	NA	NA
Trans-nonachlor	0.12	0.45	0.61	0.00	2.85	8	NV	NV	NA	NA	NA	NA

Table 3.2-4. Summary statistics for sediment organic pollutants (ng/g, dry weight) for the Oahu urbanized estuary stations (N=28). The mean and standard deviation (SD) were calculated using all the data, including the non-detects which were set to 0. The "mean when present" was calculated using the samples which had detectable concentrations of the compound. ERL and ERM values are from Long et al. (1995), with NV = no value. NA = not applicable.

Analyte	Overall mean concentration ng/g dry wt	Overall SD	Mean concentration when present	Min	Max	Frequency of detection	ERL	ERM	>ERL No. Sites	>ERM No. Sites	>ERL Area %	>ERM Area %
HMW PAHs	977.98	1916.66	1053.21	0	9112	26	1700	9600	4	0	12.1	0
LMW PAHs	37.71	59.25	55.58	0	196.5	19	552	3160	0	0	0	0
Total PAHs	1015.70	1966.94	1093.83	0	9292	26	4022	44792	2	0	4.0	0
Total PCBs	7.17	11.16	8.37	0	47.32	24	22.7	180	4	0	12.1	0
2,4'-DDD	0.09	0.48	0.09	0	0.09	1	NV	NV	NA	NA	NA	NA
2,4'-DDE	0.05	0.20	0.74	0	0.93	2	NV	NV	NA	NA	NA	NA
2,4'-DDT	0.03	0.18	0.03	0	0.03	1	NV	NV	NA	NA	NA	NA
4,4'-DDD	0.16	0.56	1.47	0	2.8	3	NV	NV	NA	NA	NA	NA
4,4'-DDE	1.54	2.85	3.93	0	10.90	11	2.2	27.0	6	0	12.1	0
4,4'-DDT	0.86	0.96	1.51	0	3.66	16	NV	NV	NA	NA	NA	NA
Total DDT	2.74	3.42	4.04	0	11.87	19	1.58	46.1	13	0	36.0	0
Aldrin	0.00	0.00	0.00	0	0	0	NV	NV	NA	NA	NA	NA
Alpha-chlordane	1.17	1.88	1.64	0	9.5	20	NV	NV	NA	NA	NA	NA
Dieldrin	0.44	1.25	2.47	0	5.02	5	0.02	8	5	0	16.1	0
Endosulfan I	0.00	0.00	0.00	0	0	0	NV	NV	NA	NA	NA	NA
Endosulfan II	0.05	0.24	0.77	0	1.23	2	NV	NV	NA	NA	NA	NA
Endosulfan Sulfate	0.00	0.00	0.00	0	0	0	NV	NV	NA	NA	NA	NA
Endrin	0.02	0.12	0.63	0	0.63	1	0.02	45	1	0	4.0	0
Heptachlor	0.00	0.00	0.00	0	0	0	NV	NV	NA	NA	NA	NA
Heptachlor Epoxide	0.02	0.06	0.24	0	0.24	2	NV	NV	NA	NA	NA	NA
Hexachloro-benzen	0.52	0.88	1.83	0	8		NV	NV	NA	NA	NA	NA
Lindane (gamma-BHC)	0.00	0.00	0.00	0	0	0	NV	NV	NA	NA	NA	NA
Mirex	0.00	0.00	0.00	0	0	0	NV	NV	NA	NA	NA	NA
Trans-nonachlor	0.77	1.72	1.65	0	7.7	13	NV	NV	NA	NA	NA	NA

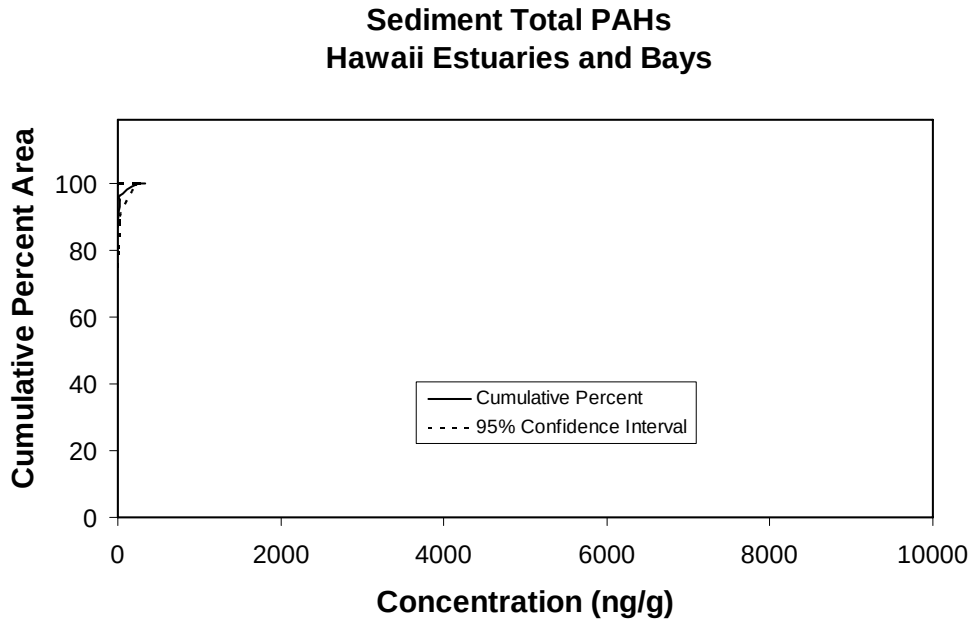

Figure 3.2-27. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. sediment concentration of total PAHs.

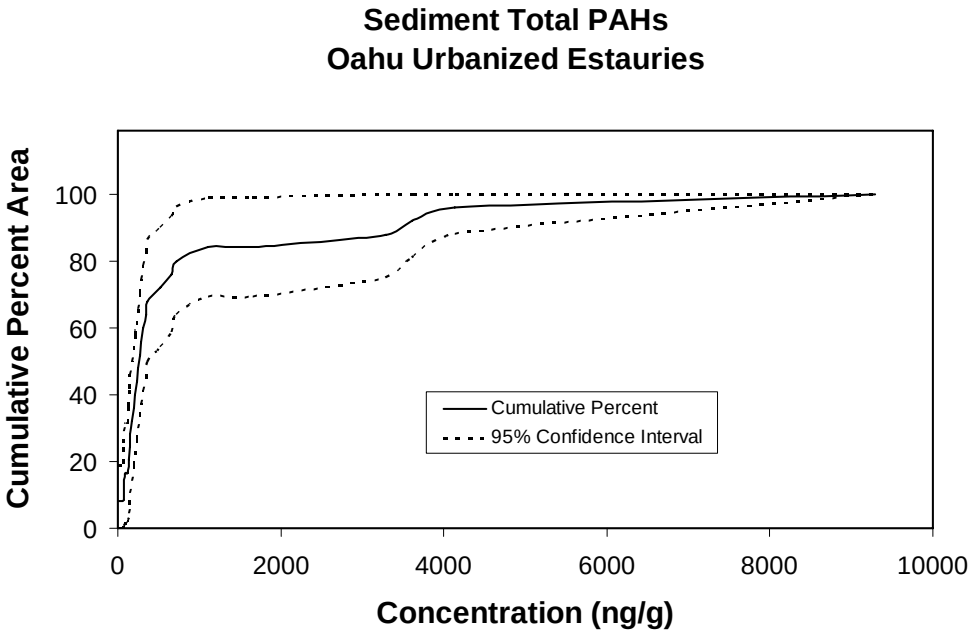

Figure 3.2-28. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. sediment concentration of total PAHs.

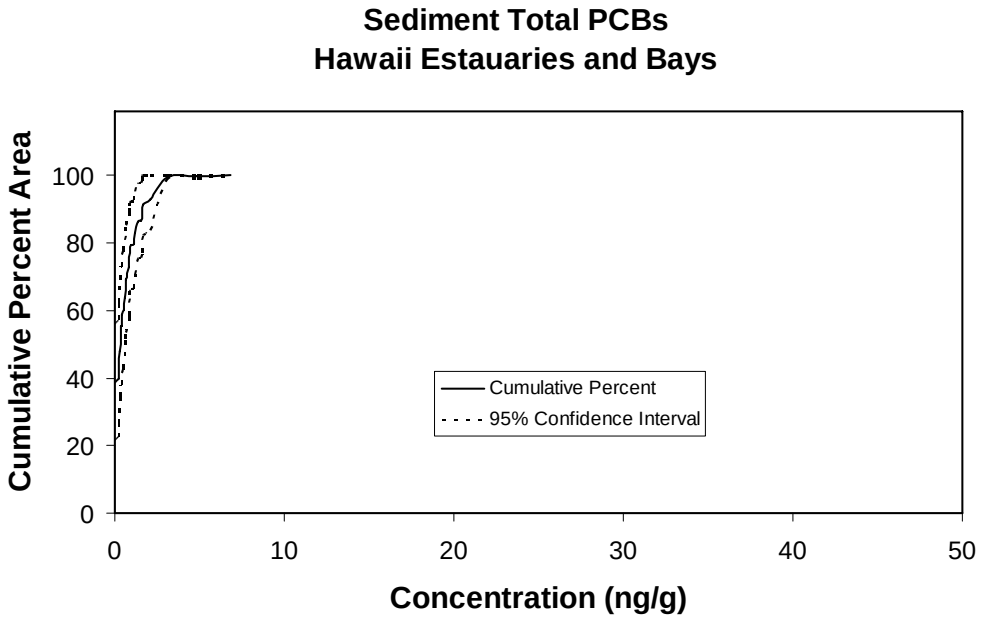

Figure 3.2-29. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. sediment concentration of total PCBs.

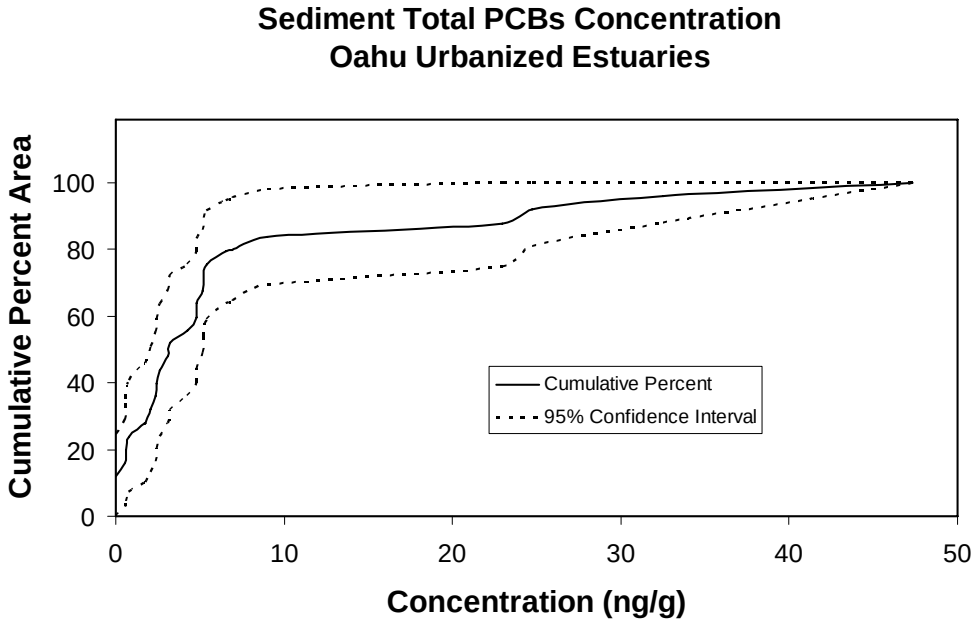

Figure 3.2-30. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. sediment concentration of total PCBs.

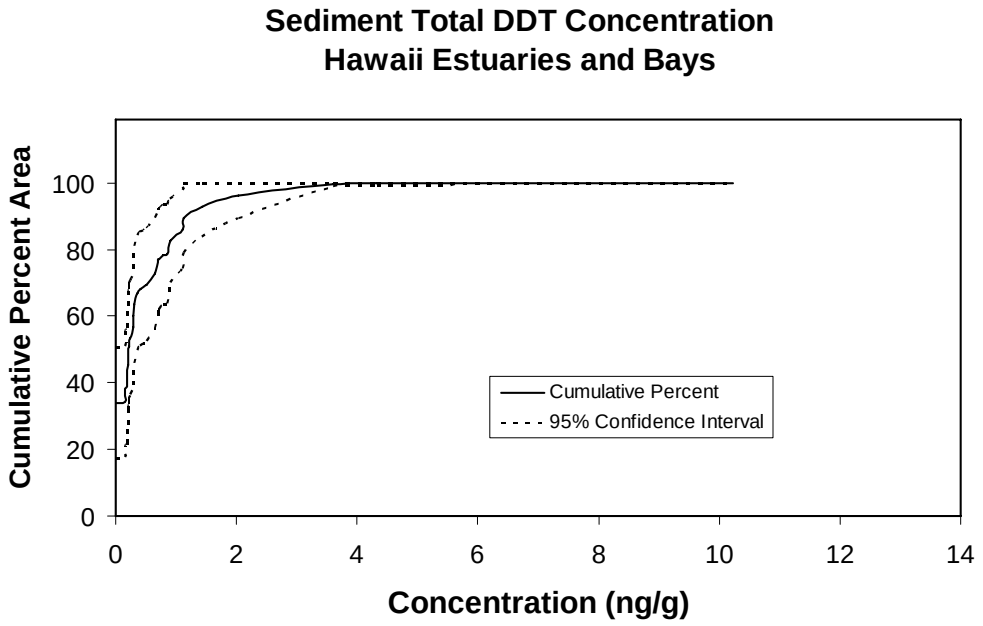

Figure 3.2-31. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. sediment concentration of total DDT.

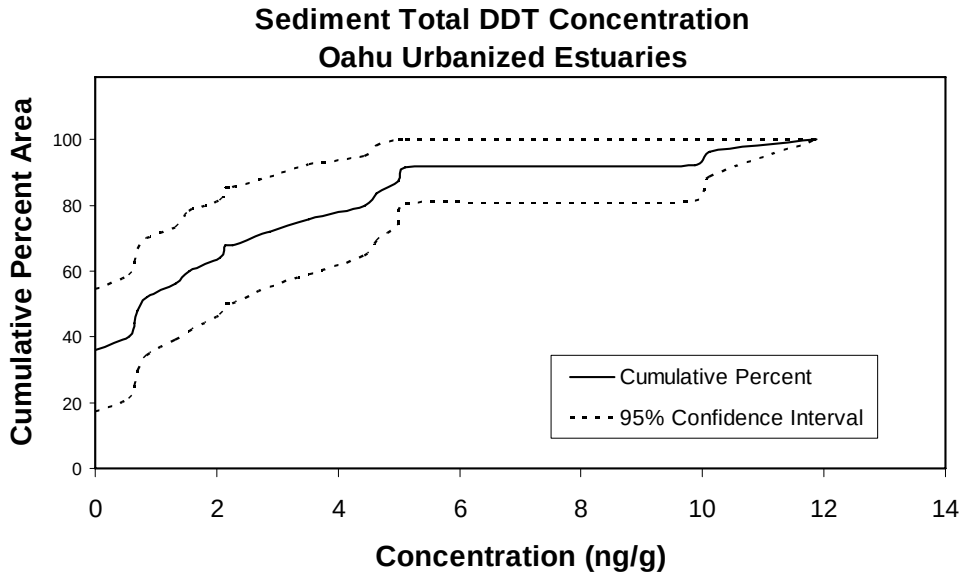

Figure 3.2-32. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. sediment concentration of total DDT.

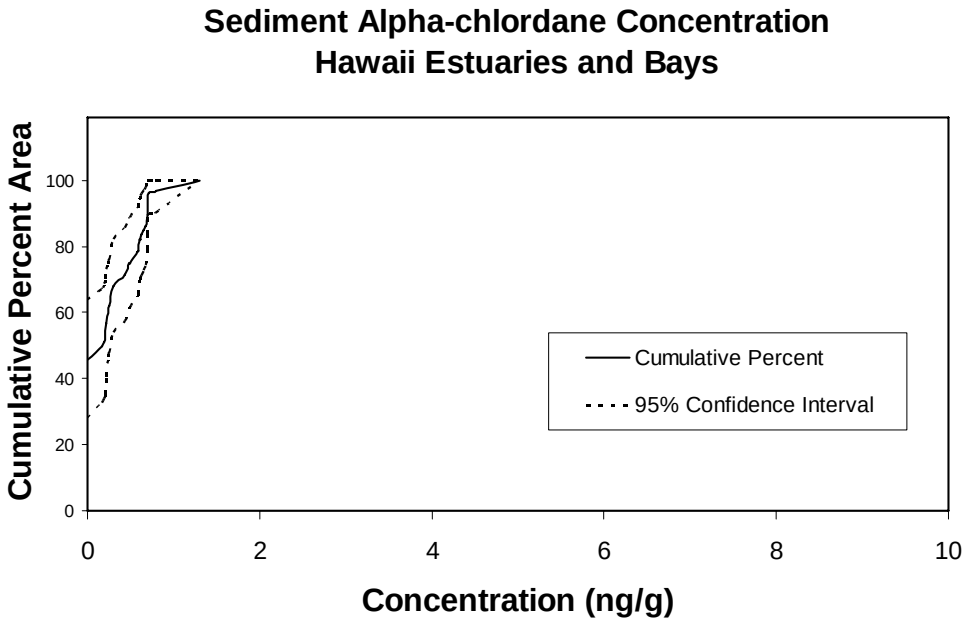

Figure 3.2-33. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. sediment concentration of alpha-chlordane.

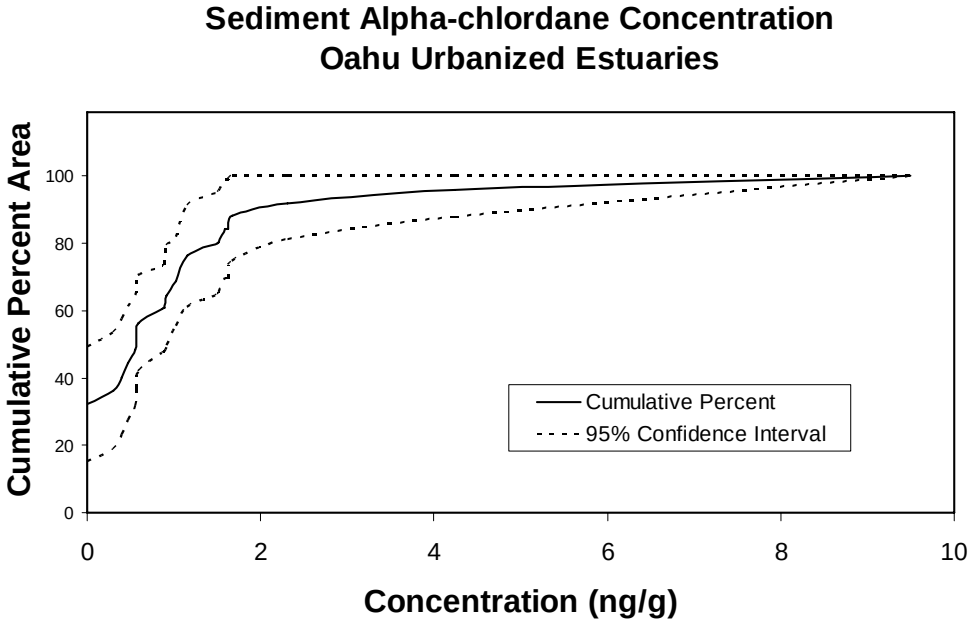

Figure 3.2-34. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. sediment concentration of alpha-chlordane.

3.2.3 Sediment Toxicity

Sediment for toxicity testing with the amphipod *Ampelisca abdita* was successfully collected at 44 of the 50 Hawaii estuaries and bays stations, and 28 of the 30 Oahu urbanized estuaries stations (see section 2.6). Control conditions for a successful toxicity test with this species require a mean of 90% survival in the five replicates in control sediments, with no replicate less than 80%. Mean control survival met the standard in all cases (90 to 98%), but three control batches had minimum replicate survival < 80%. Thus both requirements were not formally met in testing sediments collected from 17 of the 72 stations. Because the overall control survival met the standard, and it is the mean value for control survival that is used to calculate the control-corrected survival values, these 17 samples were included in the CDF analyses that follow.

The control corrected mean survivorship of *A. abdita* in successful bioassays of sediments collected at the Hawaii estuaries and bays stations ranged from 73.1% to 105.4%, across the 44 stations that were included in the analysis (Figure 3.2 -35). Approximately 10% of the area of the Hawaii estuaries and bays had control corrected mean survivorship of *A. abdita* in sediment bioassays < 80%. Lowest survival was in sediments from Stations 6 (Wahiawa Bay), 13 (Kaneohe Bay) and 49 (Hilo Bay), although these sediments were not acutely toxic, with control corrected survival values ranging from 73.1 to 78.3 percent. Approximately 16% of area in the Hawaii estuaries and bays had control corrected mean survivorship > 100%, indicating slightly (1-5%) higher survival of amphipods in test sediments than in controls.

The control corrected mean survivorship of *A. abdita* in successful bioassays of sediments collected in the Oahu urbanized estuaries was above 90% across all of the 28 stations that were included in the analysis (Figure 3.2-36). Approximately 64 % of area had control corrected mean survivorship > 100%, with the higher survival in the range of 1-9%.

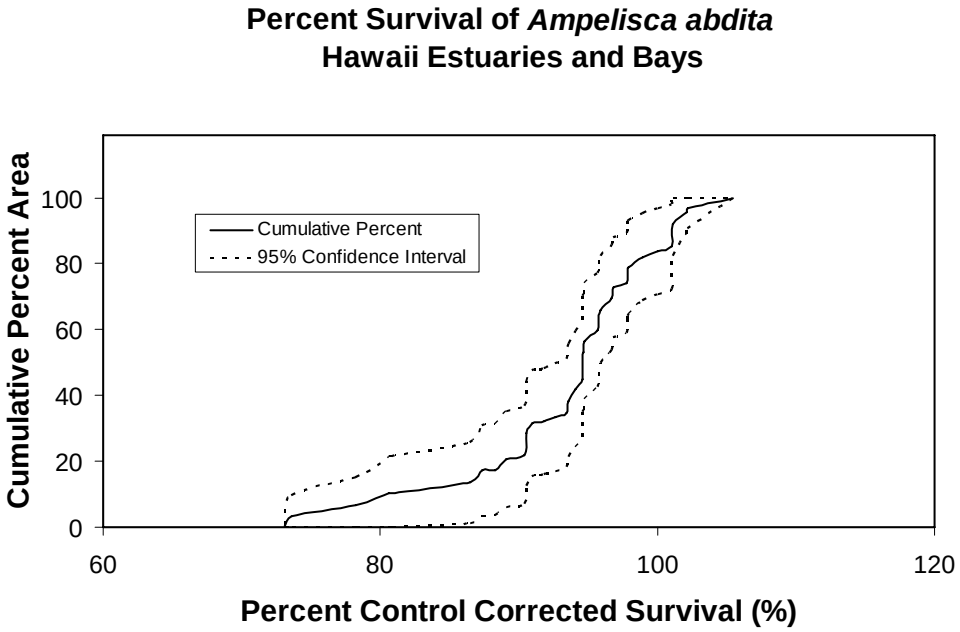

Figure 3.2-35. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. percent control corrected survivorship of *Ampelisca abdita*.

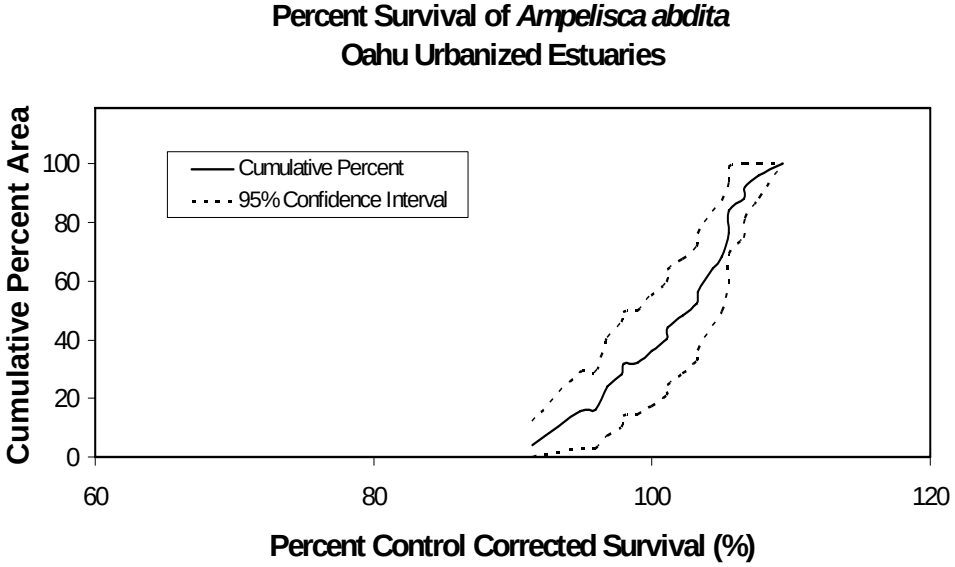

Figure 3.2-36. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. percent control corrected survivorship of *Ampelisca abdita*. Note axis differs from 3.2-35.

3.2.4 Tissue Contaminants

Residues of a suite of metals, PCBs, PAHs and pesticides were measured in the whole bodies of holothurians (*Holothuria atra and H. whitmaei*) at 11 stations in the Hawaii estuaries and bays and 2 stations in the Oahu urbanized estuaries (see Table 2-4 for list of compounds analyzed). Residues were not measured at the other stations because of the unavailability of holothurians. Because of the limited number of samples and because it is not clear that the sites with holothurians captured for residue analysis were distributed randomly the tissue residue data are presented as summary statistics rather than CDFs to estimate areas.

Holothurian tissue residues of the 12 metals are summarized in Table 3.2-5. As expected, iron and aluminum, which are abundant in volcanic soils, had the highest concentration. Aside from those two metals, nickel, averaging 8.59 µg/g (wet weight) in tissue from the Hawaii estuaries and bays and arsenic, averaging 7.55 µg/g (wet weight) in tissue samples from the Oahu urbanized estuaries, had the highest tissue metal concentrations. Total metal concentrations varied widely, with the highest concentrations at Stations 3 and 30 on Kauai and Maui, and the lowest at stations from Kaneohe Bay. Mercury, cadmium, and silver were undetected in holothurian tissue samples from either Hawaii estuaries and bays or Oahu urbanized estuaries.

Holothurian tissue residues of total PCBs, PAHs, total DDT, and other pesticides are summarized in Table 3.2-6. Total PCBs had the highest residue of organic contaminants but was found at low levels, averaging 2.91 ng/g in samples from the Hawaii estuaries and bays and 4.82 ng/g in the Oahu urbanized estuaries. Measured 4,4'-DDT constituted 100% of the total DDT and was detected in 3 of the 11 tissue samples, with maximum values of 2.90 ng/g. Tissue analysis failed to detect measurable concentrations of any of the following compounds in samples from either Hawaii estuaries and bays or the Oahu urbanized estuaries: Aldrin, Dieldrin, Endosulfan I and II, Endosulfan sulfate, Endrin, Alpha-chlordane, Gamma-chlordane, Trans-nonachlor, Heptachlor, Heptachlor Epoxide, Lindane, Mirex and Toxaphene. No PAHs were detected in tissue samples from any of the sites sampled.

Table 3.2-5. Holothurian tissue residues of metals (µg/g wet weight) from 11 Hawaii estuaries and bays sites and 2 Oahu urbanized estuaries sites. Values are the averages of all samples at a station, with the samples consisting of individuals or composites of up to 3 individuals. "Frequency of Detects" is the number of stations where the metal was detected at a level above the minimum detection limit (MDL). "No. Stations" is the number of stations in which tissue was analyzed. A total of 13 tissue samples were analyzed at 13 stations in the small estuaries.

Metal	Mean (µg/g wet)	SD	Mean when Present	Minimum	Maximum	Frequency of Detects/ No. Stations
Hawaii estuaries and bays						
Aluminum	965	2080	965	35.9	6990	11/11
Arsenic	4.47	2.34	4.47	0.92	8.70	11/11
Cadmium	0.00	0.00	0.00	0.00	0.00	0/11
Copper	0.97	1.19	0.97	0.16	3.70	11/11
Iron	1580	3150	1580	56.4	10300	11/11
Lead	0.35	0.49	0.35	0.08	1.80	11/11
Mercury	0.00	0.00	0.00	0.00	0.00	0/11
Nickel	8.59	13.4	8.59	0.21	40.5	11/11
Selenium	1.01	0.51	1.01	0.40	2.10	11/11
Silver	0.00	0.00	0.00	0.00	0.00	0/11
Tin	1.66	0.19	1.66	1.20	1.80	11/11
Zinc	4.21	5.00	4.21	1.40	18.4	11/11
Oahu urbanized estuaries						
Aluminum	74.5	28.1	74.5	54.6	94.4	2/2
Arsenic	7.55	0.07	7.55	7.50	7.60	2/2
Cadmium	0.00	0.00	0.00	0.00	0.00	0/2
Copper	0.57	0.37	0.57	0.31	0.83	2/2
Iron	98.4	1.34	98.4	97.5	99.4	2/2
Lead	0.30	0.13	0.30	0.20	0.39	2/2
Mercury	0.00	0.00	0.00	0.00	0.00	0/2
Nickel	0.13	0.10	0.13	0.05	0.20	2/2
Selenium	2.05	1.49	2.05	0.99	3.10	2/2
Silver	0.00	0.00	0.00	0.00	0.00	0/2
Tin	1.85	0.07	1.85	1.80	1.90	2/2
Zinc	4.70	0.28	4.70	4.50	4.90	2/2

Table 3.2-6. Holothurian tissue residues of total PCBs, PAHs, total DDT, and additional pesticides (ng/g wet weight) in samples from 11 Hawaii estuaries and bay sites and 2 Oahu urbanized estuaries sites. Values are the averages of all samples at a station, with the samples consisting of individuals or composites of up to 3 individuals. "Frequency of Detects" is the number of stations where the organic pollutant was detected at a level above the minimum detection limit (MDL). "No. Stations" is the number of stations from which tissue was analyzed.

Analyte	Mean (ng/g wet)	SD	Mean when Present	Minimum	Maximum	Frequency of Detects/ No. Stations
Hawaii estuaries and bays						
Total PCBs	2.91	2.82	4.57	0.00	8.10	7/11
Total PAHs	0.00	0.00	0.00	0.00	0.00	0/11
Total DDT	0.45	1.03	2.50	0.00	2.90	2/11
Other pesticides	0.00	0.00	0.00	0.00	0.00	0/11
Oahu urbanized estuaries						
Total PCBs	4.82	2.93	4.82	2.74	6.89	2/2
Total PAHs	0.00	0.00	0.00	0.00	0.00	0/2
Total DDT	1.20	1.70	2.40	0.00	2.40	1/2
Other pesticides	0.00	0.00	0.00	0.00	0.00	0/2

3.2.5 Bacterial Indicators

The Hawaii Department of Health (HDOH) has a water quality criterion for marine recreational waters for enterococci of a geometric mean of colony counts of less than 7 colony forming units (cfu) /100 ml of sample water in not less than 5 samples taken over 25-30 days. No single sample shall exceed a count of 100 cfu/ 100 ml (Section 11-54-8, HDOH, Amendment and Compilation of Chapter 11-54, Hawaii Administrative Rules, August 31, 2004). *Clostridium perfringens* is used by HDOH as an indicator of whether high levels of enterococci potentially originate from human sources (T. Teruya, HDOH). A level above 5 cfu/100 ml is considered as potentially indicative of a human related source (T. Teruya, HDOH). There is no Hawaii marine criterion for fecal coliforms, and the former freshwater recreational water criterion of 200 cfu/100 ml for 10 samples over 30 days has been replaced by an enterococci criterion. The EMAP sampling took place on a single sample date for each station, and thus does not formally meet the multi-sample requirement for the Hawaii enterococci criterion. Additionally, Hawaii has different criteria for inland waters verus marine waters, and formal interpretation of bacterial counts would need to consider salinity at the sample site. In the section below, the cfu values of the criterion are simply used as a relative benchmark for examining the bacteria data.

Processing of bacteria samples must commence within 6 hours of collection. Samples were processed by HDOH branch offices on the various islands to reduce sample holding times. Table 3.2-7 summarizes the results; overall 227 bacteria samples were collected from 77 stations (three depths at most stations). Of the 227 samples, 28 did not meet the 6-hour holding time criterion. Of the 199 samples that did meet the holding time, nine (or 4.5%) of the total exceeded the state 7 cfu/100 ml criterion for enterococci. Most of these higher values occurred at stations located at the heads of harbors and/or in proximity to streams. The highest individual sample count was 100 cfu/100 ml for enterococci in surface water from Honolulu Harbor (HI02-0080), which would be considered an exceedance of the single sample criterion by HIDOH (T. Teruya, HDOH).

For enterococci, surface water sample colony counts ranged from 0.3 to 56 cfu/100 ml for the Hawaii estuaries and bays (Figure 3.2-37), and from 0.3 to 100 cfu/100 ml for the Oahu urbanized estuaries (Figure 3.2-38). An estimated 96 % of the area of Hawaii estuaries and bays and 87 % of the area of Oahu urbanized estuaries had an enterococci colony count in surface samples of $\leq$7 cfu/100 ml (Figures 3.2-37, 38).

Surface water sample colony counts for the indicator organism *Clostridium perfringens* for Hawaii estuaries and bays ranged from 0.30 to 11 cfu/100 ml across the 49 stations where counts were measured (Figure 3.2-39). For the Oahu urbanized estuaries, surface water sample *Clostridium* colony counts ranged from 0.30 to 21.0 cfu/100 ml across the 29 stations where counts were measured (Figure 3.2-40). An estimated 99% of the area of Hawaii estuaries and bays and 88% of the area of Oahu urbanized estuaries had a *Clostridium* colony count in surface samples of $\leq$5 cfu/100 ml (Figures 3.2-39, 40).

There were a total of five stations, all on Oahu, where *Clostridium* colony counts were above 5 cfu/100 ml and enterococci counts were above 7 cfu/100 ml. Locations were in Paukauila Stream (HI02-0008), and within the urbanized estuaries of Oahu, in Pearl Harbor, the Ala Wai Canal, and Honolulu Harbor (HI02-0051, HI02-0054,HI02-0071, HI02-0079).

Surface sample counts of fecal coliform colonies ranged from 0.60 to 22.5 cfu/100 ml for the Hawaii estuaries and bays (Figure 3.2-41), and from 0.60 to 98.0 cfu/100 ml for the Oahu urbanized estuaries (Figure 3.2-42). Thus, an estimated 100% of area of both the Hawaii estuaries and bays and the Oahu urbanized estuaries had a mean fecal coliform count of $\leq$200 cfu/100 ml (Figures 3.2-41, 42).

At several stations in the Hawaii bays and estuaries, surface water sample counts of enterococci and fecal coliforms, and occasionally *Clostridium*, were higher than counts from mid-depth or bottom water samples. For example, the surface water sample was 40 to 60 times greater than mid-depth and bottom water samples from Waimea Bay, Kauai. In a few cases, such as in Kahului Bay on Maui, mid-depth sample counts exceeded surface or bottom water counts. In the Oahu urbanized estuaries, Station 71 (Ala Wai Canal) had highest counts in surface waters, Station HI02-0073 (Kewalo Basin) had higher counts near the bottom, and several stations in Honolulu Harbor and Pearl Harbor had elevated levels of bacteria throughout the water column. Station HI02-0051 (Pearl Harbor) with a colony count of 98 cfu/100 ml for fecal coliforms had data only from the shallow water depth, as the total water depth at this station was 0.01 m.

Table 3.2 -7. Summary of enterococci sampling results, with data presented both for all samples collected and for samples that met the 6-hour holding time criteria.

	Island/Island Group			
Parameter	Niihau, Kauai	Oahu	Maui	Hawaii
All Samples				
Total No. Samples	16	137	26	48
Total No. Samples > 7 cfu/100 ml	1	11	1	1
Percent of samples above 7 cfu criterion	6.3	8.0	3.9	2.1
Total No. Samples > 6 hr holding limit	13	4	10	28
Samples Within Holding Limits				
Total No. Samples < 6hr Holding Limit	3	133	16	20
Total No. Samples > 7 cfu/100 ml	0	7	1	1
Percent of samples above 7 cfu criterion	0	5.3	6.3	5.0

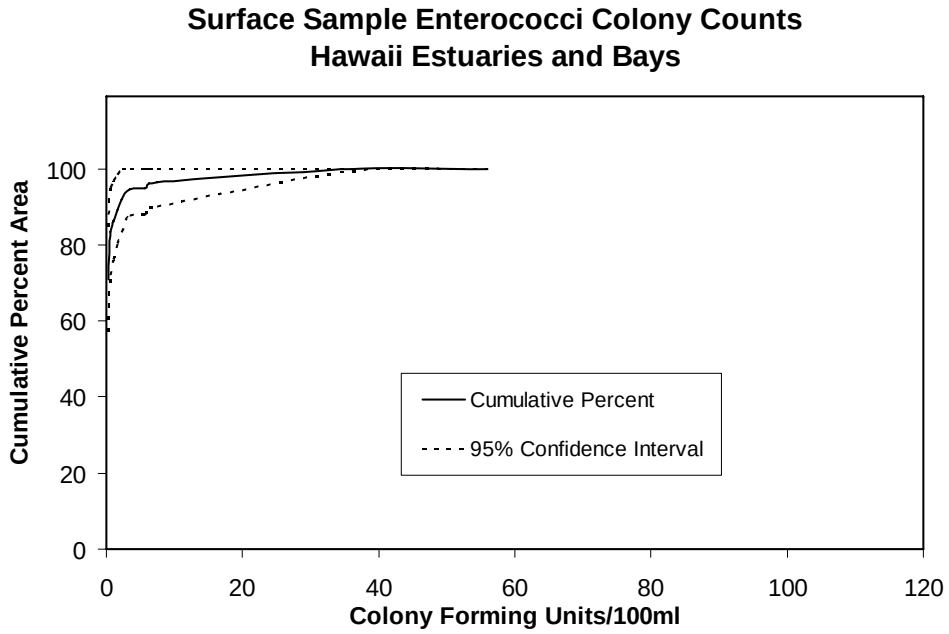

Figure 3.2-37. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. surface water sample enterococci colony counts.

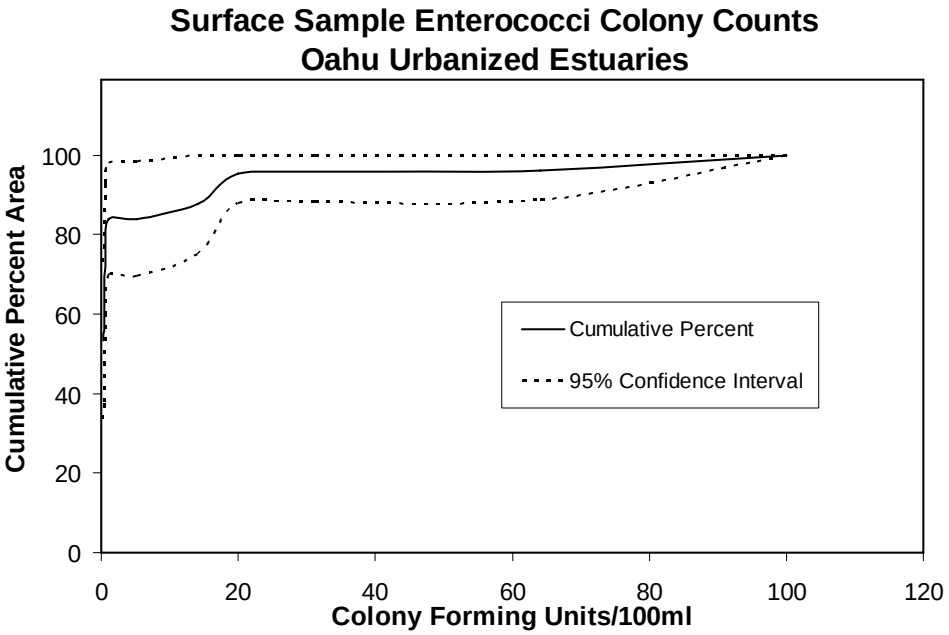

Figure 3.2-38. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. surface water sample enterococci colony counts.

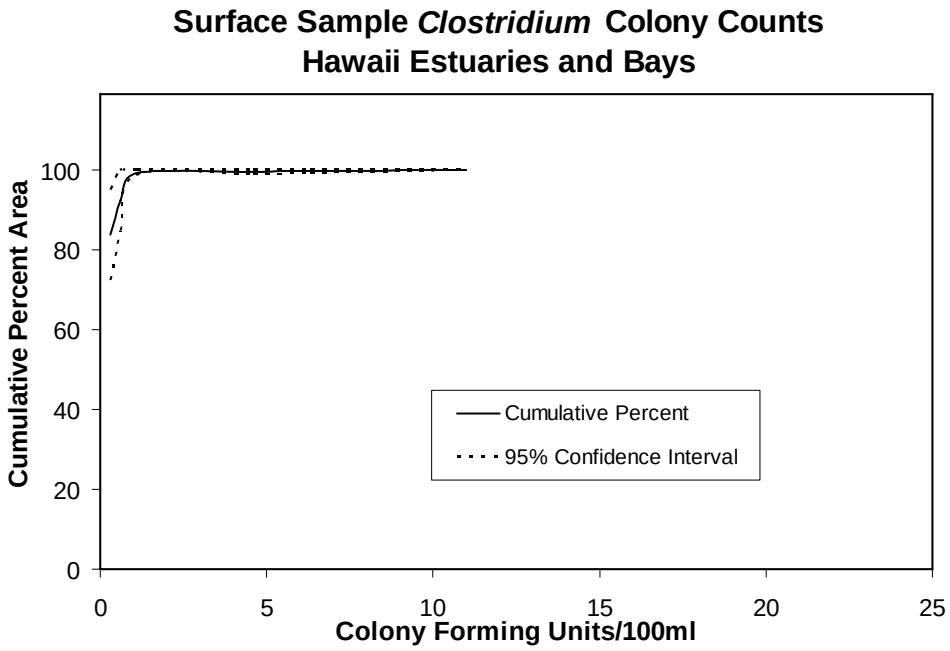

Figure 3.2-39. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. surface water sample *Clostridium* colony counts.

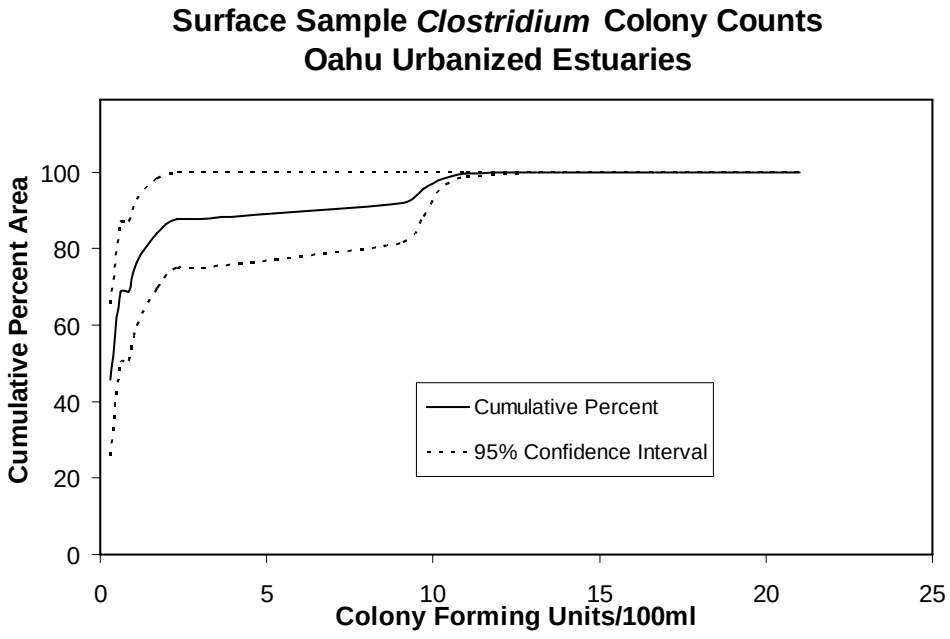

Figure 3.2-40. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. surface water sample *Clostridium* colony counts.

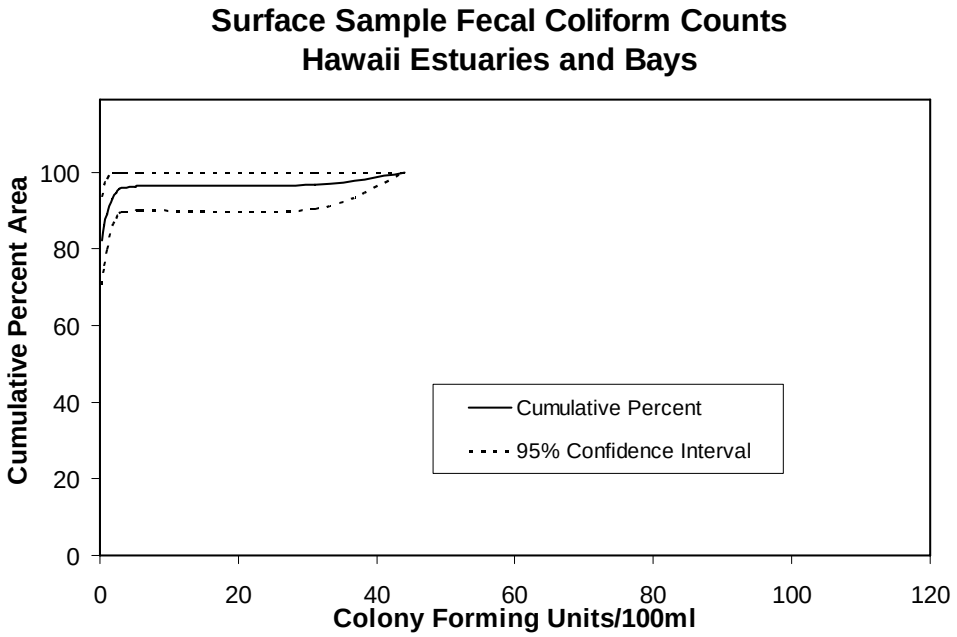

Figure 3.2-41. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. surface water sample fecal coliform counts.

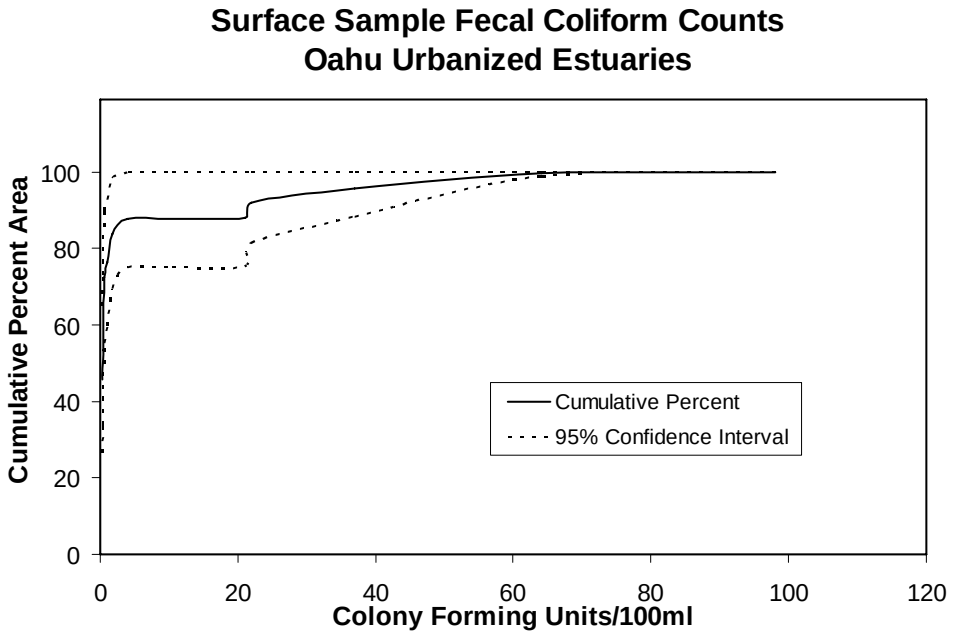

Figure 3.2-42. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. surface water sample fecal coliform counts.

3.3 Biotic Condition Indicators

Soft bottom-dwelling (benthic) invertebrates are important because they are important food resources for other motile species that may be consumed by humans. In the Hawaiian Islands, sedimentary materials from terrigenous sources are often most prevalent in protected water locations such as estuaries, at heads of bays and close to stream mouths. Many anthropogenic pollutants are known to adhere to particulate and sedimentary materials that eventually fall to the bottom and are sequestered in the sediments. The soft-bottom benthos live and feed in these sediments, and thus may serve as conduits for contaminants moving up through the food web to the human population.

Sediments were encountered at all but five stations in the 79 sites sampled. Hard bottom was the only substrate encountered at these five sites. Hard bottom included basalt boulders and pahoehoe lava substratum (Stations HI02-0004, HI02-0030, HI02-0032), limestone (Station HI02-0012) or coralline rubble (Station HI02-0037). Sediments were present and sampled at all other locations, including all 29 stations from Oahu urbanized estuaries.

3.3.1 Infaunal Abundance, Species Richness, and Taxonomic Composition

Benthic species richness on a per sample basis ranged from 4 to 52 species per sample in the samples from Hawaii estuaries and bays, and from 3 to 43 species per sample from the Oahu urbanized estuaries. On an areal basis, 50% of the area of the Hawaii estuaries and bays had a species richness less than 22 species per sample, and 90% had a richness less than 39 species per sample (Figure 3.3-1). The Oahu urbanized estuaries had a lower richness, with 50% of the area of these estuaries having fewer than 8 species per sample and 90% of the area having less than 21 species per sample (Figure 3.3-2).

The diversity index H′ (log base 2) ranged from 0.32 to 4.68 in the samples from Hawaii estuaries and bays and ranged from 0.58 to 4.39 in the Oahu urbanized estuaries (Table 3.3-1). On an areal basis, less than 50% of the area of the Hawaii estuary and bays had an H′ of 2.79 while 90% of the area had a value of 3.99 or less (Figure 3.3-3). In comparison, 50% percent of the area of the Oahu urbanized estuaries had an H′ of 1.95 or less while 90% of the area had an H′ less than 3.00 (Figure 3.3-4).

Table 3.3 -1 presents a list of the taxa identified in all sediment samples and the number of stations by island where each taxon occurred. In total, 214 taxa were identified. Polychaetes comprised 113 taxa (53% of the total) and with crustaceans, (80 taxa, 37% of the total) were the dominant groups identified in the samples. Some unidentified taxa (i.e., Nematoda) had high abundance in some samples, and with further taxonomic treatment could modify the discussion below.

Benthic infaunal density in samples from Hawaii estuaries and bays ranged from 5 to

1927 individuals per 0.0045 m^2, and similarly ranged between 8 and 1872 individuals per 0.0045 m^2 in samples from Oahu urbanized estuaries (Table 3.3-1). On an areal basis, 50% of the area of the Hawaii estuaries and bays had a benthic density less than 270 individuals per 0.0045 $m^{2,}$ and 90% of the area had a density less than 547 individuals per 0.0045 m^2 (Figure 3.3-5). In the Oahu urbanized estuaries, 50% of the area had benthic densities less than 76 individuals per 0.0045 m^2 and 90% of the area had densities less than 513 individuals per 0.0045 m^2 (Figure 3.3-6).

Fully 57 % of the polychaete taxa are classified as nonindigenous in origin, 5 percent as native, 3 percent as cryptogenic and 35 percent as indeterminate or unclassified. In the crustaceans, 65 percent of the taxa are considered to be native in origin, 4 percent as nonindigenous, one percent as cryptogenic and 30 percent as indeterminate. The percentage of nonindigenous species in the other taxa can not presently be determined either because the taxa were not identified to a sufficiently low taxonomic level to allow classification (indeterminate taxa) or because the origins of the species have yet to be determined (unclassified species) (Table 3.3-1).

The number of soft-bottom taxa recorded by island is related to sediment characteristics as well as to the relative sampling effort by island; Niihau received 3% of the sampling effort (2 stations), Kauai - 6% (5 stations), Oahu - 60% (18 stations in the extensive survey and 30 stations in the intensive survey), Molokai -1% (1 station), Maui - 11% (9 stations), and Hawaii -19% (15 stations).

The most abundant taxa collected were the Nematoda (5,801 individuals), followed by the Oligochaeta (2,762 individuals), polychaetes in the family Spionidae (*Streblospio benedicti* - 1,674 individuals, *Pygospio muscularis* - 1,074 individuals) and Harpacticoida copepods (1,559 individuals). The polychaete *Capitella capitata* is considered an indicator of organic enrichment of sediments (Bailey-Brock *et al*. 2002). This species was abundant on Maui (Station HI02-028), Hawaii (Stations HI02-0047, HI02-0050) and on Oahu (Stations HI02-0067, HI02-0075). Other polychaete species that are found in association with fine sediment grain sizes (mud bottoms) include *Armandia intermedia, Cossura coasta* and *Cossura* sp. C as well as *Sternaspis* sp., all of which were found in the harbors sampled on Oahu, Maui and Hawaii Islands. The two Niihau stations (Stations HI02-0001, HI02-0002) yielded four specimens of *Parenterodrilus taeniformis* which represents a new record for the Hawaiian polychaete fauna (Bailey-Brock *et al*. in prep.). The most abundant crustacean species was the nonindigenous tanaid, *Leptochelia dubia.*

Table 3.3 -1. Summary of the soft bottom taxa identified from 74 Hawaii EMAP stations where sediment was sampled. Given are the number of stations around a particular island that a taxon was recorded. Data are separated into the 50 sites sampled around 6 islands (the extensive survey) from the 30 intensive survey stations along Oahu's south shore. "Type" refers to the source of each taxon where Nat = native species, NIS = nonindigenous species, Crypto = cryptogenic species, I = indeterminate origin, and U = unclassified.

Taxon	Type	Number of stations	Kauai	Oahu	Oahu Urbanized estuaries	Maui	Hawaii	Niihau	Molokai	Total No. Individuals
HYDROZOA	I	4			4					4
ANTHOZOA	I	11		4	2	3	2			45
PLATYHELMINTHES	I	12		4	1	2	4		1	37
NEMERTEA	I	49	3	13	12	7	12	2		409
NEMATODA	I	64	3	15	23	7	14	1	1	5801
PRIAPULIDA	I	7	1	2		2	2			268
POLYCHAETA										
Amphiglena mediterranea	NIS	2		1	1					3
Amphiglena sp B	I	1			1					3
Amphinomidae	I	11		3	2	2	4			33
Aonides oxycephala	NIS	3		1			2			3
Aonides sp A	I	6		2		1	3			11
Aphelochaeta marioni	NIS	12		5	5		2			121
Aricidea catherinae	NIS	2			1	1				2
Armandia intermedia	NIS	20		2	8	4	5		1	217
Augeneriella dubia	NIS	1					1			1
Axiothella quadrimaculata	NIS	1				1				1
Brania rhopalophora	NIS	8		3	2	1	2			43
Capitella capitata	Crypto	28		9	12	3	4			160
Capitellidae spp	I	21		6	7	4	4			181

Taxon	Type	Number of stations	Kauai	Oahu	Oahu Urbanized estuaries	Maui	Hawaii	Niihau	Molokai	Total No. Individuals
Caulleriella acicula	NIS	2				2				62
Caulleriella sp A	I	3		1	2					4
Ceratonereis tentaculata	NIS	1					1			1
Chaetopteridae	I	8		4	4					151
Cossura coasta	Crypto	3			3					53
Cossura sp C	I	10		2	7	1				360
Dipolydora normalis	NIS	3		2			1			54
Dodecacaria laddi	Crypto	2		1			1			2
Dorvillea sp D	I	1			1					1
Eunicidae	I	1		1						4
Eumida sanguinea	NIS	1					1			1
Exogone longicornis	NIS	5		1	1	1	2			17
Exogone sp C	I	13		8	2		3			450
Glycera tesselata	NIS	5		1			4			8
Goniada emerita	NIS	1					1			1
Grubeosyllis mediodentata	NIS	1			1					3
Hesionidae sp D	I	21		5	5	2	8	1		173
Hesionura australensis	NIS	1		1						1
Hyboscolex longiseta	NIS	1		1						2
Laonice cirrata	NIS	3					3			5
Linopherus microcephala	NIS	11		4	1	1	5			75
Lumbrineridae sp A	I	1	1							1
Lumbrineris latreilli	NIS	1				1				2
Lumbrineris tetraura	NIS	16	1	7	3	2	3			59
Lysidice ninetta	NIS	1		1						3

Taxon	Type	Number of stations	Kauai	Oahu	Oahu Urbanized estuaries	Maui	Hawaii	Niihau	Molokai	Total No. Individuals
Magelona capensis	NIS	2		1				1		12
Magelona sp A	I	7	2		1	1	2		1	15
Maldanidae sp A	I	7		4	1		2			13
Marphysa conferta	NIS	1		1						1
Megalomma intermedium	NIS	3			1	2				3
Microspio granulata	NIS	1					1			1
Microspio sp A	I	2					2			19
Monticellina cf *dorsobranchialis*	I	4		1	2	1				4
Monticellina sp A	I	2			1	1				7
Myriochele oculata	NIS	17		3	6	5	3			105
Naineris sp A	I	10	1	4	1	1	2		1	39
Neanthes arenaceodentata	NIS	5		3	2					6
Neanthes succinea	NIS	2			2					2
Nematonereis unicornis	NIS	12		4	3	1	4			57
Nereis sp B	I	2				2				12
Notomastus tenuis	NIS	5		2		1	1			11
Ophiodromus angustifrons	U	3		1	1		1			3
Ophryotrocha adherens	NIS	1		1						1
Ophryotrocha sp C	I	1			1					2
Paraonella sp A	I	7		2	2		3			17
Parenterodrilus taeniformis	NIS	2					1	1		5
Pholoe sp B	I	1					1			4
Phyllochaetopterus sp A	I	2		1			1			81
Phyllochaetopterus verrilli	NIS	2		1	1					14
Phyllodoce madeirensis	NIS	4		2			2			7

Taxon	Type	Number of stations	Kauai	Oahu	Oahu Urbanized estuaries	Maui	Hawaii	Niihau	Molokai	Total No. Individuals
Pionosyllis heterocirrata	NIS	18	1	4		3	9	1		345
Pionosyllis spinisetosa	NIS	10		4	1	3	1	1		44
Pionosyllis weismanni	NIS	4					4			4
Pisione sp A	I	13	2	1		2	7	1		101
Plakosyllis quadrioculata	NIS	1		1						1
Polygordius sp A	I	2		2						2
Polynoidae sp E	I	1			1					1
Polyophthalmus pictus	NIS	7					7			25
Prionospio cirrifera	NIS	25		4	15	1	5			120
Prionospio steenstrupi	NIS	11		1		6	4			13
Progoniada sp A	Nat	1		1						1
Protodorvillea biarticulata	NIS	8		4		1	2	1		48
Protodorvillea egena	NIS	1				1				1
Protodrilus sp A	I	12		4	1		5	1	1	69
Pseudopolydora antennata	NIS	1					1			4
Pseudopolydora corallicola	NIS	5		2	3					10
Pseudopolydora sp C	I	3			3					8
Pseudovermilia occidentalis	NIS	1					1			1
Pygospio muscularis	Nat	9	1	4			3	1		1074
Questa caudicirra	NIS	13		4	1	2	5	1		95
Questa sp A	Nat	13	2	4	1	2	4			71
Serpulidae	I	1		1						2
Sabellidae sp I	I	22		8	9	4	1			834
Saccocirrus oahuensis	Nat	3		1			2			8
Saccocirrus waianaensis	Nat	5		1			4			14

Taxon	Type	Number of stations	Kauai	Oahu	Oahu Urbanized estuaries	Maui	Hawaii	Niihau	Molokai	Total No. Individuals
Salmacina dysteri	Crypto	1			1					2
Schistomeringos rudolphi	NIS	2		1			1			8
Scolelepis sp B	I	7	1	1		3	1	1		9
Scolelepis victoriensis	NIS	2		2						2
Scyphoproctus djiboutiensis	NIS	3		1	1		1			15
Sigalionidae sp B	I	3		2		1				3
Sigambra tentaculata	NIS	3					3			4
Sphaerodoropsis sp C	I	1					1			3
Sphaerosyllis riseri	NIS	4			1		3			112
Sphaerosyllis sp E	I	24		8	7	1	7	1		277
Spionidae	NIS	2			1		1			252
Spio blakei	NIS	20	2	6	1	3	8			43
Sternaspis sp A	I	13		4	8	1				131
Streblospio benedicti	NIS	4		1	3					1674
Syllidae	NIS	2					2			4
Syllides bansei	NIS	1				1				1
Syllides sp B	I	1			1					2
Syllidia armata	NIS	2			2					4
Synelmis albini	NIS	1			1					1
Synelmis sp A	I	5					5			9
Terebellidae sp A	I	2		1			1			8
Trichobranchus glacialis	NIS	2				2				4
Typosyllis aciculata orientalis	NIS	7		3	1	1	2			34
Typosyllis cornuta	NIS	14		5	1	1	6	1		134
Typosyllis variegata	Nat	3		2		1				12

Taxon	Type	Number of stations	Kauai	Oahu	Oahu Urbanized estuaries	Maui	Hawaii	Niihau	Molokai	Total No. Individuals
OLIOGOCHAETA	I	65	3	17	25	7	11	1		2762
SIPUNCULA	I	14		2	3	2	7			46
ARTHROPODA										
Arachnida	I	2		2						2
Insecta	I	6		2	1	2	1			10
CRUSTACEA	I									
Halacaridae	I	4		1	1		1	1		9
COPEPODA -HARPACTICOIDA	I	51	2	10	21	4	12	1	1	1559
COPEPODA - CALANOIDA	I	4		1	3					4
COPEPODA - CYCLOPOIDA	I	3		2			1			4
BRANCHIOPODA - CLADOCERA										
Penilia sp. A.	I	6			6					33
OSTRACODA - MYODCOPA										
Myodocope sp. A.	I	15		4	5	2	4			88
Myodocope sp. B.	I	11	1	3	5	1	1			114
Sarsiella janiceae	Nat	3		1		2				11
OSTRACODA - PODOCOPA										
Bairdia hanaumaensis	Nat	4		2			2			8
Bairdia kauaiensis	Nat	3		1		1	1			10
Cytherelloidea cf. *monodenticulata*	Nat	1				1				1
LEPTOSTRACA - NEBALACEA										
Nebalia sp.A.	I	2				1			1	2
MYSIDACEA	I	4					3		1	5
CUMACEA	I	8		3	2	1	2			27
TANIDACEA										

Taxon	Type	Number of stations	Kauai	Oahu	Oahu Urbanized estuaries	Maui	Hawaii	Niihau	Molokai	Total No. Individuals
Anatanais insularis	Nat	1					1			2
Apseudes tropicalis	Nat	5		2	2	1				26
Leptochelia dubia	NIS	28		8	9	2	8		1	913
Leptochelia sp. A.	Crypto.	2					2			3
ISOPODA										
Apanthura inornata	Nat.	3		1		1	1			21
Caecianiropsis sp. A.	Nat.	3		2			1			9
Cryptoniscus form	I	8	1	3		1	3			13
Dynamenella sp. A.	Nat	2				1	1			2
Hyssuridae sp. A.	Nat	2		1			1			5
Janira algicola	Nat	3		1		1	1			15
Joeropsis hawaiiensis	Nat	6		3	2	1				32
Metacirolana sp. A.	Nat	5		3	1	1				41
Microcharon sp. A.	Nat	2			1		1			19
Munna acarina	Nat	8	1	1		2	4			15
AMPHIPODA - HYPERIIDEA	I	1			1					1
AMPHIPODA - GAMMARIDEA										
Amphilochidae spp.	Nat	13		2	1	1	8		1	58
Ampithoe sp. A.	Nat	1						1		1
Aoroides nahili	Nat	3					3			62
Atylus nani	Nat	1					1			2
Bemlos intermedius	Nat	1					1			1
Bemlos macromanus	Nat	6				1	4		1	15
Corophium insidiosum	NIS	5		2	1	1	1			72
Cymadusa cf. *hawaiiensis*	Nat	1		1						2

Taxon	Type	Number of stations	Kauai	Oahu	Oahu Urbanized estuaries	Maui	Hawaii	Niihau	Molokai	Total No. Individuals
Dulzura laakona	Nat	4		4						83
Dulzura sp. A.	Nat	6		3	1	2				42
Elasmopus piikoi	Nat	5		3		1	1			188
"Elpeddo" sp. A.	Nat	5		2		2			1	40
Eriopisella sechellensis	Nat	11		5	1	1	4			268
Ericthonius brasiliensis	NIS	6		1		1	3		1	160
Gammaropsis atlantica	Nat	2				1	1			3
Grandidierella makena	Nat	3		1	1		1			84
Konatopus paao	Nat	13		3		2	7		1	94
Leucothoe hyhelia	Nat	4		2	1	1				8
Mandibulophoxus hawaiiloa	Nat	5	3					2		129
Melita appendiculata	Nat	2				1	1			56
Melita pahuwai	Nat	2		1			1			2
"*Paraphoxus*" sp. B.	Nat	1							1	1
Pereionotus alaniphilias	Nat	1		1						1
Photis kapapa	Nat	1		1						1
Seba ekepuu	Nat	2		1			1			275
Tethygeneia pacifica	Nat	4		2		1			1	28
DECAPODA - NATANTIA										
Alpheus leptochirus	Nat	1			1					1
Alpheus rapax (?)	Nat	3			2		1			3
Leptochela hawaiiensis	Nat	1				1				1
Lucifer chacei	Nat	4			4					7
Nikoides steinii	Nat	1		1						1
Ogyrides sp. A.	Nat	1					1			1

Taxon	Type	Number of stations	Kauai	Oahu	Oahu Urbanized estuaries	Maui	Hawaii	Niihau	Molokai	Total No. Individuals
Penaeopsis velatinus	Nat	1					1			1
Pontophilus cf. *sculptus*	Nat	1					1			1
Processa hawaiiensis	Nat	1					1			1
Processa cf. *macrognatha*	Nat	2		1			1			2
Peneid larva	I	1					1			1
Caridean larva	I	9			8	1				12
DECAPODA - ANOMURA										
Axius sp. A.	I	1					1			1
Callianassa sp. A.	I	6	1	2		3				9
Calocaris sp. A.	I	1					1			1
DECAPODA - BRACHYURA										
Calappa gallus (?)	Nat	2					2			3
Leucosia (?) sp. A.	I	1						1		1
Lissocarcinus sp. A.	I	1					1			8
Macropthalamus sp. A.	I	1							1	6
Nucia (?) sp. A.	I	2					2			4
Pilumnus sp. A.	I	2				1	1			2
Portunus orbicularis	Nat	1					1			1
Thalamita auauensis	Nat	1			1					1
Megalops larva	I	2		1	1					3
Zoea larva	I	6		1	5					8
MOLLUSCA										
Bivalvia	I	26		6	6	6	6	1	1	91
Gastropoda	I	14		3	2	2	6		1	78
PHORONIDA	I	8	1	2	3	1			1	15

Taxon	Type	Number of stations	Kauai	Oahu	Oahu Urbanized estuaries	Maui	Hawaii	Niihau	Molokai	Total No. Individuals
ECHNODERMATA	I									
Echinoidea	I	6				2	3	1		10
Holothuroidea	I	21		6	8	3	4			214
Ophiuroidea	I	4		1		1	2			7
CHAETOGNATHA	I	12			10		2			248
HEMICHORDATA	I	3		2	1					14
CHORDATA	I	3		1			2			7
UROCHORDATA	I	1			1					1
OSTEICHTHYES	I	5	1		2	1	1			5

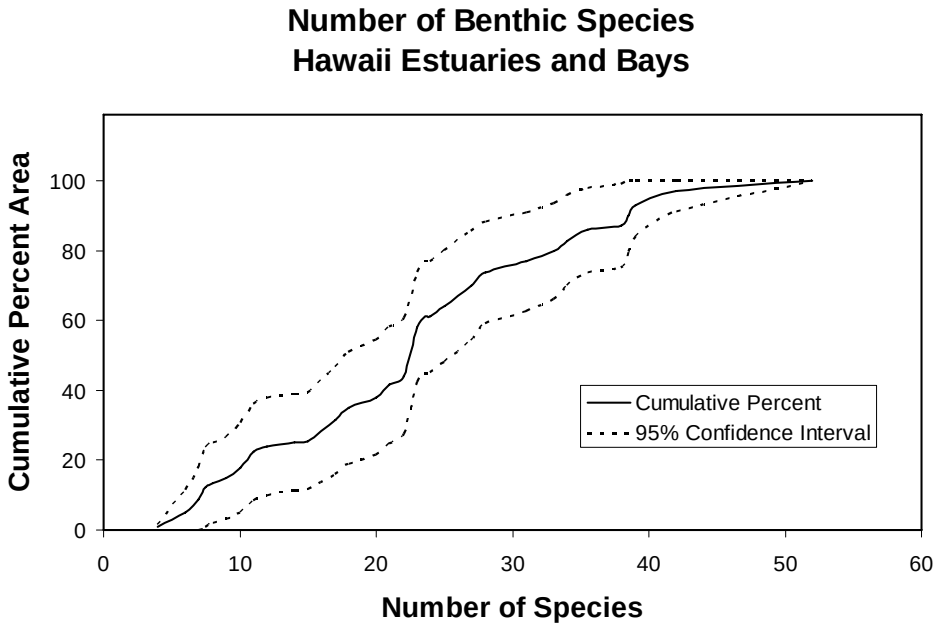

Figure 3.3 -1. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. total number of species of benthic infauna.

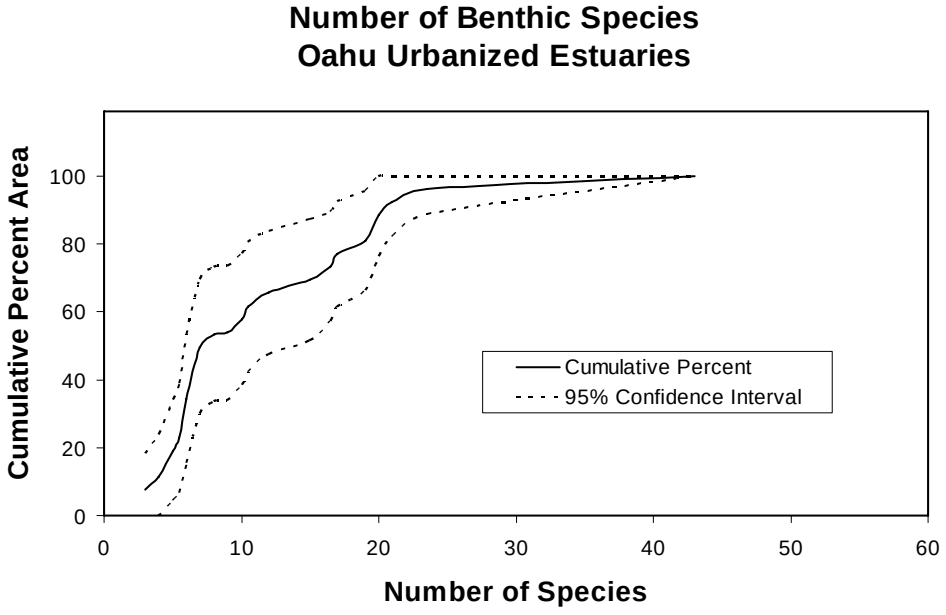

Figure 3.3 -2. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. total number of species of benthic infauna.

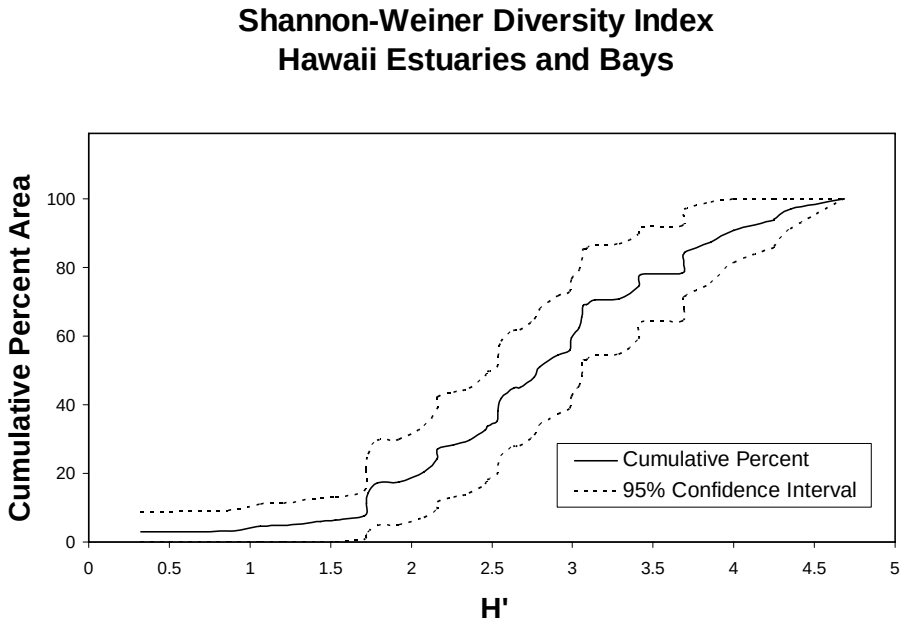

Figure 3.3 -3. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. H' diversity of the benthic infaunal community.

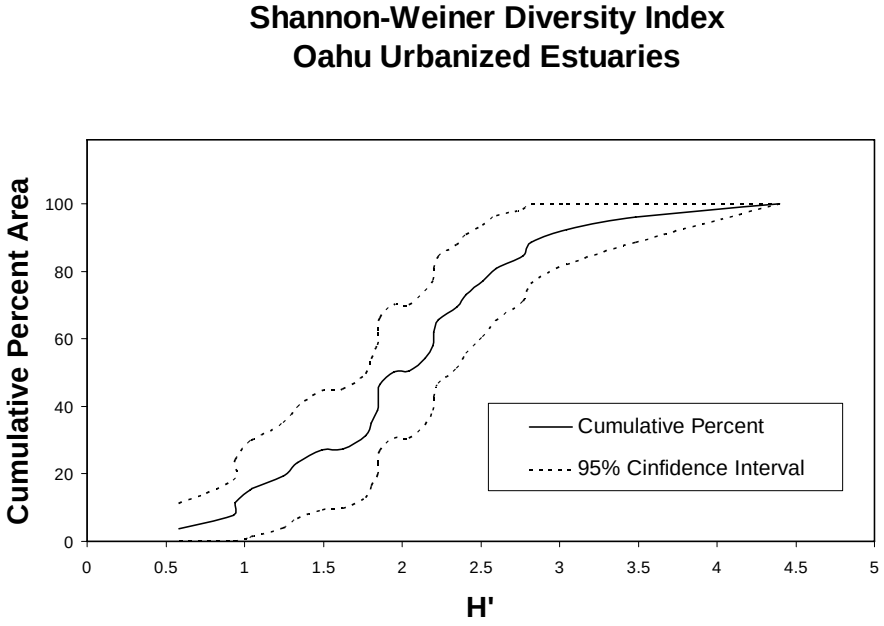

Figure 3.3 -4. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. H' diversity of the benthic infaunal community.

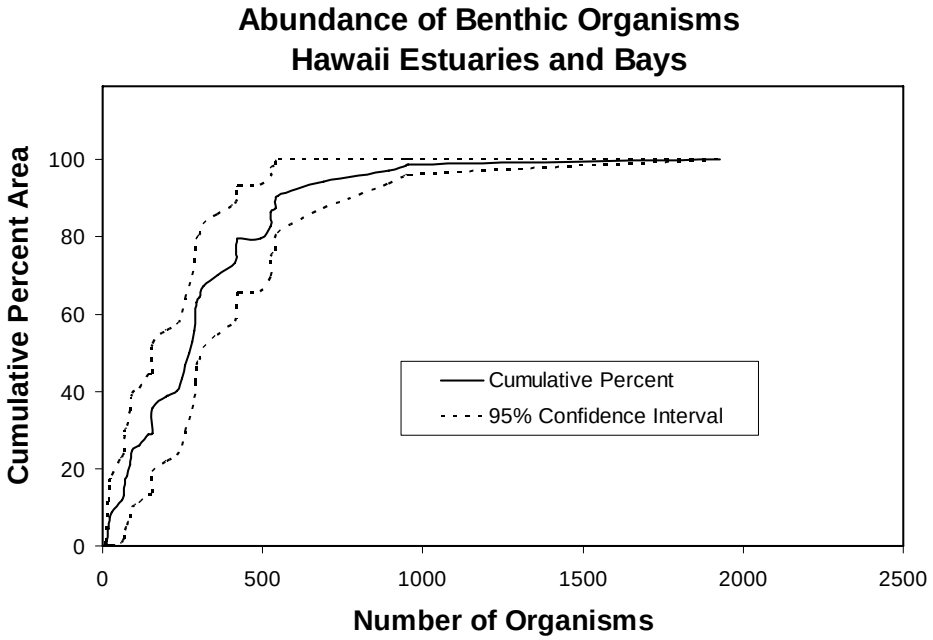

Figure 3.3 -5. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. total abundance of benthic infauna.

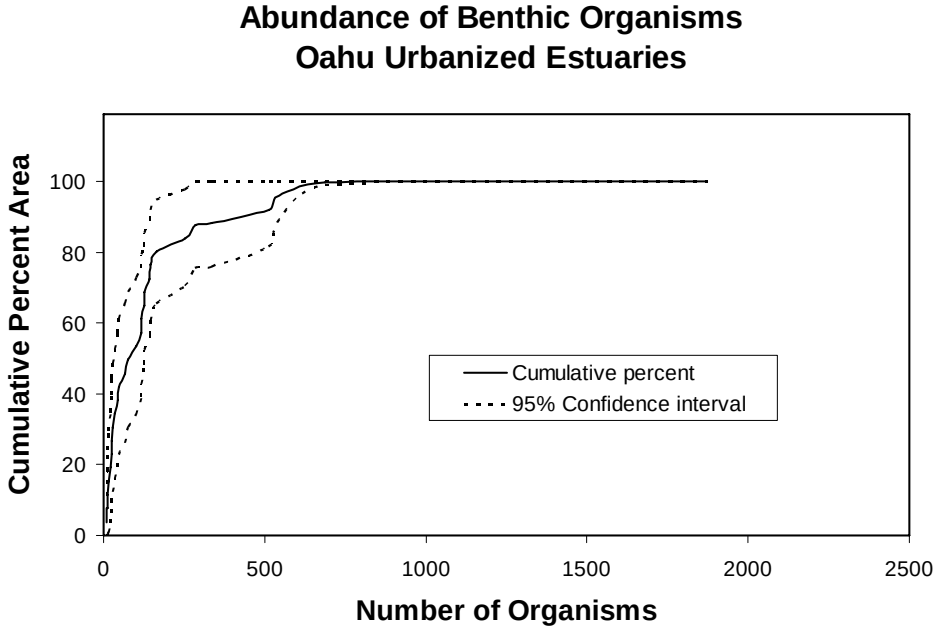

Figure 3.3 -6. Percent area (and 95% C.I.) of Oahu urbanized estuaries vs. total abundance of benthic infauna.

3.3.2 Hard Bottom Habitat Composition

Underwater biological sample collections were carried out by SCUBA divers at 38 of the 79 (or 48%) completed survey sites (Table 3.3-2). However, only three of these 38 underwater transects were completed at the 30 stations located in the Oahu urbanized estuaries. The low number of surveys at the stations in the Oahu urbanized estuaries precluded the calculation of CDFs for data collected at this group of sites.

At most of the harbor sites, surveys could not be completed due to the presence of poor visibility and/or fine mud substratum. Among the stations in Hawaii estuaries and bays, dangerous surf found on some reef crest sites along windward coasts also precluded diver sampling. Several other stations at low energy, poor visibility sites, usually in proximity to stream discharges, also could not be sampled. At locations where in-water diver surveys were not completed, all needed biological sample collections were made using standard methods (i.e., Van Veen grabs, etc.). Where sample sites occurred in coral reef settings, all biological sample collections were made using divers.

3.3.2.1 Algal Composition

Macrothalloid algae were recorded as the percent cover of each species present. In total 54 species of macroalgae were seen in the quadrat surveys. The ten most abundant algal taxa observed are given in Table 3.3-3. The mean algal coverage was 7.4%. Mean algal percent cover ranged between 0 and 70%, with 90% of the area of Hawaii estuaries and bays having an algal percent coverage less than approximately 14% (Figure 3.3-3). Among the islands, mean percentage algal coverage was as follows: Niihau - 4.6%, Kauai - 5.9%, Oahu - 9.7% Maui - 15.0% and Hawaii - 0.9%. The lower abundance of macrothalloid algal species around the island of Hawaii is probably related to the higher abundance of herbivorous invertebrates and fishes relative to other islands.

Nonindigenous algal species have become a concern in the Hawaiian Islands in recent years. There are eight species (*Acanthophora spicifera, Avrainvillea amadelpha, Gracilaria salicornia, G. tikvahiae, Hypnea musciformis, Kappahhycus alvarezii, K. stratium* and *Halophila decipiens*) generally recognized as being prominent nuisance species; three of these (*Acanthophora spicifera, Gracilaria salicornia* and *Avrainvillea amadelpha*) were encountered in this survey. These three nonindigenous species were only found at six Oahu sample sites, where they comprised a total of 53% of the algal cover. Plant abundances of the first two of these species were also among the ten most abundant algal species. No nonindigenous algae were found at any of the other survey sites although several are known to commonly occur in the waters around other islands.

Table 3.3 -2. Summary of biological parameters at all stations where underwater transect measurements were carried out.

EMAP Station ID	Island	No. Coral Species	% Coral Cover	No. Algal Species	% Algal Cover	No. Fish Species	No. Fish Individuals	Fish Biomass	No. Invertebrate Species	No. Invertebrate Individuals
HI02-0001	Niihau	1	0.2	7	8.7	10	42	4.72	5	30
HI02-0002	Niihau	0	0	1	0.4	6	35	11.2	0	0
HI02-0003	Kauai	6	21.7	6	5.9	9	57	7.5	3	3
HI02-0009	Oahu	1	11	3	13.9	1	2	0.01	2	8
HI02-0010	Oahu	6	2	5	3.2	8	19	3.7	2	6
HI02-0012	Oahu	4	1.1	12	15.8	4	9	0.8	5	195
HI02-0013	Oahu	1	0.3	11	33.3	5	31	5	5	93
HI02-0014	Oahu	6	7.1	3	2.3	12	52	12.3	0	0
HI02-0017	Oahu	2	23.4	3	4.3	13	77	40	2	4
HI02-0021	Oahu	1	0.4	0	0	2	13	0.5	5	31
HI02-0022	Oahu	0	0	5	10.3	11	60	7.3	2	2
HI02-0023	Oahu	1	5.8	4	11.1	8	61	3.9	2	45
HI02-0024	Oahu	0	0	8	9.3	2	4	2.1	2	2
HI02-0025	Oahu	4	1.2	0	0	17	68	24.3	6	29
HI02-0027	Maui	0	0	0	0	0	0	0	0	0
HI02-0028	Maui	7	38.2	7	10.6	12	61	33.1	1	1
HI02-0030	Maui	3	1.2	4	30.1	3	5	2.4	3	4
HI02-0031	Maui	0	0	0	0	2	20	0.7	1	13
HI02-0032	Maui	3	4.2	5	69.9	18	107	9.6	4	6
HI02-0033	Maui	6	34.5	1	9.3	10	27	2.8	4	64
HI02-0034	Maui	0	0	0	0	1	52	3.8	2	28
HI02-0035	Maui	0	0	0	0	0	0	0	0	0
HI02-0036	Hawaii	9	59.4	0	0	31	278	186	5 94	

EMAP Station ID	Island	No. Coral Species	% Coral Cover	No. Algal Species	% Algal Cover	No. Fish Species	No. Fish Individuals	Fish Biomass	No. Invertebrate Species	No. Invertebrate Individuals
HI02-0037	Hawaii	6	7.1	2	0.3	7	67	6.5	4	61
HI02-0038	Hawaii	5	99.7	0	0	18	162	71.4	4	106
HI02-0039	Hawaii	3	13.2	0	0	8	41	6.4	1	2
HI02-0040	Hawaii	6	43.5	1	0.4	20	107	46.7	5	42
HI02-0041	Hawaii	0	0	0	0	5	6	6.1	1	1
HI02-0042	Hawaii	8	33.8	2	6.2	13	99	26.4	5	526
HI02-0043	Hawaii	0	0	0	0	13	74	11.5	5	37
HI02-0044	Hawaii	0	0	0	0	0	0	0	0	0
HI02-0045	Hawaii	3	4.1	3	1.8	18	168	22.8	3	3
HI02-0046	Hawaii	5	4.7	5	2.8	9	46	24.7	2	3
HI02-0047	Hawaii	8	7.6	1	0.2	13	126	77.7	0	0
HI02-0050	Hawaii	0	0	0	0	1	12	5.9	0	0
HI02-0061	Oahu	1	0.5	2	17.3	13	130	58.8	1	23
HI02-0069	Oahu	1	1	7	7.2	3	12	3	4	20
HI02-0078	Oahu	0	0	4	8	0	0	0	3	3
	MEAN	2.82	11.23	2.95	7.44	8.58	56.05	19.20	2.61	39.08

Table 3.3-3. The ten most abundant algal taxa observed on the underwater transects. Algal abundance represents total number of plants observed, and percent cover was calculated for stations where the alga occurred. (* = nonindigenous species)

Freq. of occurrence	Algal Species	Type	Algal abundance	Percent cover
1	*Sargassum echinocarpum*	Phaeophyta	315.0	1.38
4	*Sargassum sp.*	Phaeophyta	196.5	0.86
10	*Padina sp.*	Phaeophyta	144.3	0.63
5	*Acanthophora spicifera**	Rhodophyta	132.2	0.57
4	*Dictyopteris sp.*	Phaeophyta	113.5	0.50
1	*Gracilaria salicornia**	Rhodophyta	99.7	0.44
2	*Microdictyon sp.*	Chlorophyta	69.5	0.30
5	*Porolithon sp.*	Rhodophyta	63.0	0.28
1	*Dictyopteris australis*	Phaeophyta	57.0	0.25
1	*Galaxaura acuminata*	Rhodophyta	56.0	0.24

Table 3.3-4. The ten most abundant coral taxa observed on the underwater transects.

Freq. of occurrence	Species	Common Name	Coral coverage	Percent of total coverage
12	*Porites compressa*	Finger coral	946.75	4.15
19	*Porites lobata*	Lobe coral	738.00	3.24
14	*Montipora capitata*	Rice coral	399.00	1.75
7	*Montipora patula*	Sandpaper rice coral	120.25	0.53
13	*Pocillopora meandrina*	Cauliflower coral	93.75	0.41
9	*Montipora flabellata*	Blue rice coral	77.50	0.34
7	*Pavona varians*	Corrugated coral	28.00	0.12
2	*Porites evermanni*	Evermann's coral	20.25	0.09
2	*Leptastrea purpurea*	Crust coral	18.00	0.08
3	*Psammocora stellata*	Stellar coral	10.50	0.05

3.3.2.2 Coral Composition

Corals were found at 26 of 38 (68%) stations surveyed. At sites with corals present, the number of coral species ranged from 1 to 9 per transect (Table 3.3-4), with a mean of 4 species per transect. Coral coverage at the 26 sites with corals present ranged from 0.2% to 99.7% with a mean of 16.4%.

By island, mean coral coverage at the sampled stations varied; Niihau had corals present at one of two sites surveyed and mean cover at those stations was 0.1%. On Kauai there was one station surveyed for corals and mean coverage along the transect surveyed was 21.7%. Eleven Oahu stations out of 14 surveyed for corals had corals present. The mean coverage at the Oahu sites with corals was 4.9% and at all Oahu sites it was 3.8%. On Maui four out of eight stations had corals present; at those stations where corals were present mean coverage was 19.5% and considering all eight Maui stations mean coverage was 9.8%. On the island of Hawaii, corals were present at 9 of 13 stations where the mean coverage was 30.3%. Considering all 13 stations, mean coral coverage amounted to 21.0%. Coral coverage is largely influenced by the presence of appropriate hard substratum on which to settle and grow, the degree of sample site exposure from occasional storm surf, and the proximity of streams. All coral species seen in this survey are native species.

3.3.2.3 Macroinvertebrate Composition

Diurnally-exposed motile macroinvertebrates were censused in 25 x 4 m transects. Motile macroinvertebrates were found at 31 of the 38 sites censused. A total of 31 taxa were identified, with a mean number of macroinvertebrate taxa per transect of 2.6. The ten most abundant macroinvertebrate taxa are given in Table 3.3-5. Six of the ten most abundant macroinvertebrate taxa were sea urchins. Mean abundance of macroinvertebrates was 39 individuals per transect. Fully 24 species (or 77% of the taxa) are native (16 species being echinoderms), one is cryptogenic (the feather duster worm - *Sabellastarte spectabilis*) and six are indeterminate. The cryptogenic feather duster worm was found only at one station within Pearl Harbor. None of the diurnally-exposed macroinvertebrates encountered in this study are rare and the sampling method is probably only accurate for a few echinoderm and mollusk species because of the normal cryptic habits of most coral reef invertebrates. Thus the data are of limited value in assessing the status of marine communities in Hawaii.

Table 3.3-5. The ten most abundant macroinvertebrate taxa observed on the underwater transects. Abundance represents the total number of individuals observed, while mean abundance is for sites where the species occurred.

Freq. of occurrence	Macroinvertebrate species	Common name	Abundance	Mean per transect	St. Dev.
12	*Echinometra mathaei*	Rock-boring urchin	862	71.83	141.47
10	*Tripneustes gratilla*	Collector urchin	226	22.60	24.38
2	*Heterocentrotus*	Red pencil urchin	62	31.00	29.00
5	*Alpheidae sp.*	Snapping shrimp	57	9.67	9.29
9	*Diadema paucispinum*	Long-spined urchin	42	4.67	5.60
5	*Eucidaris tribuloides*	Slate-pencil urchin	40	8.00	7.32
4	*Echinometra oblonga*	Oblong urchin	38	9.50	9.50
4	*Ophiocoma sp.*	Brittle star	36	9.00	5.70
1	*Sabellastarte spectabilis*	Feather duster worm	23	23.00	0.00
10	*Holothuria atra*	Black sea cucumber	19	1.90	1.14

3.3.3 Fish Species Richness, Abundance and Biomass

The visual censusses of fishes were carried out at 38 of the 79 (48%) Hawaiian NCA stations and fishes were encountered at 34 of the 38 sites. Of the 38 sites with successful fish visual surveys, only 3 sites were located among Oahu urbanized estuaries. Therefore, no CDFs were generated from this portion of the study for fish indicators.

In total, 110 species/taxa were encountered from the 38 sites. The mean number of fish taxa per transect was 9, mean number of fishes/transect was 56 and mean estimated biomass was 19 g/m^2 per transect. Within the 110 fish taxonomic groups, there are 9 taxa (*Coris* spp., *Rhinecanthus* spp., *Forcipiger* spp., *Synodus* spp., *Cantherhines* spp. *Scarus* sp., *Calatomus* sp., *Sargocentron* sp. and Goby spp.) incompletely identified. Eight of these nine taxa have no known nonindigenous or cryptogenic species in the Hawaiian fish fauna (Randall 1981, 1987) thus are all considered to be native. One taxon (Goby spp.) could contain nonindigenous or cryptogenic species thus is classified as indeterminate. Three species are nonindigenous (blue spotted grouper or roi,*Cephalopholis argus*; the blue lined snapper or ta'ape, *Lutjanus kasmira;* and the blacktail snapper to'au, *Lutjanus fulvus*), having been intentionally released in Hawaiian waters in the mid-1950's to supplement inshore fishery resources (Brock 1960). Table 3.3-6 lists the ten most abundant fish taxa recorded.

Fish species richness on a per sample basis ranged from 0 to 31 species per transect in the samples from Hawaii estuaries and bays. On an areal basis, approximately 50% of the area had a species richness less than 8 species per transect, and 90% had a fish species richness less than 18 species per sample (Figure 3.3-7).

The fish diversity index H′ (log base 2) ranged from 0 to 3.58 in the samples from Hawaii estuaries and bays. On an areal basis, less than 50% of the area had an H′ of 2.5, while 90% of the area had a value of 3.18 or less (Figure 3.3-8).

Fish abundance per transect in samples from Hawaii estuaries and bays ranged from 0 to 278 individuals. On an areal basis, 50% of the area had a fish abundance less than 48 individuals per transect, and 90% of the area had an abundance less than 126 individuals (Figure 3.3-9).

Estimated fish biomass per transect in samples from Hawaii estuaries and bays ranged from 0 to 18.6 kg per transect. On an areal basis, 50% of the area had a fish biomass less than 0.6 kg per transect and 90% of the area had a fish biomass less than 4.0 kg per transect (Figure 3.3-10).

Table 3.3-6. The ten most abundant fish taxa observed on the underwater transects. Abundance represents the total number of individuals observed on all transects.

Freq. of occurrence	Fish Species	Common Name	Abundance	Mean per transect	St. Dev.
25	*Thalassoma duperrey*	Saddleback	309	12.36	9.95
17	*Acanthurus nigrofuscus*	Brown	196	11.53	12.08
8	*Ctenochaetus strigosus*	Goldring	162	20.25	15.21
6	*Chromis vanderbilti*	Blackfin chromis	138	23.00	11.34
8	Goby spp.	Goby	136	17.00	15.67
3	*Chromis agilis*	Agile chromis	90	30.00	18.46
3	Mulloidichthys	Yellowstripe	89	29.67	17.78
5	*Acanthurus*	Whitebar	87	17.40	29.86
7	*Acanthurus triostegus*	Convict	78	11.14	14.21
4	*Scarus* spp.	Parrotfish	66	16.50	7.30

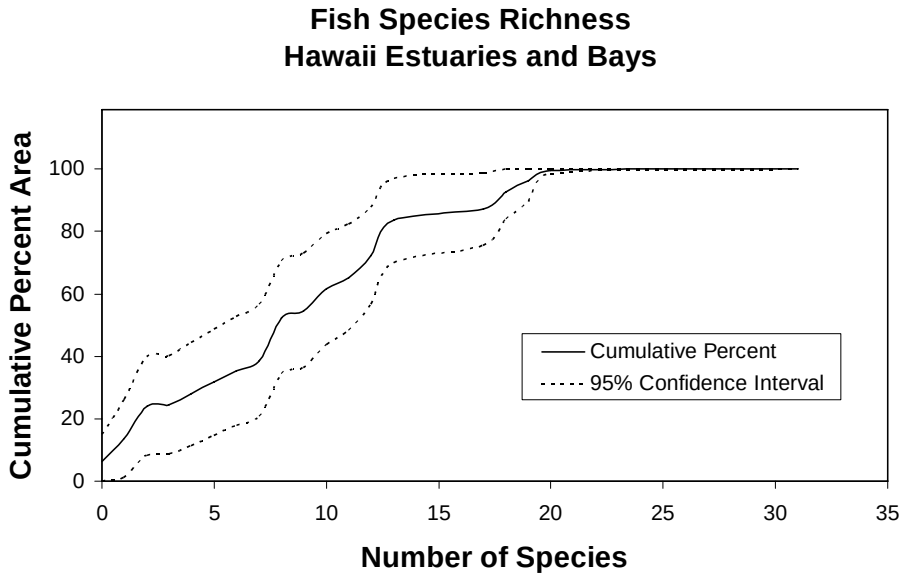

Figure 3.3 -7. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. total number of fish species observed on visual transects.

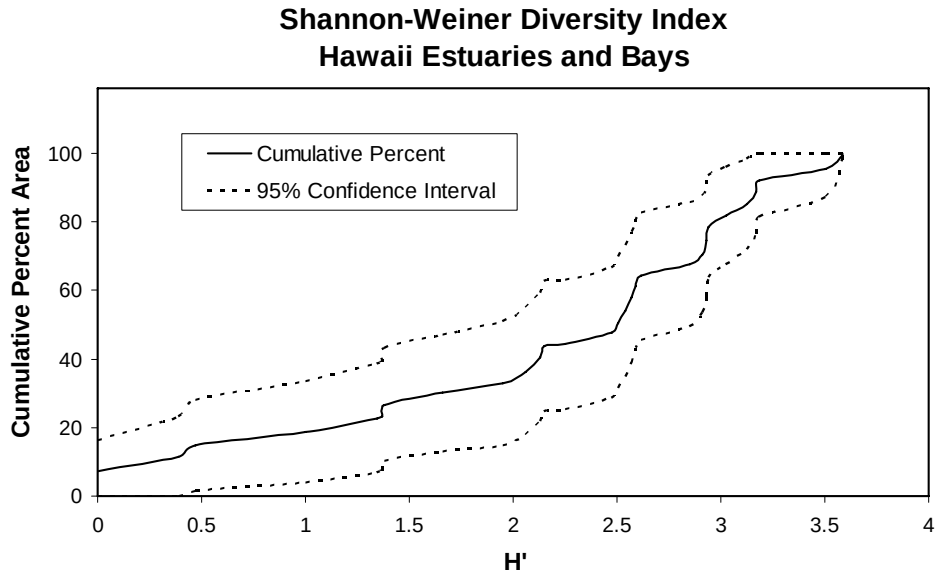

Figure 3.3 -8. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. the H' diversity index for fishes observed on visual transects.

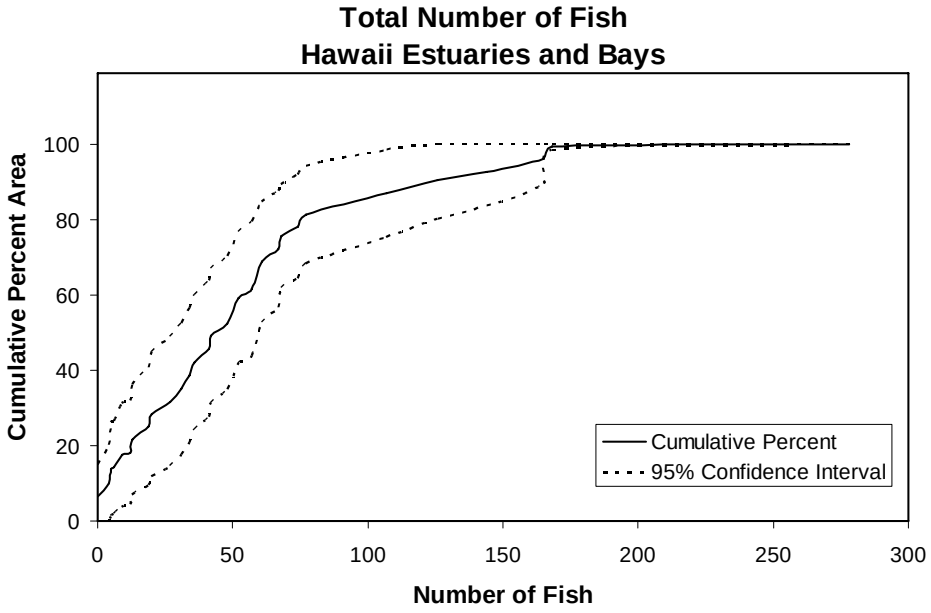

Figure 3.3 -9. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. abundance of fishes observed on visual transects.

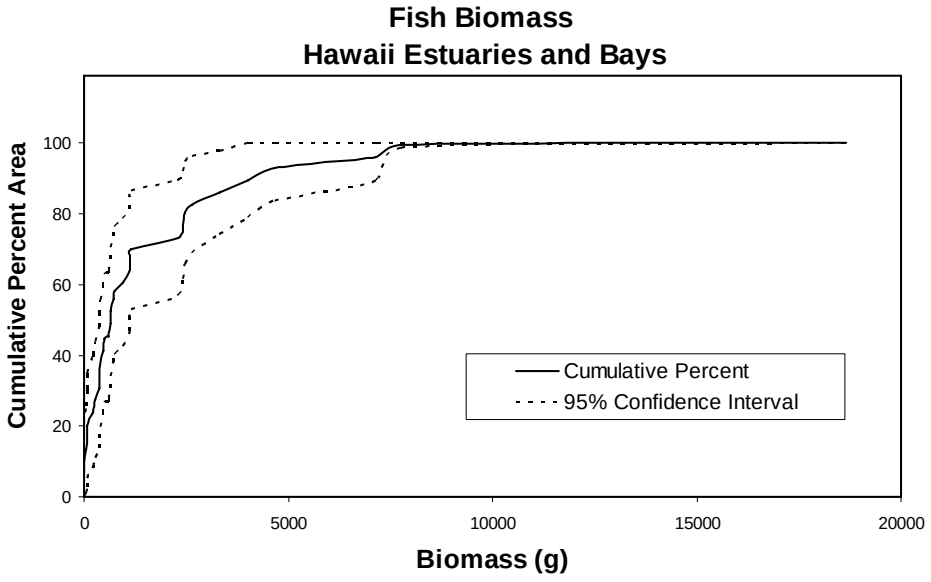

Figure 3.3 -10. Percent area (and 95% C.I.) of Hawaii estuaries and bays vs. the estimated biomass of fishes observed on visual transects.

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