



# SCIENCE

## Ecological Condition of Coastal Ocean Waters along the U.S. Western Continental Shelf: 2003



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# **Ecological Condition of Coastal Ocean Waters along the U.S. Western Continental Shelf: 2003**

**September 2008**

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## **Preface**

This document provides an assessment of the status of ecological condition in coastal-ocean waters along the U.S. continental shelf, from the Strait of Juan de Fuca, WA to the Mexican border, based on sampling conducted in June 2003. The project was a large collaborative effort by the U.S. Environmental Protection Agency (EPA), the National Oceanic and Atmospheric Administration (NOAA), and West Coast States. It also represents one of a series of assessments conducted under the Western regional component of EPA's National Coastal Assessment (NCA-West). The NCA is the coastal component of the nationwide Environmental Monitoring and Assessment Program (EMAP). The NCA-West program is administered through the EPA and implemented through partnerships with a variety of federal and state agencies, universities, and the private sector. The 2003 west-coast shelf assessment involved the participation and collaboration of EPA, NOAA, Washington Department of Ecology, Oregon Department of Environmental Quality, and the Southern California Coastal Water Research Project (SCCWRP), with additional contributions from personnel of Alaska Department of Environmental Conservation, and Moss Landing Marine Laboratories.

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## **Disclaimer**

This document has been subjected to review by the National Health and Environmental Effects Research Laboratory of EPA and the National Ocean Service of NOAA and approved for publication. Approval does not signify that the contents reflect the official views of these agencies, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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This study involved the participation of numerous representatives from a variety of federal, state, local, academic, and private institutions. Many individuals within EPA made important contributions to the study. Critical guidance and vision in establishing the overall NCA-West program was provided by Kevin Summers of Gulf Ecology Division. Tony Olsen of Western Ecology Division (WED), with technical support from staff of Computer Science Corporation, provided the sampling designs utilized for various aspects of the study. Lorraine Edmond of Region 10 and Terrence Fleming of the Region 9 Offices of EPA ably served as the regional liaisons 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.

A major portion of the study area was sampled from the NOAA ship McARTHUR II on Cruise AR-03-01-NC, which consisted of three legs encompassing the period from June 1-26, 2003. All members of the three field crews (see list below) are commended for their high level of technical expertise, teamwork and dedication to getting the required sampling completed. In particular, the dedication of the Chief Scientists for each of the three legs is greatly appreciated. These were Sarah Wilson formerly with Washington Department of Ecology (Leg 1), Larry Caton with Oregon Department of Environmental Quality (Leg 2), and Rusty Fairey with Moss Landing Marine Laboratories (Leg 3). Special appreciation also is extended to the officers and crew of the NOAA ship McARTHUR II for the superb job performed.

Sarah Wilson also was especially helpful in obtaining published and unpublished data on the location of cable crossings, hard bottom areas, and other hazards to the safe and successful conduct of field sampling. Dr. Chris Goldfinger of Oregon State University and Dr. Gary Greene of Moss Landing Marine Laboratories kindly supplied unpublished bottom type data that was of assistance in preparation of the maps for determining sample locations.

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Data coverage throughout the Southern California Bight portion of the study area (Pt. Conception, CA to the Mexican border) was made possible through coordination with a companion assessment conducted by SCCWRP during the same general time-frame using similar methods and indicators. Dr. Steven Weisberg, Director of SCCWRP, was the principal liaison for coordination with the Bight '03 study. Additional assistance with coordination of sampling and data submission was provided by Ken Schiff, Larry Cooper, and Shelly Moore of SCCWRP.

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The members of the scientific crews for the EMAP 2003 survey of ecological conditions of the western U.S. continental shelf are listed below and their contributions to this study are gratefully acknowledged. An \* indicates the Chief Scientist on the particular cruise leg.

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## List of Acronyms

CBNMS	Cordell Bank National Marine Sanctuary
CDF	Cumulative distribution function
CINMS	Channel Islands National Marine Sanctuary
CTD	Conductivity-Temperature-Depth
CRM	Certified Reference Material
CV	Coefficient of Variation
CWA	Clean Water Act
DO	Dissolved Oxygen Concentration
EAM	Ecosystem Approach to Management
EMAP	Environmental Monitoring and Assessment Program
EPA	U.S. Environmental Protection Agency
ERL	Effects Range Low
ERM	Effects Range Median
FRAM	Fishery Resource Analysis and Monitoring
GAO	U. S. General Accounting Office
GFNMS	Gulf of Farallones National Marine Sanctuary
GIS	Geographic Information System
GPS	Global Positioning System
GRTS	Generalized Random Tessellation Stratified
IEA	Integrated Ecosystem Assessment
LCM	Laboratory Control Material
MBNMS	Monterey Bay National Marine Sanctuary
MDL	Method Detection Limit
MOA	Memorandum of Agreement
MOU	Memorandum of Understanding
NCA	National Coastal Assessment
NCA-West	National Coastal Assessment - Western regional component
NCCOS	National Centers for Coastal Ocean Science
NMFS	National Marine Fisheries Service
NMS	National Marine Sanctuary
NMAO	NOAA Marine and Aircraft Operation
NOAA	National Oceanic and Atmospheric Administration
NOS	NOAA National Ocean Service
N/P	Nitrogen to Phosphorus
NWFSC	Northwest Fisheries Science Center
OCNMS	Olympic Coast National Marine Sanctuary
ORD	EPA Office of Research and Development
PAH	Polycyclic Aromatic Hydrocarbons
PAR	Photosynthetically Active Radiation
PCB	Polychlorinated Biphenyls
QA/QC	Quality Assurance/Quality Control
RL	Reporting Limit
RPD	Relative Percent Difference

SCB	Southern California Bight
SCCWRP	Southern California Water Resources Research Project
SRM	Standard Reference Material
SD	Standard Deviation
SQG	Sediment Quality Guideline
TOC	Total Organic Carbon
TSS	Total Suspended Solids
WED	Western Ecology Division

## Executive Summary

The western National Coastal Assessment (NCA-West) program of EPA, in conjunction with the NOAA National Ocean Service (NOS), conducted an assessment of the status of ecological condition of soft sediment habitats and overlying waters along the western U.S. continental shelf, between the target depths of 30 and 120 m, during June 2003. NCA-West and NOAA/NOS partnered with the West Coast states (Washington (WA), Oregon (OR), and California (CA)), and the Southern California Coastal Water Research Project (SCCWRP) Bight '03 program to conduct the survey. A total of 257 stations were sampled from Cape Flattery, WA to the Mexican border using standard methods and indicators applied in previous coastal NCA projects. A key study feature was the incorporation of a stratified-random sampling design with stations stratified by state and National Marine Sanctuary (NMS) status. Each of the three states was represented by at least 50 random stations. There also were a total of 84 random stations located within NOAA's five NMSs along the West Coast including the Olympic Coast NMS (OCNMS), Cordell Bank NMS (CBNMS), Gulf of Farallones NMS (GFNMS), Monterey Bay NMS (MBNMS), and Channel Islands NMS (CINMS). Collection of flatfish via hook-and-line for fish-tissue contaminant analysis was successful at 50 EMAP/NCA-West stations. Through a collaboration developed with the FRAM Division of the Northwest Fisheries Science Center, fish from an additional 63 stations in the same region and depth range were also analyzed for fish-tissue contaminants.

Bottom depth throughout the region ranged from 28 m to 125 m for most stations. Two slightly deeper stations from the Southern California Bight (SCB) (131, 134 m) were included in the data set. About 44% of the survey area had sediments composed of sands (< 20% silt-clay), about 47% was composed of intermediate muddy sands (20-80% silt-clay), and about 9% was composed of muds (> 80% silt-clay). The majority of the survey area (97%) had relatively low percent total organic carbon (TOC) levels of < 2%, while a small portion (< 1%) had high TOC levels (> 5%), in a range potentially harmful to benthic fauna.

Salinity of surface waters for 92% of the survey area were > 31 psu, with most stations < 31 psu associated with the Columbia River plume. Bottom salinities ranged only between 31.6 and 34.4 psu. There was virtually no difference in mean bottom salinities among states or between NMS and non-NMS stations. Temperatures of surface water (range 8.5 -19.9 °C) and bottom water (range 5.8 -14.7 °C) averaged several degrees higher in CA in comparison to WA and OR. The  $\Delta\sigma_t$  index of water-column stratification indicated that about 31% of the survey area had strong vertical stratification of the water column. The index was greatest for waters off WA and lowest for CA waters.

Only about 2.6 % of the survey area had surface dissolved oxygen (DO) concentrations  $\leq$  4.8 mg/L, and there were no values below the lower threshold (2.3 mg/L) considered harmful to the survival and growth of marine animals. Surface DO

concentrations were higher in WA and OR waters than in CA, and higher in the OC NMS than in the CA sanctuaries. An estimated 94.3% of the area had bottom-water DO concentrations  $\leq 4.8$  mg/L and 6.6% had concentrations  $\leq 2.3$  mg/L. The high prevalence of DO from 2.3 to 4.8 mg/L (85% of survey area) is believed to be associated with the upwelling of naturally low DO water across the West Coast shelf.

Mean TSS and transmissivity in surface waters (excluding OR due to sample problems) were slightly higher and lower, respectively, for stations in WA than for those in CA. There was little difference in mean TSS or transmissivity between NMS and non-NMS locations. Mean transmissivity in bottom waters, though higher in comparison to surface waters, showed little difference among geographic regions or between NMS and non-NMS locations.

Concentrations of nitrate + nitrite, ammonium, total dissolved inorganic nitrogen (DIN) and orthophosphate (P) in surface waters tended to be highest in CA compared to WA and OR, and higher in the CA NMS stations compared to CA non-sanctuary stations. Measurements of silicate in surface waters were limited to WA and CA (exclusive of the SCB) and showed that concentrations were similar between the two states and approximately twice as high in CA sanctuaries compared to OCNMS or non-sanctuary locations in either state. The elevated nutrient concentrations observed at CA NMS stations are consistent with the presence of strong upwelling at these sites at the time of sampling. Approximately 93% of the area had DIN/P values  $\leq 16$ , indicative of nitrogen limitation. Mean DIN/P ratios were similar among the three states, although the mean for the OCNMS was less than half that of the CA sanctuaries or non-sanctuary locations. Concentrations of chlorophyll *a* in surface waters ranged from 0 to  $28 \mu\text{g L}^{-1}$ , with 50% of the area having values  $< 3.9 \mu\text{g L}^{-1}$  and 10% having values  $> 14.5 \mu\text{g L}^{-1}$ . The mean concentration of chlorophyll *a* for CA was less than half that of WA and OR locations, and concentrations were lowest in non-sanctuary sites in CA and highest at the OCNMS.

Shelf sediments throughout the survey area were relatively uncontaminated with the exception of a group of stations within the SCB. Overall, about 99% of the total survey area was rated in good condition ( $<5$  chemicals measured above corresponding effect range low (ERL) concentrations). Only the pesticides 4,4'-DDE and total DDT exceeded corresponding effect range-median (ERM) values, all at stations in CA near Los Angeles. Ten other contaminants including seven metals (As, Cd, Cr, Cu, Hg, Ag, Zn), 2-methylnaphthalene, low molecular weight PAHs, and total PCBs exceeded corresponding ERLs. The most prevalent in terms of area were chromium (31%), arsenic (8%), 2-methylnaphthalene (6%), cadmium (5%), and mercury (4%). The chromium contamination may be related to natural background sources common to the region. The 2-methylnaphthalene exceedances were conspicuously grouped around the CINMS. The mercury exceedances were all at non-sanctuary sites in CA, particularly in the Los Angeles area.

Concentrations of cadmium in fish tissues exceeded the lower end of EPA's non-



cancer, human-health-risk range at nine of 50 EMAP/NCA-West and nine of 60 FRAM groundfish-survey stations, including a total of seven NMS stations in CA and two in the OCNMS. The human-health guidelines for all other contaminants were only exceeded for total PCBs at one station located in WA near the mouth of the Columbia River.

Benthic species richness was relatively high in these offshore assemblages, ranging from 19 to 190 taxa per 0.1-m<sup>2</sup> grab and averaging 79 taxa/grab. The high species richness was reflected over large areas of the shelf and was nearly three times greater than levels observed in estuarine samples along the West Coast (e.g NCA-West estuarine mean of 26 taxa/grab). Mean species richness was highest off CA (94 taxa/grab) and lower in OR and WA (55 and 56 taxa/grab, respectively). Mean species richness was very similar between sanctuary vs. non-sanctuary stations for both the CA and OR/WA regions. Mean diversity index H' was highest in CA (5.36) and lowest in WA (4.27). There were no major differences in mean H' between sanctuary vs. non-sanctuary stations for both the CA and OR/WA regions.

A total of 1,482 taxa (1,108 to species) and 99,135 individuals were identified region-wide. Polychaetes, crustaceans and molluscs were the dominant taxa, both by percent abundance (59%, 17%, 12% respectively) and percent species (44%, 25%, 17%, respectively). There were no major differences in the percent composition of benthic communities among states or between NMSs and corresponding non-sanctuary sites. Densities averaged 3,788 m<sup>-2</sup>, about 30% of the average density for West Coast estuaries. Mean density of benthic fauna in the present offshore survey, averaged by state, was highest in CA (4,351 m<sup>-2</sup>) and lowest in OR (2,310 m<sup>-2</sup>). Mean densities were slightly higher at NMS stations vs. non-sanctuary stations for both the CA and OR/WA regions.

The 10 most abundant taxa were the polychaetes *Mediomastus* spp., *Magelona longicornis*, *Spiophanes berkeleyorum*, *Spiophanes bombyx*, *Spiophanes duplex*, and *Prionospio jubata*; the bivalve *Axinopsida serricata*, the ophiuroid *Amphiodia urtica*, the decapod *Pinnixa occidentalis*, and the ostracod *Euphilomedes carcharodonta*. *Mediomastus* spp. and *A. serricata* were the two most abundant taxa overall. Although many of these taxa have broad geographic distributions throughout the region, the same species were not ranked among the 10 most abundant taxa consistently across states. The closest similarities among states were between OR and WA. At least half of the 10 most abundant taxa in NMSs were also dominant in corresponding non-sanctuary waters.

Many of the abundant benthic species have wide latitudinal distributions along the West Coast shelf, with some species ranging from southern CA into the Gulf of Alaska or even the Aleutians. Of the 39 taxa on the list of 50 most abundant taxa that could be identified to species level, 85% have been reported at least once from estuaries of CA, OR, or WA exclusive of Puget Sound. Such broad latitudinal and estuarine distributions are suggestive of wide habitat tolerances.

Thirteen (1.2%) of the 1,108 identified species are nonindigenous, with another 121 species classified as cryptogenic (of uncertain origin), and 208 species unclassified with respect to potential invasiveness. Despite uncertainties of classification, the number and densities of nonindigenous species appear to be much lower on the shelf than in the estuarine ecosystems of the Pacific Coast. Spionid polychaetes and the ampharetid polychaete *Anobothrus gracilis* were a major component of the nonindigenous species collected on the shelf.

NOAA's five NMSs along the West Coast of the U.S. appeared to be in good ecological condition, based on the measured indicators, with no evidence of major anthropogenic impacts or unusual environmental qualities compared to nearby non-sanctuary waters. Benthic communities in sanctuaries resembled those in corresponding non-sanctuary waters, with similarly high levels of species richness and diversity and low incidence of nonindigenous species. Most oceanographic features were also similar between sanctuary and non-sanctuary locations. Exceptions (e.g., higher concentrations of some nutrients in sanctuaries along the CA coast) appeared to be attributable to natural upwelling events in the area at the time of sampling. In addition, sediments within the sanctuaries were relatively uncontaminated, with none of the samples having any measured chemical in excess of ERM values. The ERL value for chromium was exceeded in sediments at the OCNMS, but at a much lower percentage of stations (four of 30) compared to WA and OR non-sanctuary areas (31 of 70 stations). ERL values were exceeded for arsenic, cadmium, chromium, 2-methylnaphthalene, low molecular weight PAHs, total DDT, and 4,4'-DDE at multiple sites within the CINMS. However, cases where total DDT, 4,4'-DDE, and chromium exceeded the ERL values were notably less prevalent at CINMS than in non-sanctuary waters of CA. In contrast, 2-methylnaphthalene above the ERL was much more prevalent in sediments at the CINMS compared to non-sanctuary waters off the coast of CA. While there are natural background sources of PAHs from oil seeps throughout the SCB, this does not explain the higher incidence of 2-methylnaphthalene contamination around CINMS. Two stations in CINMS also had levels of TOC (> 5%) potentially harmful to benthic fauna, though none of these sites exhibited symptoms of impaired benthic condition.

This study showed no major evidence of extensive biological impacts linked to measured stressors. There were only two stations, both in CA, where low numbers of benthic species, diversity, or total faunal abundance co-occurred with high sediment contamination or low DO in bottom water. Such general lack of concordance suggests that these offshore waters are currently in good condition, with the lower-end values of the various biological attributes representing parts of a normal reference range controlled by natural factors. Results of multiple linear regression, performed using full model procedures to test for effects of combined abiotic environmental factors, suggested that latitude and depth had significant influences on benthic variables region-wide. Latitude had a significant inverse influence on all three of the above benthic variables, i.e. with values increasing as latitude decreased ( $p < 0.01$ ), while depth had a significant direct influence on diversity ( $p < 0.001$ ) and inverse effect on density ( $p$

<0.01). None of these variables varied significantly in relation to sediment % fines (at  $p < 0.1$ ), although in general there was a tendency for muddier sediments (higher % fines) to have lower species richness and diversity and higher densities than coarser sediments.

Alternatively, it is possible that for some of these sites the lower values of benthic variables reflect symptoms of disturbance induced by other unmeasured stressors. The indicators in this study included measures of stressors (e.g., chemical contaminants, eutrophication) that are often associated with adverse biological impacts in shallower estuarine and inland ecosystems. However, there may be other sources of human-induced stress in these offshore systems (e.g., bottom trawling) that pose greater risks to ambient living resources and which have not been captured. Future monitoring efforts in these offshore areas should include indicators of such alternative sources of disturbance

## 1.0 Introduction

### 1.1 Program Background

The U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) both perform a broad range of research and monitoring activities to assess the status and potential effects of human activities on the health of coastal ecosystems and to promote the use of this information in protecting and restoring the Nation's coastal resources. Authority to conduct such work is provided through several legislative mandates including the Clean Water Act (CWA) of 1977 (33 U.S.C. §§ 1251 *et seq.*), National Coastal Monitoring Act (Title V of the Marine Protection, Research, and Sanctuaries Act, 33 U.S.C. §§ 2801-2805), and the National Marine Sanctuary Act of 2000. Where possible the two agencies have sought to coordinate related activities through partnerships with states and other institutions to prevent duplications of effort and bring together complementary resources to fulfill common research and management goals. Accordingly, in summer 2003, NOAA, EPA, and partnering West Coast states — Washington (WA), Oregon (OR), and California (CA) — combined efforts to conduct a joint survey of ecological condition of aquatic resources in near-coastal waters along the U.S. western continental shelf using multiple indicators of ecological condition. The study is an expansion of EPA's Environmental Monitoring and Assessment Program (EMAP) and subsequent National Coastal Assessment (NCA), which seek to assess condition of the Nation's environmental resources within a variety of coastal and terrestrial resource categories. The coastal component of EMAP/NCA on the West Coast of the U.S. began in 1999 with a focus in estuaries (see Nelson et al. 2004, 2005; Hayslip et al. 2006; Wilson and Partridge 2007; U.S. EPA 2001, 2004, 2006). The current assessment, based on sampling conducted in summer 2003, extends this work to near-coastal shelf waters (depths of 30-120 m) from the Canadian to Mexican borders (see Figures 3.1.1 – 3.1.9 below).

A focus of the study was on the collection and analysis of water, sediment, and biological samples using standard methods and indicators applied in previous coastal EMAP/NCA projects (U.S. EPA 2001, 2004; Nelson et al. 2004). A key feature was the incorporation of a stratified-random sampling design, with stations (257 total) stratified by State and National Marine Sanctuary (NMS) status. Each of the three states (WA, Oregon, California) was represented by at least 50 random stations. There also were a total of 84 random stations included within NOAA's five NMSs along the West Coast. The probabilistic sampling design provided a basis for making unbiased statistical estimates of the spatial extent of ecological condition relative to various measured indicators and corresponding thresholds of concern. These included standard EMAP/NCA ecological indicators of water quality, sediment quality, and biological condition (benthic fauna and fish).

Assessments of status relative to these various indicators are presented in the present report on a region-wide basis, by State, and by NMS vs. non-sanctuary status. The state-level information will be of value to EPA and the States in their efforts to meet

requirements under the CWA to report on the condition of each state's aquatic resources. The information on the status of NMS resources, which has been derived from standard monitoring methods and indicators that allow comparisons to the surrounding regional ecosystem and across other sanctuaries as a system, helps to fulfill the needs of system-wide monitoring strategies for the NMS Program (NMSP 2004) as well as related directives under the NMS Reauthorization Act of 2000. Moreover, because the protocols and indicators are consistent with those used in previous EMAP/NCA estuarine surveys, comparisons also can be made between conditions in offshore waters and those observed in neighboring estuarine habitats, thus providing a more holistic account of ecological conditions and processes throughout the inshore and offshore resources of the region. Such information should provide valuable input for future National Coastal Condition Reports, which historically have focused on estuaries (U.S. EPA 2001, 2004).

Lastly, results of this study should provide support to evolving interests within the U.S. and other parts of the world to move toward an ecosystem approach to management (EAM) of coastal resources (Murawski 2007; Marine Ecosystems and Management 2007). Integrated Ecosystem Assessments (IEAs) have been identified as an important component of an EAM strategy (Murawski and Menashes 2007, Levin et al. 2008). An IEA is a synthesis and quantitative analysis of information on relevant natural and socio-economic factors in relation to specified ecosystem management goals (Levin et al. 2008). Initial steps in the IEA process include the assessment of baseline conditions defining the status of the system as well as the assessment of stressor impacts and their links to source drivers and pressures. Results of the present study will be available to support such initial steps in the development of an IEA for the California Current Large Marine Ecosystem. While the focus of the present study is on indicators of ecological condition, limited socio-economic indicators have been included as well (e.g., fish contaminant levels, water clarity, marine debris), which can be used to help address some common human-dimension questions, such as "Are the fish safe to eat?" or "Is the water clean enough to swim in?"

This assessment was made possible through the cooperation of numerous organizations. The project was funded principally by EPA (Office of Research and Development, ORD) and co-managed through a Memorandum of Agreement (MOA) by staff from EPA/ORD and the NOAA National Ocean Service's (NOS) National Centers for Coastal Ocean Science (NCCOS). NOAA's Office of Marine and Aviation Operations provided three weeks of ship time on the NOAA Ship McARTHUR II, which supported the primary sampling effort conducted in June 2003 from the Strait of Juan de Fuca in Washington south to Pt. Conception, CA. The Northwest Fisheries Science Center (NWFSC), under NOAA's National Marine Fisheries Service (NMFS), provided field support and analysis of fish pathologies through a cooperative agreement with EPA. The NWFSC also supplemented the collection of fish samples for contaminant and pathology analysis through coordination of sampling conducted by their Fishery Resource Analysis and Monitoring (FRAM) Division at stations falling within the appropriate depth range during their annual west-coast groundfish surveys. State

partners included Washington Department of Ecology, Oregon Department of Environmental Quality, and the Southern California Water Resources Research Project (SCCWRP). Additional field support was provided by scientists from the three State partners, EPA Region 10, EPA ORD, the Alaska Department of Environmental Conservation, and South Slough Estuarine Research Reserve.

The intent of the study design was to include continental shelf waters all along the West Coast of the U.S., from the Strait of Juan de Fuca in Washington to the Mexican border. The coordination of two separate survey efforts was necessary in order to cover such a large area. The first was the above-mentioned June 2003 cruise conducted from the NOAA Ship McARTHUR II, which covered sampling from the Strait of Juan de Fuca south to Pt. Conception, CA. This effort was coordinated with a companion assessment conducted by SCCWRP during the same general time-frame, in the area between Pt. Conception and the Mexican border, known as the Southern California Bight (SCB). The Bight '03 assessment was conducted using a similar probabilistic sampling design and most of the same condition indicators (Allen et al. 2007, Bay et al. 2005, Ranasinghe et al. 2007, Schiff et al. 2006), and thus the data could be integrated with data from the more northern stations to provide an overall assessment of condition throughout the western U.S. continental shelf.

## **1.2 NOAA National Marine Sanctuaries**

There are currently four NMSs along the coast of California, one off the coast of Washington, and none off the coast of Oregon. All of the West Coast NMSs represent areas particularly rich in a diverse array of marine life, including marine mammals, seabirds, fishes, invertebrates and plants. The Channel Islands NMS off the coast of California is the oldest, established in 1980, and covers an area of 4,294 km<sup>2</sup> surrounding the islands of Anacapa, Santa Cruz, Santa Rosa, San Miguel and Santa Barbara out to six nautical miles offshore around each of the five islands. The Gulf of the Farallones NMS (3,237 km<sup>2</sup>) and Cordell Bank NMS (1347 km<sup>2</sup>) are adjacent to each other and located along the central California coast off San Francisco. The Gulf of the Farallones NMS was established in 1981 and includes the Farallon Islands National Wildlife Refuge. Cordell Bank NMS, established in 1989, includes Cordell Bank seamount whose summit lies only 37 meters below the surface. The Monterey Bay NMS is the most recently established NMS in California (1992), and is also the largest on the West Coast. It extends from Rocky Point in Marin County to Cambria in San Luis Obispo County, a shoreline length of 444 km and encompasses 13,784 km<sup>2</sup> of ocean.

To the north, the Olympic Coast NMS was established in 1994 and protects about 8,570 km<sup>2</sup> of the Pacific Ocean between Cape Flattery and the mouth of the Copalis River, a distance of about 217 km. Some 105 km of the sanctuary's coastline borders the Olympic National Park, while the Flattery Rocks, Quillayute Needles, and Copalis Rock National Wildlife Refuges are within the sanctuary boundaries. Maps of each of the West Coast NMS may be found at:

<http://sanctuaries.noaa.gov/pgallery/atlasmaps/welcome.html>.

### **1.3 Southern California Bight 2003 Regional Monitoring Program**

In response to the need for an integrated assessment of the condition of the southern California coastal ocean, SCCWRP brought together 58 organizations in the summer of 2003 to conduct a comprehensive assessment of the ecological condition of the SCB. This study, known as Bight'03, was the third regional-scale assessment of the SCB by SCCWRP, following earlier related efforts in 1994 and 1998. There also have been older studies of the benthic fauna of shelf, slope, and basin habitats throughout the SCB conducted by other investigators (Jones 1969, Fauchald and Jones 1978). The spatial extent of the SCCWRP-related regional assessments ranged from Pt. Conception in the north to the Mexican border. During the 2003 effort, sampling was extended to include estuaries and continental slope and basin areas down to a depth of 1,000 m. Bight'03 included three components: Coastal Ecology, Shoreline Microbiology and Water Quality. Shoreline microbiology was not a part of the scope of the EMAP study. The Water Quality component of Bight'03 (Nezlin et al. 2007) was focused on examination of the effects of storm water runoff on the SCB. Sampling did not fall within the EMAP index period and was designed to address a different set of research questions, and thus data collected under this component could not be integrated with the EMAP assessment. However, water quality data from some stations within the SCB were collected by SCCWRP under a cooperative agreement with EPA. The Coastal Ecology Component of Bight'03 assessed sediment contaminants and the effect of these contaminants on biota in the SCB, and analyzed a set of contaminants that were virtually the same as those assessed in the EMAP program (Ranasinghe et al. 2007).

## **2.0 Methods**

Methods for the 2003 survey of condition of the continental shelf of the West Coast were in general the same as those developed for the EPA National Coastal Assessment (Nelson et al. 2004), with modifications to reflect the generally deeper nature of the resource being assessed.

Sampling for a major portion of the survey area (Strait of Juan de Fuca, WA, to Point Conception, CA) was conducted on NOAA Ship McARTHUR II Cruise AR-03-01-NC, June 1-26, 2003 (Cooksey 2003). The cruise consisted of three legs: Leg 1 along the Washington coast (Seattle to Astoria, OR, June 1-8); Leg 2 along the Oregon coast (Astoria, OR to Eureka, CA, June 8-16); and Leg 3 along the California coast, from the Oregon border to Pt. Conception (Eureka, CA to Pt. Conception and back to San Francisco, CA, June 18-26). Samples were collected from the deck of the McARTHUR II during around-the-clock operations.

At each station, samples were obtained for characterization of: 1) community structure and composition of benthic macroinfauna (fauna retained on a 1.0-mm sieve); 2) concentration of chemical contaminants in sediments (metals, pesticides, PCBs, PAHs); 3) general habitat conditions (water depth, dissolved oxygen, conductivity, temperature, chlorophyll *a*, light transmittance, water-column nutrients, % silt-clay versus sand content of sediment, organic-carbon content of sediment); and 4) condition of selected demersal fish species caught by hook-and-line (contaminant body burdens and visual evidence of pathological disorders).

### **2.1 Sampling Design**

#### **2.1.1 EMAP**

A major target to be assessed was the soft-sediment benthic resources and overlying water quality of the continental shelf, in the depth range between 30 and 120 m, from the Strait of Juan de Fuca in Washington to the Mexican border. Given the high cost of research ship time and the desire to insure that attempts at sampling rocky bottoms were minimized, considerable effort was taken to develop a GIS data layer of only soft sediment habitat. No comprehensive bottom type map of the continental shelf of West Coast existed at the time of this study, although data were provided by several individuals at research institutions that were developing such maps under NOAA funding. An attempt was also made to obtain the general locations of commercial submarine cable crossings, and these zones, along with high activity shipping channels and other restricted access regions were omitted from the GIS layer defining the target resource area.

The study utilized a stratified random sampling design, known as a Generalized Random Tessellation Stratified (GRTS) survey design. The EMAP/NCA sampling effort consisted of a total of 150 stations that were distributed across the sampling area, partitioned in several ways. Each of the three states received 50 stations. In



Washington, the 50 stations were partitioned into 30 stations randomly selected within the Olympic Coast NMS (OCNMS), and 20 stations in the remainder of the shelf waters. Similarly, in California, the 50 stations were partitioned into two groups consisting of 30 stations randomly selected within the combined area of the Cordell Bank, Gulf of Farallones, Monterey Bay, and Channel Islands NMSs, and 20 stations selected in non-sanctuary waters of California north of Pt. Conception.

Each sampling region is termed a multi-density category. For each multi-density category (Appendix Table 1), geographic coordinates for the number of primary target stations listed above were determined during the study design process. Additionally, each multi-density category had an equal number of alternate sampling locations selected in case a primary site should have to be rejected due to safety concerns or the presence of rocky bottom. Because of the severe logistic constraint of the number of ship days available, when a primary station was abandoned, the nearest alternate station within the multi-density category was selected and sampling was attempted.

After completion of the field survey, additional adjustments to the frame area definitions were made. For the present report, the principal adjustment was to exclude the area of the continental shelf within the Strait of Juan de Fuca from inclusion in the resource definition. This decision was made because all bottom samples attempted at multiple stations found rocky instead of soft bottom, indicating that the region may not fit the target resource definition of soft sediment shelf habitat. Thus, weighting factors used in data analysis reflect the removal of this sample area.

### **2.1.2 Bight'03**

Data coverage throughout the SCB portion of the study area (Pt. Conception, CA to the Mexican border) was made possible through coordination with a companion assessment, the Bight'03 study conducted by SCCWRP. The basic sampling design of the Bight'03 study was the same as that used for the EMAP survey. Sampling sites were selected in a stratified random fashion in 12 multi-density categories that represented distinct regions of interest within the SCB using a Generalized Random Tessellation Stratified (GRTS) design (Ranasinghe et al. 2007). There was overlap with the target depth zone sampled by EMAP for two Bight'03 multi-density categories. Given the identical design approaches, data from Bight'03 for these two categories could be merged with EMAP data into a single statistical analysis for the West Coast shelf. Geographic coordinates for the Bight'03 stations which were included with the EMAP stations in the present analysis are provided in Appendix 1. Inspection of depth information was used to confirm that Bight'03 stations actually fell within the target depth range of the EMAP study, and some stations included in a multi-density category in the Bight'03 study were excluded from inclusion with the EMAP data. A total of 30 stations within the Channel Islands NMS and 43 stations along the mainland shelf fell with the EMAP target depth zone of 30-120 m. The list of water column parameters measured varied considerably among these stations and rarely comprised the full list of parameters measured by the EMAP study.

### **2.1.3 FRAM Groundfish Survey**

Samples from the West Coast Groundfish Surveys conducted by the Fisheries Resource Analysis and Monitoring (FRAM) Division of the Northwest Fisheries Science Center (NWFSC) of NOAA were used to supplement the pool of samples available for tissue-contaminant body-burden analysis. FRAM surveys began in 1998 and by 2003 had adopted a probability-based sampling design. However the design could not be readily integrated into that used by EMAP/NCA. The FRAM groundfish-survey area included depths from 30 fathoms (55m) to 700 fathoms (1287m) and was partitioned by International North Pacific Fishing Commission zones. Therefore, a GIS coverage of groundfish-survey sample locations was created, and the EMAP/NCA sample frame defining the region between 30 and 120 m was overlaid on this GIS data layer. A target sample number of 50 groundfish sites per state was established. In Oregon and Washington, only 28 and 21 stations, respectively, met the EMAP/NCA depth criterion, and thus all available sites were selected. In California, a subset of 50 sites was randomly selected from the list of 78 sites within the depth range. Fish from 63 sites were initially selected for contaminant analysis, but data from three of these sites were subsequently excluded from data analysis because the sites were greater than 120 m in depth. Sites from which fish were analyzed for contaminants are shown in Figs. 3.1.6-3.1.9 and are listed in Appendix Table 2.

### **2.2 Water Column Sampling**

Vertical water-column profiles of conductivity, temperature, chlorophyll *a* concentration, transmissivity, dissolved oxygen, and depth were obtained with a Sea-Bird Electronics Conductivity-Temperature-Depth (CTD) data sonde unit with additional sensors (Table 2.2.1). The unit was a SBE 9Plus with an 11Plus deck unit to provide real-time data supplied by the NOAA Ship McARTHUR II. Supplemental sensors were supplied by Washington DOE. The unit was also equipped with 12 Niskin water sample bottles to acquire discrete water samples at three designated water depths: 0.5 m below sea surface, mid-water column, and near the seabed (Figure 2.2.1). In practice, the near-surface samples were collected from just below the surface to a depth of 5.3 m. Continuous profiles of conductivity, temperature, dissolved oxygen, chlorophyll *a* (fluorometer), transmissivity, and depth were recorded during the descent and ascent of the unit. Discrete water samples were processed for nutrients, total suspended solids (TSS), and chlorophyll *a*. For nutrients and chlorophyll *a*, only surface values are reported since this is the region of the water column most likely to be affected by anthropogenic influences. For temperature, salinity, dissolved oxygen, transmissivity and TSS, only surface and bottom values are reported, since these values typically provide the maximum range of values within a station. Data for all three depths for all variables are included in the study database and are available on request from the authors.

In the assessment of estuarine waters in the NCA program, light availability in the water column was evaluated using either Secchi depth or water column

photosynthetically available radiation (PAR) measured with PAR sensors. For the Western NCA, the vertical profile PAR data were used to calculate an estimate of the percent transmittance of incident PAR at a reference depth of 1 m (Nelson et al. 2005). In the present study, a transmissometer attached to the CTD was used to measure in situ light attenuation. The instrument measured the percentage of light that reached a receiver with a narrow field of view at 25 cm from a light source generating a narrow beam. Transmissivity and percent transmittance of PAR are not directly comparable measurements.

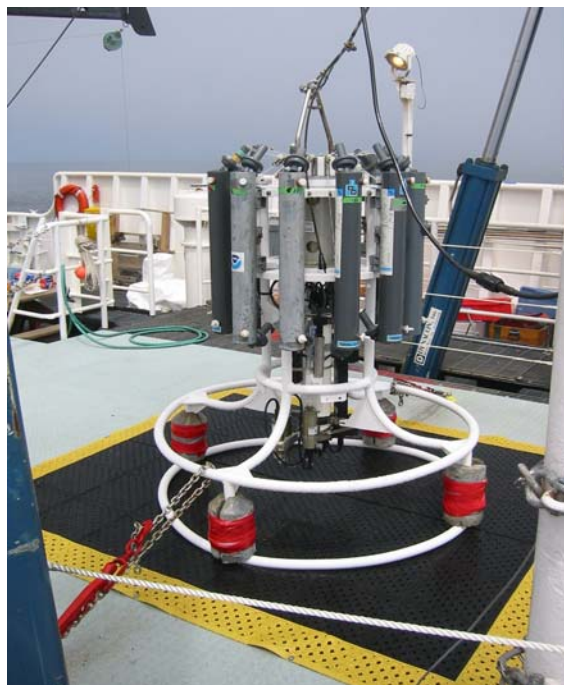


Figure 2.2.1. CTD and Niskin bottle rosette sampler on the deck of the NOAA Ship McARTHUR II.

The CTD was lowered into the water until it was completely submerged and held just below the surface for three minutes, allowing the water pump to purge any air in the system. The unit was then returned to the sea surface to begin the profile, and lowered slowly to the bottom at approximately  $0.8 \text{ m s}^{-1}$ , held near the seabed for one minute, and then recovered at a similar velocity. To prevent the equipment from hitting the seabed due to wave motion, the maximum depth to which the CTD was lowered was generally about 3-8 m above the bottom.

Table 2.2.1. Equipment used for hydrographic profile measurements.

Parameter	CTD or Sensor
Salinity	Sea-Bird Electronics SBE 9Plus Derived from conductivity (CTD)
Temperature	Sea-Bird Electronics SBE 9Plus
Dissolved oxygen	Sea-Bird Electronics SBE-43 sensor
Chlorophyll-a fluorescence	WET Labs WETStar fluorometer
Transmissivity	WET Labs C-Star transmissometer

## 2.3 Biological and Sediment Sampling

Sediment sampling was undertaken using a custom-designed Van Veen grab (Figure 2.3.1). The sampling device is composed of two 0.1-m<sup>2</sup> samplers, joined together in a single frame. The unit was 60 inches high, 42 inches in diameter and weighed 450 pounds with its full complement of four, 50-pound, stainless-steel weights. Sample material obtained by the grabs was used for analysis of macroinfaunal communities, concentration of sediment contaminants, % silt-clay, and organic-carbon content. Three grab samples were required at the majority of stations to acquire adequate sediment (approximately 2 L) for both benthic infauna (one grab) and chemistry sample processing. A grab sample was deemed successful when the grab unit was > 75% full (with no major slumping). The benthic samples were sieved onboard through 1.0-mm (WA and OR stations), or through nested 0.5-mm and 1.0-mm screens (CA stations), and preserved in 10% buffered formalin. Fauna from California stations retained in the 0.5-1.0 mm sieve fraction were processed as part of a supplemental study and are not considered in this report. Thus all benthic data reported here pertain to the > 1.0-mm fraction.

### 2.3.1 Sediment Pollutant and Tissue Analysis

Sediments and fish tissues were analyzed for a suite of organic pollutants and metals (Table 2.3.1) using analytical methods from the NOAA NS&T Program (Lauenstein and Cantillo 1993) or described in the EMAP Laboratory Methods Manual (U.S. EPA 1994). For all three states, 15 metals were analyzed in sediments and 13 metals were analyzed in whole-body fish tissues. Antimony and manganese were analyzed in tissue samples from California and Washington. A total of 21 PCB congeners (PCBs), DDT and its primary metabolites, 14 chlorinated pesticides, and 23 polynuclear aromatic hydrocarbons (PAHs) were analyzed in sediments from all three states (Table 2.3.1). The same suite of chlorinated compounds was analyzed in fish tissue except that hexachlorobenzene was not analyzed in samples from California. PAHs were measured in tissues from California and Washington and are not reported here. Total organic carbon and percent fines of the sediment were analyzed in samples from all sites.

Table 2.3.1. Compounds analyzed in sediments and fish tissues in the West Coast Shelf Assessment. All compounds were analyzed in all three states in both sediment and fish with the exceptions that PAHs, antimony and manganese were analyzed in fish tissues only in California and Washington, and hexachlorobenzene was not analyzed in fish tissues in California.

Polycyclic Aromatic Hydrocarbons (PAHs)	PCB Congeners (Congener Number and Compound)	DDT and Other Chlorinated Pesticides	Metals and Misc.
<u>Low Molecular Weight PAHs</u> 1-methylnaphthalene 1-methylphenanthrene 2-methylnaphthalene 2,6-dimethylnaphthalene 2,3,5-trimethylnaphthalene Acenaphthene Acenaphthylene Anthracene Biphenyl Dibenzothiophene Fluorene Naphthalene Phenanthrene  <u>High Molecular Weight PAHs</u> Benz(a)anthracene Benzo(a)pyrene Benzo(b)fluoranthene Benzo(k)fluoranthene Benzo(g,h,i)perylene Chrysene Dibenz(a,h)anthracene Fluoranthene Indeno(1,2,3-c,d)pyrene Pyrene	8: 2,4'-dichlorobiphenyl 18: 2,2',5-trichlorobiphenyl 28: 2,4,4'-trichlorobiphenyl 44: 2,2',3,5'-tetrachlorobiphenyl 52: 2,2',5,5'-tetrachlorobiphenyl 66: 2,3',4,4'-tetrachlorobiphenyl 77: 3,3',4,4'-tetrachlorobiphenyl 101: 2,2',4,5,5'-pentachlorobiphenyl 105: 2,3,3',4,4'-pentachlorobiphenyl 110: 2,3,3',4',6-pentachlorobiphenyl 118: 2,3',4,4',5-pentachlorobiphenyl 126: 3,3',4,4',5-pentachlorobiphenyl 128: 2,2',3,3',4,4'-hexachlorobiphenyl (CA as 128/266) 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	<u>DDTs</u> 2,4'-DDD 4,4'-DDD 2,4'-DDE 4,4'-DDE 2,4'-DDT 4,4'-DDT  <u>Cyclopentadienes</u> Aldrin Dieldrin Endrin  <u>Chlordanes</u> Alpha-Chlordane Heptachlor Heptachlor Epoxide Trans-Nonachlor  <u>Others</u> Endosulfan I Endosulfan II Endosulfan Sulfate Hexachlorobenzene Lindane (gamma-BHC) Mirex Toxaphene	<u>Metals</u> Aluminum Antimony Arsenic Cadmium Chromium Copper Iron Lead Manganese Mercury Nickel Selenium Silver Tin Zinc  <u>Miscellaneous</u> Total Organic Carbon Percent Fines



Figure 2.3.1. Close-up view of double Van Veen grab sampler used for bottom sampling.

## 2.4 Fish Tissue

### 2.4.1 EMAP

The NOAA Ship McARTHUR II had only recently entered service and was not yet fitted out to conduct trawl operations at the time of the EMAP/NCA Assessment. Instead, hook-and-line fishing methods (Figure 2.4.1) were used in an effort to capture bottom fish for inspection of external pathologies and for subsequent analysis of chemical contaminants in tissues of selected species. Any captured fish were identified and inspected for gross external pathologies. Selected species, primarily the Pacific sanddab (*Citharichthys sordidus*), also were frozen for subsequent chemical contaminant body-burden analysis. Water depths less than 80 m were generally fished quite easily with hook-and-line. Fishing at night, in high currents and in deeper water depths was difficult and was often unproductive. In particular, during the California leg of the cruise, high winds and seas physically hindered the ability to keep fishing gear on the bottom at many stations.

### 2.4.2 Bight'03

While a variety of fish studies were conducted as part of Bight'03 (Allan et al. 2007), there were no collections of benthic fish species for tissue contaminant analysis.



Figure 2.4.1. Hook-and-line fishing for fish tissue sampling aboard the NOAA ship McARTHUR II.

### **2.4.3 FRAM Groundfish Survey**

At the FRAM sites, bottom trawl operations were conducted by commercial fishing vessels chartered by NOAA. GPS and net-mounted sensors recorded time series of position, depth, temperature, and net dimension readings during trawling and other environmental observations were collected manually. At the conclusion of each trawl operation, species composition, fish sex, length, weight and other observations were gathered either manually or by various electronic equipment. Fish were frozen on board and transferred to EPA or state partners for analysis of fish-tissue contaminants.

## **2.5 Quality Assurance**

### **2.5.1 Quality Assurance/ Quality Control of Chemical Analyses**

The quality assurance/quality control (QA/QC) program for the NCA-West program is defined by the "Environmental Monitoring and Assessment Program (EMAP): National Coastal Assessment Quality Assurance Project Plan 2001-2004" (U.S. EPA 2001). A performance-based approach is used which, depending upon the compound, includes: 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. The objective of this performance-based approach is to assist the laboratories in meeting desired Data Quality Objectives (DQOs) as defined in the EMAP Quality Assurance Project Plan (U.S. EPA 2001).

A measure of whether the analytical procedure is sufficient to detect the analytes at environmental levels of concern is the Method Detection Limits (MDLs). Approved laboratories were expected to perform in general agreement with the target MDLs presented for NCA analytes (Table A7-2 in U.S. EPA 2001). 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 3-5 times the MDL. In these analyses, concentrations between the MDL and the RL were included in the calculation of the means or cumulative distribution functions (CDFs), while values below the MDL were set to zero.

One measure of accuracy of the analytical procedure is the “relative accuracy,” which is based on computing the percent deviation of the laboratory’s value from the true or “accepted” values in CRMs, LCMs, or SRMs. The requirements for PAHs, PCBs, and pesticides are that the “Lab’s value should be within  $\pm 30\%$  of true value on average for all analytes, not to exceed  $\pm 35\%$  of true value for more than 30% of individual analytes” (U.S. EPA 2001). For metals and other inorganic compounds, the laboratory’s value for each analyte should be within  $\pm 20\%$  of the true value of the CRM, LCM, or SRM. Another measure of accuracy is the percent recovery from matrix spikes. High percent recoveries in matrix spikes indicate that the analytical method and instruments can adequately quantify the analyte but do not evaluate the ability of the analytical procedure to extract the compound from natural tissue or sediment matrices. Measures of precision are the “relative percent differences” (RPD) or coefficient of variation (CV) of replicate samples, with the objective that the RPD or CV should be  $<30\%$ .

A post-analysis assessment of the success of the analytical laboratories in meeting NCA QA/QC requirements was conducted by the QA manager of the Western Ecology Division. The percent recovery from certified/standard materials, recovery from matrix spikes, and the average RPD for non-zero sample replicates and matrix spikes are given in Appendix Tables 3a – 3c and summarized here.

## **2.5.2 Metals in Sediments**

The recommended MDL (Table A7-2 in U.S. EPA, 2001) varies by metal, ranging from 0.01  $\mu\text{g/g}$  for mercury to 1500  $\mu\text{g/g}$  for aluminum. The MDLs for metals in sediment were met by each state with the following exceptions. Oregon had a MDL for antimony of 0.3  $\mu\text{g/g}$  versus the recommended detection limit of 0.2  $\mu\text{g/g}$ . Washington had a MDL for selenium of 0.84  $\mu\text{g/g}$  versus the recommended detection limit of 0.1  $\mu\text{g/g}$ . Oregon had a MDL for tin of 0.5  $\mu\text{g/g}$  versus the recommended detection limit of



0.1 µg/g. Washington had a high MDL for tin (20 µg/g) however due to the method of calculating the MDL for this compound the RL (0.2 µg/g ) was lower than the MDL and close to the recommended detection level of 0.1 µg/g.

California and Oregon met all the DQOs for the average deviation for all sediment metals, deviations for the individual metals, and for precision. California had a low accuracy for silver while Oregon had a low accuracy for tin. Washington met the precision and the matrix spike recovery DQOs for all metals. However, the average deviation for the 15 metals in Washington was 29.8%, exceeding the DQO of an average of 20% for metals. Failure to meet this DQO was due to the high deviance (>90%) for arsenic, selenium, and tin, and values for these metals should be interpreted cautiously for samples from Washington.

### **2.5.3 Organics in Sediments**

The recommended MDLs (Table A7-2 in U.S. EPA, 2001) are 10 ng/g for PAHs and 1 ng/g for PCBs, DDTs, and chlorinated pesticides. All three states met the MDL requirements for all the organic compounds with the exception of toxaphene in California which had a MDL of 10 ng/g. With the exception of PCBs for one of two standards used by Washington, all three states met the DQOs for recovery from matrix spikes and for precision for all the organic compounds.

In terms of accuracy, California met the DQOs that the average deviation for all PCBs was within ±30% of the average value within the standard reference material as well as that 70% of the individual PCB congeners were measured within ±35% of the true values. Washington failed to meet the recommended average deviation from reference materials of <30% for PCBs. The major factor driving this failure was PCB congener 105 which had a percent deviation of 192%. When all the PCB congeners are considered, 83% of the individual congeners were within ±35% of true values. Oregon accuracy for PCBs was not as high as the other two states, with an average difference between the reported PCB values and the certified values of 115% or 71% if PCB 170 is excluded. Only three of the 19 PCB congeners were within ±35% of true value in the standards even though recoveries were high in the matrix spikes. In analyzing the sediment PCB data, the Oregon data should be interpreted cautiously as should the PCB 105 data from Washington.

Both California and Oregon met the accuracy DQOs for sediment DDTs, though Oregon had poor accuracy with 2,4'-DDE. In Washington, all three of the DDTs measured in the standard reference material exceeded the value in the standard by >50%. In analyzing the sediment DDT data, the Washington values should be interpreted cautiously

The standard reference materials used by the three states did not contain most of the non-DDT pesticides, so that it was necessary to use the recoveries in the matrix spikes as a measure of accuracy. In California, all the recoveries from the spiked matrix

was within 2-12% of the true value while in Oregon 10 of the 12 non-DDT pesticides were within  $\pm 35\%$  of the value in the spiked matrix. Accuracy was not as good in Washington with 7 of the 12 pesticides within  $\pm 35\%$  of the spiked value. Because recoveries from a spiked matrix is not as rigorous an evaluation of accuracy as those derived from natural matrices, small differences in concentrations should not be over interpreted.

California met the accuracy DQOs for sediment PAHs. In Oregon, the average percent deviation from the true value for PAHs was 40% compared to the DQO of 30%. Eight of the 20 PAHs measured in the reference material deviated from the true values by  $> 35\%$ , though only benzo(b)fluoranthene and dibenz(a,h)anthracene showed deviations  $> 50\%$ . Washington also failed to meet the overall standard, with an average percent deviation for all PAHs of 44%. Nine of the 23 PAHs measured in Washington deviated by  $> 35\%$  from the true value, with 6 of these compounds deviating by  $> 50\%$  (2,3,5-trimethylnaphthalene, 2,6-dimethylnaphthalene, acenaphthylene, benzo(k)fluoranthene, dibenz(a,h)anthracene, dibenzothiophene). The PAH data should be interpreted with consideration that Oregon and Washington did not achieve the average overall DQOs for PAHs and, in particular, data for compounds deviating by  $> 50\%$  should be interpreted cautiously.

#### **2.5.4 Metals in Tissue**

The recommended MDL (Table A7-2 in U.S. EPA, 2001) in tissue varies by metal, ranging from 0.01  $\mu\text{g/g}$  for mercury to 50  $\mu\text{g/g}$  for iron and zinc. All three states met the MDL recommendations for metals in tissue with the following exceptions: At 0.015  $\mu\text{g/g}$ , Oregon's MDL for mercury was slightly higher than the recommended detection of 0.01  $\mu\text{g/g}$ . Both Oregon and Washington exceeded the recommended MDL for tin of 0.05  $\mu\text{g/g}$  with detection limits of 0.15  $\mu\text{g/g}$  and 0.2 - 0.22  $\mu\text{g/g}$  respectively. All three states met the requirement for precision. Oregon and Washington met the DQO that recovery of metals from matrix spikes should be in the range of 50%-120% of the spiked concentration. However, California did not conduct any matrix spikes with tissues. In terms of accuracy, all three states met the average and individual DQOs, though the Washington standard reference material contained only 7 of the 13 metals.

#### **2.5.5 Organics in Tissue**

The recommended MDLs (Table A7-2 in U.S. EPA, 2001) in tissue are 2.0 ng/g for both PCBs and the chlorinated pesticides. All three states met the MDL recommendations for organics in tissues with the following exceptions: Oregon had a MDL of 20 ng/g for endosulfan I, endosulfan II, and endosulfan sulfate. Oregon had a MDL of 200 ng/g for toxaphene while California had a detection limit of 10 ng/g. Oregon had a detection limit of 10 ng/g for endrin. All three states met the requirement for precision that the average RPD or CV for PCBs and pesticides in replicate samples be  $< 30\%$ . Oregon and Washington met the DQO that recovery of PCBs and pesticides from matrix spikes be in the range of 50%-120% of the spiked concentration. However,

California did not conduct any matrix spikes with tissues.

In terms of accuracy, California met the DQOs that the average deviation for all PCBs was within  $\pm 30\%$  of the average value within the standard material as well as that 70% of the individual PCB congeners were measured within  $\pm 35\%$  of true value. Both Washington and Oregon failed the DQO that the average deviation for the PCBs should be within  $\pm 30\%$  of the average value in the standard. Additionally, only 3 of the 17 PCB congeners measured in Oregon and none of the 10 congeners measured in Washington were within  $\pm 35\%$  of the value in the standard. Because of this low accuracy when assessed with standard reference materials, the tissue PCB data from Oregon and Washington need to be interpreted cautiously.

In both California and Oregon, the average percent deviation of the four DDTs measured in the reference material was less than or equal to the DQO of 30%. However, the value for 4,4'-DDE in Oregon differed from the reference material by  $>50\%$ . In comparison, all four of the DDTs measured in Washington deviated from the standard reference material by  $\geq 63\%$ . Because of the low accuracy when assessed with standard reference materials, the tissue DDT data from Washington and the Oregon 4,4'-DDE values should be interpreted cautiously.

California analyzed only two of the 14 non-DDT pesticides in the standard reference material and did not conduct matrix spikes with tissues as an alternate demonstration of recovery. Accuracy for the compounds measured in the reference material (dieldrin and trans-nonachlor) was good; however without values for the other pesticides it is not possible to assess the overall accuracy for the non-DDT pesticides in California. Washington and Oregon measured most of the non-DDT pesticides in either their reference material and/or in a spiked matrix. Average deviation for the pesticides in both states failed the DQO and deviations for most individual pesticides were  $> 35\%$  from the reference material or the spiked matrix. Because of the uncertain accuracy in the California tissue values and the low accuracy in Oregon and Washington, the tissue values for the non-DDT pesticides should be used cautiously.

## **2.6 Statistical Data Analyses**

The use of a probability-based sampling design allows the development of estimates of the extent of area, with 95% confidence intervals, of the West Coast Shelf resource (30 – 120 m) corresponding to any specified value of the measured indicator. Analysis of indicator data was conducted by calculation of cumulative distribution functions (CDFs), an analysis approach that has been used extensively in other EMAP/NCA coastal studies (Summers et al. 1993, Strobel et al. 1995, Hyland et al. 1996, U.S. EPA 2004, 2006). A detailed discussion of methods for calculation of the CDFs used in EMAP analyses is provided in Diaz-Ramos et al. (1996). Results of the CDF analysis are presented in the present report primarily as the values of an indicator which correspond to given percentiles of the cumulative distribution. Where known

thresholds of concern exist, e.g. dissolved oxygen concentration < 2.3 mg/L, percentiles are reported for such values. Where thresholds of concern have not been developed, e.g., the benthic variables, indicator values that represent common reporting values for frequency distributions (e.g., the median, 90<sup>th</sup> percentile, upper and lower quartiles), are presented. Data presented graphically in this report are primarily in the form of CDFs, pie charts, and simple bar graphs representing the mean +1 standard deviation of the indicator values.

## **2.7 Sampling, Data Integration, and Data Quality Issues**

The initial effort to develop a sampling frame representing only soft-sediment areas of the West Coast was generally a success, and a limited number of stations within the EMAP cruise effort had to be abandoned as a result of encountering rocky bottom. Primarily this occurred in the Strait of Juan de Fuca (Section 2.1 above), and the frame definition was adjusted *a posteriori* to remove this area. There were two additional stations abandoned on the Washington shelf, no stations were abandoned on the Oregon shelf, and two stations were abandoned on the California shelf as a result of encountering rocky bottom. All abandoned stations were replaced with alternate stations from the initial sampling design.

During the Oregon leg of the EMAP cruise, there were malfunctions of the CTD sensors which affected data for temperature, salinity, depth, and dissolved oxygen at numerous stations on the Oregon shelf. Questionable data due to equipment malfunction were flagged in the database and removed from data analyses. All Oregon Total Suspended Solids (TSS) data were flagged as questionable and removed from analyses. Filters for TSS appear to have been inadequately washed to remove salt crystals.

While the Bight '03 and NCA-West/EMAP studies were both designed as probability-based surveys, and the initial presumption was that data could be easily merged, the studies were executed and managed separately, and some data integration and compatibility issues arose as a result. For example, water-column nutrient samples were not collected at all Bight '03 stations within the target depth range for the NCA-West/EMAP survey. For those samples collected, only nitrate and nitrite were analyzed, whereas the NCA-West/EMAP samples were analyzed for nitrate, nitrite and ammonium, and thus the studies were not directly comparable for total dissolved nitrogen. Tissue contaminant samples of demersal fishes were generally not collected under the Bight '03 program. In the case of some multi-density categories, the Bight '03 program was unable to sample the target number of primary stations called for in the sample design, and no alternate stations were occupied. Thus the multi-density category weights for the data analysis were adjusted based on the actual number of stations occupied.

### 3.0. Results and Discussion

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, estimates of the percentage of shelf area above or below published benchmark values of the indicator are also presented. For example, estimates are made of the percentage of area having sediment contaminants in excess of corresponding Effects Range Median (ERM) or Effects Range Low (ERL) sediment quality guideline values of Long et al. (1995) where such values are available (see Section 3.2.2). In other cases where there are no relevant benchmarks available from the literature, common statistical percentiles (e.g., 50<sup>th</sup>, 90<sup>th</sup>, upper and lower quartiles) are used to assist in the interpretation of spatial patterns.

#### 3.1 Sampling Locations

A total of 146 stations from Cape Flattery, WA, to Pt. Conception, CA were successfully sampled as part of Cruise AR-03-01-NC (Figures 3.1.1- 3.1.5, Appendix Table 1). Data from one additional station off Santa Catalina Island that was a part of the NCA continental shelf assessment design were also provided by SCCWRP. An additional three stations within the NCA that were within the Channel Islands could not be sampled because of rocky bottom and were abandoned. Data from fifty stations were obtained within Washington waters. Data from fifty stations were also obtained within Oregon waters, although a sample for sediment infauna was not obtained at Station OR03-0010. Data from forty-seven stations were obtained in California waters (46 north of Pt. Conception and one off Santa Catalina Island). Although there was some evidence of washing of the sediments from the infaunal sample at Station CA03-0140, the data were included in the analyses. Of those 147 stations, 57 occurred within National Marine Sanctuary (NMS) boundaries, including 30 in the Olympic Coast NMS, 12 in the Gulf of Farallones NMS, 14 in Monterey Bay NMS, and one in Cordell Bank NMS.

A total of 110 additional stations were successfully sampled for some or all of the NCA parameters within the target depth range by participants in the Bight '03 survey. These stations were located within the Channel Islands NMS (27 stations) and throughout the SCB (83 stations, Figures 3.1.5). The 83 stations were distributed in five multi-density categories that were part of the Bight '03 survey design, with sample numbers per category ranging from 6 to 29 (Appendix Table 1). Rocky bottom was prevalent in the Channel Islands NMS and many stations in the original sampling design could not be sampled.

Fish from a total of 91 stations within Washington, Oregon, and California waters (Fig. 3.1.6 – 3.1.9) were collected for EPA for fish tissue contaminants as part of NOAA's FRAM Groundfish survey. Due to resource limitations, samples from 63 stations were actually analyzed, while three of these stations were excluded when they

were found to have been sampled outside the target depth range (Appendix Table 2).

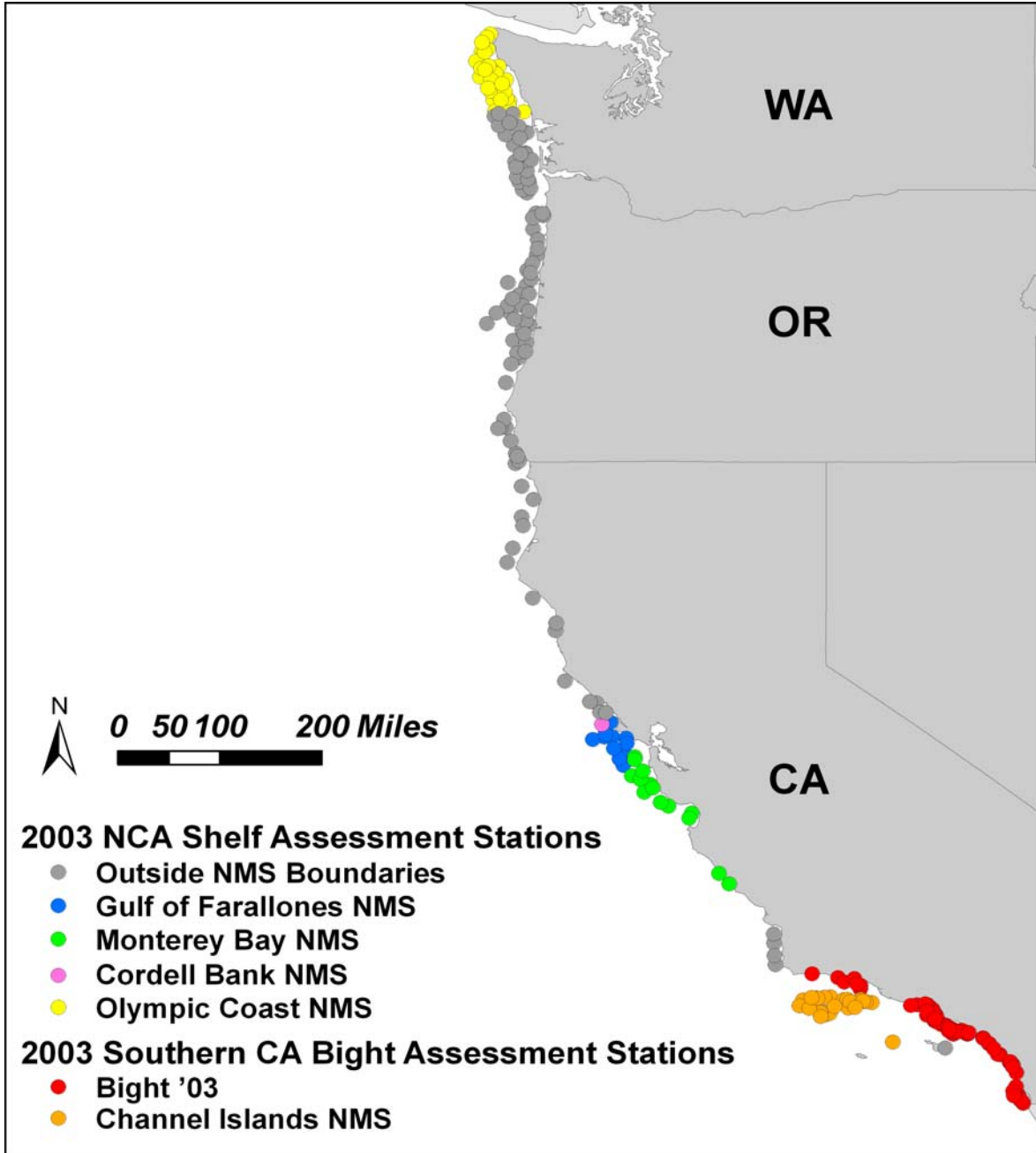


Figure 3.1.1. Distribution of sampling stations for the NCA 2003 West Coast Shelf Assessment. Data from stations sampled as part of the Bight '03 program that were within the target depth range were included in the NCA analyses. All stations within the Channel Islands were sampled by participants in the Bight '03 program.

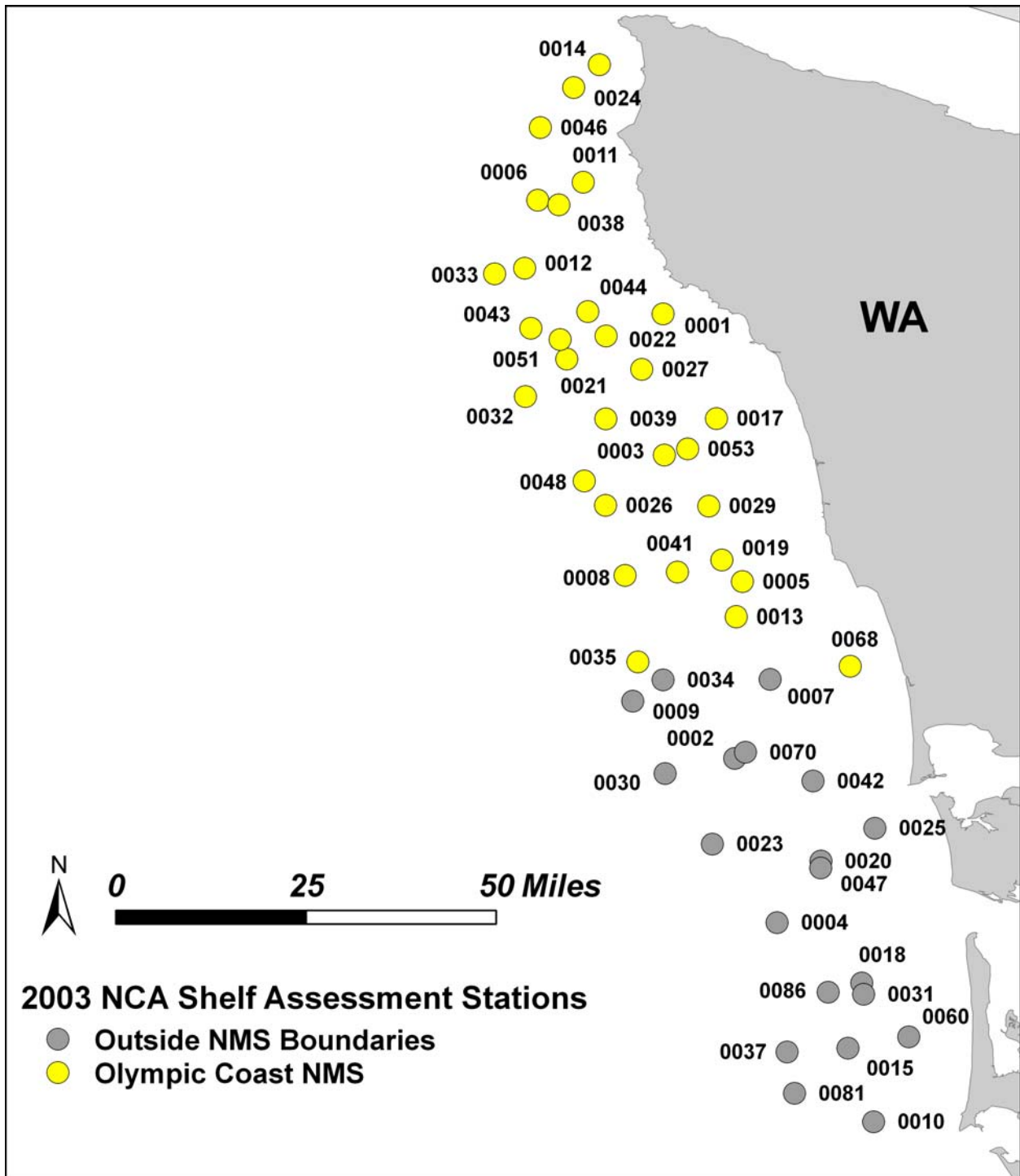


Figure 3.1.2. Distribution of sampling stations for the NCA 2003 West Coast Shelf Assessment along the continental shelf of Washington, showing stations within or outside of the Olympic Coast NMS. Numbers are the last 4 digits of the EMAP Station ID (Appendix Table 1).

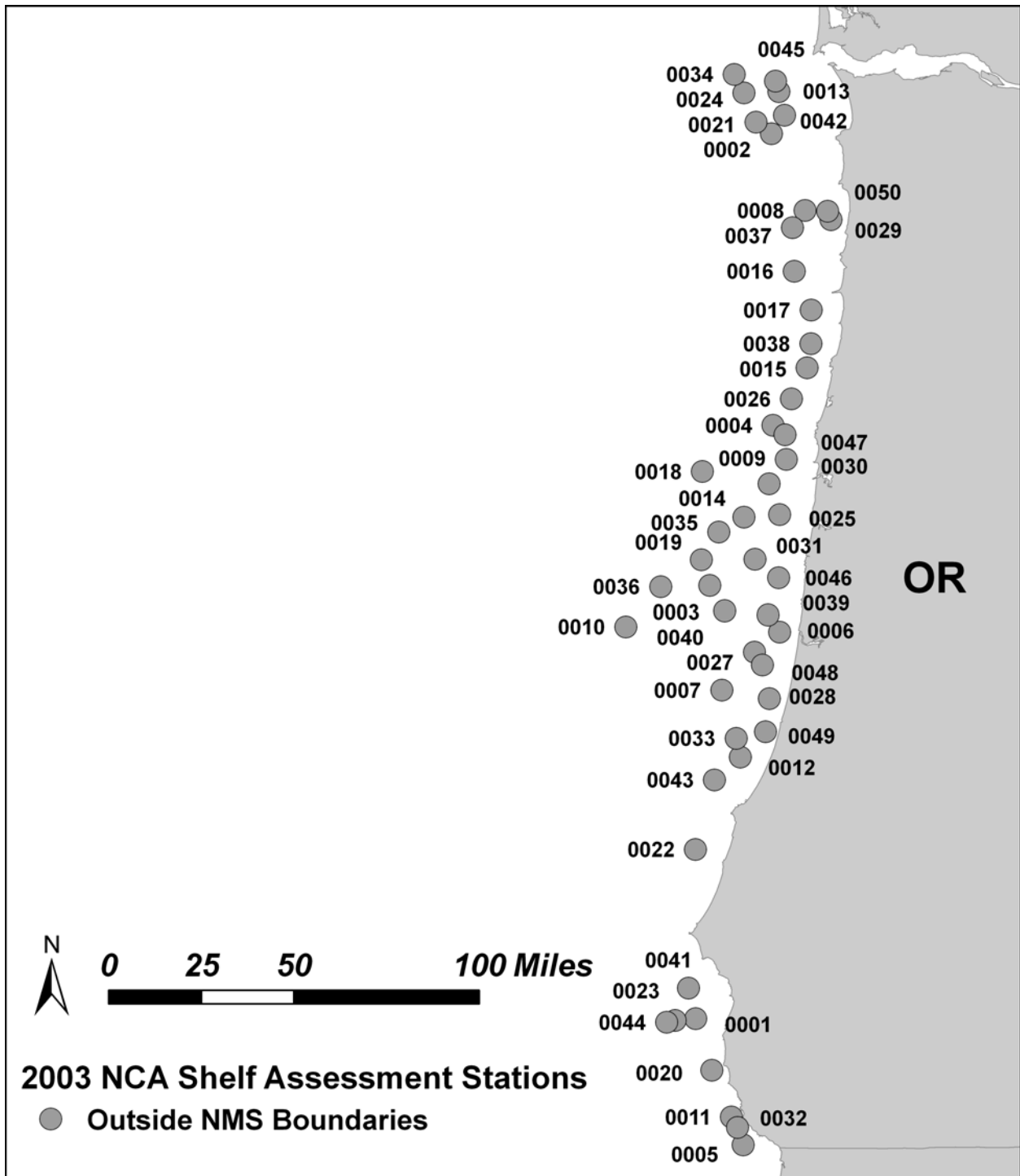


Figure 3.1.3. Distribution of sampling stations for the NCA 2003 West Coast Shelf Assessment along the continental shelf of Oregon. Numbers are the last 4 digits of the EMAP Station ID (Appendix Table 1).



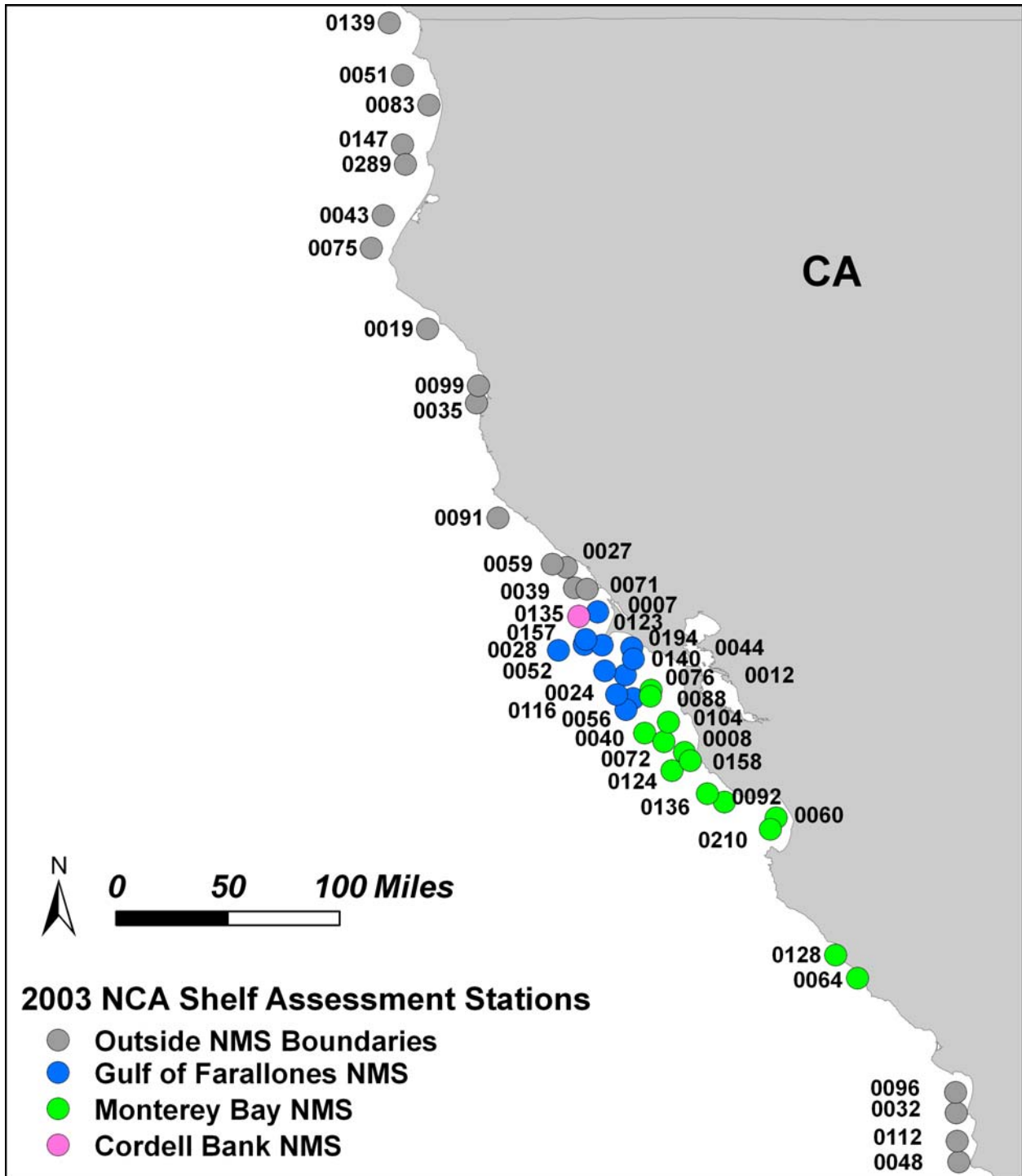


Figure 3.1.4. Distribution of sampling stations for the NCA 2003 West Coast Shelf Assessment along the continental shelf of California north of Pt. Conception. The region includes three NMS. Numbers are the last 4 digits of the EMAP Station ID (Appendix Table 1).

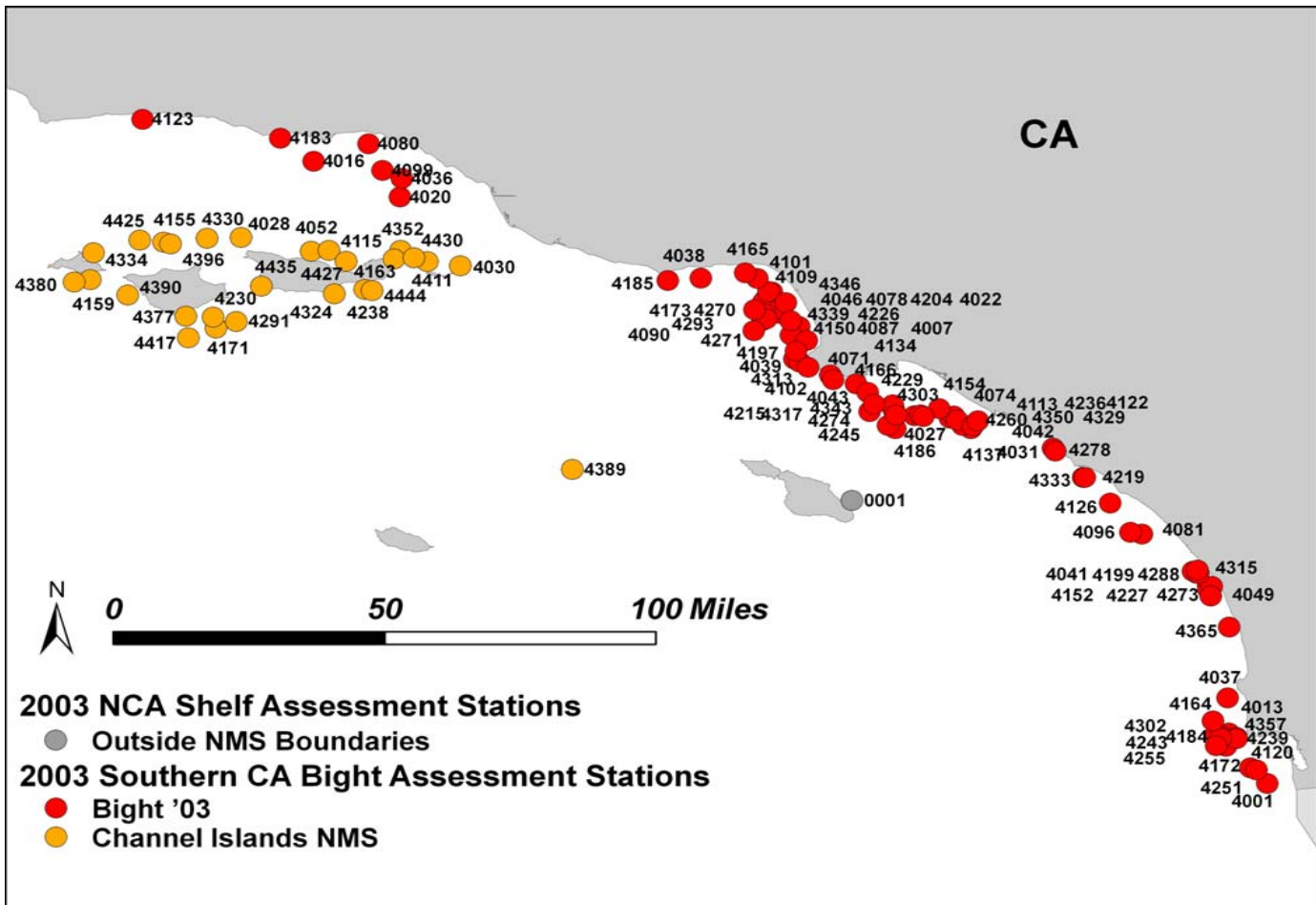


Figure 3.1.5. Distribution of sampling stations for the NCA 2003 West Coast Shelf Assessment along the continental shelf of California south of Pt. Conception within the Southern California Bight. Numbers are the last 4 digits of the EMAP Station ID (Appendix Table 1).

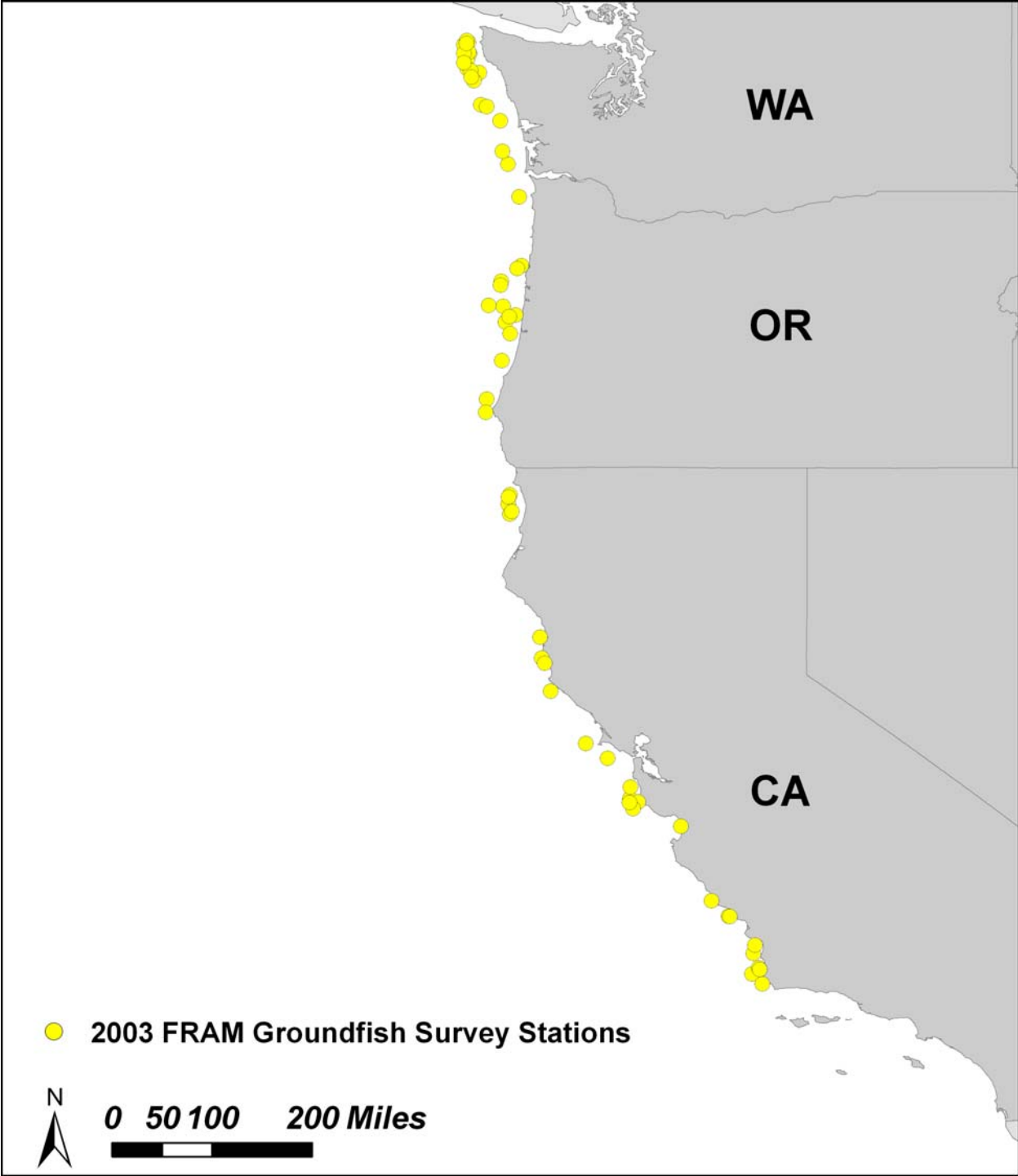


Figure 3.1.6. Distribution of sampling stations for the 2003 FRAM Groundfish Survey from which fish tissue samples were collected for analysis by NCA.

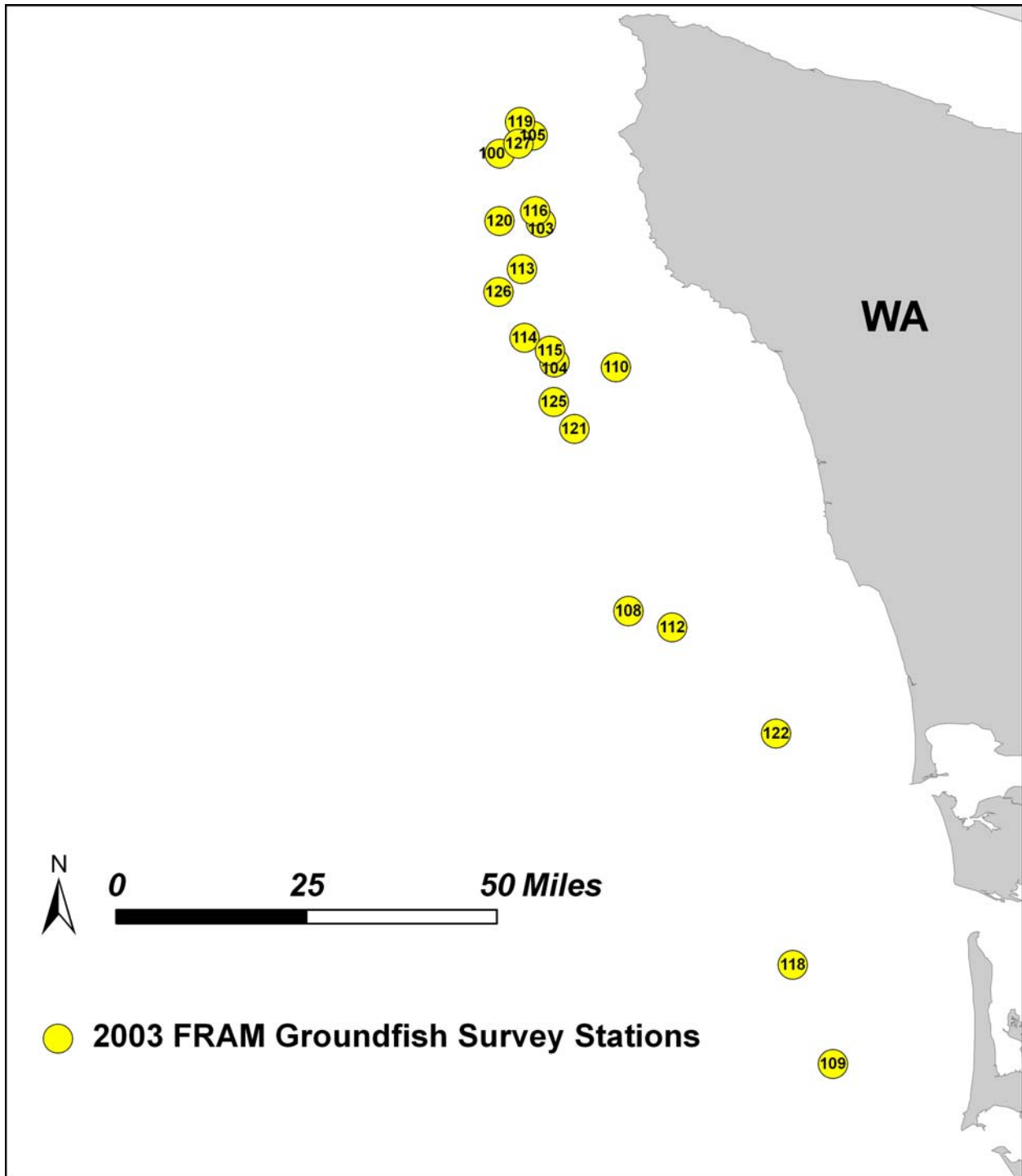


Figure 3.1.7. Distribution of sampling stations for the 2003 FRAM Groundfish Survey along the continental shelf of Washington, from which fish tissue samples were collected for analysis by NCA. Numbers are the last 3 digits of the EMAP Station ID (Appendix Table 2).

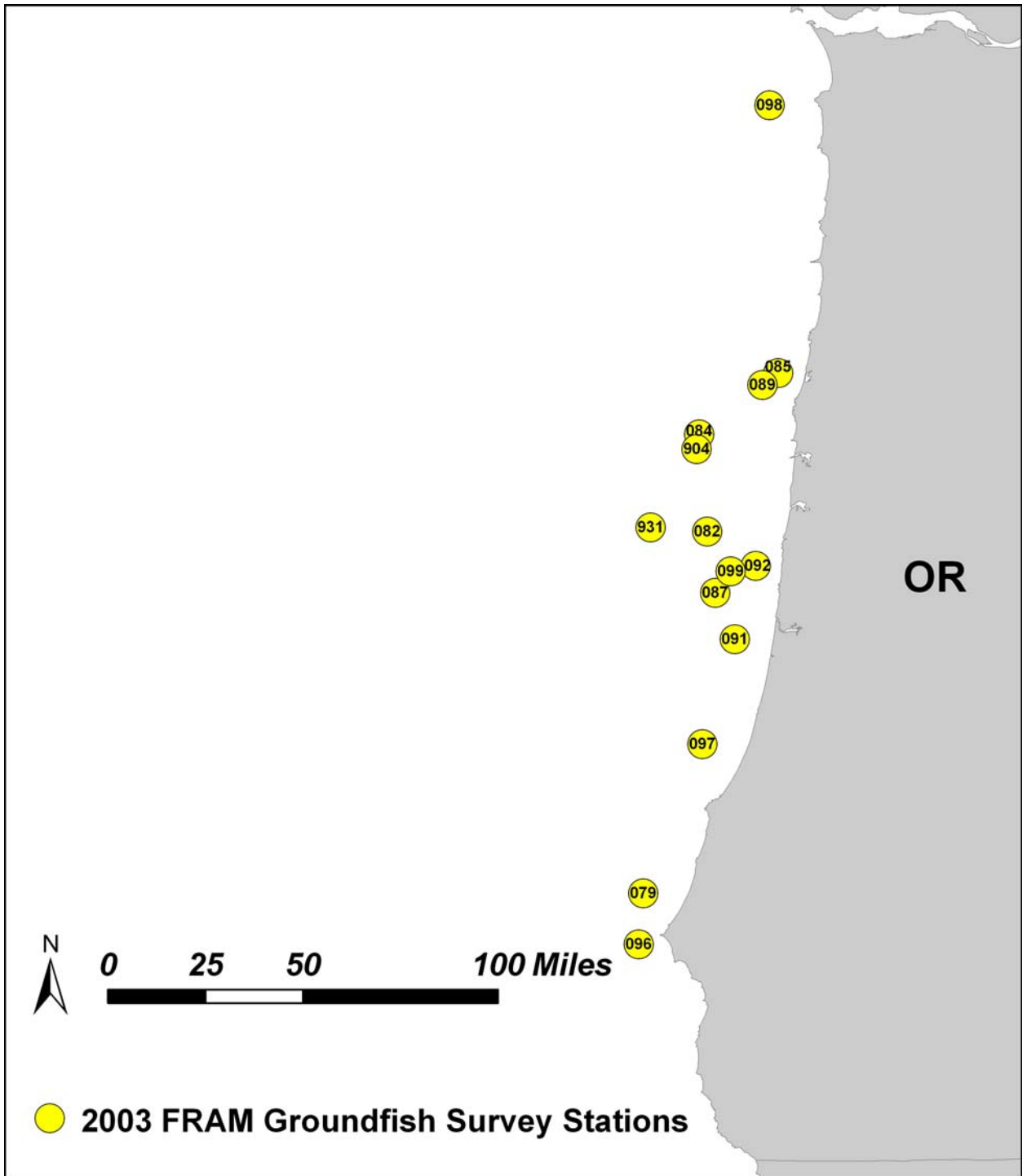


Figure 3.1.8. Distribution of sampling stations for the 2003 FRAM Groundfish Survey along the continental shelf of Oregon, from which fish tissue samples were collected for analysis by NCA. Numbers are the last 3 digits of the EMAP Station ID (Appendix Table 2).

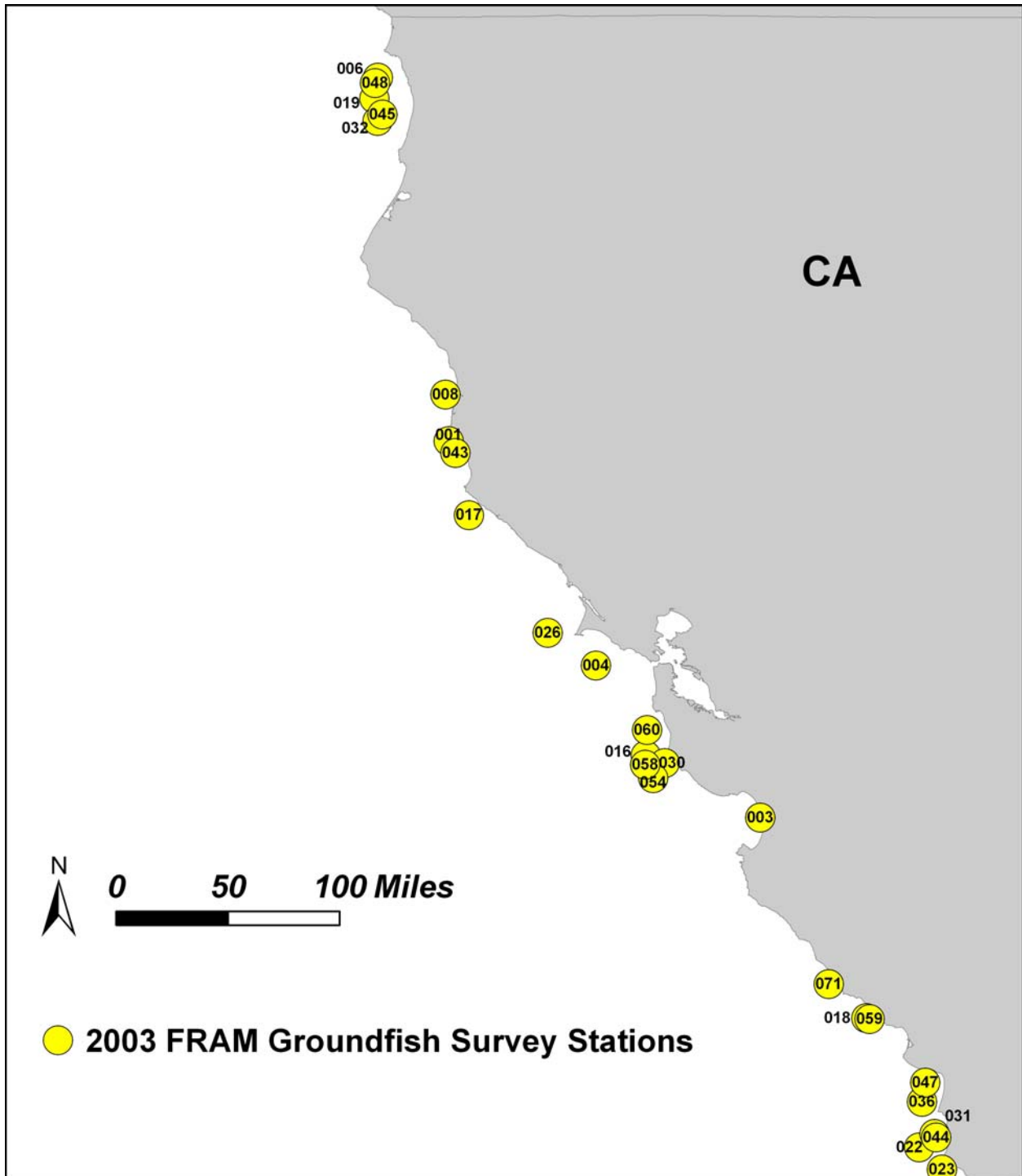


Figure 3.1.9. Distribution of sampling stations for the 2003 FRAM Groundfish Survey along the continental shelf of northern California, from which fish tissue samples were collected for analysis by NCA. Numbers are the last 3 digits of the EMAP Station ID (Appendix Table 2).

Bottom depth for the 257 stations sampled in waters of the West Coast shelf ranged from 28 m to 138 m. Four stations, all from the SCB sampled as part of the Bight '03 study, exceeded the target frame depth of 120 m but were included in the analyses in order to obtain adequate sample numbers from some multi-density categories. The mean depth of the waters of the West Coast shelf sampled was 72.6 m (Figure 3.1.10).

A variety of bottom types was encountered among the various stations. Along the Pacific coastline of Washington, the seabed was mostly fine sand, with a higher incidence of silt and clay in water depths greater than 60 m. Five stations in Washington could not be sampled due to the presence of hard bottom and thus were replaced with alternate sites from the sampling design. Three stations in the Strait of Juan de Fuca could not be sampled because they fell in an area of seabed composed of coarse gravel, cobbles and rock fragments. These stations were replaced with reserve sites along the Pacific coastline, outside the Strait of Juan de Fuca, and near the mouth of the Columbia River. Along the Oregon coastline, fine sand was also the most common bottom type encountered. The sediment collected during the California leg of the cruise was highly variable and included both fine sands and silty sediments. The highest percentages of fine sediments were found at California stations. Two stations along the California coastline had to be abandoned due to rocky conditions and were replaced with alternate stations. Further details on sediment composition are presented in Section 3.3.1 below.

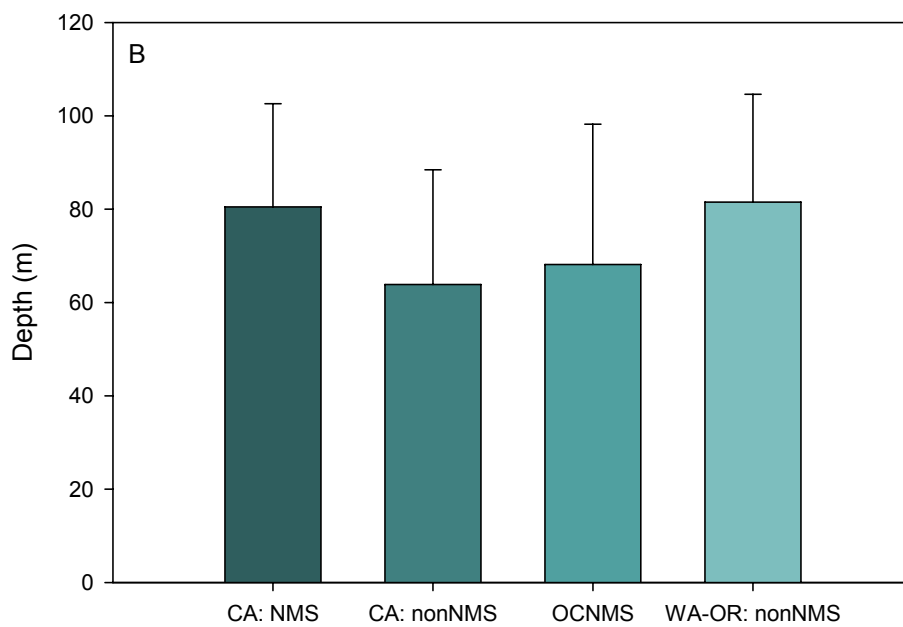
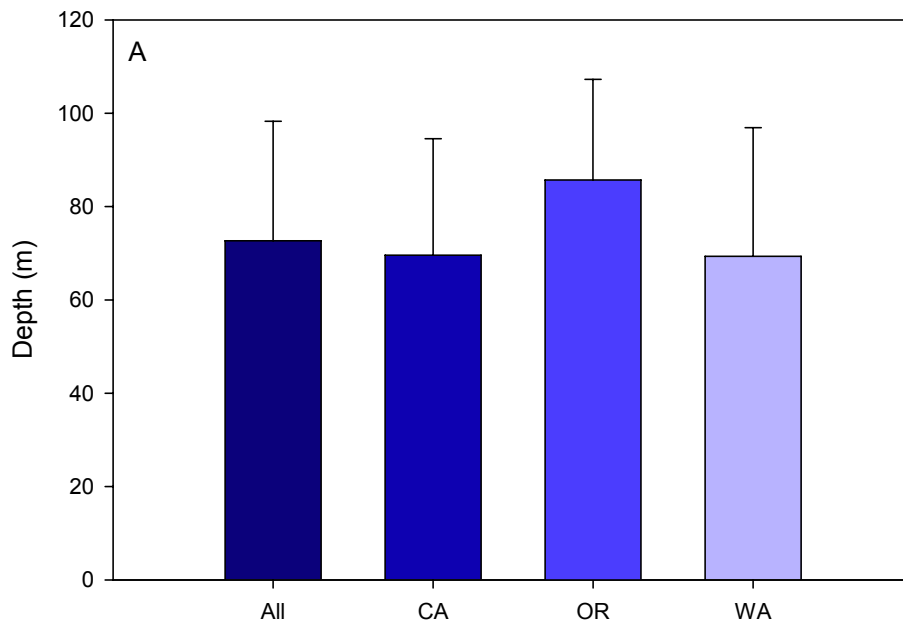


Figure 3.1.10. Mean +1 SD station depths compared among (A) all, California, Oregon, and Washington sample locations, and (B) California NMS, California non-NMS, Olympic Coast NMS, and Washington-Oregon non-NMS sample locations.



## **3.2 Water Column Characteristics**

### **3.2.1 Salinity**

Salinity in the surface waters of the West Coast shelf for the 140 stations for which data were obtained ranged from 21.2 to 34.0 psu. The 50<sup>th</sup> percentile of area had a surface salinity of 33.3 psu, while the 90<sup>th</sup> percentile had a salinity of 33.9 psu. An estimated 8% of area had a surface salinity of  $\leq 31$  psu. The majority of stations with surface salinity  $\leq 31$  psu were located off the mouth of the Columbia River or farther south along the Oregon coast, presumably within the plume from the Columbia River (Figure 3.2.1). Surface salinity was generally less than 33 psu to the north of Cape Blanco, Oregon, and greater than 33 psu to the south of Cape Blanco (Figure 3.2.1). Reflecting this pattern, mean surface salinities were slightly lower in Washington and Oregon than California (Figure 3.2.2 A), and slightly lower in the OCNMS as compared to the CA NMSs (Figure 3.2.2 B).

Bottom salinity ranged only between 31.6 and 34.4 psu for the 164 stations for which data were obtained. The 50<sup>th</sup> percentile of area had a bottom salinity of 33.9 psu, while the 90<sup>th</sup> percentile had a salinity of 34.0 psu. An estimated 3.3% of the area of the shelf surveyed had a bottom salinity of  $< 33$  psu, represented by seven stations all located within the northern region of the Washington shelf. There was virtually no difference in the mean bottom salinity among states or between NMS and non-NMS stations (Figure 3.2.3).

### **3.2.2 Water Temperature**

Temperature in the surface water of the West Coast shelf for the 140 stations for which data were obtained ranged from 8.5 °C to 19.9 °C. The 50<sup>th</sup> percentile of area had a surface-water temperature of 11.9 °C, while the 90<sup>th</sup> percentile had a surface water temperature of 13.5 °C. Mean surface-water temperatures were similar between Washington and Oregon, while the California average was several °C higher (Figure 3.2.4 A). Highest mean surface temperatures were observed in the CA non-NMS stations. The CA NMS stations were similar to the OCNMS (Figure 3.2.4 B), reflecting the fact that most measurements were obtained from the NMS off the central California coast, while temperature data were missing from the Channel Islands NMS.

Temperature in the bottom water of the West Coast shelf for the 164 stations for which data were obtained ranged from 5.8 °C to 14.7 °C. The 50<sup>th</sup> percentile of area had a bottom-water temperature of 7.8 °C, while the 90<sup>th</sup> percentile had a bottom water temperature of 9.7 °C. Bottom-water temperatures for stations on the California coast were generally warmer by several °C than those from Oregon and Washington (Figure 3.2.5 A). The bottom-water temperatures for the CA NMS stations were slightly higher than the OCNMS (Figure 3.2.5 B) and probably would be much higher if temperature data from the

Channel Islands NMS were available to include in the CA NMS average. California non-NMS locations had the highest mean bottom-water temperature, resulting from the facts that many of the measurements were obtained within the Southern California Bight and that temperature data for NMSs in California were from more northerly locations exclusive of the Channel Islands NMS.

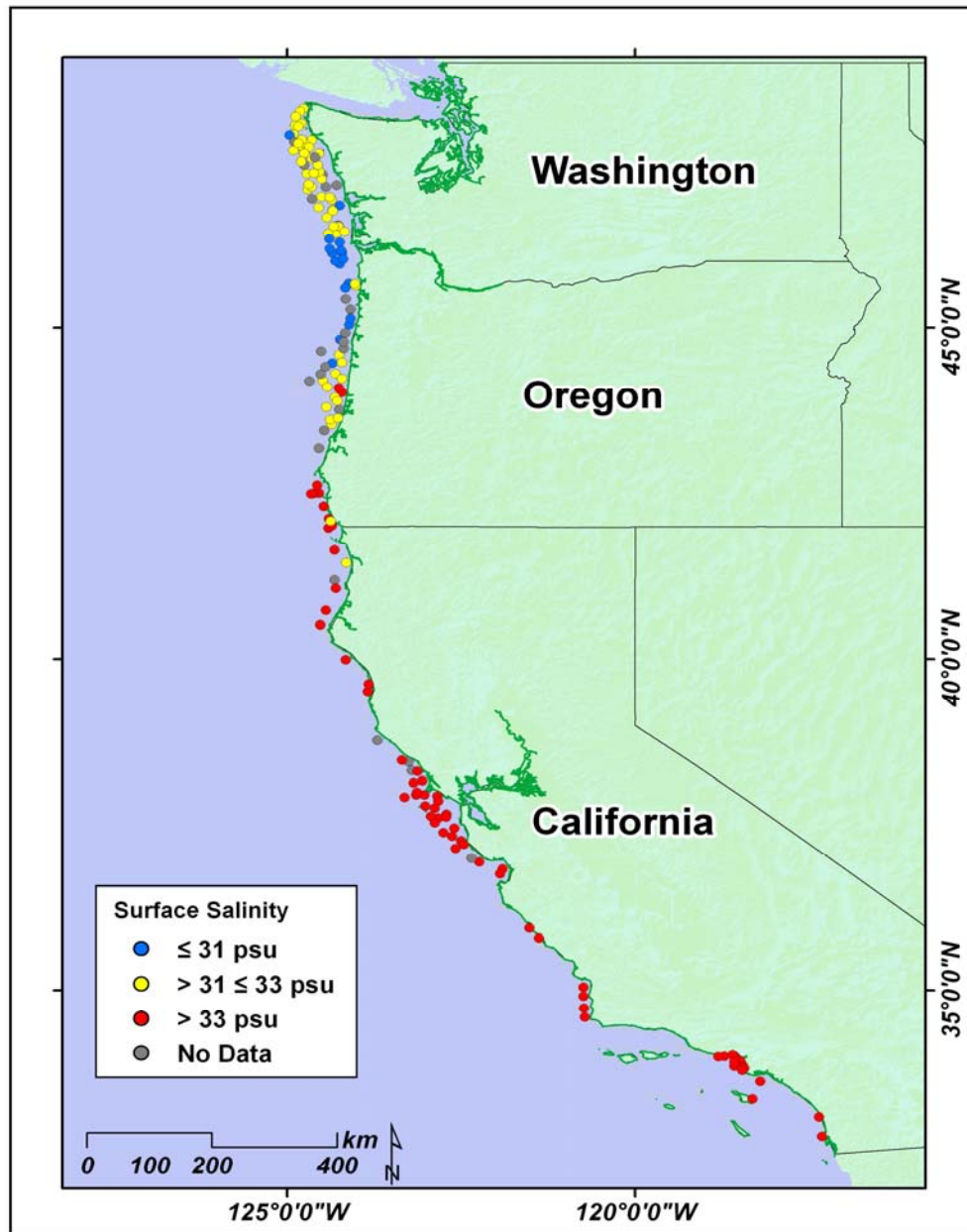


Figure 3.2.1. Distribution of surface salinity values for the West Coast Shelf sampling area, June 2003.

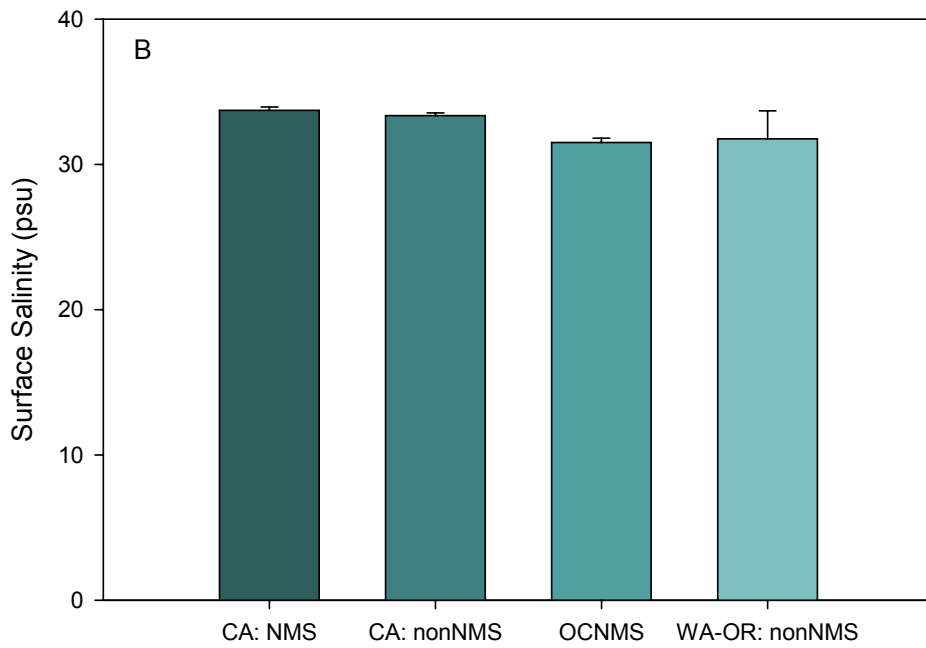
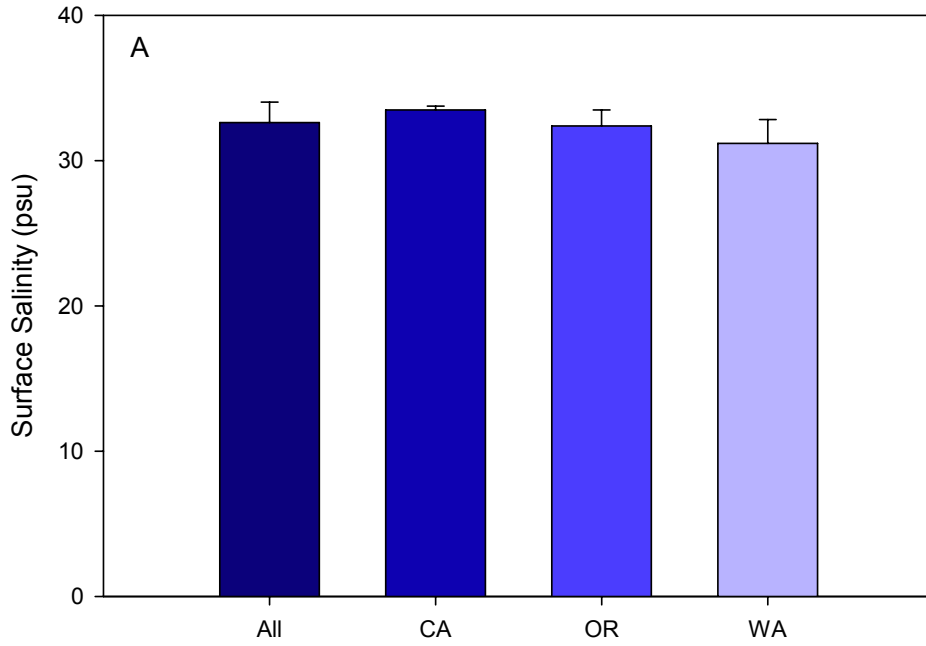


Figure 3.2.2. Mean +1 SD surface salinity compared among (A) all, California, Oregon, and Washington sample locations, and (B) California NMS, California non-NMS, Olympic Coast NMS, and Washington-Oregon non-NMS sample locations.

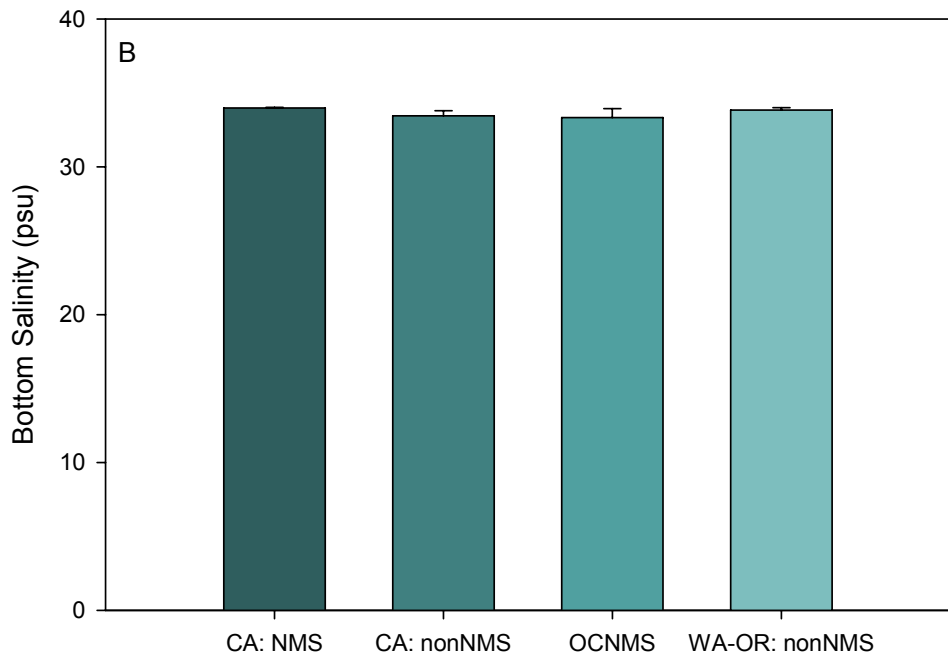
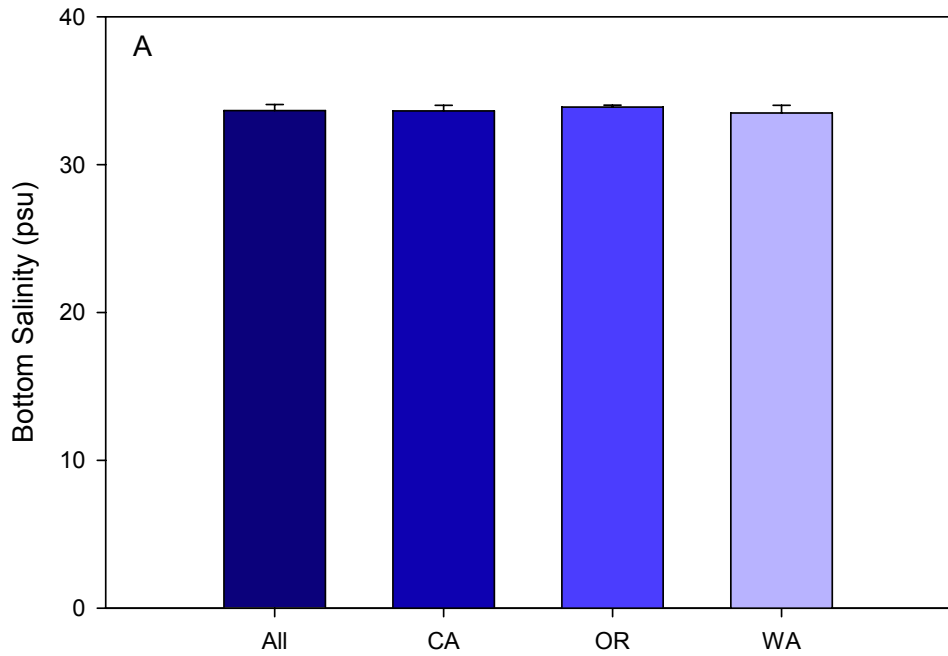


Figure 3.2.3. Mean +1 SD bottom salinity compared among (A) all, California, Oregon, and Washington sample locations, and (B) California NMS, California non-NMS, Olympic Coast NMS, and Washington-Oregon non-NMS sample locations.

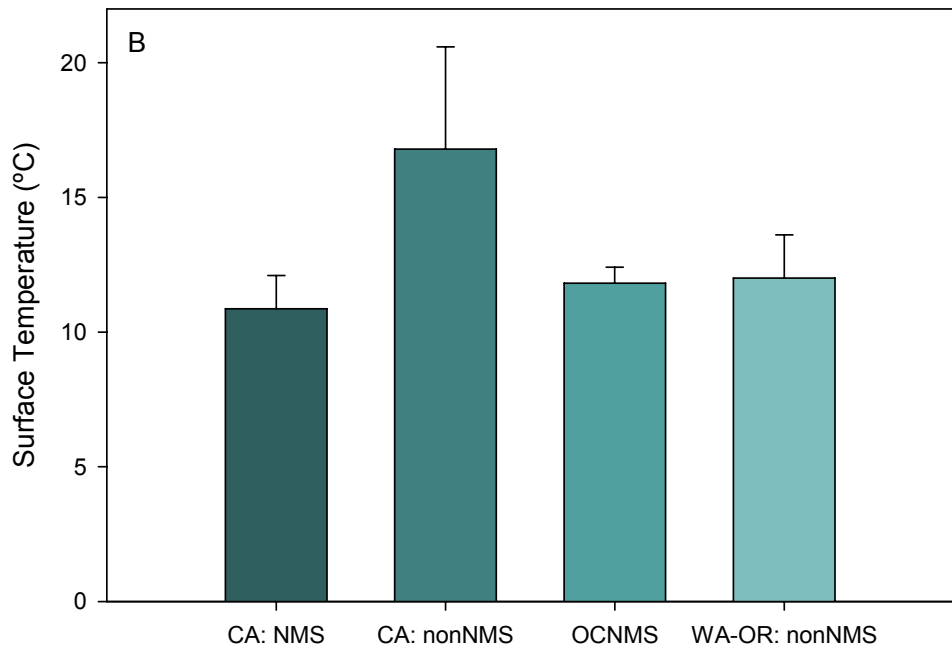
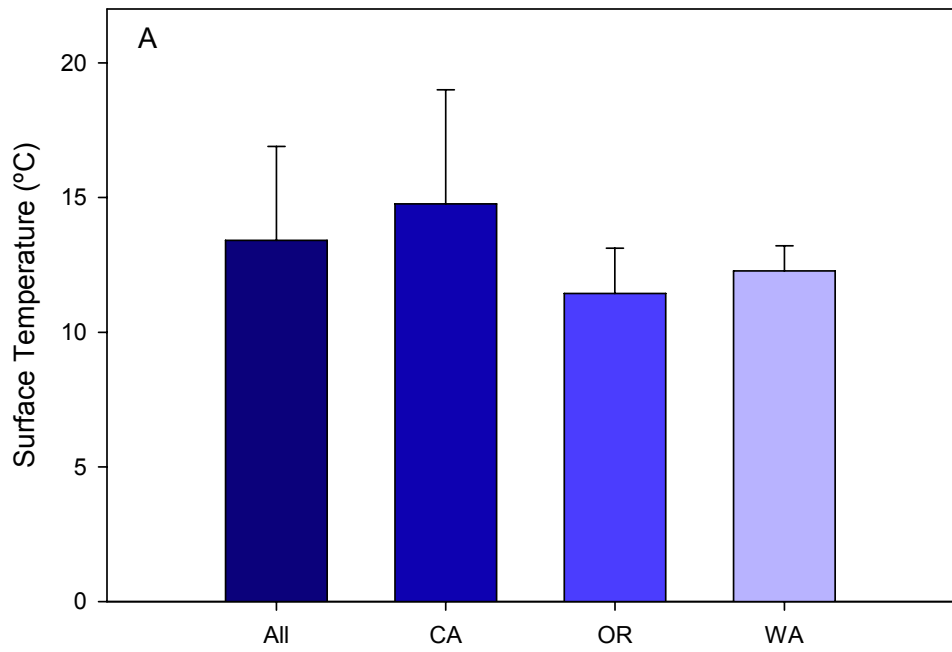


Figure 3.2.4. Mean +1 SD surface temperature compared among (A) all, California, Oregon, and Washington sample locations, and (B) California NMS, California non-NMS, Olympic Coast NMS, and Washington-Oregon non-NMS sample locations.

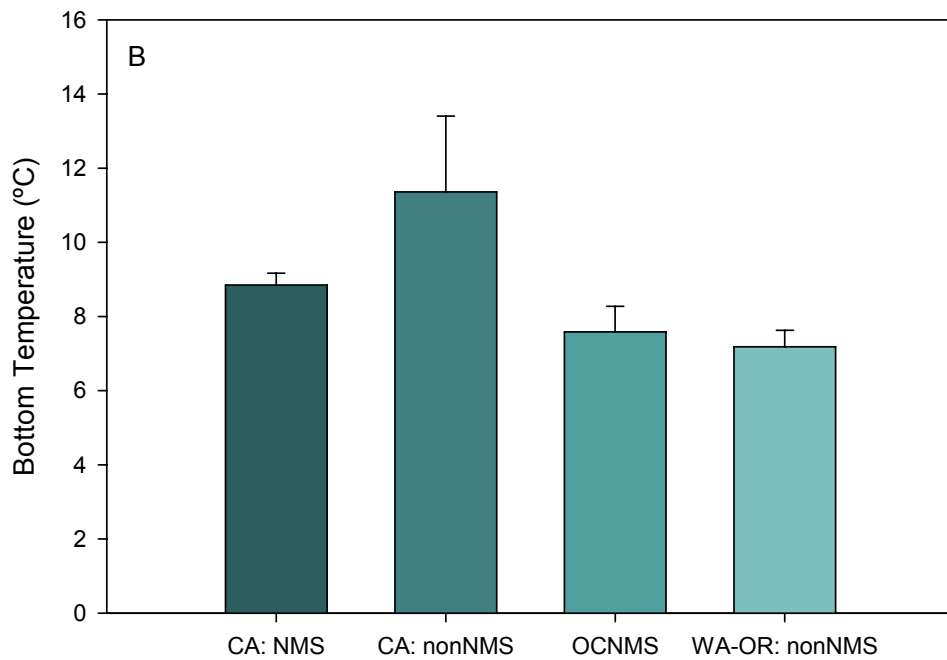
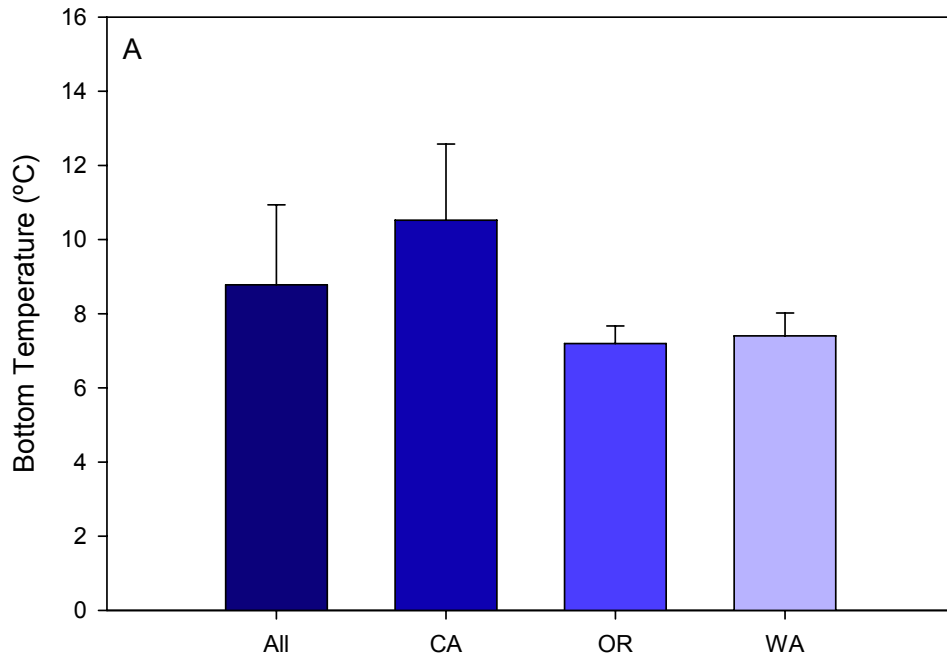


Figure 3.2.5. Mean +1 SD bottom temperature compared among (A) all, California, Oregon, and Washington sample locations, and (B) California NMS, California non-NMS, Olympic Coast NMS, and Washington-Oregon non-NMS sample locations.

### 3.2.3 Water-Column Stratification

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

The  $\Delta\sigma_t$  index for the 140 stations from waters of the West Coast shelf for which data were available ranged from 0.9 to 10.6. Approximately 30.5% of the area of waters of the West Coast shelf had  $\Delta\sigma_t$  index values greater than 2, indicating strong vertical stratification of the water column. The mean stratification index was greatest for waters off Washington and least for California waters (Figure 3.2.6). The mean stratification index was lowest for the CA NMS locations and less than half the mean for the CA non-NMS stations. During the sampling of the central California coast where three of the CA NMS are located, extremely high winds were encountered, and it is likely that wind induced upwelling greatly reduced water-column stratification in this region. The Bakun upwelling index reflects the intensity of large-scale, wind-induced coastal upwelling based on estimates of offshore Ekman transport driven by geostrophic wind stress. Index values for 36° N latitude for the West Coast in June 2003 (source:

[http://www.pfeg.noaa.gov/products/PFEL/modeled/indices/upwelling/NA/upwell\\_menu\\_NA.html](http://www.pfeg.noaa.gov/products/PFEL/modeled/indices/upwelling/NA/upwell_menu_NA.html)) showed that the peak upwelling period for the month occurred in the period June 17-24, exactly at the time when the CA NMS stations were being sampled (Figure 3.2.7).

### 3.2.4 Dissolved Oxygen

The range of dissolved oxygen (DO) concentrations in the surface waters of the West Coast shelf (data available for 140 stations) was 4.1 mg/L to 13.3 mg/L. U.S. EPA (2000a) proposed that a DO value below 2.3 mg/L is harmful to the survival and growth of marine animals based on data from the Virginian biogeographic province. A DO value of > 4.8 mg/L is considered the chronic protective value for growth, i.e. the ceiling above which DO conditions should support both survival and growth of most marine species. Values between 2.3 and 4.8 mg/L are potentially harmful to larval recruitment, depending on duration. Only approximately 2.6 % of the area of waters of the West Coast shelf had surface DO concentrations  $\leq$  4.8 mg/L. The 50<sup>th</sup> percentile of area had a surface-water DO concentration of 9.8 mg/L. Surface DO concentrations were higher in Washington and Oregon waters than in California and higher in the OC NMS than in the CA NMSs (Figure 3.2.8).

Bottom-water DO concentrations region-wide ranged from 2.1 to 8.3 mg/L across the 140 stations with acceptable DO data. Unfortunately, an instrument

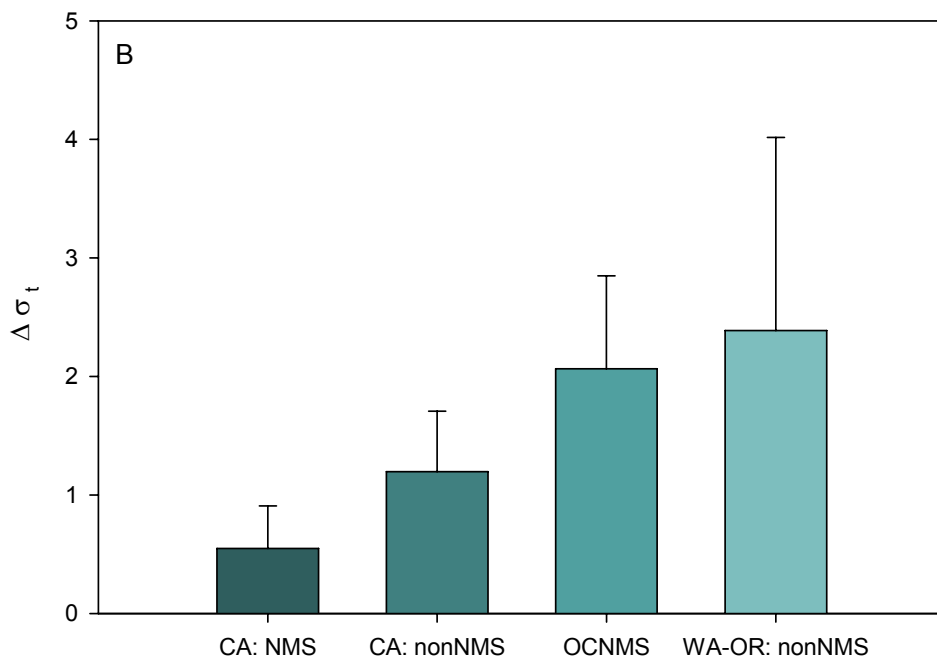
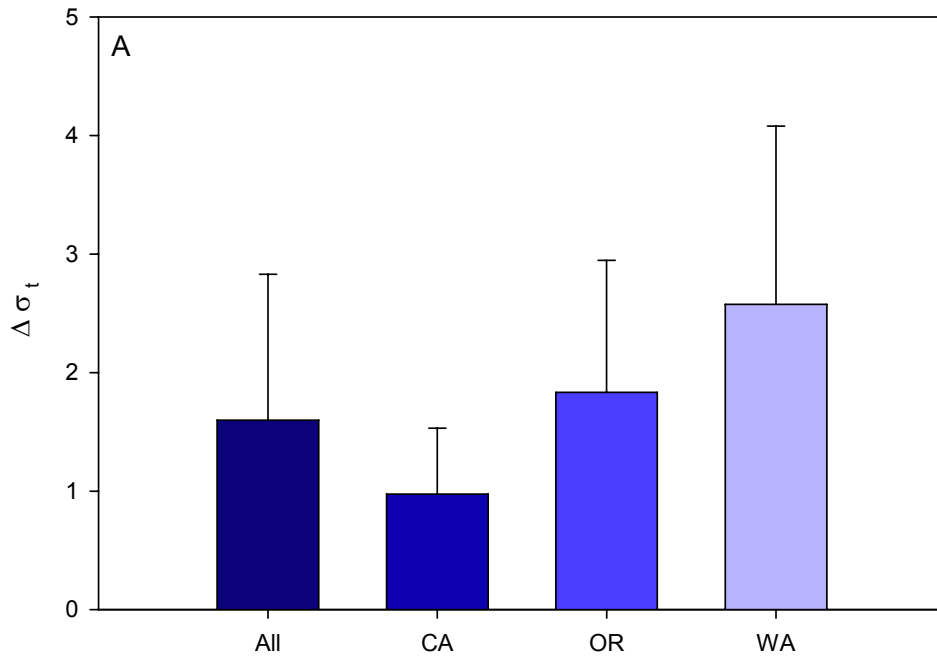


Figure 3.2.6. Mean +1 SD water-column stratification index ( $\Delta\sigma_t$ ) compared among (A) all, California, Oregon, and Washington sample locations, and (B) California NMS, California non-NMS, Olympic Coast NMS, and Washington-Oregon non-NMS sample locations.



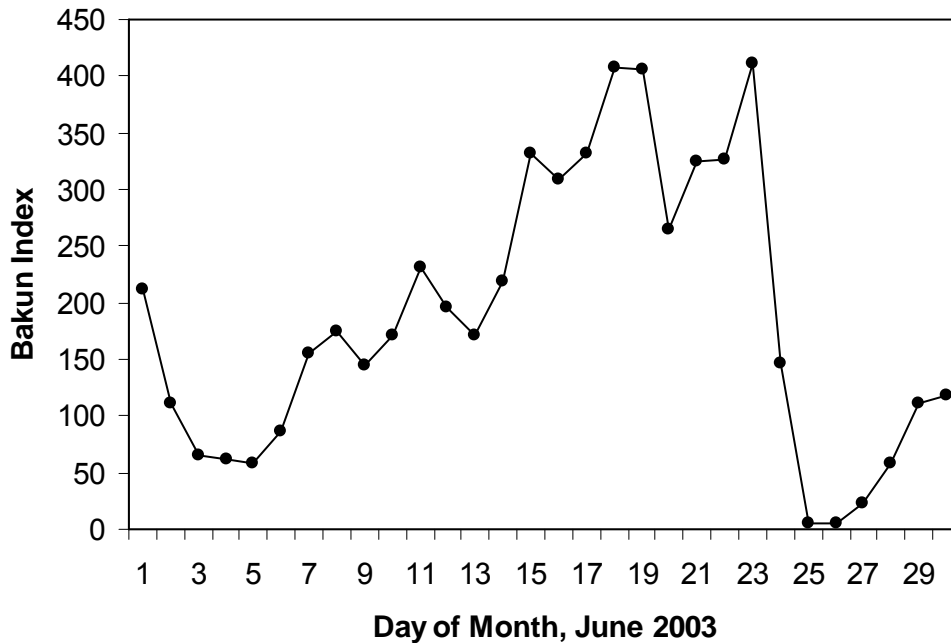


Figure 3.2.7. Bakun upwelling index for 36° N latitude for the West Coast in June 2003.

cable problem resulted in a failure to collect DO data from many stations along the north and central Oregon coast. An estimated 94.3% of the shelf area had a bottom-water DO concentration  $\leq 4.8$  mg/L and 6.6% of the area (6 of the 140 stations where DO data were available) had a bottom-water DO concentration  $\leq 2.3$  mg/L. There was no geographic concentration of stations with bottom-water DO in this  $\leq 2.3$  mg/L range (Figure 3.2.9). Stations with bottom-water DO  $\geq 4.8$  mg/L were concentrated at the extreme southern and northern ends of the survey region. Mean bottom-water DO concentrations were lower at Oregon stations than for Washington and California locations (Figure 3.2.10 A). Mean bottom DO was lower at the CA NMS stations than at the CA non-NMS stations, presumably resulting from the strong upwelling occurring during the sampling period that moved deeper low-DO water into the area (Figure 3.2.10 B).

Hypoxia on the continental shelf of the West Coast appears to be associated with upwelling conditions in the region, while severe hypoxic events in inshore shelf areas ( $< 70$  m) may be associated with changes in cross-shelf current patterns (Grantham et al. 2004). It appears that the frequency of shelf hypoxia has increased in recent years, and that shelf anoxia has now been observed at inner-shelf stations within 2 km of the surf zone (Chan et al. 2008).

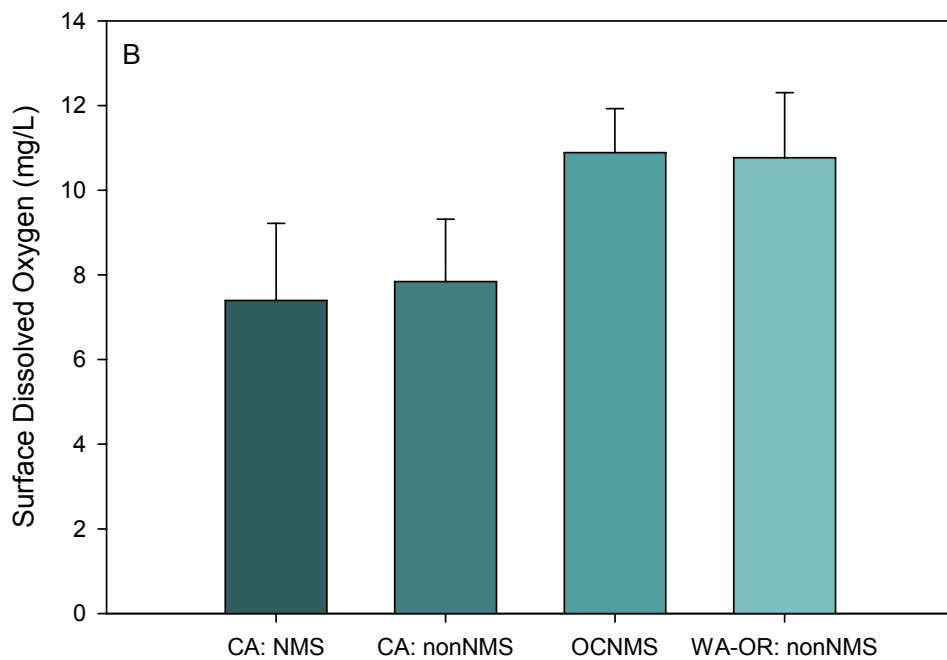
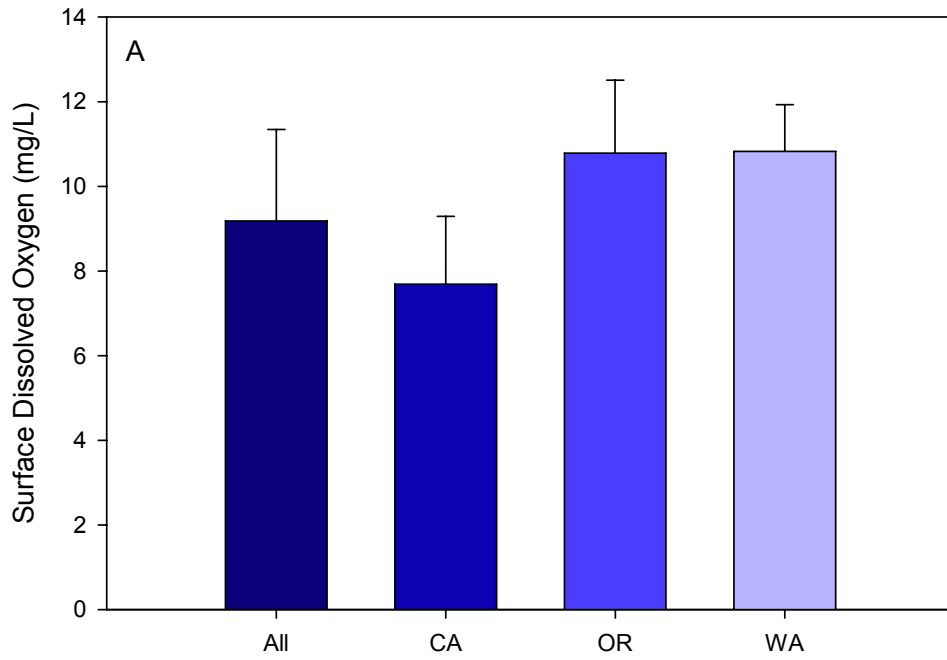


Figure 3.2.8. Mean +1 SD surface dissolved oxygen compared among (A) all, California, Oregon, and Washington sample locations, and (B) California NMS, California non-NMS, Olympic Coast NMS, and Washington-Oregon non-NMS sample locations.

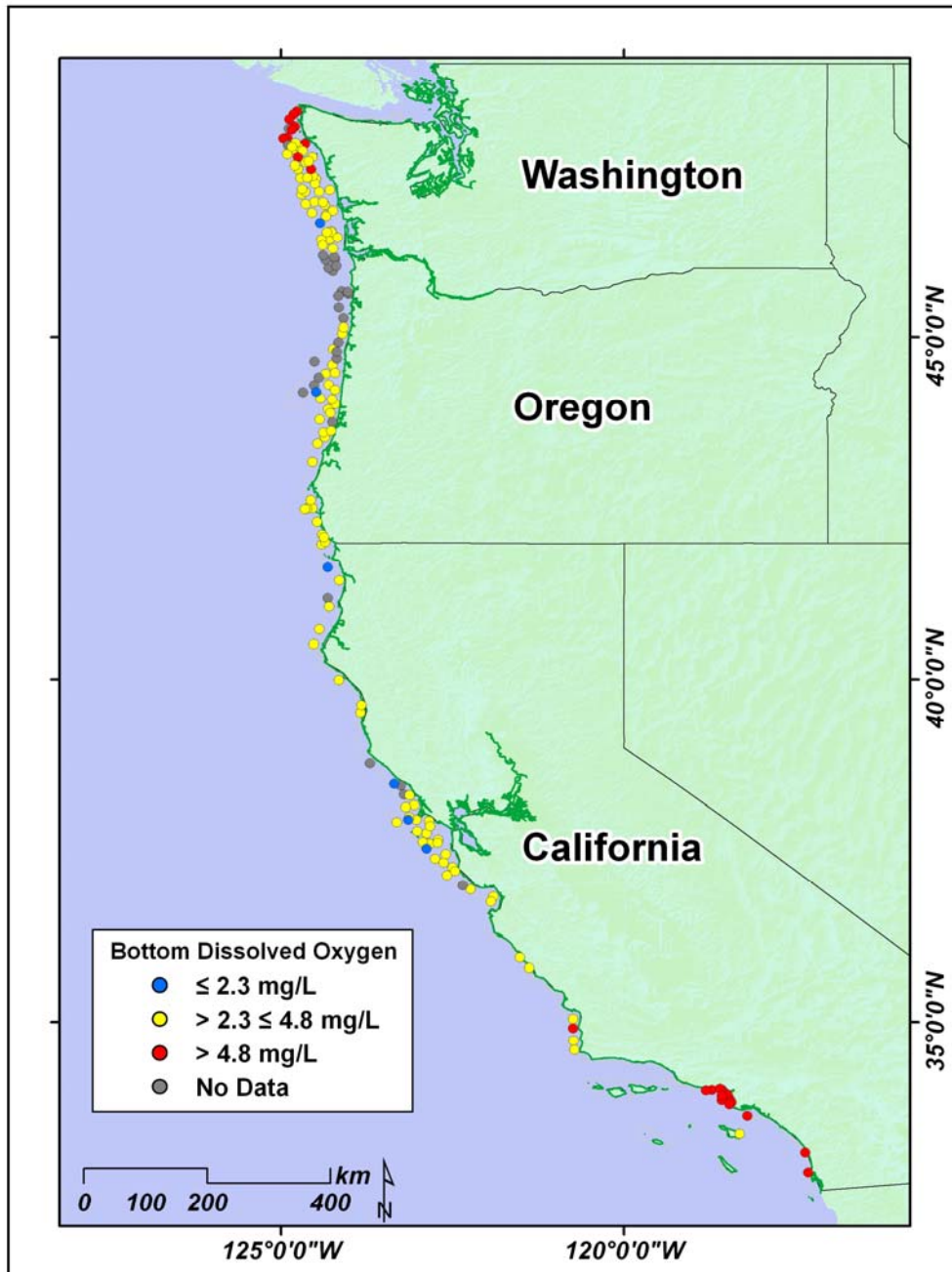


Figure 3.2.9. Distribution of bottom dissolved oxygen concentration values for the West Coast Shelf sampling area, June 2003.

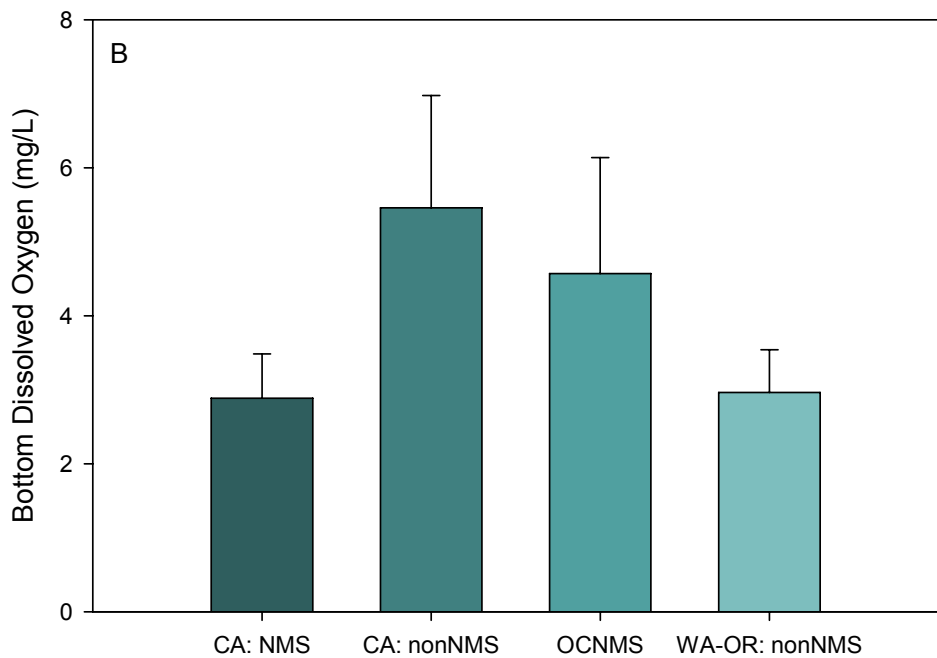
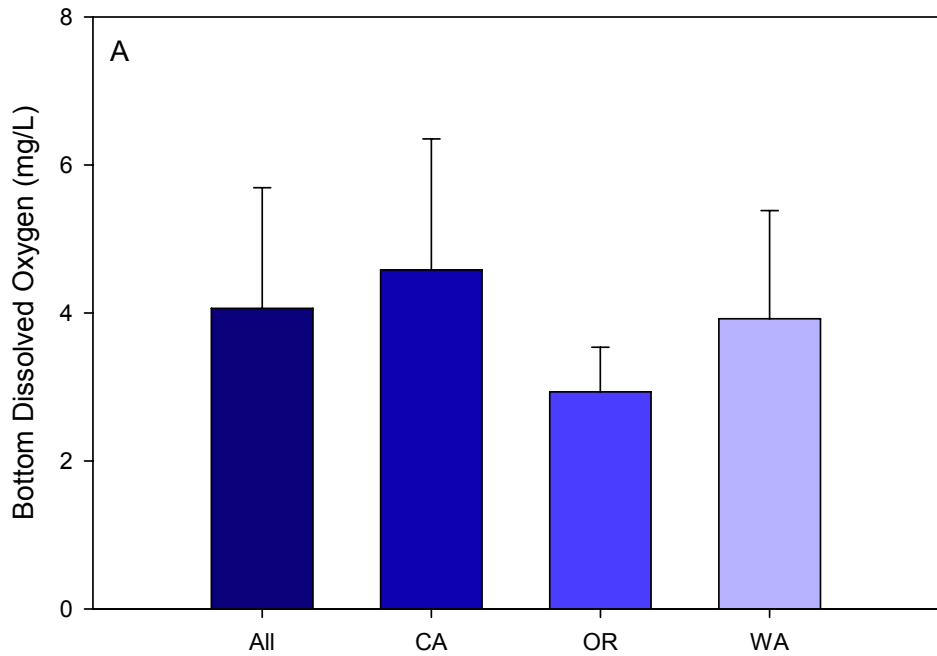


Figure 3.2.10. Mean +1 SD bottom dissolved oxygen compared among (A) all, California, Oregon, and Washington sample locations, and (B) California NMS, California non-NMS, Olympic Coast NMS, and Washington-Oregon non-NMS sample locations.

### 3.2.5 Total Suspended Solids

The surface values for Total Suspended Solids (TSS) in waters of the West Coast shelf ranged from 0 to 10 mg/L for the 137 stations with data. Because the TSS samples from Oregon were not properly processed, these data were not included in the present analysis. The 50<sup>th</sup> percentile of the survey area had a TSS concentration of 4.0 mg/L, and the 90<sup>th</sup> percentile of area corresponded to a TSS concentration of 7.4 mg/L. Mean TSS in surface waters was slightly higher for stations in Washington than for those in California (Figure 3.2.11A). There was little difference in mean TSS between NMS and non-NMS locations (Figure 3.2.11B).

### 3.2.6 Transmissivity

Transmissivity in the surface waters of the West Coast shelf ranged from 13.7% to 98.9% across the 140 stations with acceptable data. The 50<sup>th</sup> percentile of the survey area had transmissivity of 74.3%, and the 90<sup>th</sup> percentile of area had a transmissivity of 86.8%. Mean transmissivity in surface waters was higher for stations in California than for those in Oregon and Washington and showed little difference between stations inside vs. outside NMSs (Figure 3.2.12).

Transmissivity in the bottom waters of the West Coast shelf ranged from 5.0% to 95.2% across the 175 stations with acceptable data. The 50<sup>th</sup> percentile of the survey area had transmissivity of 85.6% and the 90<sup>th</sup> percentile of area had a transmissivity of 91.6%. Mean transmissivity in bottom waters showed little difference among geographic regions or between NMS and non-NMS locations (Figure 3.2.13). Across the West Coast shelf, bottom waters had relatively higher mean transmissivity than surface waters (Figures 3.2.12; 3.2.13).

### 3.2.7 Nutrients

The surface-water concentration of nitrate + nitrite in waters of the West Coast shelf ranged from 0 to 546.6 µg/L at the 188 stations with data. The 50<sup>th</sup> percentile of area of the surface waters of the West Coast shelf sampled had a nitrate + nitrite concentration of 26.2 µg/L, with the 90<sup>th</sup> percentile of area characterized by a nitrate + nitrite concentration of 354 µg/L. The mean value of nitrate + nitrite concentration in surface waters was highest in California as compared to Washington and Oregon and three times higher in the CA NMS stations as compared to the CA non-NMS stations (Figure 3.2.14). The elevated nitrate + nitrite observed at the CA NMS stations is consistent with the presence of strong upwelling at these sites at the time of sampling.

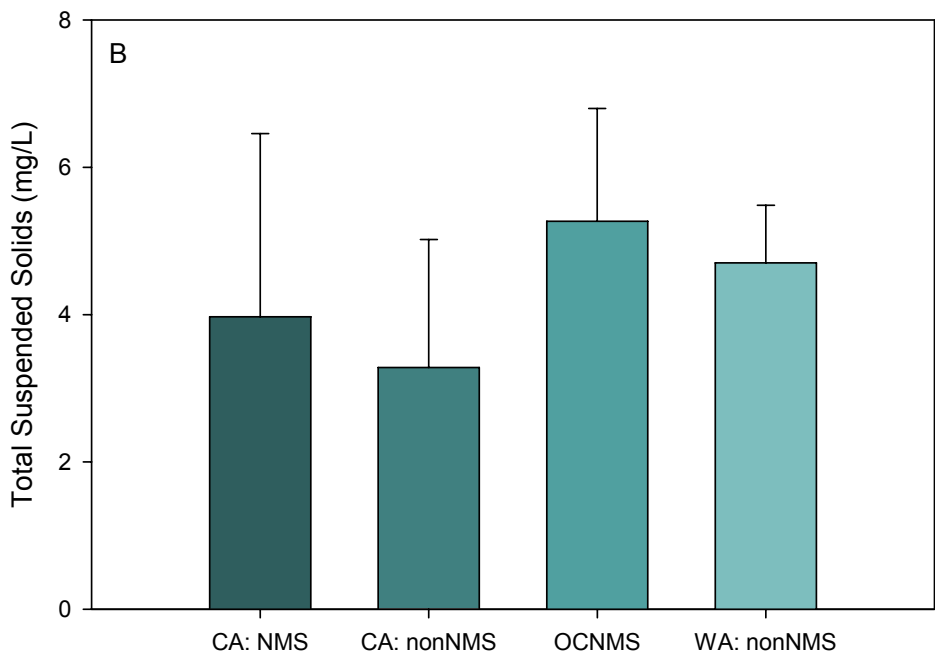
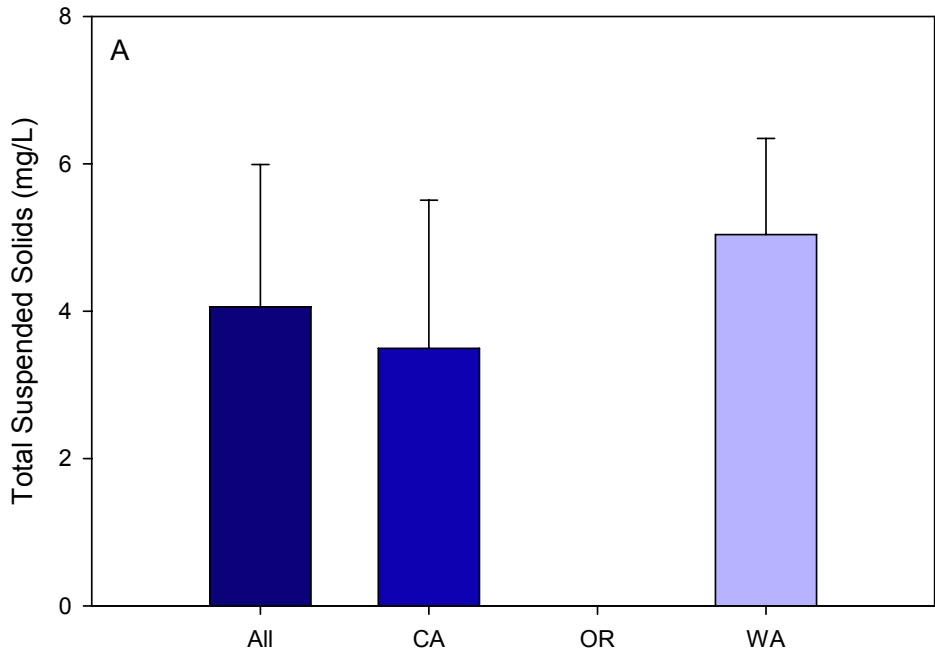


Figure 3.2.11. Mean +1 SD surface Total Suspended Solids compared among (A) all, California, and Washington sample locations, and (B) California NMS, California non-NMS, Olympic Coast NMS, and Washington non-NMS sample locations. Oregon data was not acceptable.

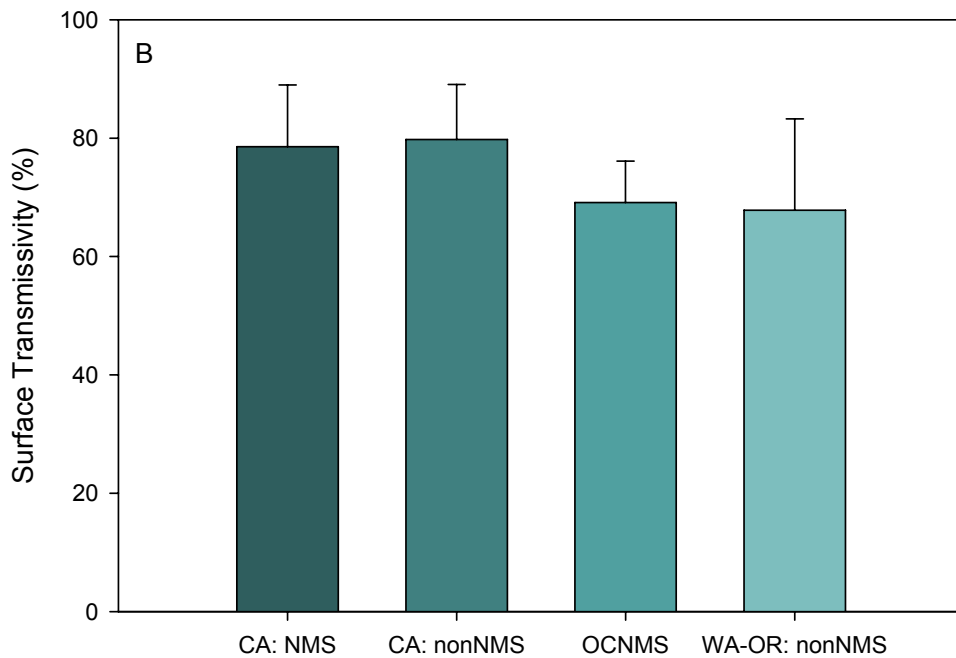
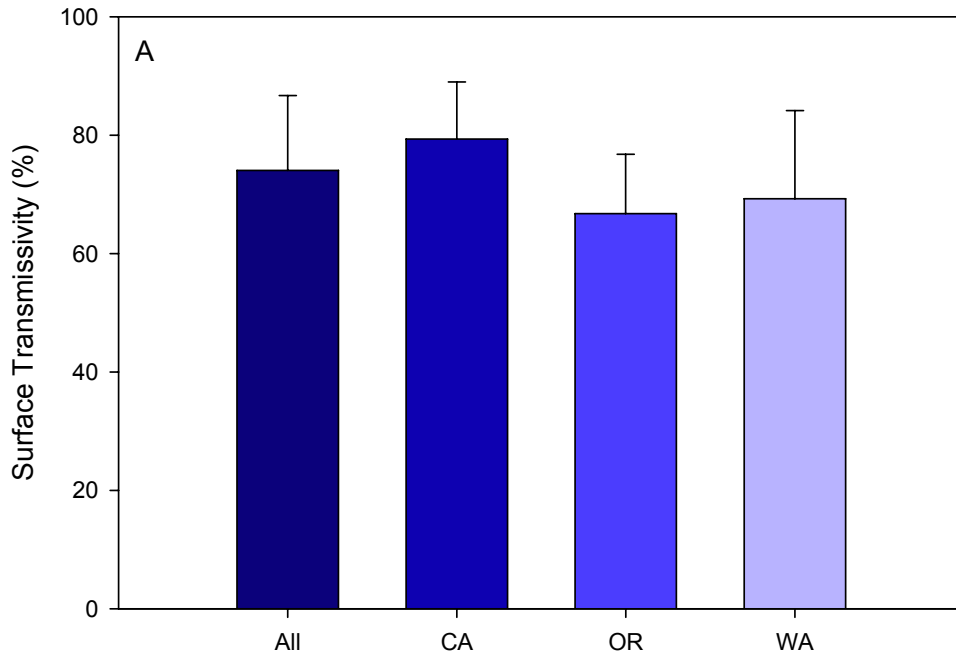


Figure 3.2.12. Mean +1 SD surface transmissivity compared among (A) all, California, Oregon, and Washington sample locations, and (B) California NMS, California non-NMS, Olympic Coast NMS, and Washington-Oregon non-NMS sample locations.

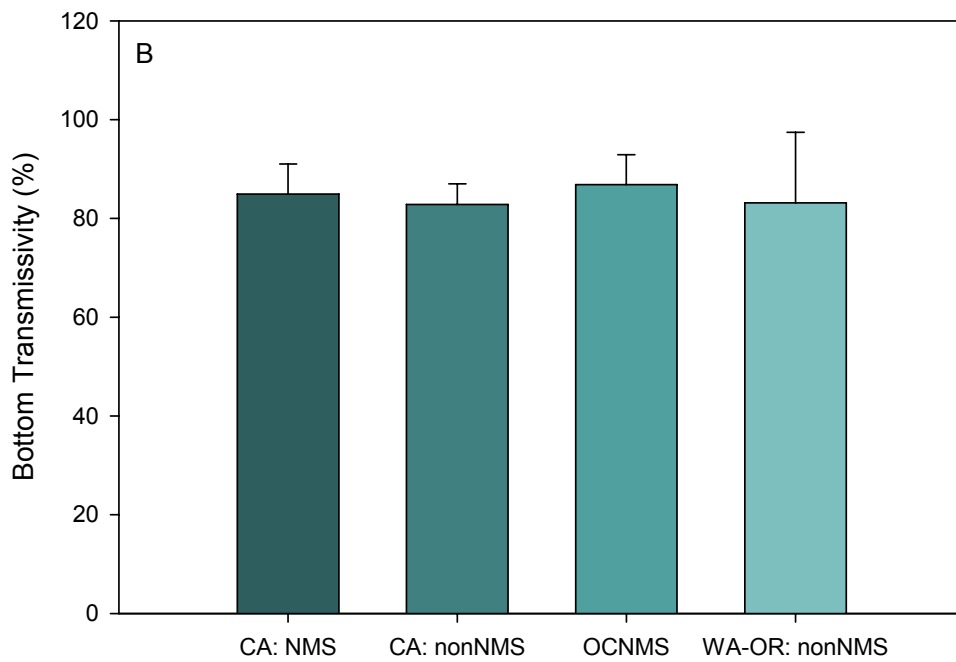
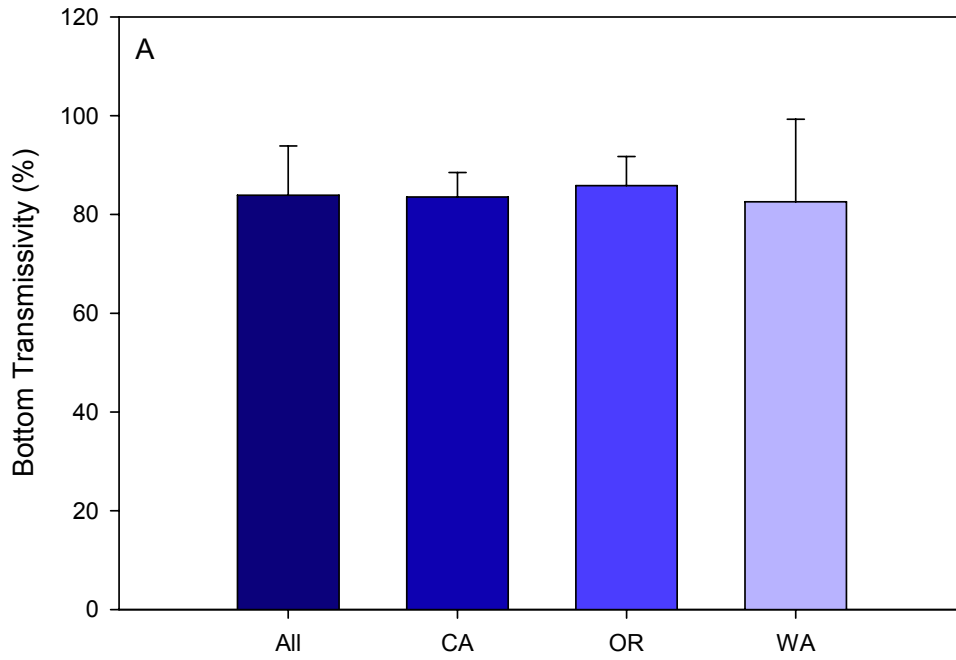


Figure 3.2.13. Mean +1 SD bottom transmissivity compared among (A) all, California, Oregon, and Washington sample locations, and (B) California NMS, California non-NMS, Olympic Coast NMS, and Washington-Oregon non-NMS sample locations.



The surface-water concentration of ammonium in waters of the West Coast shelf, exclusive of the waters of the SCB for which ammonium was not analyzed, ranged from 0 to 50 µg/L at the 146 stations for which data were available. The 50<sup>th</sup> percentile of area of the surface waters of the West Coast shelf sampled had an ammonium concentration of 2.2 µg/L, with the 90<sup>th</sup> percentile of total area characterized by an ammonium concentration of 21.4 µg/L. The mean value of ammonium in surface waters was highest in California and Oregon and lowest in Washington, with the lowest mean concentration of ammonium being found from stations sampled in the OCNMS (Figure 3.2.15).

The surface-water concentration of total dissolved inorganic nitrogen (DIN: nitrogen as nitrate + nitrite + ammonium) in waters of the West Coast shelf, exclusive of the waters of the SCB for which ammonium was not analyzed, ranged from 0.1 to 596.7 µg/L for the 146 stations with data. The 50<sup>th</sup> percentile of area of the surface waters of the West Coast shelf sampled had a DIN concentration of 47.4 µg/L, with the 90<sup>th</sup> percentile of total area characterized by a DIN concentration of 367 µg/L. The mean value of DIN concentration in surface waters was highest in California as compared to Washington and Oregon (Figure 3.2.16 A). DIN concentration for the CA NMSs was slightly higher than for the CA non-NMS stations, but the difference was much smaller than was the case for nitrate + nitrite only (Figure 3.2.16 B).

The surface-water concentration of orthophosphate in waters of the West Coast shelf ranged from 0 to 80.1 µg/L for the 188 stations with data. The 50<sup>th</sup> percentile of area of the surface waters of the West Coast shelf sampled had an orthophosphate concentration of 11.4 µg/L, with the 90<sup>th</sup> percentile of total estuarine area characterized by a concentration of 61 µg/L. The mean value of orthophosphate concentration in surface waters was higher in California than in Washington and Oregon, where values were similar (Figure 3.2.17 A). Mean orthophosphate concentration in surface waters of the CA NMSs was more than three times greater than the mean value for the OCNMS and the non-NMS areas of the shelf (Figure 3.2.17 B). The elevated orthophosphate values are again consistent with the occurrence of upwelling during sampling of the CA NMS stations.

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 7.9 to 24.0, across the 146 stations in waters of the West Coast shelf where sufficient measurements were collected to compute the ratio. Approximately 93% of area of the West Coast shelf had N/P values  $\leq 16$ . The 50<sup>th</sup> percentile of area of the waters of the West Coast shelf sampled had a ratio of 12.8, while the 90<sup>th</sup> percentile of area had a ratio of 14.6. The mean N/P values were similar for the three states, while that for the OCNMS

was less than half that of the CA NMS and non-NMS areas (Figure 3.2.18). Examination of the Bakun upwelling index at 48° N shows that there was downwelling occurring in the region of the OCNMS just prior to the sampling at this location, and only weak upwelling occurring during the sampling period.

Silicate concentrations of water samples were analyzed by the states of Washington and California (exclusive of the SCB), but not Oregon. Therefore there were only 97 sample sites with silicate data available. The surface-water concentration of silicate in waters of the West Coast shelf within Washington and California ranged from 0 to 2040.5 µg/L. The 50<sup>th</sup> percentile of area of the waters of the West Coast shelf sampled had a silicate concentration of 307 µg/L, with the 90<sup>th</sup> percentile of area characterized by a concentration of 973 µg/L. The mean silicate concentration for surface waters was similar between Washington and California locations, while the mean silicate concentration for the CA NMSs was approximately twice that of the OCNMS and the non-NMS locations (Figure 3.2.19). These results are again consistent with the spatial patterns of upwelling on the shelf during the sampling period.

### **3.2.8 Chlorophyll *a***

The surface-water concentration of chlorophyll *a* for the 187 stations sampled in waters of the West Coast shelf ranged from 0 to 28 µg/L (Figure 3.2.20). The 50<sup>th</sup> percentile of area of the waters of the West Coast shelf sampled had a chlorophyll *a* concentration of 3.9 µg/L, while the 90<sup>th</sup> percentile had a chlorophyll *a* concentration of 14.5 µg/L. The mean chlorophyll *a* concentration for surface waters in California was less than half that of locations in Washington and Oregon locations (Figure 3.2.20 A). The lowest mean chlorophyll *a* concentration was for the CA non-NMS locations, while the mean for the CA NMS locations was approximately 60% of that found in the OCNMS (Figure 3.2.20 B).

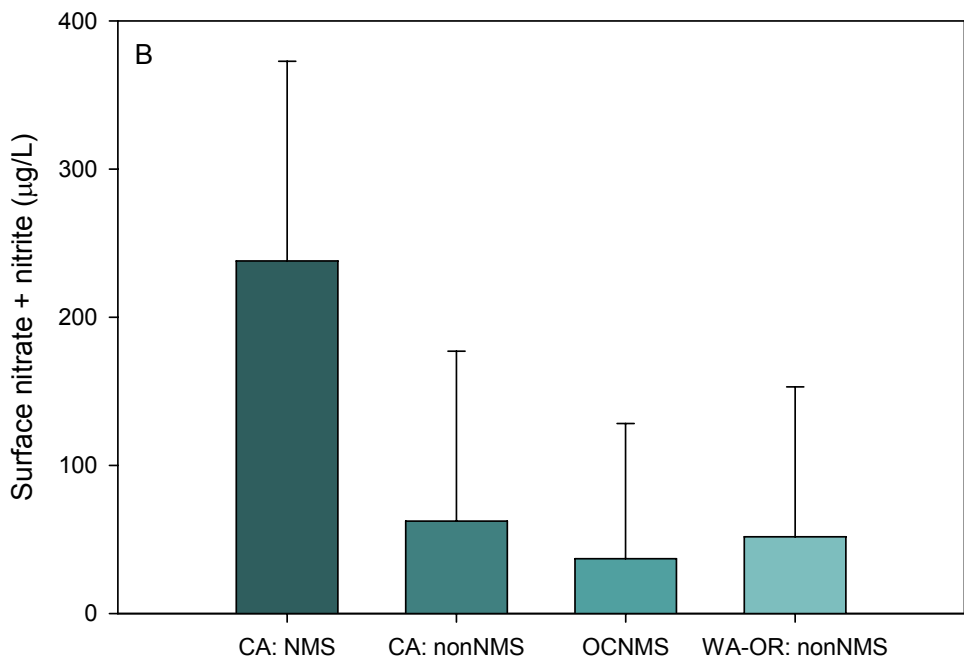
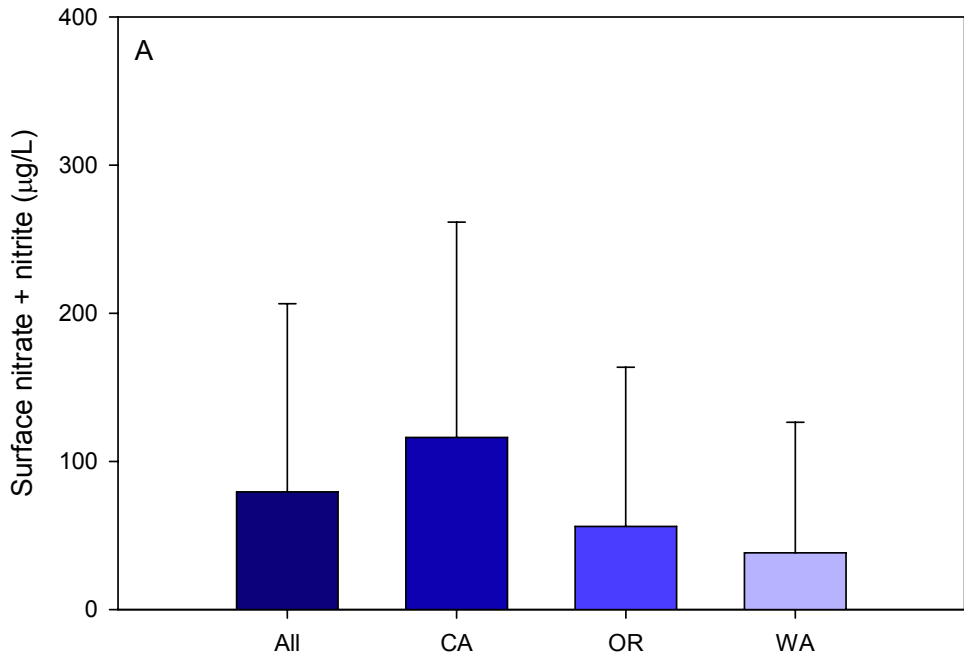


Figure 3.2.14. Mean +1 SD surface nitrate + nitrite compared among (A) all, California, Oregon, and Washington sample locations, and (B) California NMS, California non-NMS, Olympic Coast NMS, and Washington-Oregon non-NMS sample locations.

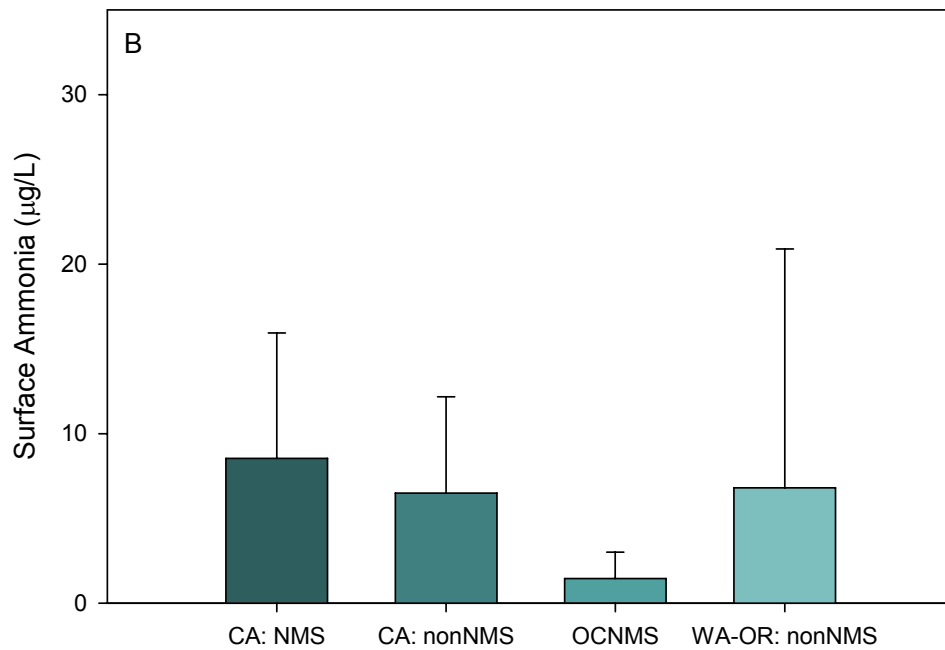
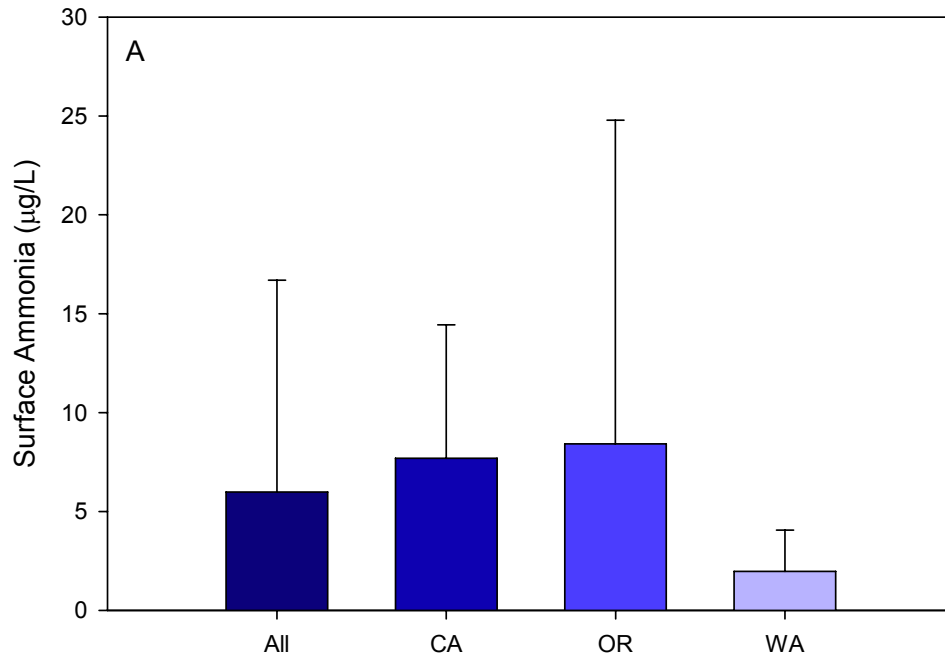


Figure 3.2.15. Mean +1 SD surface ammonia compared among (A) all, California, Oregon, and Washington sample locations, and (B) California NMS, California non-NMS, Olympic Coast NMS, and Washington-Oregon non-NMS sample locations. SCB stations not included due to lack of ammonia data.

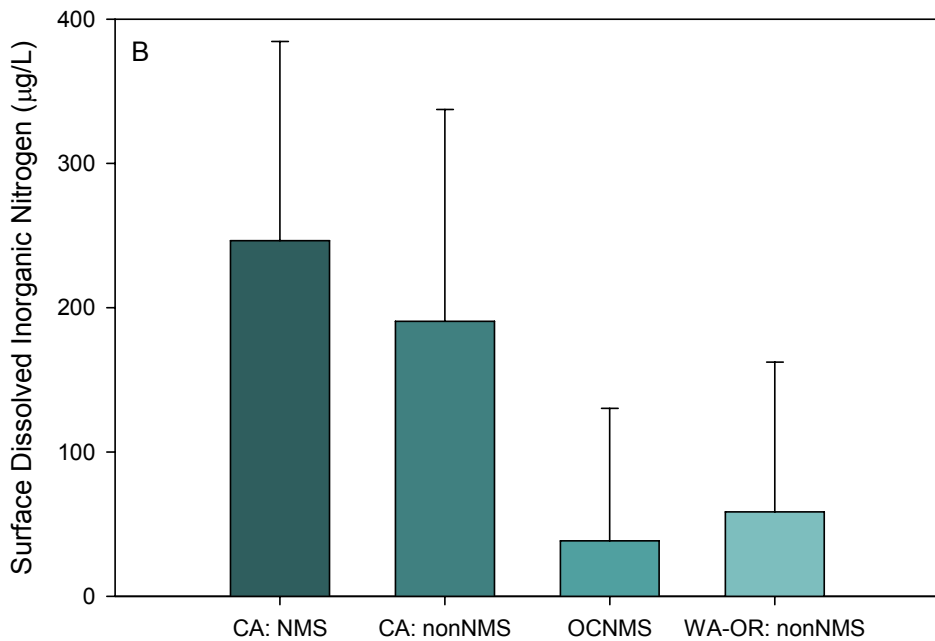
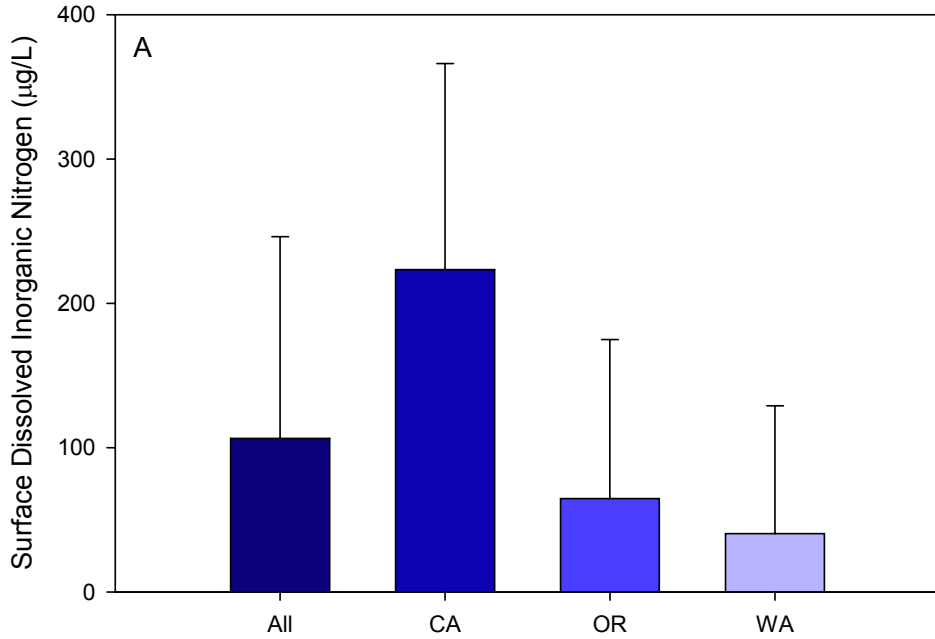


Figure 3.2.16. Mean +1 SD surface dissolved inorganic nitrogen compared among (A) all, California, Oregon, and Washington sample locations, and (B) California NMS, California non-NMS, Olympic Coast NMS, and Washington-Oregon non-NMS sample locations. California Bight stations not included due to lack of ammonium data.

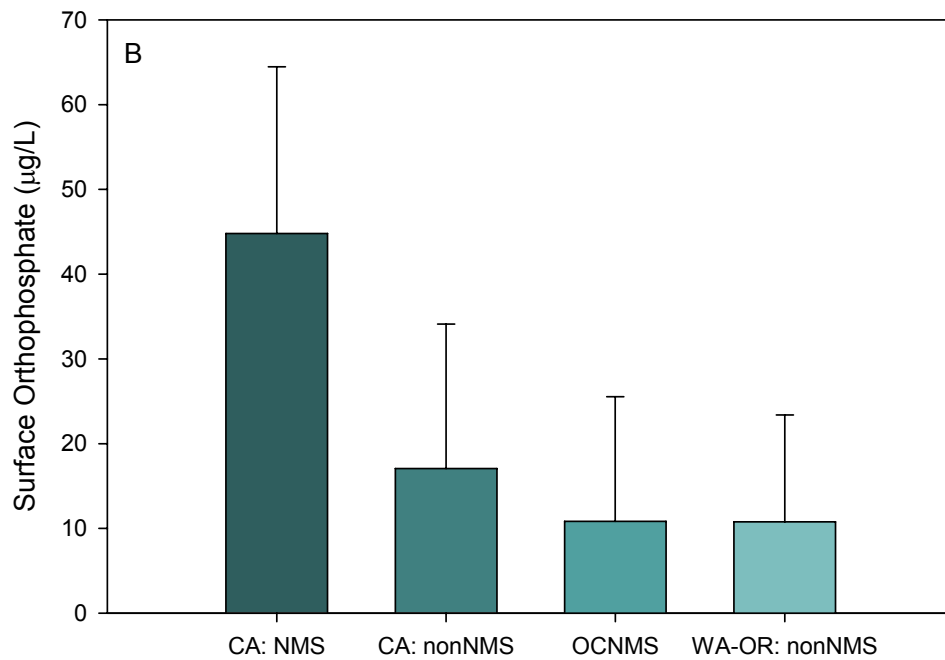
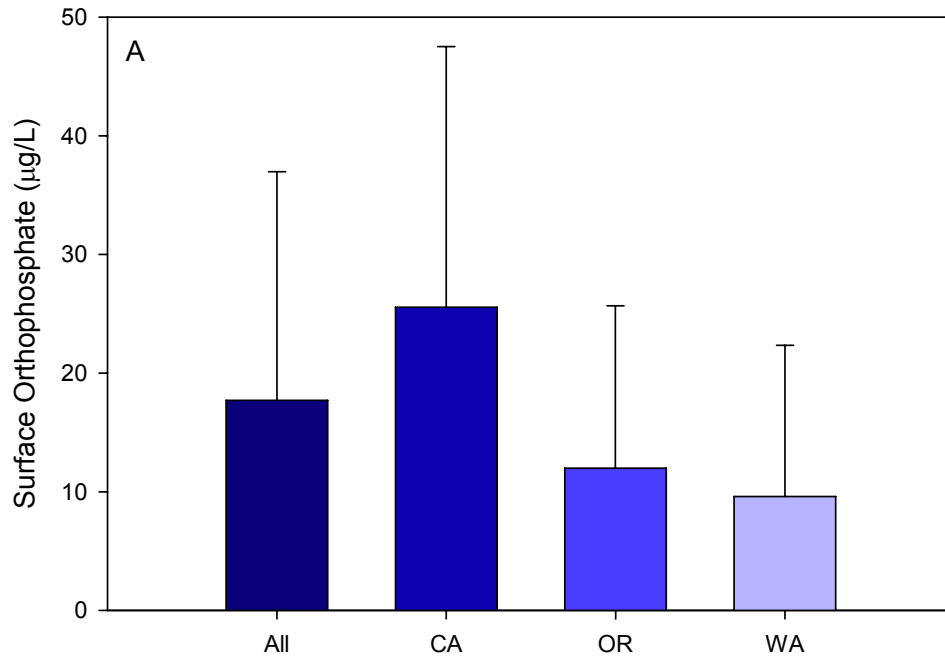


Figure 3.2.17. Mean +1 SD surface orthophosphate compared among (A) all, California, Oregon, and Washington sample locations, and (B) California NMS, California non-NMS, Olympic Coast NMS, and Washington-Oregon non-NMS sample locations.

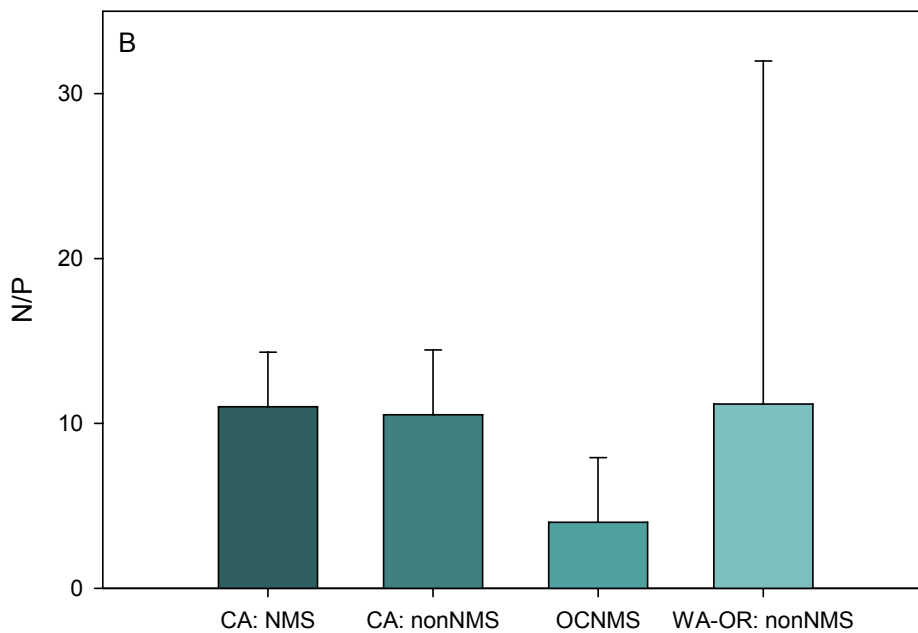
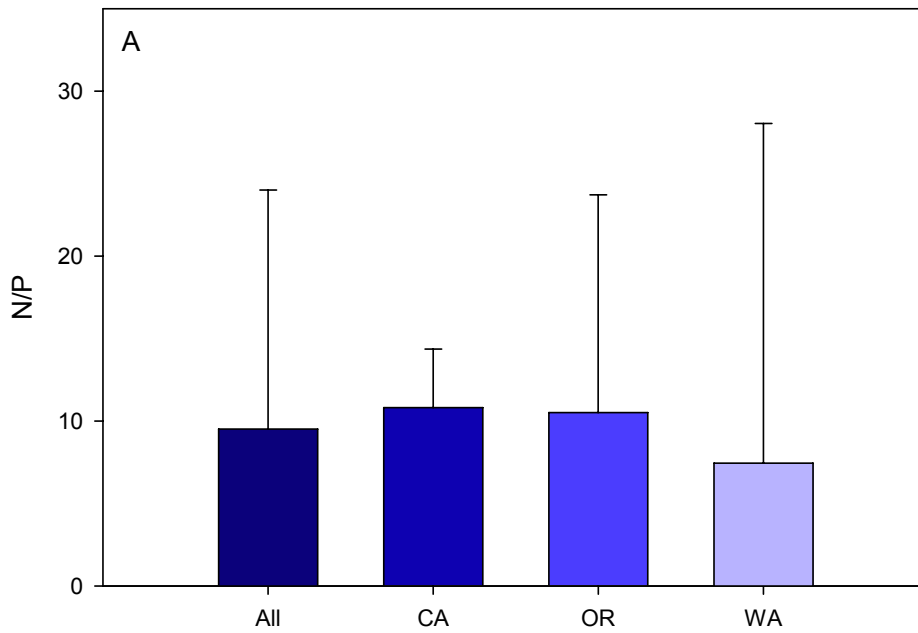


Figure 3.2.18. Mean +1 SD N/P ratio in surface waters compared among (A) all, California, Oregon, and Washington sample locations, and (B) California NMS, California non-NMS, Olympic Coast NMS, and Washington-Oregon non-NMS sample locations. California Bight stations not included due to lack of ammonium data.

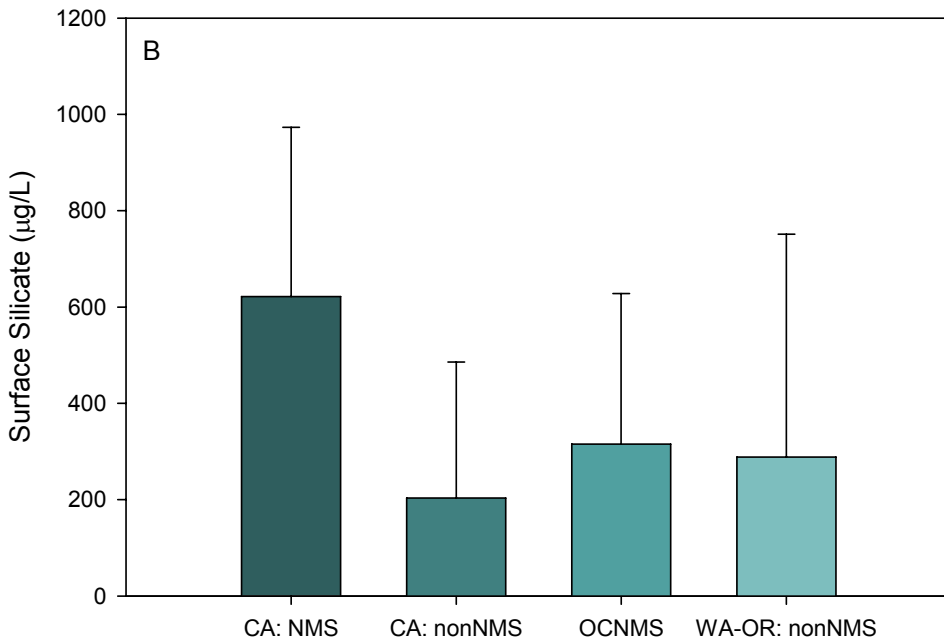
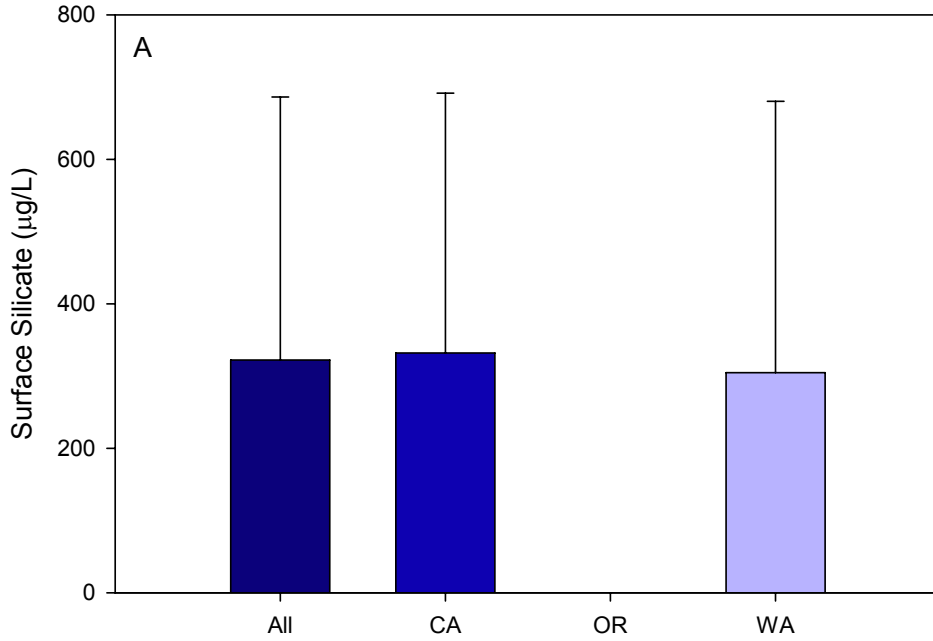


Figure 3.2.19. Mean +1 SD surface silicate concentration compared among (A) all, California, and Washington sample locations, and (B) California NMS, California non-NMS, Olympic Coast NMS, and Washington non-NMS sample locations. Silicate was not measured at stations in Oregon or in the SCB (see text).



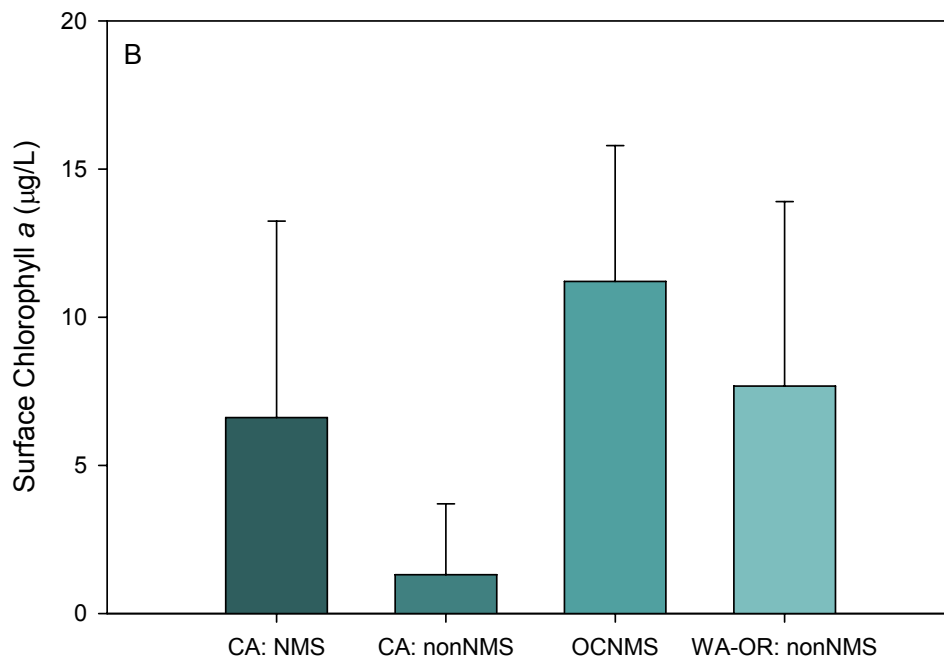
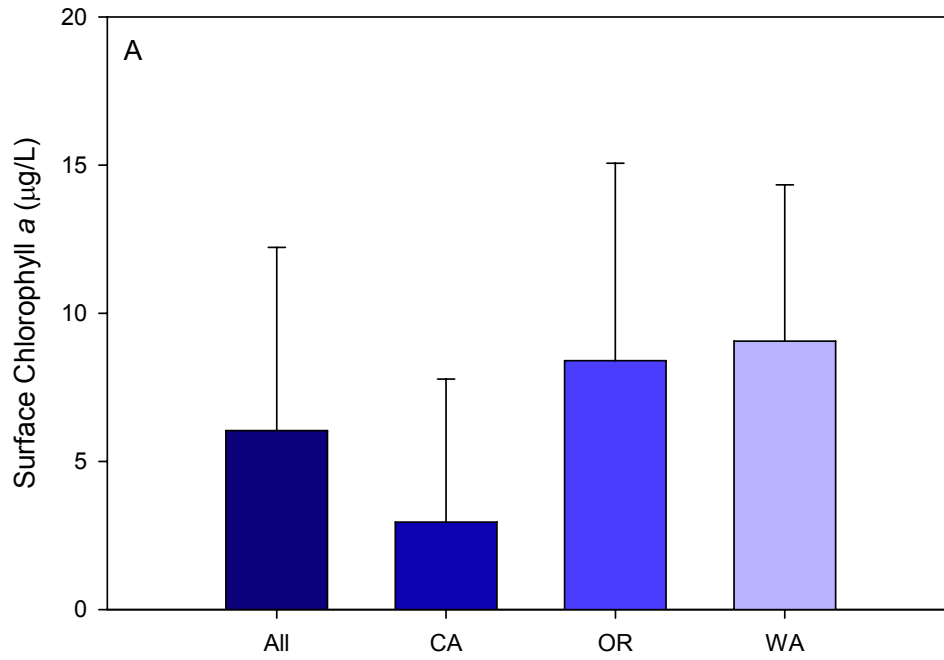


Figure 3.2.20. Mean +1 SD surface chlorophyll *a* concentration compared among (A) all, California, Oregon, and Washington sample locations, and (B) California NMS, California non-NMS, Olympic Coast NMS, and Washington-Oregon non-NMS sample locations.

### 3.3 Sediment Quality

Table 3.3.1 provides a summary of the means and ranges of sediment physical characteristics and chemical contaminant concentrations for all West Coast stations combined as well as by individual states (CA, Oregon, Washington) and National Marine Sanctuary (NMS) vs. non-sanctuary status. The latter comparison includes California sanctuaries (Channel Islands NMS, Monterey Bay NMS, Gulf of the Farallones NMS, and Cordell Bank NMS) vs. non-sanctuary stations in California and stations in the Olympic Coast NMS (OCNMS) vs. non-sanctuary stations in Oregon and Washington. Appendix 4 also provides a breakdown of this information by individual station. Sediment-quality data were available at 257 stations throughout the region for chemical contaminant variables, 255 stations for sediment grain size, and 256 stations for TOC.

#### 3.3.1 Sediment Composition: Grain Size and TOC

The percentage of silt-clay in sediments ranged from 0.5% to 98.7% region-wide (Table 3.3.1, Fig. 3.3.1). Approximately 44% of the overall survey area had sediments composed of sands (< 20% silt-clay), 47% was composed of intermediate muddy sands (20-80% silt-clay), and 9% was composed of muds (> 80% silt-clay). All mud sediments (> 80% silt-clay) occurred in California. The majority of California sediments consisted of intermediate muddy sands, while Oregon and Washington were dominated by sands (Fig. 3.3.2).

Percent total organic carbon (TOC) in sediments exhibited a wide range (0.0% to 7.6%) throughout the region (Table 3.3.1, Fig. 3.3.3). The majority of the survey area (97%) had relatively low TOC levels of < 2%, while a small portion (< 1%), consisting of two sites in California, had high TOC levels (> 5%; Fig. 3.3.4). About 2% of the survey area (represented by 10 sites) had intermediate levels of TOC (2-5%). In comparison, estuarine habitats along the U.S. West Coast have high levels of TOC in similarly limited areas (< 1%) and intermediate levels of TOC over slightly broader areas (11% of the estuarine area) (U.S. EPA 2004). The upper and lower thresholds of 2% and 5% used here for evaluating the biological significance of sediment TOC content are adopted from earlier EPA National Coastal Condition Reports (e.g., U.S. EPA 2004). Hyland et al. (2005) also identified TOC concentrations > 3.6% (36 mg/g) as an upper range associated with a high risk of degraded benthic condition from multiple coastal areas around the world. The portion of the present survey area with TOC in excess of this slightly more conservative cut point also was relatively small (< 1%) and limited to California. The three sites in California with sediment TOC content in excess of either upper threshold (3.6% or 5%) were in the Channel Islands NMS (CINMS) (Fig. 3.3.4, Appendix 4). The cause of the elevated TOC at these sites is unknown at this time.

Table 3.3.1. Comparison of sediment physical characteristics and chemical contaminant concentrations for (A) West Coast vs. individual states and (B) National Marine Sanctuaries (NMS) vs. non-NMS.

A. Data	All		CA		OR		WA	
	Mean (STD)	Range	Mean (STD)	Range	Mean (STD)	Range	Mean (STD)	Range
Physical Char.								
TOC (%)	0.7 (0.8)	0 - 7.6	0.9 (0.9)	0.1 - 7.6	0.4 (0.3)	0 - 1.4	0.4 (0.4)	0 - 1.4
% Fines	31.7 (25.2)	0.5 - 98.7	41.2 (24.8)	1.2 - 98.7	14.2 (13.8)	0.9 - 49.9	19.7 (20.4)	0.5 - 65.3
Metals (µg/g)								
Arsenic	4.7 (2.4)	0 - 14.3	3.9 (2.2)	0 - 14.3	6.8 (2.3)	4.2 - 13.6	5.3 (1.3)	3.2 - 10.5
Cadmium	0.4 (0.5)	0 - 4.9	0.5 (0.6)	0 - 4.9	0.2 (0.3)	0 - 1.4	0.1 (0.1)	0 - 0.5
Chromium	65.2 (57.3)	6.2 - 296.5	45.6 (35.9)	6.2 - 224	129.5 (85.4)	19.5 - 296.5	62.1 (18.4)	25.6 - 124
Copper	12.1 (8.3)	0 - 70.6	11.8 (9.5)	0 - 70.6	13 (7.1)	3.6 - 33.7	12.1 (3.7)	5.6 - 21
Lead	8.3 (4.1)	1.4 - 27.8	6.8 (4.1)	1.4 - 27.8	11.4 (1.4)	8.7 - 14.5	10.1 (3.3)	2.9 - 16.7
Mercury	0.1 (0.1)	0 - 0.6	0.1 (0.1)	0 - 0.6	0 (0)	0 - 0.1	0 (0)	0 - 0.1
Silver	0.1 (0.3)	0 - 2.9	0.1 (0.3)	0 - 2.9	0 (0)	0 - 0.1	0.3 (0.3)	0 - 2
Zinc	51.6 (30.2)	7.2 - 400.3	48.7 (36.2)	7.2 - 400.3	51.7 (19.5)	17.5 - 81.4	60.2 (10.7)	38 - 88.4
Organics (ng/g)								
Acenaphthlene	0.6 (1.7)	0 - 10	0.9 (2)	0 - 10	0 (0)	0 - 0	0.5 (0.7)	0 - 2.1
Acenaphthylene	0.4 (1.9)	0 - 25.8	0.2 (2.1)	0 - 25.8	0 (0)	0 - 0	1.3 (1.9)	0 - 6.1
Anthracene	0.4 (1.2)	0 - 8	0.1 (0.7)	0 - 6.2	0 (0)	0 - 0	1.6 (2.2)	0 - 8
Benz(a)anthracene	2.2 (6.2)	0 - 40.9	2.5 (7.2)	0 - 40.9	0 (0)	0 - 0	3.6 (5.3)	0 - 18
Benzo(a)pyrene	2.5 (6.9)	0 - 64.5	2.3 (7.5)	0 - 64.5	0 (0)	0 - 0	5.5 (7.1)	0 - 25
Chrysene	2.3 (5.2)	0 - 41.1	2.7 (6.1)	0 - 41.1	0 (0)	0 - 0	3.3 (3.7)	0 - 12
Dibenzo(a,h)anthracene	0.2 (0.7)	0 - 4	0.1 (0.3)	0 - 1.9	0 (0)	0 - 0	1 (1.3)	0 - 4
Fluoranthene	3.6 (7.2)	0 - 40	2.8 (5.3)	0 - 37.2	0 (0)	0 - 0	9.7 (11.4)	0 - 40
Fluorene	1.2 (3.6)	0 - 23.5	1.5 (4.4)	0 - 23.5	0 (0)	0 - 0	1.7 (1.8)	0 - 5.9
2-Methylnaphthalene	14.4 (35.7)	0 - 217	21.9 (44)	0 - 217	0 (0)	0 - 0	5.3 (5.2)	0 - 25
Naphthalene	8.6 (19.4)	0 - 110.4	12 (23.7)	0 - 110.4	0 (0)	0 - 0	6.6 (7.8)	0 - 26
Phenanthrene	5.2 (8.4)	0 - 46	4.8 (7.7)	0 - 32	0 (0)	0 - 0	11.3 (10.6)	0 - 46
Pyrene	4.7 (9.3)	0 - 54.4	4.2 (8.5)	0 - 54.4	0 (0)	0 - 0	10.9 (12.9)	0 - 54
Low molecular weight PAH	55.8 (112.4)	0 - 644.4	75.3 (136.6)	0 - 644.4	0 (0)	0 - 0	50.2 (46.4)	0 - 199.9
High molecular weight PAH	23.0 (46.7)	0 - 343.7	20.8 (42.8)	0 - 343.7	0 (0)	0 - 0	52.8 (64.2)	0 - 226.8
Total PAHs	78.8 (124.9)	0 - 644.4	96.2 (140.7)	0 - 644.4	0 (0)	0 - 0	103 (103.2)	0 - 347.4
Total DDT								
4,4'-DDE	46.3 (298.9)	0 - 3905.7	75.8 (380)	0 - 3905.7	0 (0)	0 - 0	0.1 (0.2)	0 - 0.8
	36.6 (229.8)	0 - 2970	59.7 (291.4)	0 - 2970	0 (0)	0 - 0	0 (0.1)	0 - 0.4
Total PCBs								
	2.7 (14.5)	0 - 165.1	4.4 (18.4)	0 - 165.1	0 (0)	0 - 0	0 (0)	0 - 0

B. Data	CA: NMS		CA: non-NMS		OCNMS		OR-WA: non-NMS	
	Mean (STD)	Range	Mean (STD)	Range	Mean (STD)	Range	Mean (STD)	Range
Physical Char.								
TOC (%)	1.2 (1.4)	0.2 - 7.6	0.7 (0.4)	0.1 - 2.4	0.3 (0.4)	0 - 1.3	0.4 (0.4)	0 - 1.4
% Fines	33.8 (24)	1.2 - 94	44.9 (24.4)	2.4 - 98.7	17.5 (22.2)	0.5 - 65.3	16.7 (15.3)	0.7 - 57
Metals (µg/g)								
Arsenic	3.8 (1.9)	2 - 14.3	4 (2.3)	0 - 12.1	4.8 (0.9)	3.2 - 7	6.6 (2.1)	3.5 - 13.6
Cadmium	0.7 (0.5)	0 - 2.2	0.4 (0.6)	0 - 4.9	0.1 (0.1)	0 - 0.3	0.2 (0.3)	0 - 1.4
Chromium	46.1 (34)	6.2 - 224	45.4 (36.9)	6.8 - 221	64.7 (20.3)	27.3 - 124	109.1 (79.3)	19.5 - 296.5
Copper	6.9 (2.7)	0.9 - 12.6	14.4 (10.8)	0 - 70.6	11 (3.6)	6.8 - 21	13.2 (6.3)	3.6 - 33.7
Lead	4.6 (1.5)	1.4 - 7.3	7.9 (4.6)	2.2 - 27.8	9.3 (3.1)	4.6 - 16.7	11.4 (2.1)	2.9 - 15.5
Mercury	0 (0)	0 - 0.1	0.1 (0.1)	0 - 0.6	0 (0)	0 - 0.1	0 (0)	0 - 0.1
Silver	0 (0)	0 - 0.3	0.2 (0.4)	0 - 2.9	0.2 (0.4)	0 - 2	0.1 (0.2)	0 - 1.4
Zinc	35.5 (12.2)	7.2 - 66.5	55.6 (42.3)	11.5 - 400.3	58.4 (9.7)	39 - 81.5	55 (18.3)	17.5 - 88.4
Organics (ng/g)								
Acenaphthylene	2 (2.9)	0 - 10	0.3 (1)	0 - 6.6	0.4 (0.5)	0 - 1.7	0.2 (0.5)	0 - 2.1
Acenaphthylene	0.1 (0.3)	0 - 1.5	0.3 (2.5)	0 - 25.8	0.8 (1.4)	0 - 5.2	0.6 (1.5)	0 - 6.1
Anthracene	0.3 (1.1)	0 - 6.2	0 (0.3)	0 - 3.3	1.1 (1.6)	0 - 5.6	0.7 (1.8)	0 - 8
Benz(a)anthracene	2 (7.5)	0 - 40.9	2.8 (7)	0 - 33.9	2.7 (4.2)	0 - 14	1.4 (4.1)	0 - 18
Benzo(a)pyrene	1 (3)	0 - 17.1	3 (9)	0 - 64.5	4 (6.1)	0 - 22	2.2 (5.5)	0 - 25
Chrysene	0.8 (1.8)	0 - 10.7	3.7 (7.2)	0 - 41.1	3 (3.3)	0 - 10	1.1 (2.8)	0 - 12
Dibenzo(a,h)anthracene	0.1 (0.3)	0 - 1.9	0.1 (0.3)	0 - 1.8	0.8 (1.2)	0 - 3.8	0.4 (1)	0 - 4
Fluoranthene	1.9 (4)	0 - 23.5	3.3 (5.8)	0 - 37.2	7.3 (9.1)	0 - 32	3.8 (9.4)	0 - 40
Fluorene	3.1 (6.9)	0 - 23.5	0.6 (1.9)	0 - 11.4	1.7 (1.8)	0 - 5.9	0.5 (1.2)	0 - 5.1
2-Methylnaphthalene	49.5 (60.2)	0 - 217	7.4 (21.4)	0 - 169	5.9 (5.9)	0 - 25	1.2 (2.8)	0 - 12
Naphthalene	26.8 (31.2)	0 - 104	4.3 (13.2)	0 - 110.4	5 (6.2)	0 - 21	2.6 (6.5)	0 - 26
Phenanthrene	5 (8.5)	0 - 32	4.8 (7.2)	0 - 30.4	11.4 (10.7)	0 - 46	3.2 (7.6)	0 - 31
Pyrene	3.9 (8.8)	0 - 42.6	4.4 (8.3)	0 - 54.4	8.2 (9.8)	0 - 33	4.3 (10.8)	0 - 54
Low molecular weight PAH	158.4 (184.9)	0 - 644.4	31.8 (72.2)	0 - 577.4	51 (48.7)	0.7 - 199.9	14 (32.1)	0 - 120.6
High molecular weight PAH	12.4 (24.8)	0 - 133.9	25.2 (49.2)	0 - 343.7	40.7 (52.3)	0 - 178.8	20.3 (51.5)	0 - 226.8
Total PAHs	170.8 (183.1)	4.4 - 644.4	57 (91.4)	0 - 577.4	91.7 (91.2)	1.9 - 300.4	34.2 (83.1)	0 - 347.4
Total DDT								
Total DDT	0.3 (1.5)	0 - 9.6	115.4 (465)	0 - 3905.7	0 (0.1)	0 - 0.3	0 (0.1)	0 - 0.8
4,4'-DDE	0.3 (1.5)	0 - 9.6	90.8 (356.4)	0 - 2970	0 (0)	0 - 0.15	0 (0.1)	0 - 0.4
Total PCBs								
Total PCBs	0.1 (0.9)	0 - 6.7	6.6 (22.4)	0 - 165.1	0 (0)	0 - 0	0 (0)	0 - 0

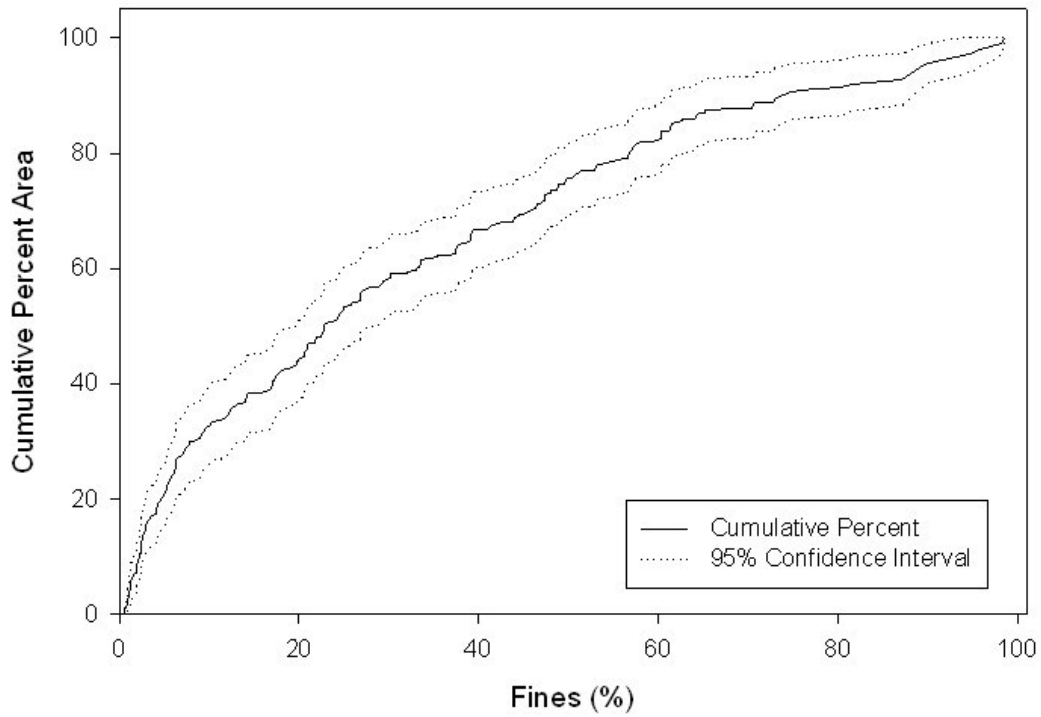


Figure 3.3.1. Percent area (and 95% confidence interval) of overall West Coast Shelf sampling area vs. sediment percent fines (silt/clay).

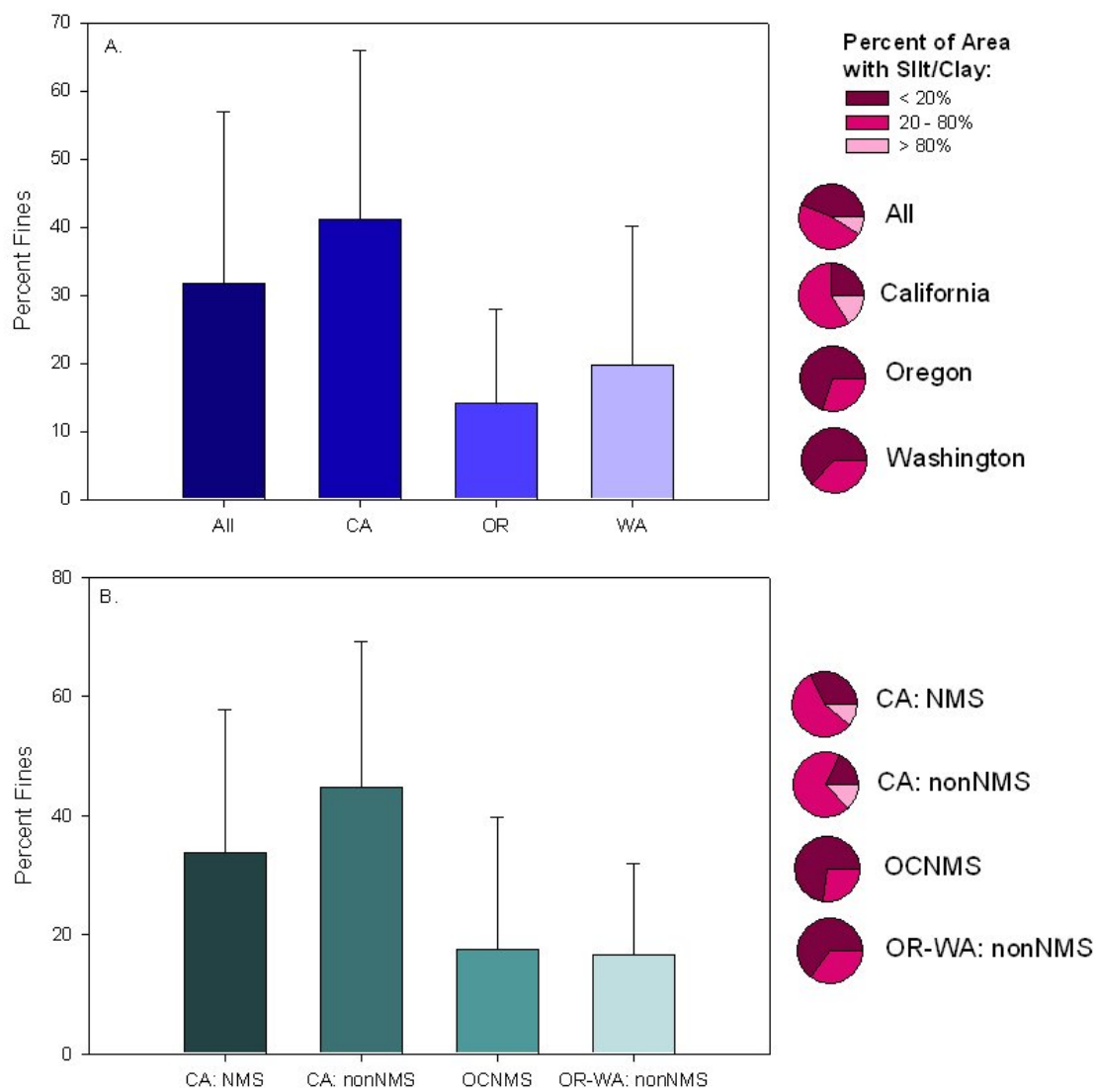


Figure 3.3.2. Comparison of sediment percent silt/clay (mean + 1 SD) by (A) West Coast vs. individual states and (B) National Marine Sanctuary (NMS) vs. non-NMS stations.

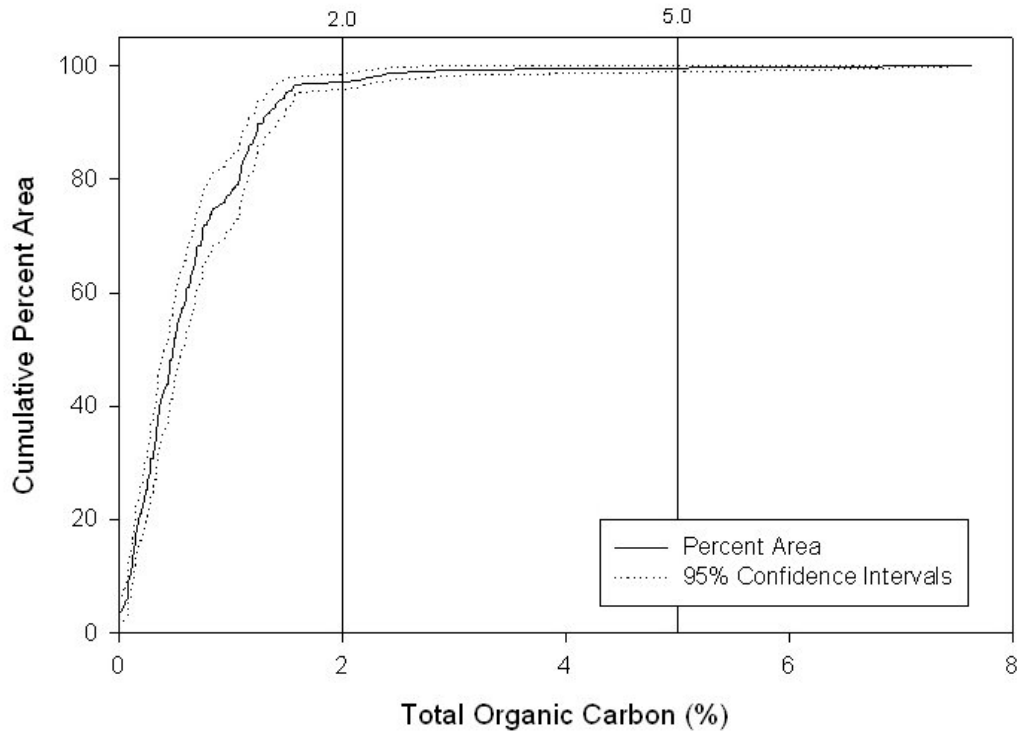


Figure 3.3.3. Percent area (and 95% confidence interval) of overall West Coast Shelf sampling area vs. sediment percent Total Organic Carbon (TOC).

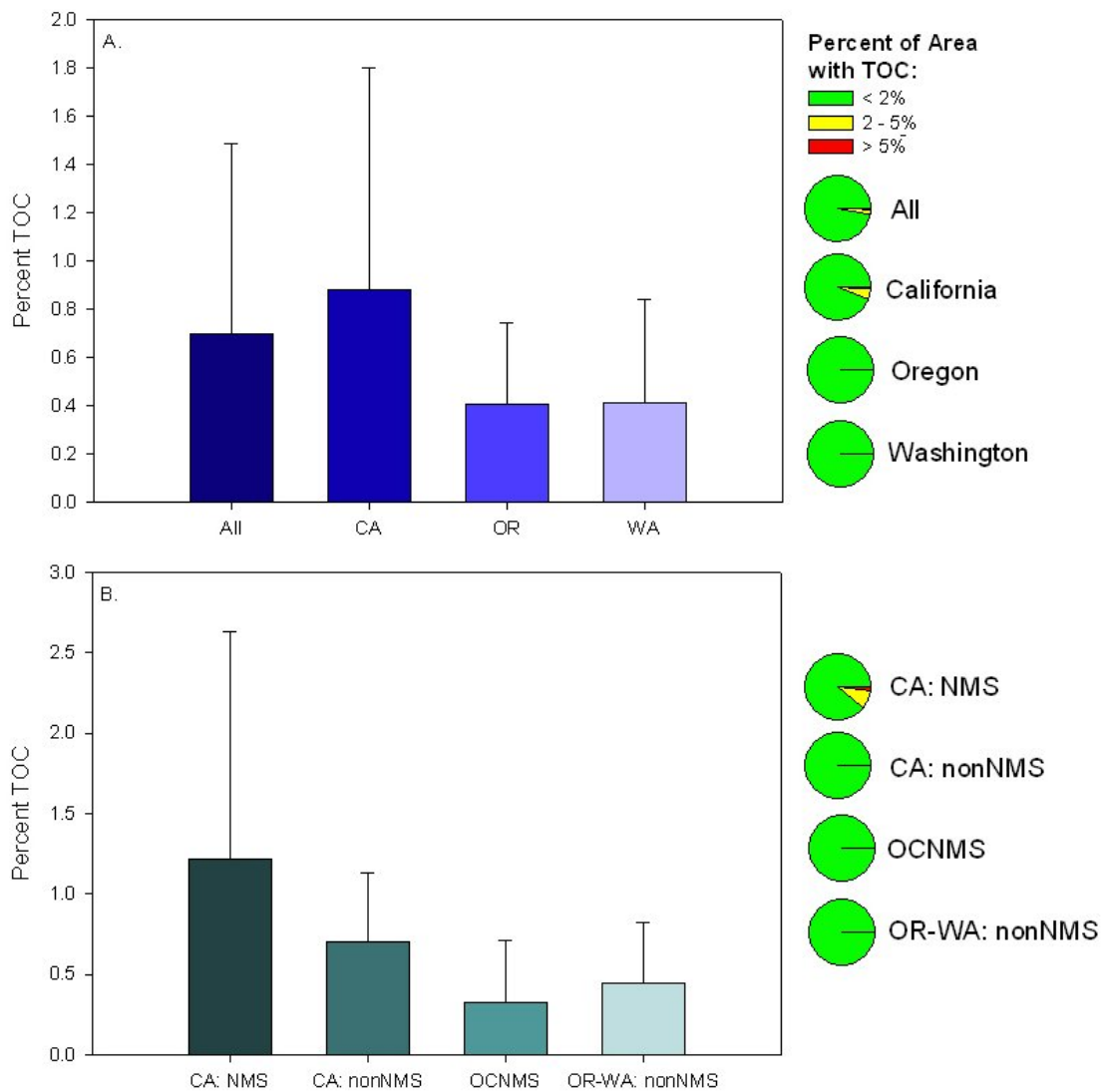


Figure 3.3.4. Comparison of sediment percent Total Organic Carbon (TOC, mean + 1 SD) by (A) West Coast vs. individual states and (B) National Marine Sanctuary (NMS) vs. non-NMS stations.



### 3.3.2 Sediment Contaminants: Metals and Organics

Effects Range-Low (ERL) and Effects Range-Median (ERM) sediment quality guideline (SQGs) values from Long et al. (1995) were used to help in interpreting the biological significance of observed chemical contaminant levels in sediments. ERL values are lower-threshold bioeffect limits, below which adverse effects of the contaminants on sediment-dwelling organisms are not expected to occur. In contrast, ERM values represent mid-range concentrations of chemicals above which adverse effects are more likely to occur. A list of 28 chemicals, or chemical groups, for which ERL and ERM guidelines have been developed is provided in Table 3.3.2 along with the corresponding SQG values (from Long et al. 1995). Nickel was excluded from the present assessment because the SQG values have a low reliability for West Coast conditions, where naturally high crustal concentrations of the metal exist (Long et al. 1995, Long et al. 2000). Lauenstein et al. (2000) also found historical background concentrations of nickel in sediment cores along the West Coast in a range of 35-70 µg/g, which bracket the nickel ERM value of 51.6 µg/g. Any site with one or more chemicals (other than nickel) that exceeded corresponding ERM values was rated as having poor sediment quality, any site with five or more chemicals between corresponding ERL and ERM values was rated as fair, and any site that had less than five ERLs exceeded and no ERMs exceeded was rated as good (*sensu* U.S. EPA 2004).

Sediments throughout the shelf survey area were relatively uncontaminated except for a group of stations in the SCB. Overall, about 99% of the total survey area (represented by 230 stations) had a rating of good, < 1% (represented by seven stations) had fair conditions with  $\geq 5$  chemicals in excess of ERL values, and < 1% (represented by 22 stations) had poor conditions with  $\geq 1$  chemical in excess of the higher-threshold ERM values (Fig. 3.3.5). The pesticides 4,4'-DDE and total DDT were the only two contaminants that exceeded corresponding ERM values (Tables 3.3.3, 3.3.4). The ERM for total DDT was exceeded at 17 stations (representing < 1% of the overall survey area) and the ERM for 4,4'-DDE was exceeded at 22 stations (representing < 1% of the overall survey area). All of these sites were in California near Los Angeles. Total DDT and 4,4'-DDE were found in excess of the lower-threshold ERL values at 41 and 31 stations respectively, all of which again were in California, mostly in the Los Angeles area (Tables 3.3.3, 3.3.4; Figs. 3.3.6, 3.3.7).

Ten other contaminants, including seven metals (As, Cd, Cr, Cu, Hg, Ag, Zn), 2-methylnaphthalene, low molecular weight PAHs, and total PCBs were found at moderate concentrations in excess of corresponding, lower-threshold ERL values (Tables 3.3.3, 3.3.4). The most prevalent in terms of area were chromium (31%), arsenic (8%), 2-methylnaphthalene (6%), cadmium (5%), and mercury (4%). The 2-methylnaphthalene and mercury exceedances were limited entirely to California. The mercury exceedances were all at non-sanctuary sites in California, particularly in the Los Angeles area (Fig. 3.3.8), while the 2-methylnaphthalene exceedances were conspicuously grouped around the

CINMS (Fig. 3.3.9).

Chromium ERL exceedances were much more widespread, with sediments exceeding the ERL value at sites along all three states (Fig. 3.3.10). Oregon had the highest incidence: 30 of 50 stations, representing 60% of the total survey area (Tables 3.3.3, 3.3.4). The highest concentration (296.5 µg/g) and highest mean concentration (129.5 µg/g) also occurred off Oregon (Table 3.3.1). Chromium is naturally present in soils in the Pacific Northwest Coast range. Chromium was originally mined from black sand deposits along the Oregon coast in Coos County, and a low-grade ore was mined in the 1940's to 1950's in Oregon and northern California, and to a lesser extent in Washington, under a federal stockpiling program (Baber et al. 1959). A report by EPA Region X on the ecological condition of the estuaries of Oregon and Washington (Hayslip et al. 2006) actually excluded chromium, as well as nickel and copper, from its aggregate sediment contamination indicator. Chromium was excluded in that report because the natural concentration of this metal in the earth's crust and marine shales (100 and 90 µg/g, respectively; Krauskopf and Bird 1995) is greater than the ERL (81 µg/g).

With a few exceptions, sediments within West Coast National Marine Sanctuaries (NMSs) were relatively uncontaminated (Tables 3.3.1, 3.3.3, 3.3.4; Fig. 3.3.5). The OCNMS had no chemicals in excess of ERM values and only two chemicals, chromium and silver, were found in excess of the lower-threshold ERL values (Table 3.3.2). There were only four of 30 stations in the OCNMS with such chromium exceedances, compared to 31 of 70 stations in nearby non-sanctuary waters off the coast of Washington and Oregon. Similarly, CINMS had no chemicals in excess of ERM values. Three metals (As, Cd, Cr), 2-methylnaphthalene, low molecular weight PAHs, total DDT, and 4,4'-DDE were found at moderate concentrations, between corresponding ERL and ERM values, at multiple sites within the CINMS. However, total DDT, 4,4'-DDE, and chromium ERL exceedances were notably less prevalent at CINMS than in non-sanctuary waters of California (Figs. 3.3.6, 3.3.7, 3.3.10). DDT and its metabolites are well known legacy pesticides in the SCB, and the distributions seen in this survey reflect patterns seen in previous years (Schiff 2000, Schiff et al. 2006). In contrast, 2-methylnaphthalene contamination, albeit at moderately low levels (between ERL and ERM values), was much more prevalent in sediments at the CINMS compared to non-sanctuary waters off the coast of California. For example, the ERL value was exceeded at 19 of the 27 CINMS stations, compared to only 3 of 103 stations in non-sanctuary waters (Table 3.3.4, Fig. 3.3.9). Schiff et al. (2006) attribute such elevated levels of PAHs in the California region to proximity of oil production platforms and reduced degradation of the compounds under cold water conditions. However, this does not explain the higher incidence of 2-methylnaphthalene contamination specifically around CINMS relative to neighboring non-sanctuary waters in the region.

In comparison to the present sediment quality ratings for offshore waters

(98% of the total survey area rated as good, < 1% rated as fair, and < 1% rated as poor), estuarine habitats along the West Coast show a relatively higher incidence of sediment contamination, particularly in the moderate concentration ranges. For example, U.S. EPA (2004), based on the same contaminants and methods, found 79% of estuarine sediments along the West Coast of the U.S. in good condition, 18% in fair condition, and 3% in poor condition. While only two contaminants (4,4'-DDE and total DDT) were found in excess of ERM guideline values in the present offshore study, several contaminants were found above ERM levels in adjacent estuaries, including chromium, mercury, copper, DDT, several PAHs, and PCBs. In the present offshore survey, all stations where ERM values were exceeded (22 stations) were in California near Los Angeles. In the estuarine assessment, there were 24 stations where ERMs were exceeded, including 20 in California (majority in the San Francisco estuary and Los Angeles Harbor area) and four in Washington (three in the Puget Sound system and one in the Columbia River).

Table 3.3.2. ERM and ERL guidance values in sediments (Long et al. 1995).

Metals ( $\mu\text{g/g}$ )	ERL	ERM
Arsenic	8.2	70
Cadmium	1.2	9.6
Chromium	81	370
Copper	34	270
Lead	46.7	218
Mercury	0.15	0.71
Nickel	20.9	51.6
Silver	1	3.7
Zinc	150	410
Organics (ng/g)	ERL	ERM
Acenaphthene	16	500
Acenaphthylene	44	640
Anthracene	85.3	1100
Fluorene	19	540
2-Methylnaphthalene	70	670
Naphthalene	160	2100
Phenanthrene	240	1500
Benzo(a)anthracene	261	1600
Benzo(a)pyrene	430	1600
Chrysene	384	2800
Dibenz(a,h)Anthracene	63.4	260
Fluoranthene	600	5100
Pyrene	665	2600
Low molecular weight PAHs	552	3160
High molecular weight PAHs	1700	9600
Total PAHs	4020	44800
4,4-DDE	2.2	27
Total DDT	1.58	46.1
Total PCBs	22.7	180

Table 3.3.3. Comparison of the % area of sediments with chemical contaminants in excess of corresponding ERL and ERM sediment quality guidelines.

Analyte	All		CA		OR		WA		CA: NMS		CA: non-NMS		OCNMS		WA-OR: non-NMS	
	ERL	ERM	ERL	ERM	ERL	ERM	ERL	ERM	ERL	ERM	ERL	ERM	ERL	ERM	ERL	ERM
Metals (µg/g)																
Arsenic	8	0	6	0	14	0	4	0	3	0	7	0	0	0	13	0
Cadmium	5	0	8	0	2	0	0	0	15	0	<1	0	0	0	<1	0
Chromium	31	0	24	0	60	0	10	0	8	0	40	0	13	0	47	0
Copper	<1	0	<1	0	0	0	0	0	0	0	<1	0	0	0	0	0
Mercury	4	0	8	0	0	0	0	0	0	0	16	0	0	0	0	0
Silver	<1	0	<1	0	0	0	4	0	0	0	<1	0	3	0	1	0
Zinc	<1	0	<1	0	0	0	0	0	0	0	<1	0	0	0	0	0
Organics (ng/g)																
2-Methyl naphthalene	6	0	11	0	0	0	0	0	18	0	<1	0	0	0	0	0
Low molecular weight PAH	<1	0	1	0	0	0	0	0	3	0	<1	0	0	0	0	0
Total DDT	4	<1	8	1	0	0	0	0	2	0	13	2	0	0	0	0
4,4'-DDE	4	<1	7	1	0	0	0	0	2	0	11	2	0	0	0	0
Total PCBs	<1	0	<1	0	0	0	0	0	0	0	<1	0	0	0	0	0

Table 3.3.4. Comparison of the number of stations with chemical contaminants in excess of corresponding ERL and ERM sediment quality guideline values.

Analyte	All		CA		OR		WA		CA: NMS		CA: non-NMS		OCNMS		WA-OR: non-NMS	
	ERL	ERM	ERL	ERM	ERL	ERM	ERL	ERM	ERL	ERM	ERL	ERM	ERL	ERM	ERL	ERM
Metals (µg/g)																
Arsenic	16	0	7	0	7	0	2	0	2	0	5	0	0	0	9	0
Cadmium	16	0	15	0	1	0	0	0	9	0	6	0	0	0	1	0
Chromium	54	0	19	0	30	0	5	0	3	0	16	0	4	0	31	0
Copper	5	0	5	0	0	0	0	0	0	0	5	0	0	0	0	0
Mercury	21	0	21	0	0	0	0	0	0	0	21	0	0	0	0	0
Silver	6	0	4	0	0	0	2	0	0	0	4	0	1	0	1	0
Zinc	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0
Organics (ng/g)																
2-Methyl naphthalene	22	0	22	0	0	0	0	0	19	0	3	0	0	0	0	0
Low molecular weight PAH	4	0	4	0	0	0	0	0	3	0	1	0	0	0	0	0
Total DDT	41	17	41	17	0	0	0	0	3	0	38	17	0	0	0	0
4,4'-DDE	31	22	31	22	0	0	0	0	3	0	28	22	0	0	0	0
Total PCBs	8	0	8	0	0	0	0	0	0	0	8	0	0	0	0	0

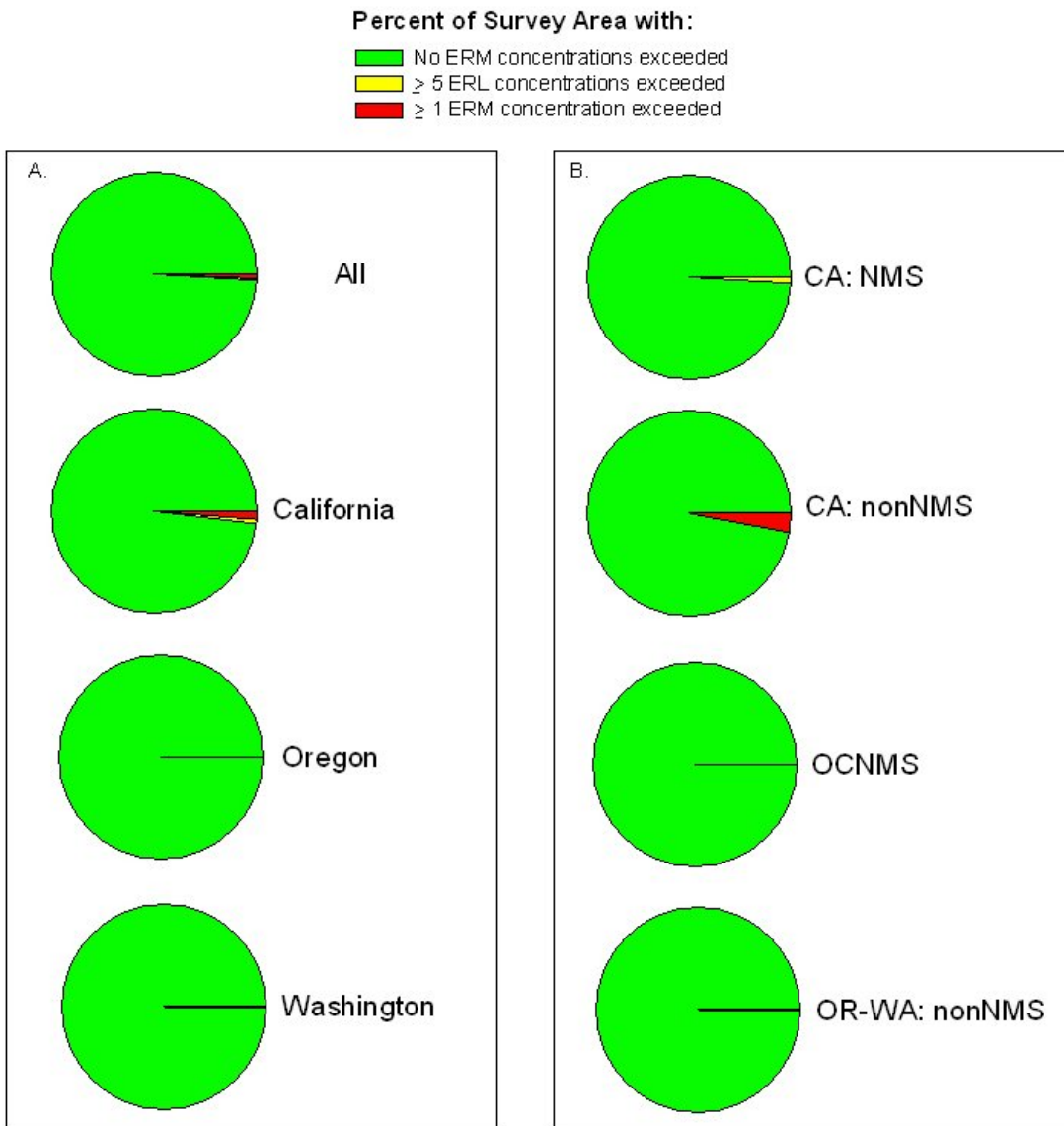


Figure 3.3.5. Comparison of the spatial extent of sediment contamination by (A) West Coast vs. individual states and (B) National Marine Sanctuary (NMS) vs. non-NMS stations.

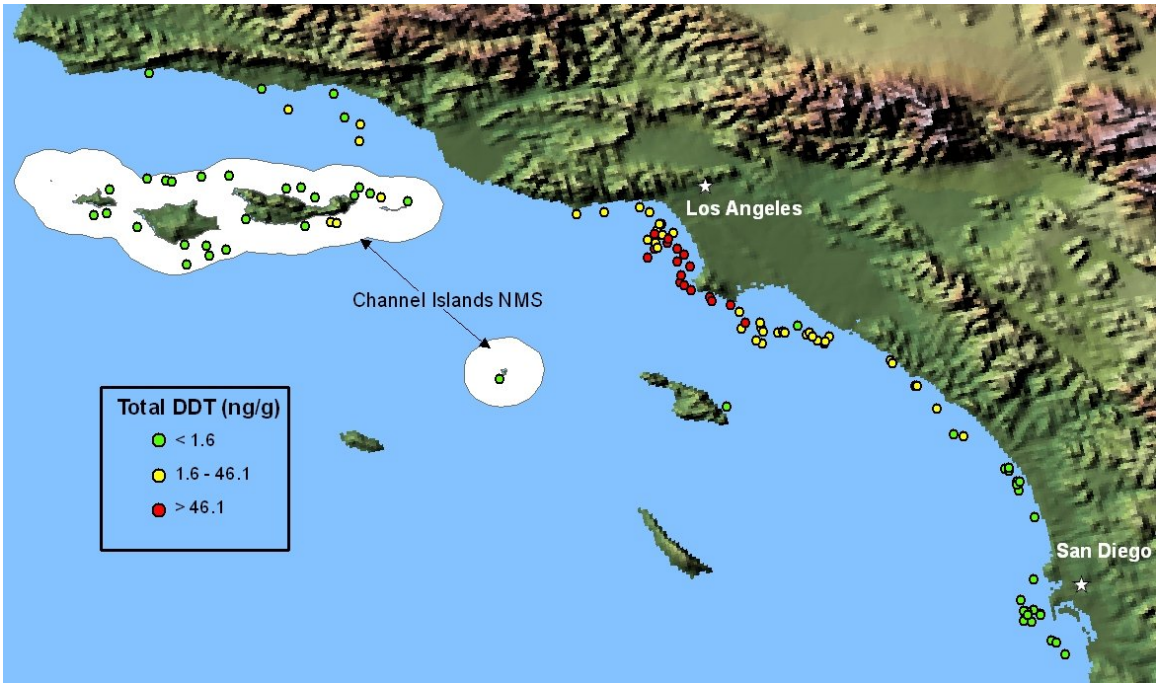


Figure 3.3.6. Distribution of Total DDT concentrations in sediments along the SCB relative to ERL and ERM guidelines.

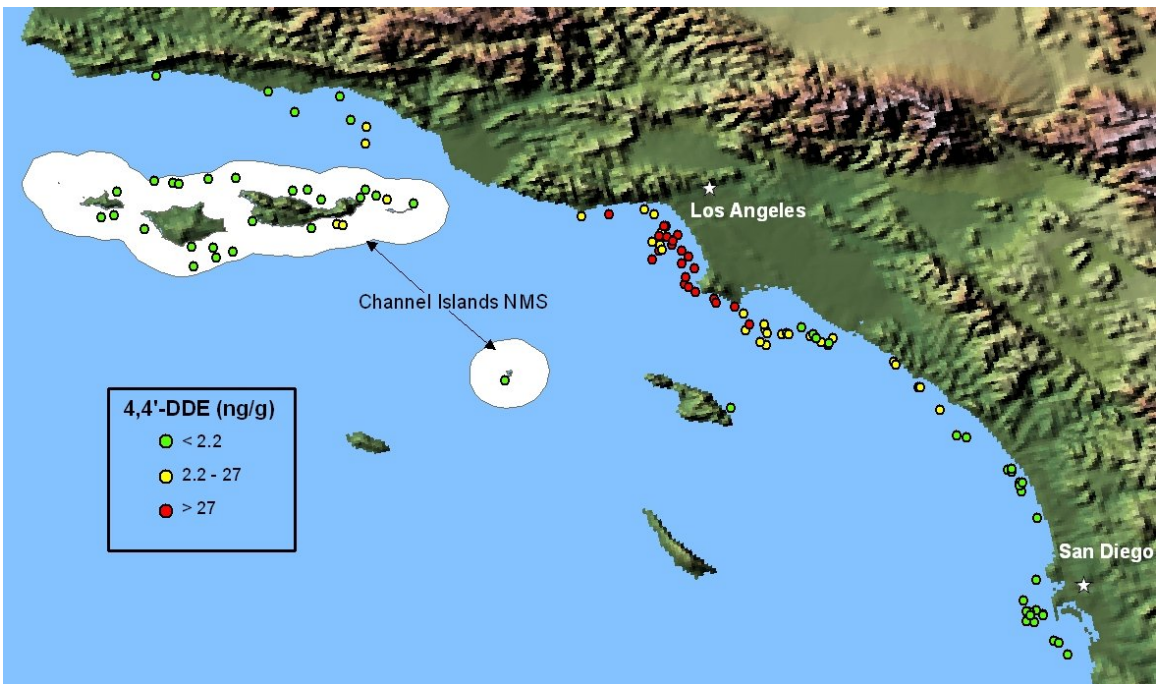


Figure 3.3.7. Distribution of 4,4'-DDE concentrations in sediments along the SCB relative to ERL and ERM guidelines.

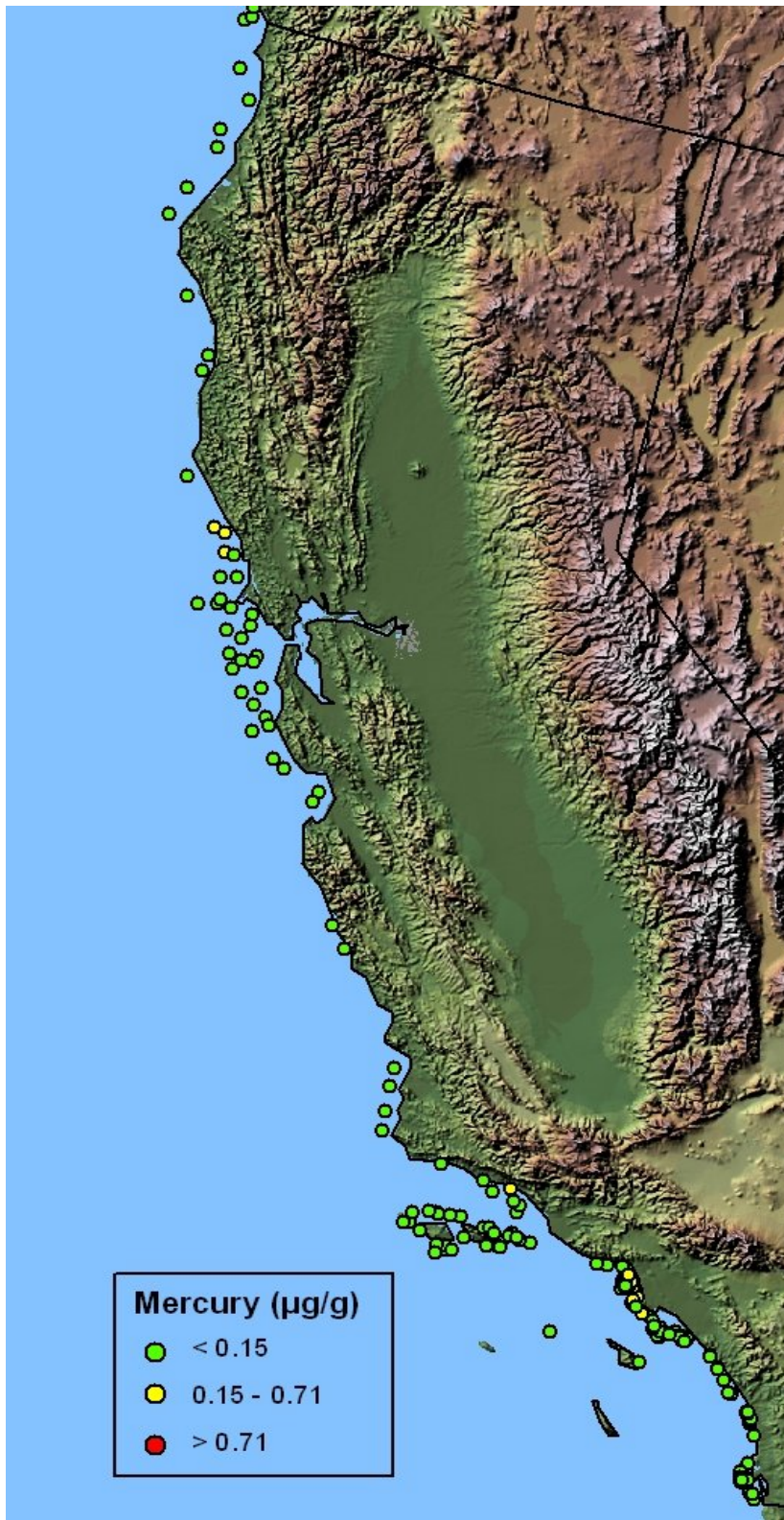


Figure 3.3.8. Distribution of mercury concentrations in sediments along the continental shelf of California relative to ERL and ERM guidelines.



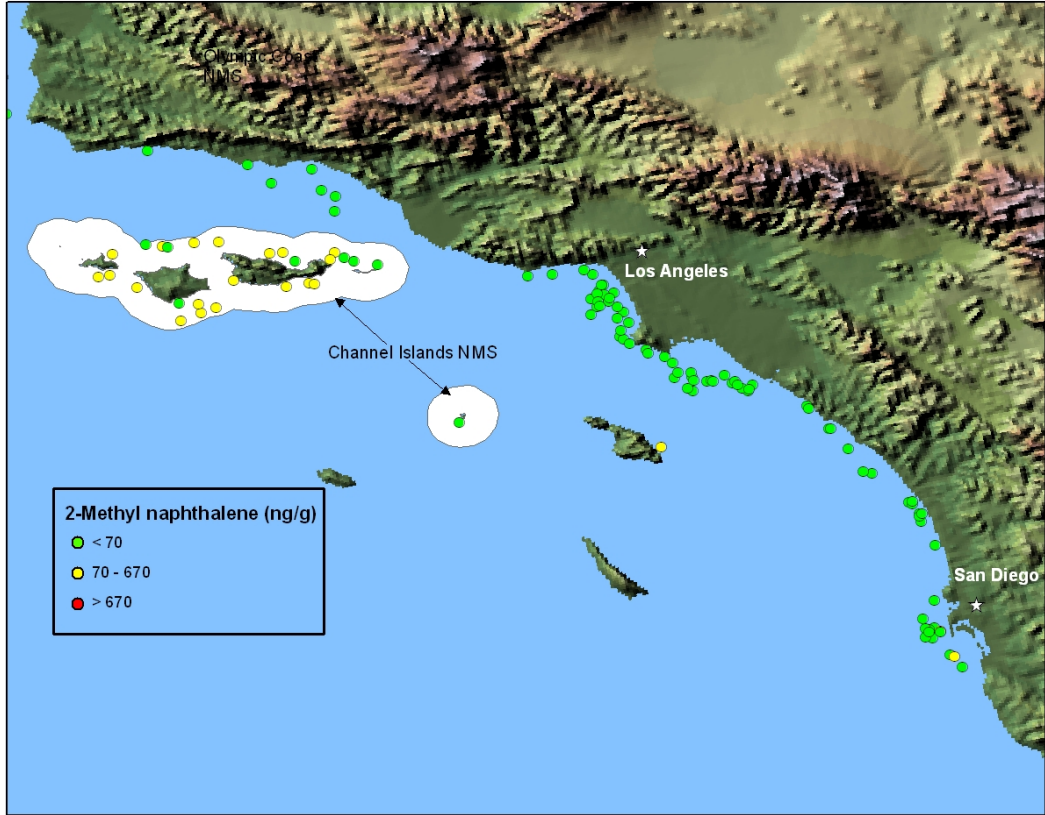


Figure 3.3.9. Distribution of 2-methylnaphthalene concentrations in sediments along the SCB relative to ERL and ERM guidelines.



Figure 3.3.10. Distribution of chromium concentrations in sediments along the western U.S. continental shelf relative to ERL and ERM guidelines.

### 3.4 Fish Tissue Contaminants

Concentrations of a suite of metals, PCBs, and pesticides (Table 2.3.1) were measured in whole fish collected from both the EMAP/NCA-West and FRAM groundfish surveys. All fish selected for analysis were flatfish (Pleuronectiformes) because of their commercial value and because of their potential contact with sediment-associated contaminants due to their affinity to bottom habitats. Because fish were collected from only about a third of all sites in the probabilistic EMAP/NCA-West survey, and because FRAM survey sites were not probability-based, CDFs and spatial estimates of condition could not be computed for fish-tissue contaminants. Patterns of contaminant concentrations throughout the region and the incidence of contaminant levels in excess of human-health guidelines are presented however.

Concentrations of selected contaminants in whole fish were compared with risk-based EPA advisory guidelines for recreational fishers, using non-cancer (systemic) health endpoints associated with the consumption of four 8-oz meals per month (Table 3.4.1), which is the comparison basis used in National Coastal Condition Reports (U.S. EPA 2000b, 2001, 2004, 2006). It is important to keep in mind that the guidelines used are for fish fillets, while the concentrations measured in the EMAP/NCA-West and FRAM surveys are for whole fish. Data presented here are for the parameters of interest in NCCR, including several metals, total PAH, total DDT and several other pesticides, including chlordane, dieldrin, endosulfan, endrin, heptachlor, hexachlorobenzene, lindane, mirex, and toxaphene (Table 3.4.1).

#### 3.4.1 EMAP

Collection of targeted flatfish, based on hook-and-line methods, was successful at only 50 of the 147 EMAP/NCA-West stations sampled. Fish were collected from 21 stations in Washington, 20 in Oregon and nine in California. No benthic fish were collected from the SCB as part of the EMAP/NCA-West survey. Eight of the nine California samples, 13 of the 21 Washington samples, and none of the Oregon samples were collected in National Marine Sanctuaries. Species selected for analysis included Pacific sanddab (*Citharichthys sordidus*), speckled sanddab (*Citharichthys stigmaeus*), butter sole (*Isopsetta isolepis*), and Dover sole (*Microstomus pacificus*). No fish that were collected exhibited evidence of obvious pathological disorders based on visual inspections in the field. Contaminants were measured in 55 composites, including some laboratory duplicates for QA, of flatfish tissue from the 50 stations. Results are summarized in Tables 3.4.2 and 3.4.3.

**Cadmium** - The lower cadmium non-cancer health-risk guideline value was exceeded in at least one composite at nine stations, including six of the 20 stations where fish were collected in Oregon (OR03-0006, 0009, 0010, 0017, 0039 and 0040; Fig. 3.1.3) and three of the nine stations in California (CA03-0052, 0060 and 0064; Fig. 3.1.4). While the stations from Oregon were not in a NMS, the three stations in California were within the Monterey Bay and Gulf of Farallones NMSs.

Tissue cadmium levels were not strongly correlated with sediment cadmium levels at corresponding stations (Fig. 3.4.1,  $r^2 = 0.049$ ).

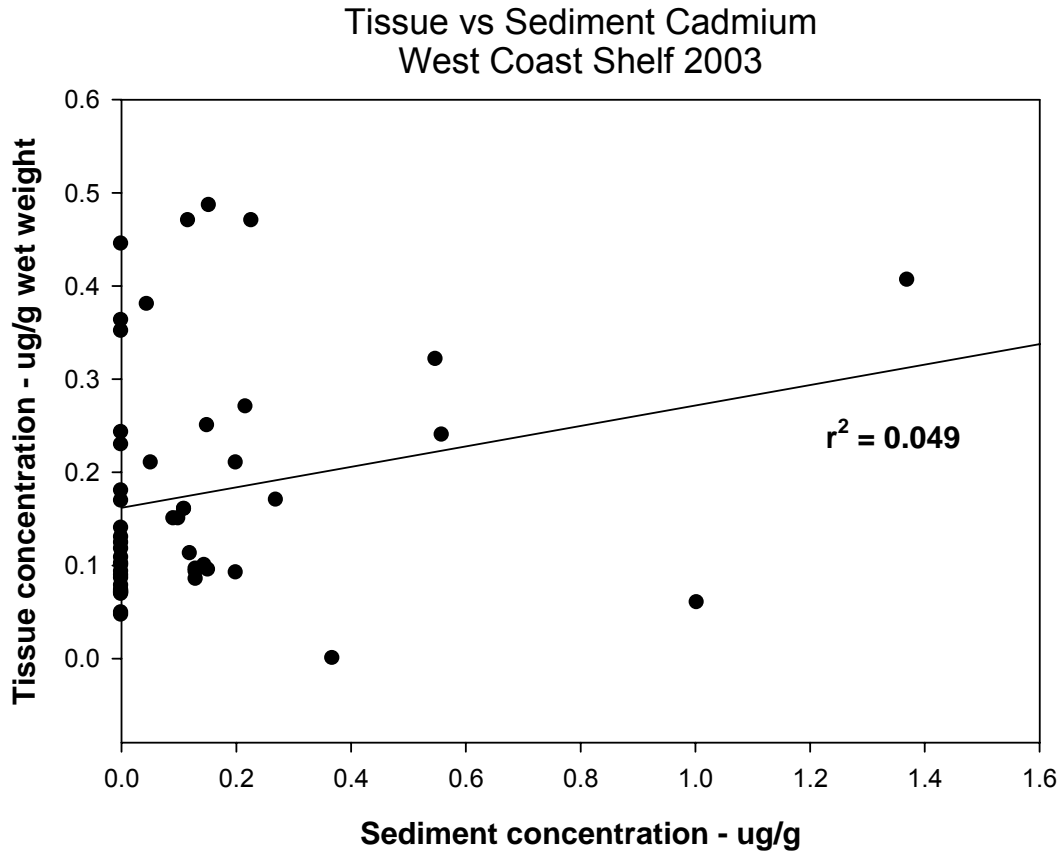


Figure 3.4.1. Tissue vs. sediment concentration of cadmium at corresponding stations from the EMAP/NCA-West 2003 shelf survey including samples from Washington, Oregon and California.

**Other parameters** - The lower value in the range of non-cancer health-risk guideline values for total PCB was exceeded at one of 21 stations in Washington (WA03-0086), just north of the mouth of the Columbia River (Fig. 3.1.2). This observation may have resulted from the bioaccumulation of PCB in fish from within the Columbia River, and subsequent migration out of the estuary. The health-risk guideline values for all metals other than cadmium and all pesticides measured were not exceeded in fish collected in the EMAP/NCA-West survey. Data for all stations and parameters are summarized in Table 3.4.2 by state and in Table 3.4.3 by NMS vs. non-NMS status.

Table 3.4.1. Risk-based EPA advisory guidelines for recreational fishers<sup>a</sup>

Metals µg/g	Concentration Range <sup>b</sup>	Health Endpoint
Arsenic (inorganic) <sup>c</sup>	3.5-7.0	Non-cancer
Cadmium	0.35-0.70	Non-cancer
Mercury (methyl) <sup>d</sup>	0.12-0.23	Non-cancer
Selenium	5.9-12.0	Non-cancer
Organics ng/g		
Chlordane	590-1200	Non-cancer
DDT (total)	59-120	Non-cancer
Dieldrin	59-120	Non-cancer
Endosulfan	7000-14000	Non-cancer
Endrin	350-700	Non-cancer
Heptachlor Epoxide	15-31	Non-cancer
Hexachlorobenzene	940-1900	Non-cancer
Lindane	350-700	Non-cancer
Mirex	230-470	Non-cancer
Toxaphene	290-590	Non-cancer
PCB (total)	23-47	Non-cancer

<sup>a</sup> From U.S. EPA 2000b

<sup>b</sup> Range of concentrations associated with non-cancer health endpoint risk for consumption of four 8-oz meals per month

<sup>c</sup> Inorganic arsenic estimated as 2% of total arsenic

<sup>d</sup> U.S. EPA 2000b recommends analyzing for total mercury with the use of a conservative assumption that all mercury is present as methylmercury, and thus comparison is made to the methylmercury risk based guideline.

Table 3.4.2. Comparison by state of the concentrations of metals ( $\mu\text{g/g}$  wet weight) and organic compounds ( $\text{ng/g}$  wet weight) measured in fish tissue composites from fish collected in the 2003 EMAP/NCA-West. An asterisk indicates that the lower level of the health risk guideline range (Table 3.4.1) was exceeded for this contaminant in at least one fish composite sample.

Data	All		CA		OR		WA	
	Mean (STD)	Range	Mean (STD)	Range	Mean (STD)	Range	Mean (STD)	Range
Metals $\mu\text{g/g}$								
Arsenic (inorganic)	0.0 (0.0)	0.0 - 0.1	0.0 (0.0)	0.0 - 0.0	0.0 (0.0)	0.0 - 0.1	0.0 (0.0)	0.0 - 0.1
Cadmium*	0.2 (0.1)	0.0 - 0.5*	0.3 (0.1)	0.1 - 0.5*	0.2 (0.2)	0.0 - 0.5*	0.1 (0.1)	0.0 - 0.3
Chromium	0.2 (0.2)	0.0 - .8	0.0 (0.0)	0.0 - 0.0	0.1 (0.1)	0.0 - 0.2	0.5 (0.2)	0.2 - 0.8
Copper	1.0 (1.2)	0.0 - 5.0	0.5 (0.2)	0.4 - 0.9	0.1 (0.3)	0.0 - 1.3	1.9 (1.1)	0.6 - 5.0
Lead	0.0 (0.1)	0.0 - 0.5	0.0 (0.0)	0.0 - 0.0	0.0 (0.0)	0.0 - 0.2	0.1 (0.1)	0.0 - 0.5
Mercury (total)	0.0 (0.0)	0.0 - 0.1	0.0 (0.0)	0.0 - 0.0	0.0 (0.0)	0.0 - 0.1	0.1 (0.0)	0.0 - 0.1
Selenium	0.4 (0.1)	0.3 - 0.6	0.4 (0.0)	0.4 - 0.5	0.4 (0.1)	0.3 - 0.6	0.5 (0.0)	0.4 - 0.6
Silver	0.0 (0.0)	0.0 - 0.1	0.0 (0.0)	0.0 - 0.0	0.0 (0.0)	0.0 - 0.1	0.0 (0.0)	0.0 - 0.0
Zinc	11.8 (2.1)	7.1 - 16.6	8.9 (1.3)	7.1 - 11.0	12.1 (1.8)	9.4 - 16.6	12.8 (1.6)	7.4 - 15.9
Organics $\text{ng/g}$								
Total DDT	2.2 (3.5)	0.0 - 18.8	8.5 (4.7)	3.4 - 18.8	0.5 (0.9)	0.0 - 2.9	1.2 (0.9)	0.0 - 3.3
4,4'-DDE	2.2 (3.5)	0.0 - 18.8	8.5 (4.7)	3.4 - 18.8	0.5 (0.9)	0.0 - 2.9	1.2 (0.9)	0.0 - 3.3
Other Pesticides	0.0 (0.0)	0.0 - 0.0	0.0 (0.0)	0.0 - 0.0	0.0 (0.0)	0.0 - 0.0	0.0 (0.0)	0.0 - 0.0
Total PCBs*	0.9 (4.9)	0.0 - 36.2*	0.0 (0.0)	0.0 - 0.0	0.0 (0.0)	0.0 - 0.0	2.0 (7.3)	0.0 - 36.2*

Table 3.4.3. Comparison by NMS vs. non-sanctuary concentrations of metals ( $\mu\text{g/g}$  wet weight) and organic compounds ( $\text{ng/g}$  wet weight) measured in fish-tissue composites from fish collected in the 2003 EMAP/NCA-West survey. An asterisk indicates that the low level of the health risk guideline range (Table 3.4.1) was exceeded for this contaminant in at least one fish composite sample.

Data	CA: NMS		CA: non-NMS		OCNMS		OR-WA: non-NMS	
	Mean (STD)	Range	Mean (one sample)	Range (one sample)	Mean (STD)	Range	Mean (STD)	Range
<b>Metals <math>\mu\text{g/g}</math></b>								
Arsenic (inorganic)	0.0 (0.0)	0.0 - 0.0	0.0	0.0	0.0 (0.0)	0.0 - 0.1	0.0 (0.0)	0.0 - 0.1
Cadmium*	0.3 (0.1)	0.1 - 0.5*	0.2	0.2	0.1 (0.0)	0.0 - 0.2	0.2 (0.1)	0.0 - 0.5*
Chromium	0.0 (0.0)	0.0 - 0.0	0.0	0.0	0.5 (0.2)	0.3 - 0.8	0.2 (0.2)	0.0 - 0.8
Copper	0.6 (0.2)	0.4 - 0.9	0.4	0.4	2.1 (1.3)	0.8 - 5.0	0.6 (1.0)	0.0 - 3.4
Lead	0.0 (0.0)	0.0 - 0.0	0.0	0.0	0.0 (0.1)	0.0 - 0.2	0.0 (0.1)	0.0 - 0.5
Mercury (total)	0.0 (0.0)	0.0 - 0.0	0.0	0.0	0.1 (0.0)	0.0 - 0.1	0.0 (0.0)	0.0 - 0.1
Selenium	0.4 (0.0)	0.4 - 0.5	0.4	0.4	0.5 (0.0)	0.4 - 0.6	0.4 (0.1)	0.3 - 0.6
Silver	0.0 (0.0)	0.0 - 0.0	0.0	0.0	0.0 (0.0)	0.0 - 0.0	0.0 (0.0)	0.0 - 0.1
Zinc	9.1 (1.2)	7.5 - 11.0	7.1	7.1	13.1 (1.4)	10.9 - 15.9	12.1 (1.7)	7.4 - 16.6
<b>Organics <math>\text{ng/g}</math></b>								
Total DDT	7.3 (2.9)	3.4 - 12.6	18.8	18.8	1.1 (0.8)	0.0 - 2.4	0.8 (1.0)	0.0 - 3.3
4,4'-DDE	7.3 (2.9)	3.4 - 12.6	18.8	18.8	1.1 (0.8)	0.0 - 2.4	0.8 (1.0)	0.0 - 3.3
Other Pesticides	0.0 (0.0)	0.0 - 0.0	0.0	0.0	0.0 (0.0)	0.0 - 0.0	0.0 (0.0)	0.0 - 0.0
Total PCBs*	0.0 (0.0)	0.0 - 0.0	0.0	0.0	0.6 (0.9)	0.0 - 2.5	1.3 (6.5)	0.0 - 36.2*

### 3.4.2 FRAM Groundfish Survey

Fish were analyzed for contaminants in 99 tissue composites from 60 stations sampled in 2003 by the Fisheries Resource Analysis and Monitoring (FRAM) Division of the Northwest Fisheries Science Center (NWFSC) of NOAA as part of their western groundfish survey program (Figs. 3.1.6-3.1.9; Appendix Table 2). Fish collected from FRAM stations that were within the EMAP/NCA-West sampling frame were transferred to EPA for subsequent analysis. Species selected for analysis included Pacific sanddab (*Citharichthys sordidus*), petrale sole (*Eopsetta jordani*), rex sole (*Glyptocephalus zachirus*), Dover sole (*Microstomus pacificus*) and English sole (*Parophrys vetulus*). Data for all stations and parameters are summarized in Table 3.4.4.

**Cadmium** - The lower end of the range of cadmium values associated with non-cancer risks was exceeded in at least one composite at nine stations coastwide, including five sites in California, mostly near San Francisco Bay (CEW03419-016, 054, and 058 in the Monterey Bay NMS; 026 in Cordell Bank NMS; and 022 not in a NMS; Fig. 3.1.9); two in Oregon (CEW03419-082 and 087 not in a NMS; Fig. 3.1.8); and two in Washington (CEW03419-112 and 116 both in the Olympic Coast NMS; Fig. 3.1.7). Fish from Station CEW03419-058, south of San Francisco Bay (Fig.3.1.9), had cadmium in excess of the upper end of the non-cancer health-risk range.

**Mercury** - Fish consumption has been reported to be a major source of mercury in humans. The human-health risk guideline level for mercury was not exceeded in this study, though concentrations approached that level in some composites. The mercury concentrations reported in this study are total mercury, whereas the form of mercury that may cause human-health effects is methyl mercury. However, the U.S. EPA recommends an approach where total mercury concentration is measured, and with the use of a conservative assumption that all mercury is present as methylmercury, a comparison is made to the methylmercury risk based guideline (U.S. EPA 2000b). This conservative approach is viewed as being both protective of human health and most cost effective. The presence of selenium in these fish tissue samples may reduce the health impacts of methyl mercury, as selenium sequesters mercury, making it metabolically unavailable (for a review, see Raymond and Ralston 2004).

**Other parameters** - The health-risk guideline values for metals (other than cadmium), PCBs, and pesticides were not exceeded in fish collected from the FRAM survey (Table 3.4.4). The maximum concentration of total DDT measured was 30.4 ng/g, which is below the risk guideline. One composite sample from Washington (CEW03419-122) had an aldrin concentration of 0.64 ng/g, but the other composite from the same station had no aldrin, and aldrin was undetected in all other samples. Levels of all other pesticides were undetectable.



Table 3.4.4. Concentrations of metals ( $\mu\text{g/g}$  wet weight) and organic compounds ( $\text{ng/g}$  wet weight) measured in tissue composites of fish collected from 60 stations in the 2003 FRAM survey. Frequency of detection is the number of stations (among 60) where the parameter was detected at a level above the minimum detection limit (MDL) in flatfish. An asterisk indicates that the low level of the health risk guidelines range was exceeded in at least one fish composite sample.

Contaminant	Mean	Maximum	Minimum	Frequency of Detection	Health Risk Guideline Range
Metals ( $\mu\text{g/g}$ ):					
Inorganic					
Arsenic	0.1	0.2	0.0	60/60	3.5-7.0
Cadmium*	0.2	1.5*	0.0	45/60	0.35-0.70
Chromium	0.2	1.0	0.0	34/60	-
Copper	0.5	2.6	0.0	47/60	-
Lead	0.0	0.1	0.0	4/60	-
Mercury	0.0	0.1	0.0	52/60	0.12-0.23
Selenium	0.4	1.8	0.0	44/60	5.9-12.0
Silver	0.0	0.0	0.0	1/60	-
Zinc	10.0	13.8	6.5	60/60	-
Organics ( $\text{ng/g}$ ):					
Total PCB	0.3	3.8	0.0	11/60	23-47
Total DDT	5.0	30.4	0.0	41/60	59-120
4,4"-DDE	5.0	30.4	0.0	41/60	-
Other					
Pesticides*	0.0	0.3	0.0	1/60	-

The State of Washington measured metals and organics in fillets of fish separately from the remains (whole fish minus fillets). This procedure provides some data for estimating file levels of contaminants from measurements of contaminant levels in whole fish from California and Oregon. Cadmium levels were undetectable in all fish fillets, suggesting that the levels reported for whole fish might not be accurate for fillets, and levels of cadmium in fish fillets from fish sampled in this study might be below EPA health-risk guidance values. For other metals, the ratio of mean values in fillets to mean values in remains was variable, ranging from 0.30 to 1.35 (Table 3.4.5). Total PCBs at one station were undetectable in remains, but measured 2.8  $\text{ng/g}$  in fillets. At other stations, the ratio of levels in fillets vs. remains averaged 0.24. For total DDT, the ratio of levels in fillets vs. remains averaged 0.98.

Table 3.4.5. Ratios of concentrations of measured chemical parameters in fillets vs. remains of fish in flatfish collected in Washington for the 2003 FRAM groundfish survey.

Contaminant	Mean in Fillets	Mean in Remains	Mean of Ratios
<b>Metals (<math>\mu\text{g/g}</math>)</b>			
Inorganic Arsenic	0.06	0.07	0.98
Cadmium	0.00	0.08	-
Chromium	0.33	0.48	0.68
Copper	0.27	0.82	0.30
Lead	0.00	0.00	-
Mercury	0.06	0.04	1.35
Nickel	0.00	0.00	-
Selenium	0.29	0.29	0.94
Silver	0.00	0.00	-
<b>Organics (ng/g)</b>			
Total PCB	0.30	1.21	0.24
Total DDT	0.06	0.07	0.98
Other Pesticides	0.0	0.0	-

### 3.5 Status of Benthic Communities

Macrobenthic infauna ( $> 1 \text{ mm}$ ) were sampled at a total of 256 stations throughout the study region. A single grab ( $0.1 \text{ m}^2$ ) was collected at all stations except three, at which duplicates were taken, thus resulting in a total of 259 benthic grabs. The duplicate samples were averaged for the calculation of CDFs and other analysis purposes. The resulting data are used here to assess the status of benthic community characteristics (taxonomic composition, diversity, abundance and dominant species), biogeographic patterns, the incidence of nonindigenous species, and potential linkages to ecosystem stressors throughout the western U.S. continental shelf from the Strait of Juan de Fuca, WA to the Mexican border. Assessments are presented on a region-wide basis, by state (WA, Oregon, California), and by NMS vs. non-sanctuary status. The latter comparison includes California sanctuaries (Channel Islands NMS, Monterrey Bay NMS, Gulf of the Farallones NMS, and Cordell Bank NMS) vs. non-sanctuary stations in California and stations in the Olympic Coast NMS (OCNMS) vs. non-sanctuary stations in Oregon and Washington. Characteristics of the shelf benthos are also compared to those of neighbouring estuaries along the West Coast, using 1999-2000 data on estuaries from the NCA-West database (Nelson et al. 2004, 2005; U.S. EPA 2004, Hayslip et al. 2006).

### 3.5.1 Taxonomic Composition

A total of 1,482 taxa were identified region-wide, of which 1,108 were identified to the species level. Polychaetes were the dominant taxa, both by percent abundance (59% region-wide, Fig. 3.5.1) and percent taxa (44% region-wide, Fig. 3.5.2, Table 3.5.1). Crustaceans and molluscs were the second and third most dominant taxa respectively, both by percent abundance (17% crustaceans, 12% molluscs) and percent taxa (25% crustaceans, 17% molluscs). Collectively, these three groups represented 88% of the total faunal abundance and 86% of the taxa throughout the region. Crustaceans were represented mostly by amphipods (202 identifiable taxa, 14% of the total number of taxa) followed by decapods (49 taxa, 3.3% of total taxa) and cumaceans (39 taxa, 2.6% of total taxa) (Table 3.5.1). Molluscs were composed mostly of bivalves (116 taxa, 7.8% of total taxa) and gastropods (112 taxa, 7.5% of total taxa). High proportions of polychaete and amphipod species are also characteristic of estuaries along the West Coast, though there are notable differences in the relative proportions of other taxonomic groups (Table 3.5.2). For example, species of larval insects represented 2.9% of total taxa in the NCA-West estuarine data set, but were absent in the present shelf samples. In contrast, ophiuroids and holothurians are more specious on the shelf than in estuaries. Also, while oligochaetes as a group represent only 0.2% of the total faunal abundance on the shelf, Nelson et al. (2005) reported them as being dominant (among the 10 most abundant) members of the estuarine benthos along the West Coast.

Polychaetes, crustaceans, and molluscs dominated the benthic fauna consistently across the three states and NMS vs. non-sanctuary categories (Fig. 3.5.1, 3.5.2). Similar to the region-wide pattern, polychaetes were the most dominant, by both percent abundance and species richness, consistently across all strata. However, while crustaceans were the second-most abundant group in California (similar to the region-wide pattern), molluscs were proportionally more abundant than crustaceans in Oregon and Washington. There were no major differences in the percent composition of benthic communities between NMSs and corresponding non-sanctuary sites. However, molluscs were proportionally more abundant and specious than crustaceans at non-sanctuary sites in Oregon and Washington than at the OCNMS.

### 3.5.2 Diversity

Species richness, expressed as the number of taxa present in a 0.1-m<sup>2</sup> grab, was relatively high in these offshore shelf assemblages. A total of 1,482 taxa were identified region-wide from the 259 benthic grabs. Species richness ranged from 19 to 190 taxa/grab and averaged 79 taxa/grab (Table 3.5.3, Fig. 3.5.3). In comparison, the NCA-West estuarine data (Nelson et al. 2004, 2005; U.S. EPA 2004, Hayslip et al. 2006) show an average of 26 taxa/grab in estuaries along the West Coast (Table 3.5.3). Only five of the 256 shelf stations,

representing about 2% of the shelf area, had  $\leq 26$  taxa/grab (Fig. 3.5.4). This greater species richness was reflected over large areas of the shelf. For example, approximately 50% of the area of the shelf had species richness  $\geq 67$  taxa/grab and 10% of the shelf had  $\geq 110$  taxa/grab (Fig. 3.5.4, Table 3.5.3). In comparison, the corresponding CDF 50<sup>th</sup> percentile value for estuaries was 49 taxa/grab and the 10<sup>th</sup> percentile value was 90 taxa/grab (Table 3.5.3). Species richness along the shelf was highest off California (mean of 94 taxa/grab) and nearly equally lower in Oregon and Washington (means of 55 and 56 taxa/grab, respectively). Estuarine means by state were much lower for California (24 taxa/grab) and Oregon (11 taxa/grab) though similar for Washington (48 taxa/grab) (Table 3.5.3). Average species richness was very similar between sanctuary vs. non-sanctuary stations for both the California and Oregon/Washington regions (Fig. 3.5.3).

A more detailed examination of species richness, using quartile ranges, further confirmed a pattern of increasing species richness along the shelf with decreasing latitude (Figs. 3.5.3, 3.5.5). There were 61 stations with values in the upper quartile of all stations (i.e., values  $> 100$  taxa/grab). All but one of these sites (WA03-0015) were in California, most were in the SCB. A correlation analysis (SAS 2003) revealed a highly significant negative association between numbers of species and latitude (Pearson's correlation coefficient  $r = -0.61$ ,  $p < 0.0001$ ). This is different from the pattern observed in estuaries. For example, the NCA-West 1999-2000 database for estuaries shows that the highest species richness among the three states was in Washington, especially in Puget Sound (Table 3.5.3; also see Partridge 2007). In fact, all estuarine stations with  $> 100$  taxa/grab were in Washington. The high species richness reported here for shelf waters, particularly those off the California coast, is consistent with an earlier study by Hyland et al. (1991) for offshore waters of the Santa Maria Basin, which showed numbers of species ( $> 0.5$ -mm size) averaging about 100 to 150/grab ( $0.1 \text{ m}^2$ ) at comparable outer shelf/upper slope depths under 200 m.

The high species richness, as well as a relatively even distribution of species abundances within samples, also resulted in fairly high values of the diversity index  $H'$  (log base 2) for many stations across the region. Values ranged from 2.04 to 6.63/grab and averaged 5.01/grab region-wide (Table 3.5.3, Fig. 3.5.6). Approximately 50% of the shelf area had  $H'$  values  $\geq 4.82$ , and 10% of the area had  $H'$  values  $\geq 5.80$  (Fig. 3.5.7). In comparison, mean diversity and the CDF 50<sup>th</sup> percentile point for estuarine habitat along the West Coast correspond to lower  $H'$  values of 2.41 and 3.84, respectively (Table 3.5.3). Mean  $H'$  in the present shelf survey was highest in California (5.36) and lowest in Washington (4.27) (Fig. 3.5.7, Table 3.5.3). There were no major differences in mean  $H'$  between sanctuary vs. non-sanctuary stations for both the California and Oregon/Washington regions.

Table 3.5.1. Summary of major taxonomic groups for the west-coast shelf region wide.

Taxonomic Group	Number identifiable taxa	% Total identifiable taxa
Phylum Protozoa	1	0.1
Phylum Porifera	1	0.1
Phylum Cnidaria		
Class Hydrozoa	10	0.7
Class Anthozoa	52	3.5
Phylum Platyhelminthes	9	0.6
Phylum Nemertea	32	2.2
Phylum Nemata	1	0.1
Phylum Sipuncula	10	0.7
Phylum Mollusca		
Class Gastropoda	112	7.5
Class Aplacophora	10	0.7
Class Bivalvia	116	7.8
Class Polyplacophora	6	0.4
Class Scaphopoda	9	0.6
Phylum Echiura	6	0.4
Phylum Annelida		
Class Polychaeta	648	43.7
Class Clitellata		
Subclass Hirudinea	1	0.1
Subclass Oligochaeta	1	0.1
Phylum Arthropoda		
Subphylum Crustacea		
Class Malacostraca		
Order Leptostraca	3	0.2
Order Decapoda	49	3.3
Order Mysida	6	0.4
Order Cumacea	39	2.6
Order Tanaidacea	16	1.1
Order Isopoda	43	2.9
Order Amphipoda	202	13.6
Class Maxillopoda	5	0.3
Class Ostracoda	14	0.9
Subphylum Chelicerata	7	0.4
Phylum Phoronida	2	0.1
Phylum Ectoprocta	1	0.1
Phylum Brachiopoda	2	0.1
Phylum Echinodermata		
Class Asteroidea	4	0.3
Class Ophiuroidea	25	1.7
Class Echinoidea	8	0.5
Class Holothuroidea	19	1.3
Phylum Hemichordata	5	0.3
Phylum Chordata	7	0.5
<i>Total</i>	1482	100

Table 3.5.2. Comparison of the proportion of taxa within major taxonomic groups on the shelf vs. West Coast estuaries. Each value is the number of species within the corresponding taxonomic group divided by the total number of species.

Taxonomic Group	Shelf	Estuaries*
Polychaetes	44%	36%
Amphipods	14%	14%
Decapods	3.3%	3.4%
Cumaceans	2.6%	2.6%
Bivalves	7.8%	8.3%
Gastropods	7.5%	7.8%
Ophiuroids	1.7%	1.2%
Holothurians	1.3%	0.7%
Insect larvae	0	2.9%
Total species	1482	1303
# Grabs (0.1 m <sup>2</sup> each)	259	345

\* Based on 1999-2000 data from the EPA National Coastal Assessment – Western Regional Component (NCA-West) database for estuaries (Nelson et al. 2004, 2005; U.S. EPA 2004; Hayslip et al. 2006).

Table 3.5.3. Comparison of the number of taxa, H' diversity (log<sub>2</sub>), and densities (m<sup>-2</sup>) of benthic infaunal assemblages on the shelf vs. West Coast estuaries.

Benthic Variable	Stratum	Shelf						Estuaries*					
		# Stations (n)	Mean	Min	Max	Areal 50 <sup>th</sup> percentile	Areal 90 <sup>th</sup> Percentile	# Stations (n)	Mean	Min	Max	Areal 50 <sup>th</sup> percentile	Areal 90 <sup>th</sup> Percentile
# taxa (grab <sup>-1</sup> )	Regionwide	256	79	19	190	67	110	345	26	0	198	49	90
	WA	50	56	23	102			97	48	0	198		
	OR	49	55	19	100			126	11	10	65		
	CA	157	94	25	190			122	24	10	95		
H' (grab <sup>-1</sup> )	Regionwide	256	5.01	2.04	6.63	4.82	5.80	345	2.41	0	6.36	3.84	5.60
	WA	50	4.27	2.04	5.41			97	3.43	0	6.36		
	OR	49	4.65	2.97	5.93			126	1.52	0	4.10		
	CA	157	5.36	3.04	6.63			122	2.52	0	5.56		
Density (m <sup>-2</sup> )	Regionwide	256	3788	540	22,980	3080	7250	345	10,653	0	415,820	4100	15,100
	WA	50	3467	770	16,060			97	65,562	0	57,830		
	OR	49	2310	540	7260			126	4896	20	81,190		
	CA	157	4351	690	22,980			122	19,857	70	415,820		

\* Based on 1999-2000 data from the EPA National Coastal Assessment – Western Regional Component (NCA-West) database for estuaries (Nelson et al. 2004, 2005; U.S. EPA 2004, Hayslip et al. 2006).

Table 3.5.4. Fifty most abundant benthic taxa in the West Coast shelf survey region wide. Average density per m<sup>2</sup>, and percent frequency of occurrence based on 256 grabs. Classification: Native = native species; Crypto = cryptogenic species (of uncertain origin); Indeter = indeterminate taxa (not identified to a level that would allow determination of origin).

Taxa Name	Taxon	Classification	Average #/m <sup>2</sup>	% Frequency
<i>Mediomastus</i> spp.	Polychaete	Indeter	141.9	62.9
<i>Axinopsida serricata</i>	Bivalve	Native	124.8	67.2
<i>Magelona longicornis</i>	Polychaete	Native	105.3	23.0
<i>Amphiodia urtica</i>	Ophiuroid	Native	87.5	43.4
<i>Spiophanes berkeleyorum</i>	Polychaete	Native	86.8	77.0
<i>Pinnixa occidentalis</i>	Decapoda	Native	82.0	27.3
<i>Spiophanes bombyx</i>	Polychaete	Native	81.2	41.8
<i>Euphilomedes carcharodonta</i>	Ostracod	Native	73.6	46.1
<i>Spiophanes duplex</i>	Polychaete	Native	73.2	44.9
<i>Prionospio jubata</i>	Polychaete	Native	67.2	71.9
<i>Chloeia pinnata</i>	Polychaete	Native	55.0	40.2
<i>Owenia fusiformis</i>	Polychaete	Crypto	48.2	10.9
<i>Myriochele striolata</i>	Polychaete	Native	47.7	10.5
<i>Galathowenia oculata</i>	Polychaete	Crypto	45.1	33.2
<i>Ampelisca agassizi</i>	Amphipod	Native	43.4	30.5
<i>Decamastus gracilis</i>	Polychaete	Native	42.0	46.1
<i>Paraprionospio pinnata</i>	Polychaete	Native	39.3	70.7
<i>Scoletoma luti</i>	Polychaete	Native	38.6	31.3
<i>Euclymeninae</i> sp. A	Polychaete	Native	37.2	58.6
<i>Amphiodia</i> spp.	Ophiuroid	Indeter	34.7	48.0
<i>Sternaspis fossor</i>	Polychaete	Crypto	34.7	46.9
<i>Rochefortia tumida</i>	Bivalve	Native	33.4	41.0
<i>Euclymeninae</i>	Polychaete	Indeter	29.7	49.6
<i>Lumbrineris cruzensis</i>	Polychaete	Native	28.6	45.7
<i>Levinsenia gracilis</i>	Polychaete	Crypto	28.5	38.3
<i>Ampelisca careyi</i>	Amphipod	Native	28.0	62.5
<i>Pholoe glabra</i>	Polychaete	Native	26.7	44.9
Phoronida	Phoronid	Indeter	26.7	28.1
<i>Aphelochaeta glandaria</i>	Polychaete	Native	25.8	33.2
<i>Paradiopatra parva</i>	Polychaete	Native	25.6	37.1
<i>Prionospio lighti</i>	Polychaete	Native	25.5	34.4
<i>Monticellina cryptica</i>	Polychaete	Native	23.8	29.3
Edwardsiidae	Actiniarian	Indeter	23.6	10.9
<i>Aricidea catherinae</i>	Polychaete	Crypto	23.4	36.3
<i>Pseudofabriciola californica</i>	Polychaete	Native	23.2	2.3
<i>Photis</i> spp.	Amphipod	Indeter	21.1	32.8



Taxa Name	Taxon	Classification	Average #/m <sup>2</sup>	% Frequency
<i>Maldane sarsi</i>	Polychaete	Crypto	20.8	40.2
Amphiuridae	Ophiuroid	Indeter	20.6	49.2
<i>Leptochelia dubia</i>	Tanaidacea	Crypto	19.7	32.4
<i>Glycera nana</i>	Polychaete	Native	18.7	53.5
Nemertea	Nemertean	Indeter	18.5	27.3
<i>Rhepoxynius boreovariatus</i>	Amphipod	Native	17.5	19.1
<i>Polygordius</i> spp.	Polychaete	Indeter	17.4	1.2
<i>Leitoscoloplos pugettensis</i>	Polychaete	Native	17.0	32.0
<i>Acila castrensis</i>	Bivalve	Native	16.6	24.2
<i>Aphelochaeta monilaris</i>	Polychaete	Native	16.3	31.3
<i>Scalibregma californicum</i>	Polychaete	Native	15.9	35.9
Fabriciinae	Polychaete	Indeter	15.7	2.0
<i>Ampelisca brevisimulata</i>	Amphipod	Native	15.4	34.8
<i>Macoma carlottensis</i>	Bivalve	Native	14.8	21.1

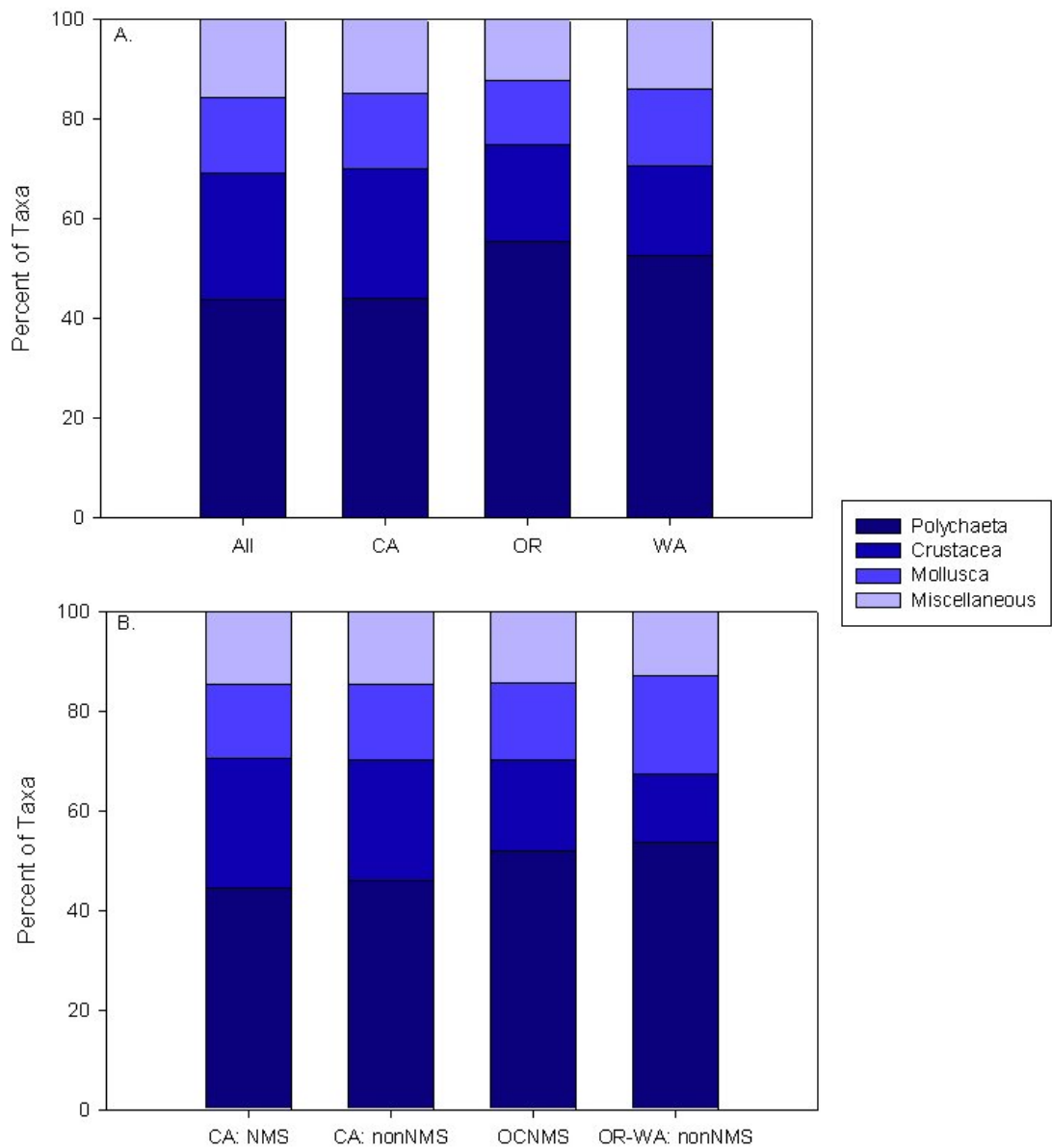


Figure 3.5.1. Comparison of percent faunal composition by abundance among (A) all, California, Oregon, and Washington sample locations, and (B) California NMS, California non-NMS, Olympic Coast NMS, and Washington-Oregon non-NMS sample locations.

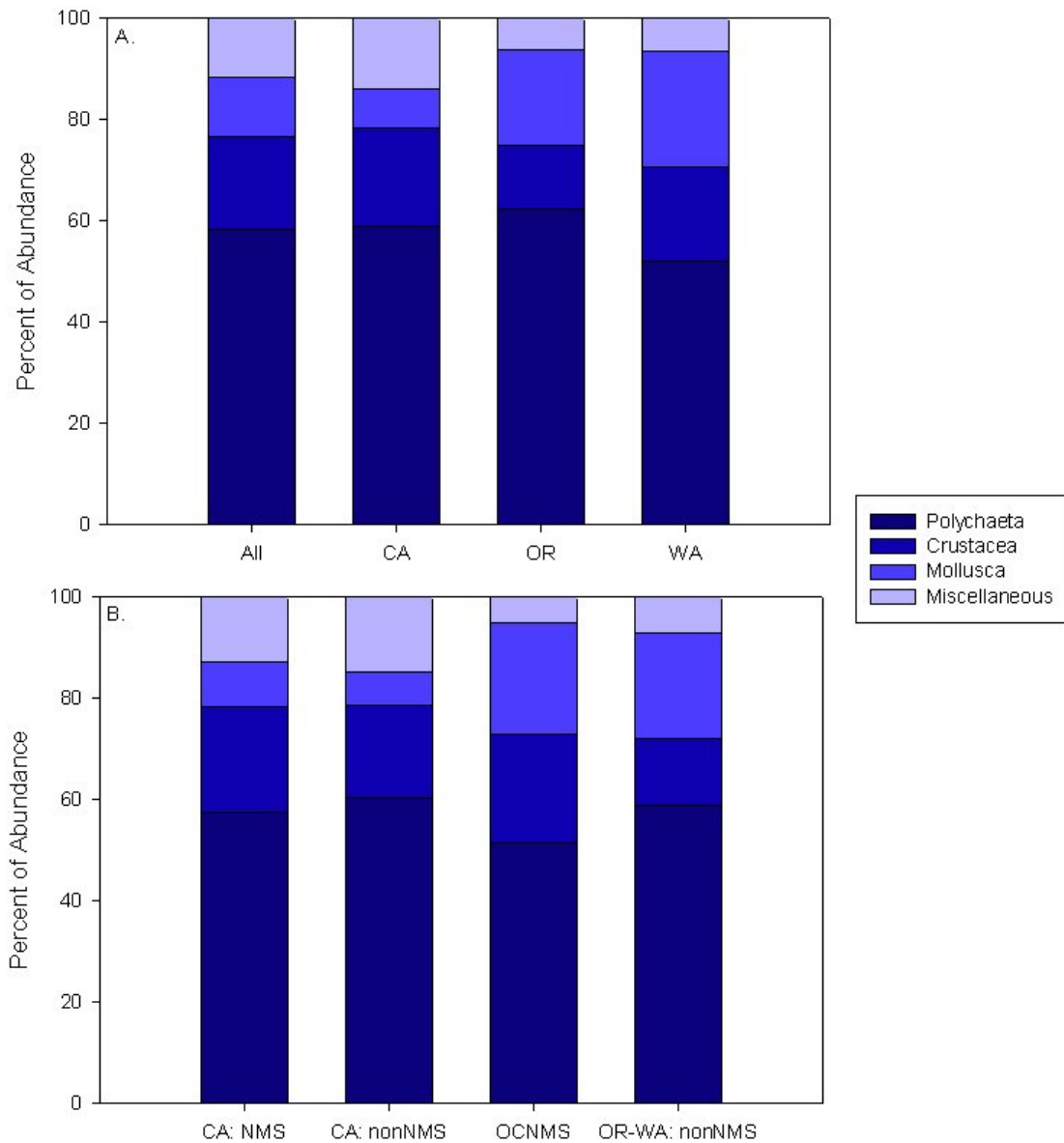


Figure 3.5.2. Comparison of percent faunal composition by taxa among (A) all, California, Oregon, and Washington sample locations, and (B) California NMS, California non-NMS, Olympic Coast NMS, and Washington-Oregon non-NMS sample locations.

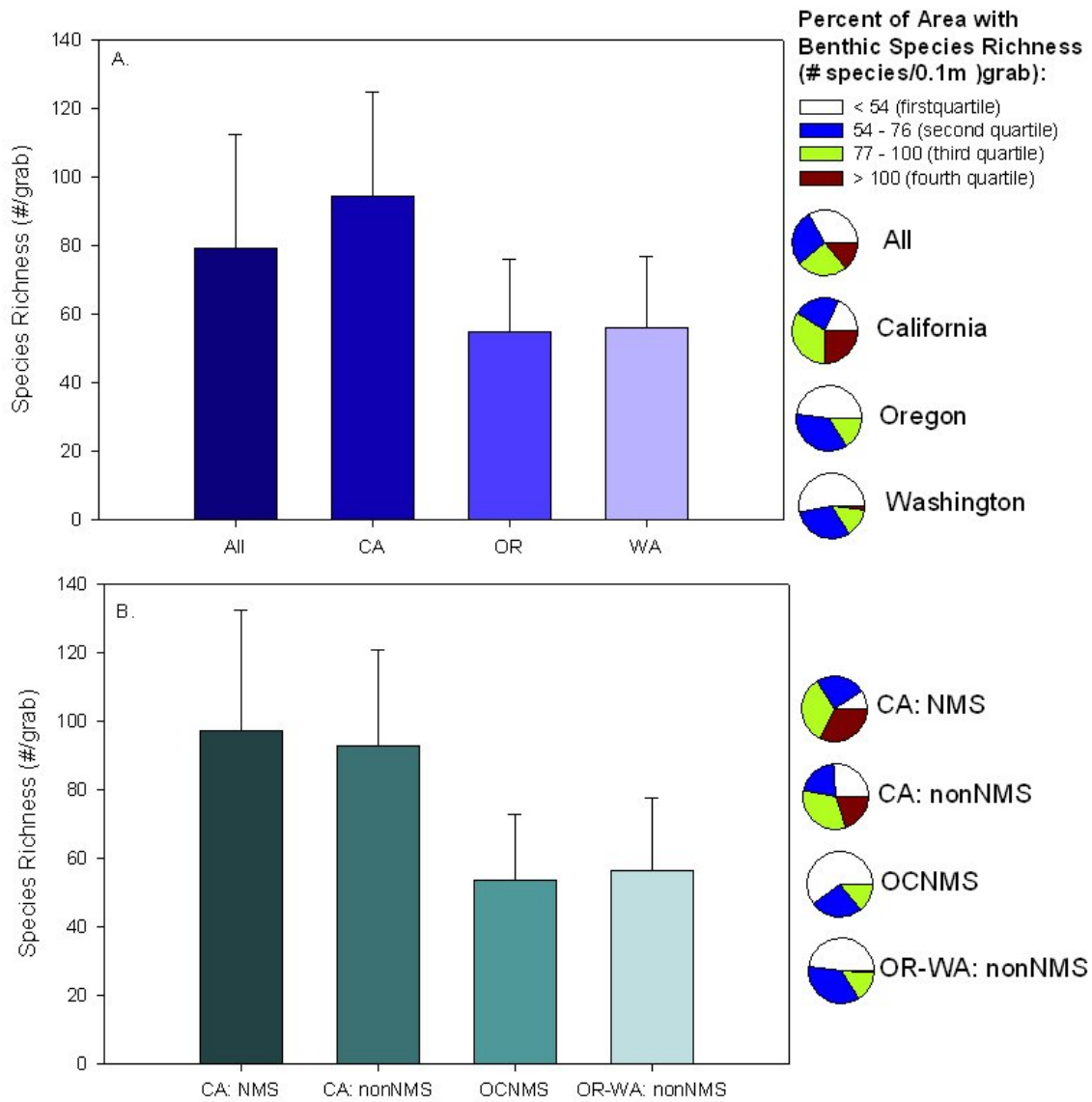


Figure 3.5.3. Comparison of benthic species richness (mean no. taxa/grab + 1 SD) among (A) all, California, Oregon, and Washington sample locations, and (B) California NMS, California non-NMS, Olympic Coast NMS, and Washington-Oregon non-NMS sample locations. Pie charts show quartile ranges of values.

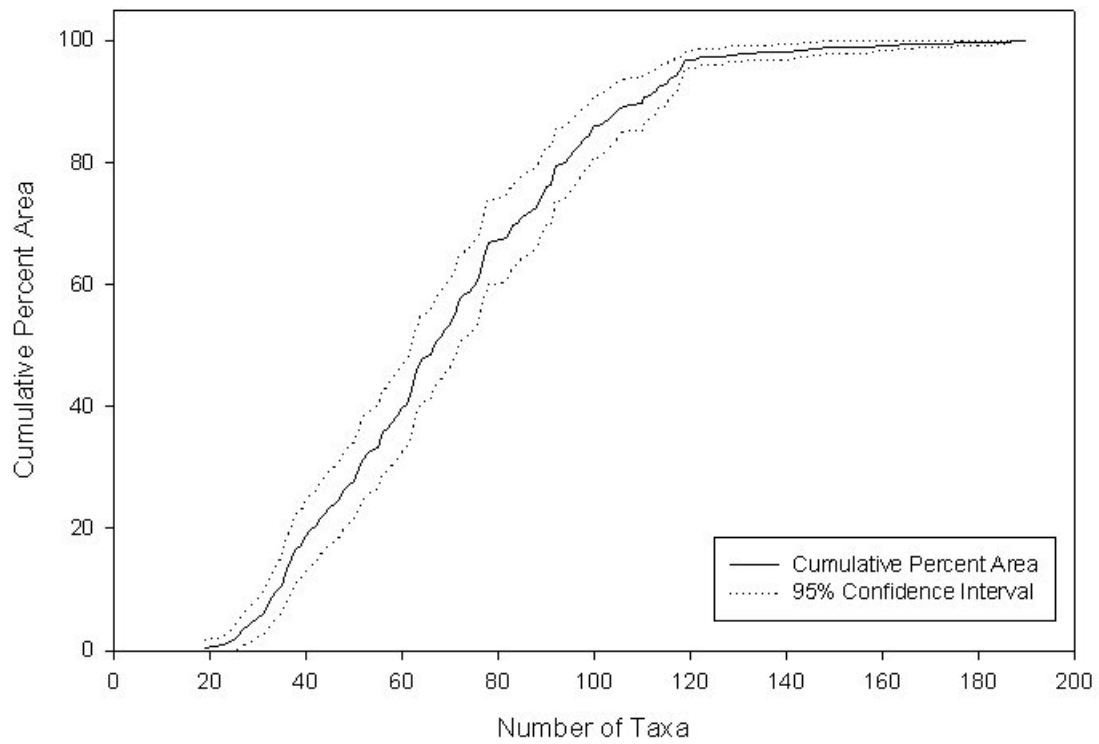


Figure 3.5.4. Percent area (and 95% confidence interval) of overall West Coast Shelf vs. benthic species richness (# taxa/0.1-m<sup>2</sup> grab).

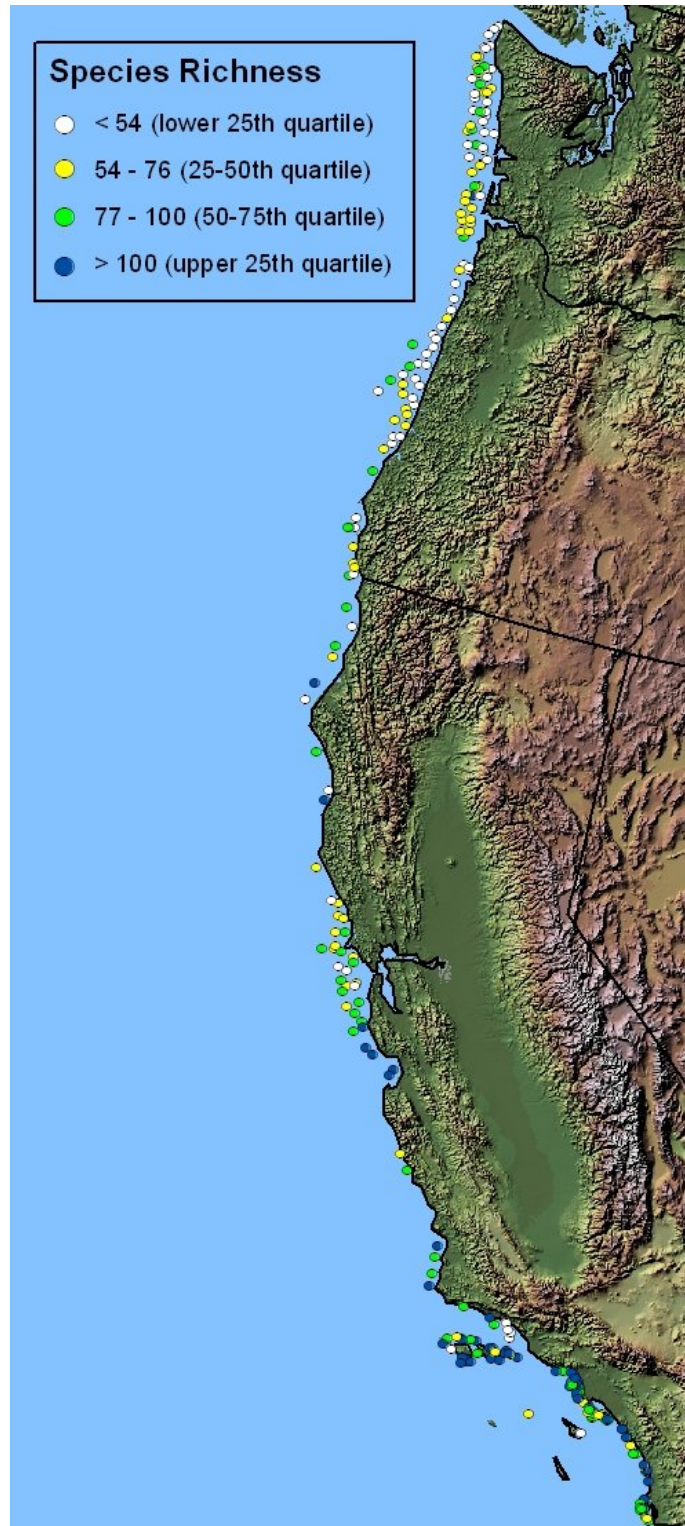


Figure 3.5.5. Map illustrating the distribution of benthic species richness (# taxa per 0.1-m<sup>2</sup> grab) throughout the West Coast region.

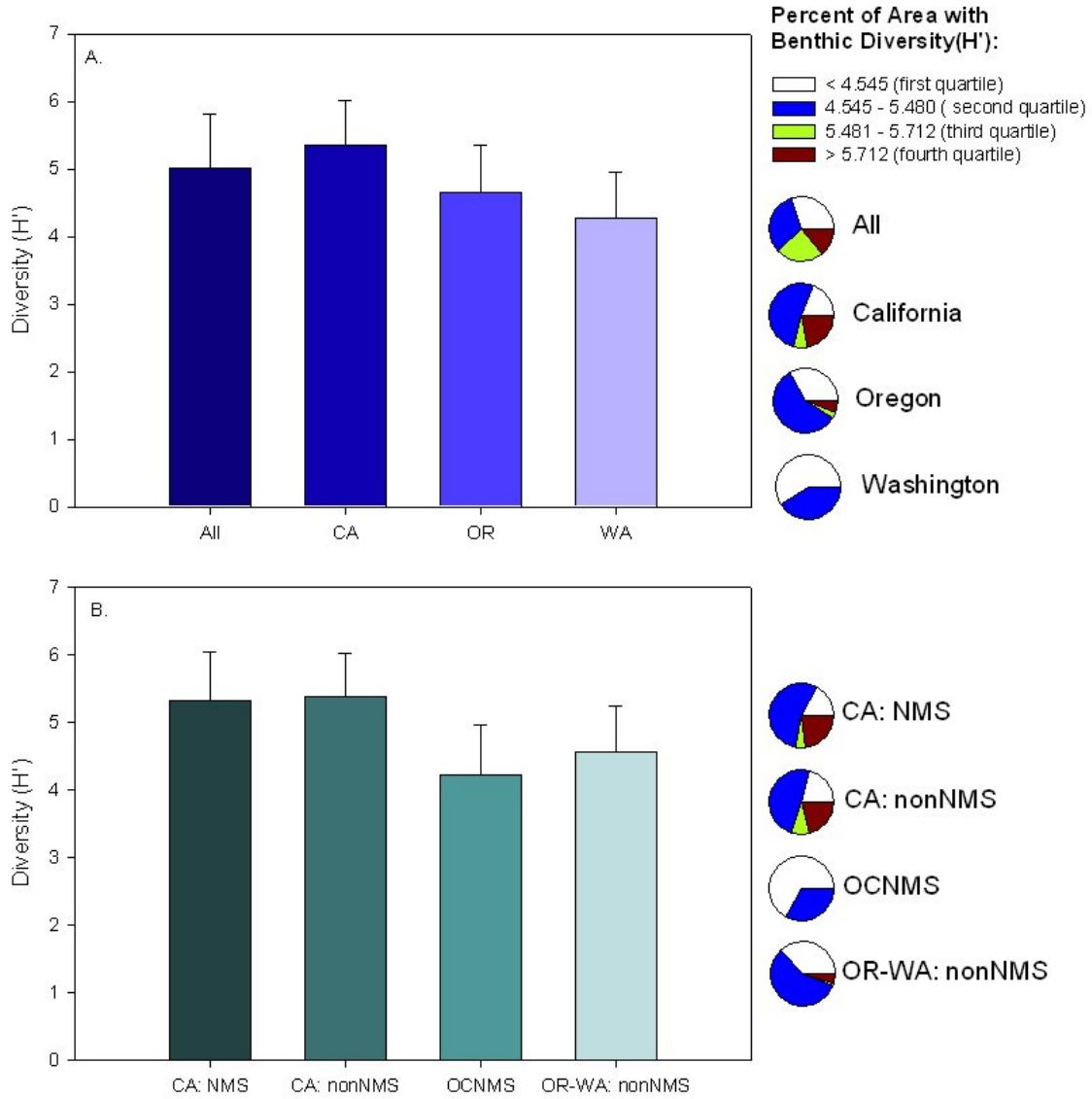


Figure 3.5.6. Comparison of benthic species diversity ( $H'$ , mean + 1 SD) among (A) all, California, Oregon, and Washington sample locations, and (B) California NMS, California non-NMS, Olympic Coast NMS, and Washington-Oregon non-NMS sample locations. Pie charts show quartile ranges of values.

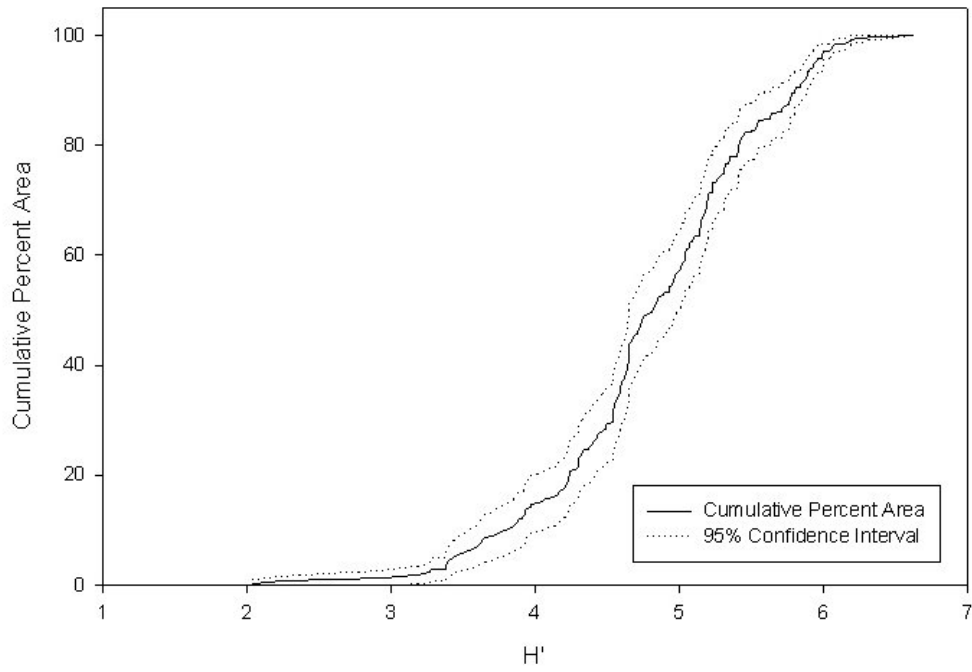


Figure 3.5.7. Percent area (and 95% confidence interval) of overall West Coast Shelf vs. Shannon-Wiener  $H'$  ( $\log_2$ ) diversity index.



### 3.5.3 Abundance and Dominant Taxa

A total of 99,135 individual specimens were collected across the 256 stations (259 0.1-m<sup>2</sup> grab samples) throughout the region. Densities ranged from 540 to 22,980 m<sup>-2</sup> and averaged 3,788 m<sup>-2</sup> (Fig. 3.5.8, Table 3.5.3, Appendix Table 4). On a spatial basis, about 50% of the shelf area had densities  $\geq 3,080$  m<sup>-2</sup> and about 10% of the area had densities  $\geq 7,250$  m<sup>-2</sup> (Fig. 3.5.9). In comparison, the NCA-West estuarine data (Nelson et al. 2004, 2005; U.S. EPA 2004; Hayslip et al. 2006) show much higher densities of benthic infauna in estuaries along the West Coast (e.g., mean of 10,653 m<sup>-2</sup> and range of 0 to 415,820 m<sup>-2</sup>) (Table 3.5.3). However, the higher mean and maximum densities in the latter case are due to a greater frequency of high-density patches in these shallower estuarine systems. Spatially, while 10% of the estuarine area along the West Coast had high densities  $\geq 15,100$  m<sup>-2</sup>, 50% of the area had lower densities  $\leq 4,100$  m<sup>-2</sup>, which is only moderately higher than that estimated for the corresponding percentage of shelf area (3,080 m<sup>-2</sup>). Densities on the shelf in excess of 10,653 m<sup>-2</sup>, the estuarine mean density, were limited to about 2% of the shelf area. Densities of benthic fauna in the present offshore survey, averaged by state, were highest in California (mean of 4,351 m<sup>-2</sup>) and lowest in Oregon (mean of 2,310 m<sup>-2</sup>) (Fig. 3.5.8, Table 3.5.3). Mean densities were slightly higher at NMS stations vs. non-sanctuary stations for both the California and Oregon/Washington regions.

The 50 most abundant taxa found in shelf waters throughout the region are listed in Table 3.5.4. The 10 most abundant members on this list include the polychaetes *Mediomastus* spp., *Magelona longicornis*, *Spiophanes berkeleyorum*, *Spiophanes bombyx*, *Spiophanes duplex*, and *Prionospio jubata*; the bivalve *Axinopsida serricata*; the ophiuroid *Amphiodia urtica*; the decapod *Pinnixa occidentalis*; and the ostracod *Euphilomedes carcharodonta*. *Mediomastus* spp. and *A. serricata* were the two most abundant taxa overall. There are clear differences between these dominant shelf fauna and those found in estuarine habitats along the West Coast. As an example, with the exception of *Mediomastus* spp., none of these 50 shelf species also appear on the list of dominant (10 most abundant) estuarine fauna reported by Nelson et al. (2005). The latter estuarine list (based only on 1999 data from the NCA-West database, thus excluding Puget Sound, the San Francisco estuary, and the main stem of the Columbia River) included the amphipods *Americorophium spinicorne*, *A. salmonis*, and *Eogammarus confervicolus* complex; oligochaetes; and the polychaetes *Streblospio benedicti*, *Mediomastus* sp, *Mediomastus californiensis*, *Pygospio elegans*, *Pseudopolydora paucibranchiata*, and *Neanthes limnicola* (Nelson et al. 2005). Thus, while estuaries have been found to be dominated by polychaetes, amphipods, and oligochaetes, the shelf environment was characterized by a broader range of taxonomic groups, including the occurrence of bivalves, ophiuroids, decapods, and ostracods as dominant members in addition to polychaetes. Another notable characteristic of these dominant shelf fauna is their relatively low densities. Average densities of the 10 most abundant

shelf taxa ranged from 67 to 142 m<sup>-2</sup> (Table 3.5.4). In comparison, average densities of the 10 most abundant taxa in estuaries were much higher, ranging from 197 to 5,242 m<sup>-2</sup> (Nelson et al. 2005).

In addition to inshore-offshore differences, there were notable regional variations in the dominant offshore fauna. Though many of these fauna have broad geographic distributions throughout the region (see next section), except for the polychaete *Spiophanes bombyx*, the same taxa did not appear as members of the 10 most abundant taxa consistently across all three states (Table 3.5.5A). The closest similarities were between Oregon and Washington. For example, the polychaete *Mediomastus* spp. and ophiuroid *Amphiodia urtica* were the two most abundant taxa in California, while in Oregon and Washington the same two species, the polychaete *Magelona longicornis* and bivalve *Axinopsida serricata*, were the two most abundant taxa. There also was less variation between NMS vs. non-sanctuary status. For example, at least half of the 10 most abundant taxa in NMSs were also dominant in corresponding non-sanctuary waters (Table 3.5.5B).

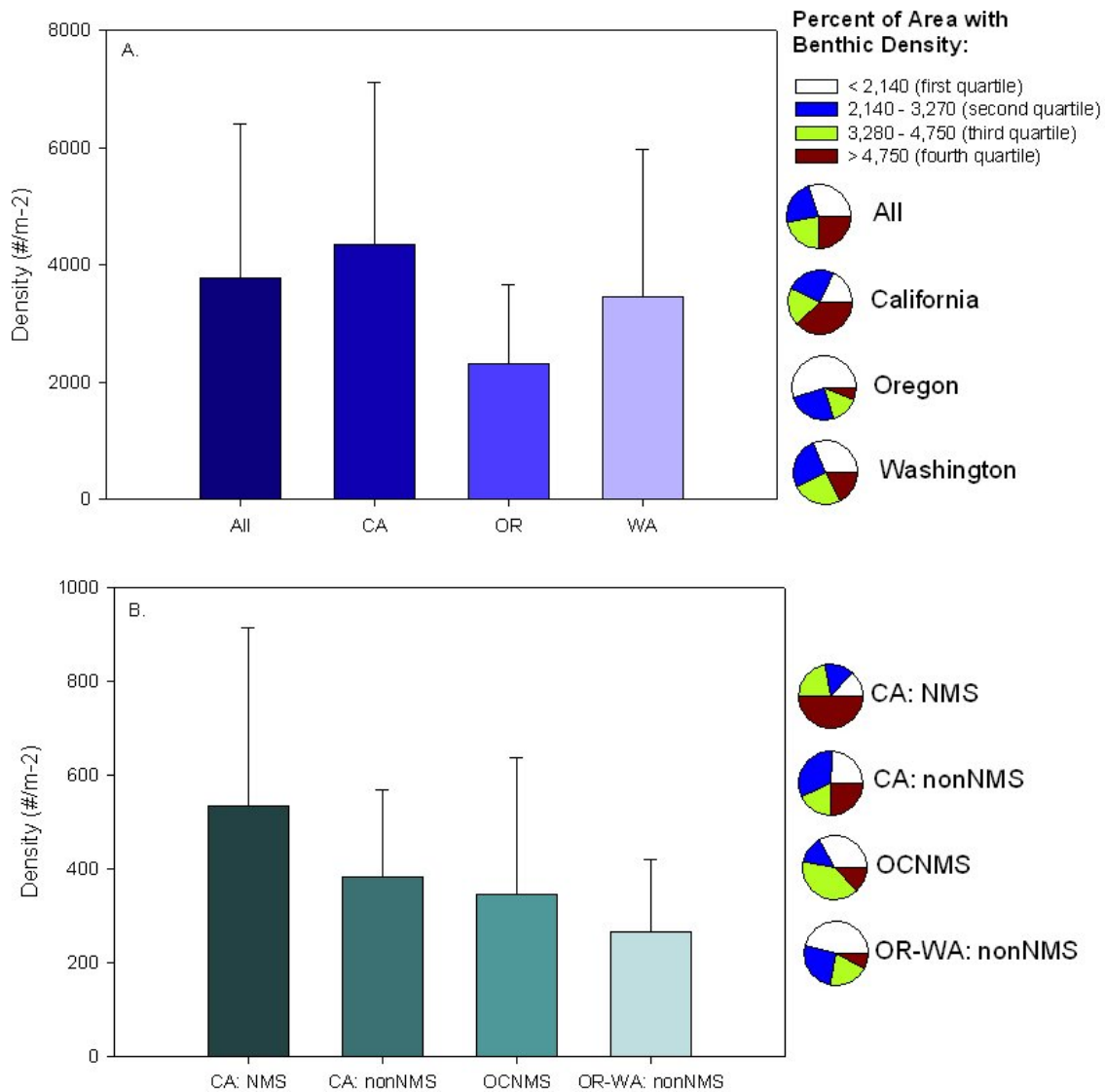


Figure 3.5.8. Comparison of benthic density (mean + 1 SD) among (A) all, California, Oregon, and Washington sample locations, and (B) California NMS, California non-NMS, Olympic Coast NMS, and Washington-Oregon non-NMS sample locations. Pie charts show quartile ranges of values.

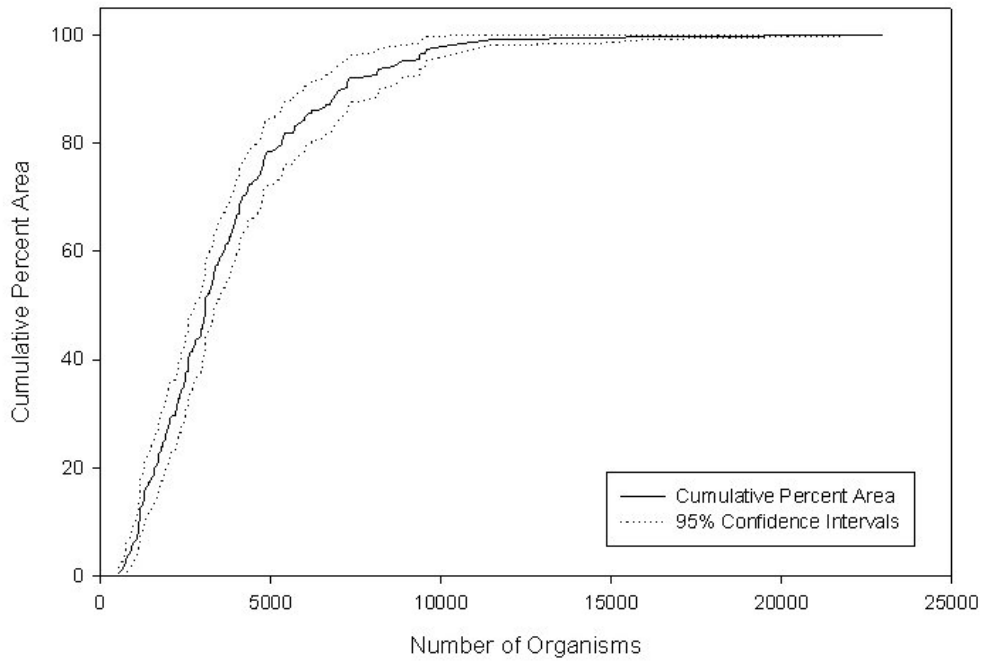


Figure 3.5.9. Percent area (and 95% confidence interval) of overall West Coast Shelf vs. benthic abundance (number of individuals/m<sup>2</sup>).

Table 3.5.5. Comparison of dominant (10 most abundant) taxa among (A) all, California, Oregon, and Washington sample locations, and (B) California NMS, California non-NMS, Olympic Coast NMS, and Washington-Oregon non-NMS sample locations.

A. West Coast			CA			OR			WA		
Taxa	Mean	%	Taxa	Mean	%	Taxa	Mean	%	Taxa	Mean	%
	n	Freq.			Freq.			Freq.			Freq.
<i>Mediomastus</i> spp.	142	63	<i>Mediomastus</i> spp.	217	78	<i>Magelona longicornis</i>	167	51	<i>Axinopsida serricata</i>	384	92
<i>Axinopsida serricata</i>	125	67	<i>Amphiodia urtica</i>	143	71	<i>Axinopsida serricata</i>	129	80	<i>Magelona longicornis</i>	284	54
<i>Magelona longicornis</i>	105	23	<i>Pinnixa occidentalis</i>	133	41	<i>Galathowenia oculata</i>	101	78	<i>Owenia fusiformis</i>	235	26
<i>Amphiodia urtica</i>	88	43	<i>Spiophanes duplex</i>	119	73	<i>Spiophanes berkeleyorum</i>	91	73	<i>Spiophanes bombyx</i>	179	58
<i>Spiophanes berkeleyorum</i>	87	77	<i>Spiophanes berkeleyorum</i>	105	80	<i>Prionospio jubata</i>	61	61	<i>Ampelisca agassizi</i>	167	30
<i>Pinnixa occidentalis</i>	82	27	<i>Chloeia pinnata</i>	89	64	<i>Scoletoma luti</i>	61	55	<i>Euphilomedes carcharodonta</i>	134	44
<i>Spiophanes bombyx</i>	81	42	<i>Myriochele striolata</i>	78	17	<i>Spiophanes bombyx</i>	52	29	<i>Galathowenia oculata</i>	126	68
<i>Euphilomedes carcharodonta</i>	74	46	<i>Prionospio jubata</i>	77	83	<i>Acila castrensis</i>	43	57	<i>Scoletoma luti</i>	83	62
<i>Spiophanes duplex</i>	73	45	<i>Euphilomedes carcharodonta</i>	74	54	<i>Paradiopatra parva</i>	40	39	<i>Rhepoxynius boreovariatus</i>	72	62
<i>Prionospio jubata</i>	67	72	<i>Spiophanes bombyx</i>	59	41	<i>Amaeana occidentalis</i>	39	10	<i>Ampelisca careyi</i>	71	70

B. CA: NMS			CA: nonNMS			OCNMS			OR-WA: nonNMS		
Taxa	Mean	%	Taxa	Mean	%	Taxa	Mean	%	Taxa	Mean	%
	n	Freq.			Freq.			Freq.			Freq.
<i>Mediomastus</i> spp.	427	18	<i>Amphiodia urtica</i>	187	34	<i>Owenia fusiformis</i>	384	3	<i>Magelona longicornis</i>	242	15
<i>Pinnixa occidentalis</i>	231	10	<i>Spiophanes duplex</i>	159	32	<i>Axinopsida serricata</i>	347	11	<i>Axinopsida serricata</i>	219	23
Edwardsiidae	108	9	<i>Mediomastus</i> spp.	107	30	<i>Spiophanes bombyx</i>	259	9	<i>Galathowenia oculata</i>	115	21
<i>Spiophanes berkeleyorum</i>	108	17	<i>Spiophanes berkeleyorum</i>	104	32	<i>Ampelisca agassizi</i>	255	5	<i>Scoletoma luti</i>	92	17
<i>Decamastus gracilis</i>	105	14	<i>Chloeia pinnata</i>	83	28	<i>Magelona longicornis</i>	191	5	<i>Spiophanes berkeleyorum</i>	75	20
<i>Chloeia pinnata</i>	101	12	<i>Pinnixa occidentalis</i>	82	15	<i>Galathowenia oculata</i>	111	7	<i>Euphilomedes carcharodonta</i>	59	9
<i>Rochefortia tumida</i>	99	12	<i>Euphilomedes carcharodonta</i>	78	21	<i>Euphilomedes carcharodonta</i>	104	5	<i>Prionospio jubata</i>	56	16
<i>Myriochele striolata</i>	99	4	<i>Prionospio jubata</i>	72	34	<i>Ampelisca careyi</i>	93	9	<i>Spiophanes bombyx</i>	54	8
<i>Prionospio jubata</i>	85	18	<i>Spiophanes bombyx</i>	68	14	<i>Polygordius</i> spp.	87	0	<i>Acila castrensis</i>	46	15
<i>Pseudofabriciola californica</i>	83	0	<i>Myriochele striolata</i>	67	7	<i>Rhepoxynius boreovariatus</i>	69	8	<i>Amphiodia</i> spp.	36	15

### 3.5.4 Biogeographical Distributions

The 2003 probabilistic survey is one of the few regional-scale studies of the benthos on the continental shelf of the U.S. Pacific Coast. As such, the data are well suited to addressing a number of biogeographic questions. The first question addressed is whether the shelf fauna have restricted along-coast distributions or whether they have wide latitudinal distributions. To address this question, we utilized the Marine Ecosystems of the World (MEOW) biogeographic schema recently proposed by The Nature Conservancy (Spalding et al. 2007). The MEOW scheme is hierarchical, with 12 Realms composed of 62 provinces, which in turn are composed of 232 ecoregions. Based on this scheme, we therefore evaluated the presence of species across the seven ecoregions of the Temperate Northern Pacific Realm that border the U.S. Pacific Coast (Fig. 3.5.10). These seven ecoregions include all the ecoregions of the Cold Temperate Northwest Pacific Province and the northernmost ecoregion in the Warm Temperate Northeast Pacific Province, and span from the upper half of the Baja Peninsula in Mexico to the Aleutian Islands in Alaska. Ecoregions within the Arctic Realm bordering northern Alaska are not considered, nor are the two other ecoregions of the Baja Peninsula that do not border the United States.

Appendix Table 5 summarizes the biogeographic distributions, by ecoregion, of the 39 most abundant taxa that were identified to species (from Table 3.5.4). Distributional data were derived from the present study, previous EMAP surveys including unpublished data from Alaskan surveys (Max Hober and Douglas Dasher), and the Pacific Coast Ecosystem Information System (PCEIS). PCEIS is a database synthesizing the distributions of native and nonindigenous marine/estuarine species of the Pacific Coast being developed by EPA and the USGS (Lee and Reusser 2008). Of the 39 abundant species collected along the California-Oregon-Washington shelf, almost 95% of them were found in both the SCB and Northern California ecoregions, while 87% were found in both the Oregon, Washington, Vancouver Coast and Shelf ecoregion and in the Puget Trough/ Georgia Basin ecoregion. The percentage of species occurring off the coast of Canada (North American Pacific Fjordland ecoregion) and the Gulf of Alaska drops to about 72% and 59%, respectively. With 14 of the 39 species reported from the Aleutians, the percentage of the species reported declines to 36% in the most northern ecoregion of the Temperate Northern Pacific Realm.

These distributional patterns potentially could be confounded by taxonomic uncertainties. For example, seven of the species in Table 3.5.4 are classified as cryptogenic species, which are species of uncertain origin (Carlton 1996). All of these cryptogenic species occur in more than one of the MEOW provinces and at least one possible explanation for their wide distributions is that they actually represent a suite of sibling species that can not be readily distinguished morphologically. Even for natives there can be confusion about the specific identity of a species. For example, the native amphipod *Ampelisca careyi* may be a variant of *A. unsocalae* (Chapman 2007). To reduce this source

of uncertainty, the analysis was repeated excluding 14 problematic species (Appendix Table 5). Removal of these problematic species reduces the percentage species overlap in all the ecoregions but did not substantially alter the general biogeographic pattern. Southern and Northern California ecoregions still had the highest percentage of species, with 92% and 88% of the species, respectively. As with the full set of species, a high percentage (> 75%) of the species were found in Puget Sound and along the coasts of Oregon and Washington, with a reduction northward up into the Gulf of Alaska and then a further reduction in the Aleutian ecoregion.

Another source of uncertainty in defining biogeographic ranges is the different levels of sampling along the coast. The SCB ecoregion has been intensively sampled (see SCAMIT 2001), as has Puget Sound. Northern California, Oregon, and Washington shelves have not been sampled as intensively, although the fauna of this section of the coast is reasonably well known (e.g., Carlton 2007). The data for northern Canada (N. American Pacific Fjordland ecoregion) were derived primarily from the dataset for the Haida Gwaii archipelago

([http://gcmd.nasa.gov/KeywordSearch/Metadata.do?Portal=caobis&MetadataType=0&KeywordPath=&MetadataView=Full&EntryId=OBIS.Gwaii\\_Inv](http://gcmd.nasa.gov/KeywordSearch/Metadata.do?Portal=caobis&MetadataType=0&KeywordPath=&MetadataView=Full&EntryId=OBIS.Gwaii_Inv)). While limited in spatial extent, this dataset includes information on more than 2,500 taxa. The Gulf of Alaska distributions were derived primarily from the EMAP 2002 survey in South-central Alaska (Saupe et al. 2005), unpublished data from the 2004 Southeast Alaska EMAP survey, and pre- and post-Exxon Valdez oil spill surveys of Prince William Sound (Hines and Ruiz 2000, Hoberg and Feder 2002). These various sources should be adequate to detect the occurrence of abundant species in most cases. In comparison, the sources for the Aleutians were more sparse and included unpublished data from the 2006-7 EMAP surveys in the Aleutians, reports on Alaskan and Canadian bivalves (Bernard 1967, Macpherson 1971, Baxter 1987), and the Global Biodiversity Information Facility (GBIF; <http://data.gbif.org/>). It is possible that the absence of some species from Aleutian ecoregion is result of the more limited sampling in this region.

Even with these sources of uncertainty, it can be concluded that the majority of the abundant benthic species on the California-Oregon-Washington shelf have wide latitudinal distributions along the Pacific Coast of the United States. All three of the abundant bivalves, the pinnixid crab *Pinnixa occidentalis*, six polychaetes, and possibly the amphipod *A. careyi* extend from Southern California into the Aleutians. Another eight species have been reported from Southern California to the Gulf of Alaska. Conversely, only the sabellid polychaete *Pseudofabriciola californica* was limited to a single ecoregion, while the amphipod *Rhepoxynius boreovariatus* and the polychaetes *Myriochele striolata* and possibly *Monticellina cryptica* have been reported from only two of the ecoregions.

While the majority of species have wide latitudinal ranges, most species show differences in abundance among the three ecoregions within the 2003 EMAP sampling frame. The polychaete *Magelona longicornis* and bivalve *Axinopsida serricata* are examples of species with maximum densities in the northern portion of the sampling frame, the Oregon, Washington, Vancouver Shelf & Coast ecoregion (Figs. 3.5.11, 3.5.12). The ophiuroid *Amphiodia urtica* is an example of a species with maximum densities in the SCB ecoregion (Fig. 3.5.13), while *Pinnixa occidentalis* has its maximum densities in the middle of the coast, in the Northern California ecoregion (Fig. 3.5.14).

The second question that we address is whether there is a unique shelf fauna different from that found in Puget Sound or the coastal estuaries. The Puget Sound ecoregion has a high species overlap with the shelf fauna, with 87% of the abundant species on the shelf also reported from Puget Sound (Appendix Table 5). While portions of Puget Sound are estuarine, much of Puget Sound resembles the shelf with its greater depth and high salinity, which presumably explains much of the species' overlap. Three of the five species not found in Puget Sound were not found along the Oregon-Washington coast, suggesting that they are limited to more southern latitudes in general, rather than from Puget Sound specifically. The other two abundant species (*Chloeia pinnata* and *Paradiopatra parva*) not found in Puget Sound are found in the Oregon, Washington, Vancouver Shelf & Coast ecoregion. However, *Chloeia pinnata* was not found north of 44 degrees in the present survey and may not be well adapted to the most northern latitudes within the ecoregion. In contrast, *Paradiopatra parva* was found in the present survey up to 48 degrees latitude, suggesting that there are specific conditions within Puget Sound that limit its distribution or abundance.

Less expected was the extent of faunal overlap with the coastal estuaries. Almost 85% (33) of the most abundant shelf species have been reported at least once from the coastal estuaries of California, Oregon, or Washington exclusive of Puget Sound. Thus, it appears that the habitat requirements for many of the shelf species are sufficiently broad to allow at least colonization in estuarine ecosystems, though it is not clear whether they establish self-maintaining populations in all cases. Of the habitat requirements likely to limit shelf species from estuaries, the lower and variable salinities in estuaries are likely to be critical, if not the most critical, factors. Among the species reported from estuaries, one possibility is that they are able to colonize only the high-salinity Southern California estuaries, such as San Diego, which are euhaline (> 30 psu) over most of their area. Of the 33 species found in estuaries, eight (*Prionospio jubata*, *Paradiopatra parva*, *Monticellina cryptica*, *Aricidea catherinae*, *Pseudofabriciola californica*, *Maldane sarsi*, *Scalibregma californicum*, and *Ampelisca brevisimulata*) have been reported only from Southern California estuaries. In comparison to the Southern California estuaries, small estuaries in the Pacific Northwest undergo large salinity shifts both seasonally and tidally, so that species found in small estuaries are likely to have relatively broad salinity



tolerances. Based on the 1999, 2001 and 2002 EMAP surveys (Nelson et al. 2004, 2005, 2007), as well as an EPA survey of the benthos in small estuaries (Lee et al. 2003, unpublished data), a species list of 137 species has been developed for the small estuaries of the Oregon, Washington, Vancouver Coast and Shelf ecoregion. Of the 33 abundant shelf species found in estuaries, eight (*Spiophanes bombyx*, *Owenia fusiformis*, *Paraprionospio pinnata*, *Rochefortia tumida*, *Prionospio lighti*, *Leptochelia dubia*, and *Leitoscoloplos pugettensis*) were found in these small estuaries.

These biogeographic patterns suggest that the abundant shelf species can be broken into three broad salinity-tolerance groups. The 14 species not found within estuaries or only within Southern California estuaries can be classified as putative stenohaline species. The eight species found within the small estuaries would have the largest relative salinity tolerances, while the remaining 11 species found in moderate and large estuaries outside of Southern California presumably would have intermediate salinity tolerances. While factors other than salinity limit species' distributions, biogeographical patterns offer an approach to generating preliminary relative salinity tolerances for a large number of species.

The present analysis draws information from both the quantitative EMAP/NCA survey and from qualitative reports of species' distributions, with each approach providing a different insight into a species' habitat requirements. Biogeographic distributions (Appendix Table 5) can be considered an indicator of species' broad tolerances while the distributional shifts in abundance (Figs. 3.5.11 – 3.5.14) can be considered an indicator of species' habitat preferences. Thus, the wide latitudinal and estuarine distributions of most species are suggestive of wide habitat tolerances among these abundant shelf species. However, the pattern of high abundance occurring in only one or two ecoregions as observed for several species (e.g., *P. californica*, *M. longicornis*, *C. pinnata* and *P. occidentalis*) suggests a substantially reduced preferred habitat range for this set of abundant species. Presumably, species with a more limited preferred habitat range would be relatively more susceptible to climate change than those with wide ranges. However, species' responses to sea-surface temperature increases are complex and may vary among cold-water and warm-water species (e.g., Lima et al. 2007). Nonetheless, future work on comparing species' biogeographic and preferred habitat ranges with sea-surface temperature patterns (e.g., MODIS) by ecoregion is one potential avenue to evaluating relative risk to climate change for coastal species. It is worth noting that such analyses are greatly facilitated by the continuing evolution of biological information systems at global (e.g., GBIF) and regional (e.g., PCEIS) scales.

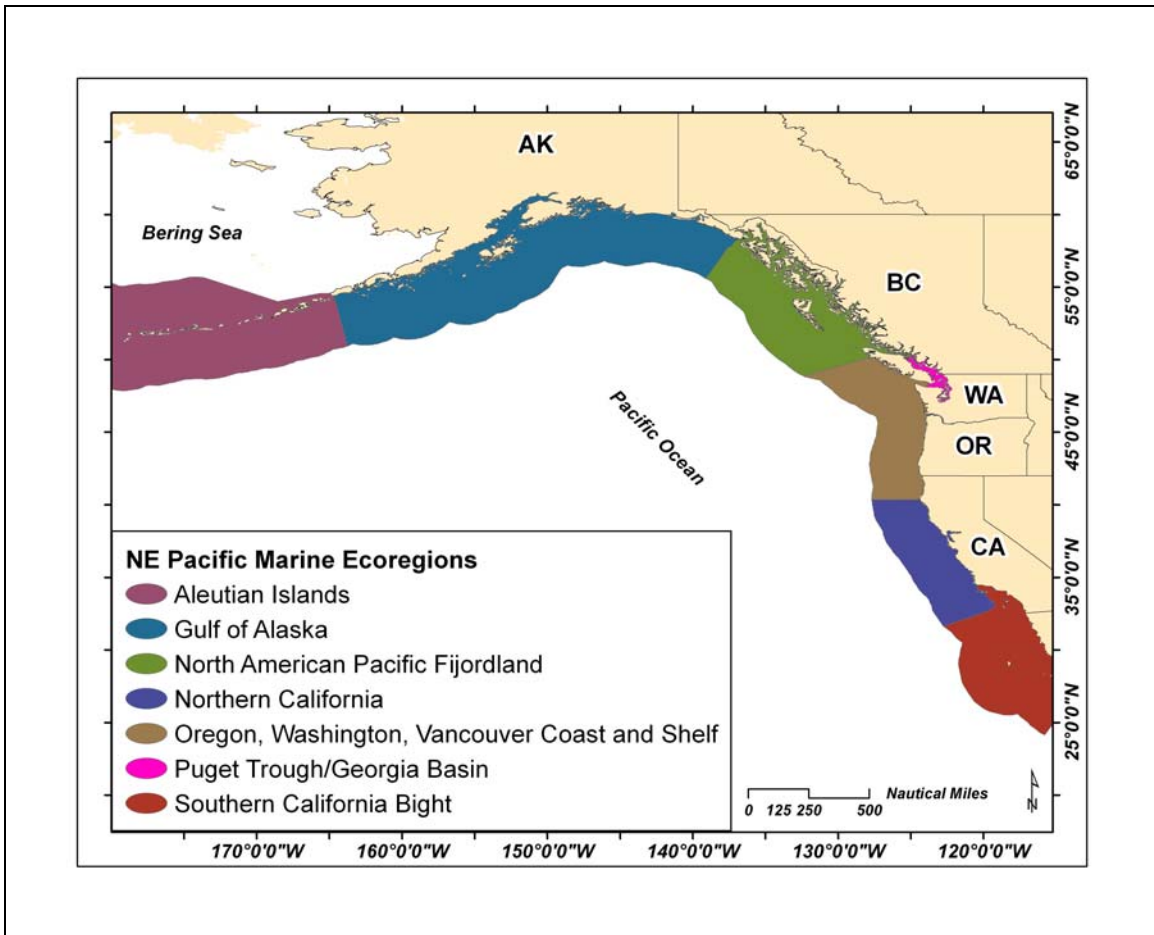


Figure 3.5.10. Marine ecoregions bordering the Pacific Coast of the United States from Southern California through the Aleutian Islands based on the MEOW biogeographic schema (Spalding et al. 2007). The ecoregions constituting the Cold Temperate Northeast Pacific Realm are the Aleutian Islands, Gulf of Alaska, North American Pacific Fjordland, Puget Trough/Georgia Basin, Oregon, Washington, Vancouver Coast and Shelf, and Northern California. The Southern California Bight ecoregion falls in the Warm Temperate Northeast Pacific Realm.

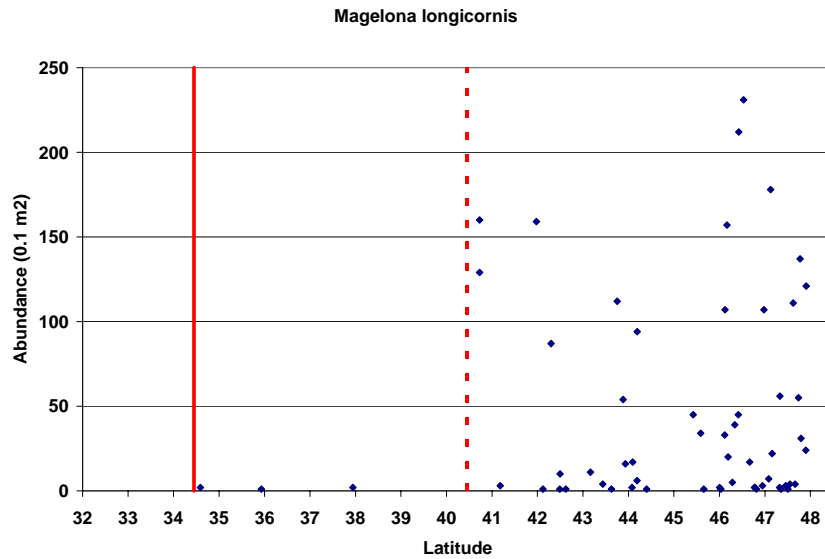


Figure 3.5.11. Latitudinal pattern of abundance of the polychaete *Magelona longicornis*. The solid vertical line is the boundary between the Southern California Bight ecoregion and Northern California ecoregion. The dashed line is the boundary between the Northern California ecoregion and Oregon, Washington, Vancouver Coast and Shelf ecoregion.

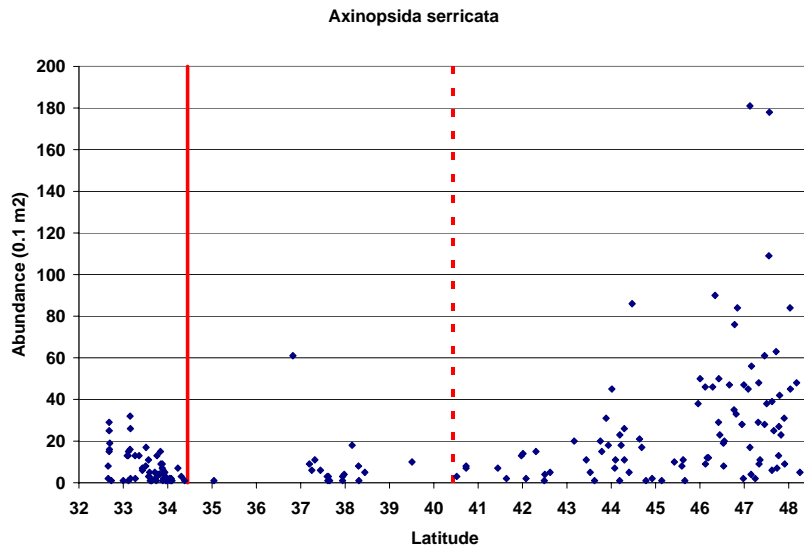


Figure 3.5.12. Latitudinal pattern of abundance of the bivalve *Axinopsida serricata*. The solid vertical line is the boundary between the Southern California Bight and Northern California ecoregions. The dashed line is the boundary between the Northern California and Oregon, Washington, Vancouver Coast and Shelf ecoregions.

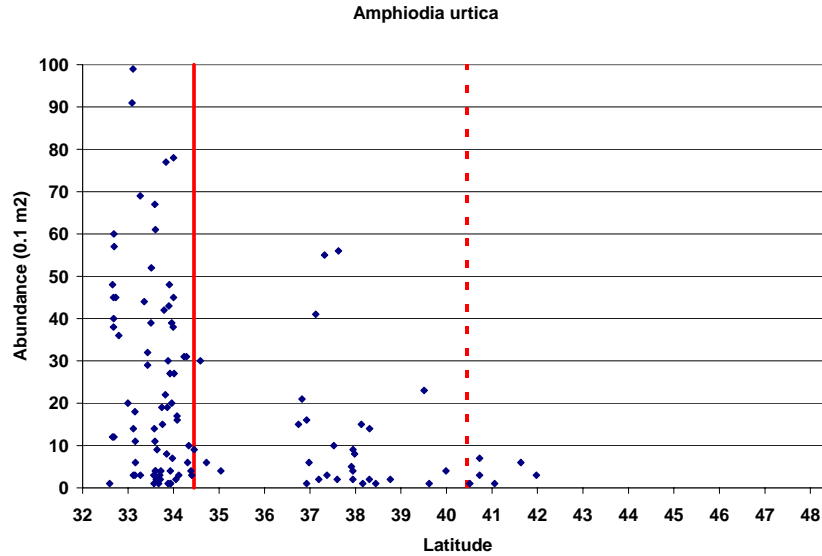


Figure 3.5.13. Latitudinal pattern of abundance of the ophiuroid *Amphiodia urtica*. The solid vertical line is the boundary between the Southern California Bight ecoregion and Northern California ecoregion. The dashed line is the boundary between the Northern California ecoregion and Oregon, Washington, Vancouver Coast and Shelf ecoregion.

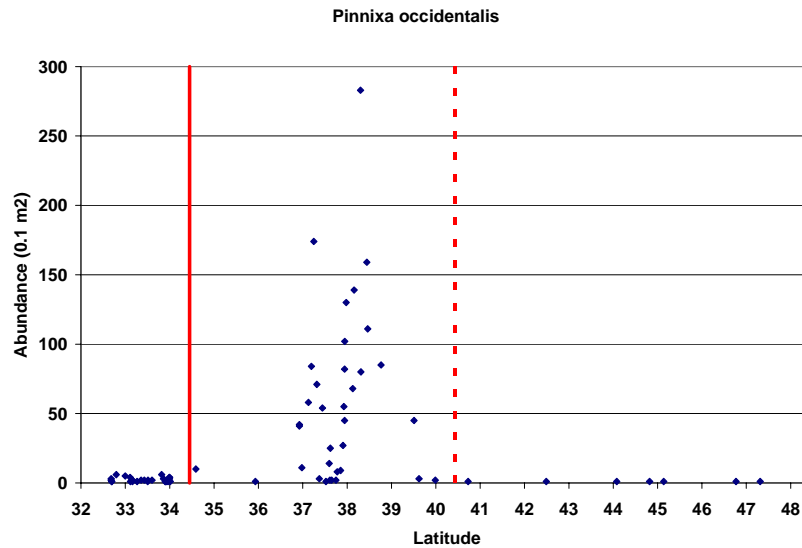


Figure 3.5.14. Latitudinal pattern of abundance of the decapod *Pinnixa occidentalis*. The solid vertical line is the boundary between the Southern California Bight ecoregion and Northern California ecoregion. The dashed line is the boundary between the Northern California ecoregion and Oregon, Washington, Vancouver Coast and Shelf ecoregion.

### 3.5.5 Nonindigenous Species

Taxa were classified as native, nonindigenous, cryptogenic, indeterminate, or unclassified. Cryptogenic species are species of uncertain origin (Carlton, 1996) and may include potential introductions, sibling species, or species that have yet to be sufficiently well resolved taxonomically over their global range. Indeterminate taxa are those not identified with sufficient taxonomic resolution to classify as native, nonindigenous, or cryptogenic (Lee et al. 2003). Unclassified species are those that have yet to be analyzed sufficiently to render a final classification. The classifications used here follow the Pacific Ecosystem Information System (PCEIS), a geo-referenced database of native and nonindigenous species of the Northeast Pacific being developed by the EPA and USGS (Lee and Reusser 2008).

Of the 1,108 taxa identified to species, 13 species are currently classified as nonindigenous (Table 3.5.6), though there are uncertainties about the taxonomic resolution of several of these species. In addition, another 121 species are classified as cryptogenic and 208 species are unclassified. The taxonomic uncertainties with the putative nonindigenous species and the large number of cryptogenic and unclassified species reflect both the lack of detailed analysis of the invasion status of shelf species as well as the difficulties inherent in harmonizing taxonomy on a global scale. Thus the present analysis should be considered preliminary until additional information becomes available on the taxonomy and classification of these uncertain species.

The 13 nonindigenous species constitute only 1.2% of the taxa that were identified to species or, excluding the cryptogenic and unclassified species, 1.7% of the native species. Even with the uncertainty over the classification of some species, the number of nonindigenous species appears to be much lower on the shelf than in the estuarine ecosystems of the Pacific Coast. For example, 42 nonindigenous species were found in the probabilistic survey of tidal wetlands of the Pacific Coast (Nelson et al. 2007a), while over 200 nonindigenous species have been found in the San Francisco Estuary (Cohen and Carlton 1995). Additionally, the nonindigenous species were in low abundance. None of the nonindigenous species were included in the 50 most abundant taxa (Table 3.5.4), and combined they constituted only 0.4% of the total individuals or 0.7% of the abundance of the natives. This is in contrast to many Pacific Coast estuaries, where nonindigenous species constitute a substantial if not major portion of the total abundance (Nelson et al. 2005), and from the San Francisco Estuary in particular, where nonindigenous species are the numerical dominants in most of the benthic assemblages (Lee et al. 2003). The most abundant nonindigenous species were the spionid polychaete *Laonice cirrata* and the ampharetid polychaete *Anobothrus gracilis*, which had average abundances of 0.40 and 0.29 individuals per grab, respectively (Table 3.5.6). While neither of these species was abundant, both were moderately frequent, occurring in 23%

and 15% of the samples. However, none of the other nonindigenous species occurred in more than 7% of the samples.

One similarity between the shelf nonindigenous species and those in coastal estuaries and Puget Sound is the predominance of non-native spionid polychaetes. Five of the 13 nonindigenous species on the shelf are spionids (*L. cirrata*, *D. bidentata*, *D. caulleryi*, *D. quadrilobata*, and *P. paucibranchiata*), while 14 nonindigenous spionids have been reported from coastal waters (Lee and Reusser 2008). However, the shelf and estuarine assemblages differ in the identity of the dominant spionid invaders. In comparison to *Laonice* and the *Dipolydora* species on the shelf, the most frequently occurring nonindigenous spionids in estuaries are *Polydora cornuta*, *Pseudopolydora kempfi*, *Pseudopolydora paucibranchiata* and *Streblospio benedicti*. Although *P. paucibranchiata* was found on the shelf, it was reported from only two of the 256 samples. Another notable difference between shelf and estuarine invaders is the absence of the three most widespread estuarine invaders, the amphipods *Grandidierella japonica* and *Monocorophium insidiosum* and the bivalve *Mya arenaria*. *Monocorophium acherusicum* is also one of the most frequently occurring invaders in coastal estuaries, and though it was found on the shelf, it apparently has a very low abundance, since only a single individual was reported.

Future resolution of the taxonomy and native ranges of the shelf fauna will reduce the uncertainty in evaluating the extent of invasion along the coast. Nonetheless, this preliminary analysis indicates that the shelf benthos is substantially less invaded than estuaries along the Pacific Coast when measured either by the number of nonindigenous species or by their abundance. Additionally, the common and widespread invaders in estuaries are either absent or in very low abundance on the shelf. The absence or low abundance of these estuarine invaders indicates that, at least to date, the offshore discharge of ballast water has not resulted in widespread invasion of the offshore benthic assemblages.

### **3.5.6 Potential Linkage to Stressor Impacts**

Multi-metric benthic indices are often used as indicators of pollution-induced degradation of the benthos (see review by Diaz et al. 2004) and have been developed for a variety of estuarine applications (Engle et al. 1994, Weisberg et al. 1997, Van Dolah et al. 1999, Llannso et al. 2002a, 2002b). A desired feature of these indices is the ability to differentiate impaired vs. unimpaired benthic condition, based on a number of key biological attributes (e.g., numbers of species, diversity, abundance, relative proportions of sensitive vs. dominant species, biomass), while attempting to take into account variations associated with natural controlling factors. While a related index has been developed for the Southern California mainland shelf (Smith et al. 2001), there is

Table 3.5.6. Nonindigenous species from the shelf survey. “Comments and Qualifiers” documents some of the taxonomic uncertainties for the shelf nonindigenous species. Taxa Codes: AM = amphipod; B = bivalve; G = Gastropod; P = polychaete.

Species	Taxa Code	Mean Abundance	% Frequency	Comments & Qualifiers
<i>Laonice cirrata</i>	P	0.405	23.2	“The NEP specimens would be considered introduced if they are true <i>L. cirrata</i> , but cryptogenic if a sibling species. Characters currently used to separate species of <i>Laonice</i> may not be adequate” (TNA 2001)
<i>Anobothrus gracilis</i>	P	0.290	15.1	“Southern California specimens & other NEP animals probably belong to <i>A. bimaculatus</i> Fauchald 1972, described from western Mexico rather than <i>A. gracilis</i> , and would therefore be regarded as native.” (TNA 2001)
<i>Podocerus cristatus</i>	AM	0.212	2.7	“A likely species complex reported widely from warm temperate waters” (Chapman 2007).
<i>Trochochaeta multisetosa</i>	P	0.166	6.6	“First reported from the NEP in San Francisco Bay as <i>Disoma franciscanum</i> , which was synonymized with <i>T. multisetosum</i> after examination of type material (Pettibone 1963).” (TNA 2001).
<i>Ericthonius brasiliensis</i>	AM	0.158	1.9	“Taxonomy poorly resolved: open coast populations (in habitats such as <i>Phyllospadix</i> ) and harbor populations (likely introduced) probably represent different species” (Chapman 2007).
<i>Dipolydora bidentata</i>	P	0.124	3.9	“History & direction of introductions unknown.” (TNA, 2001).
<i>Dipolydora caulleryi</i>	P	0.124	5.0	“This species is very similar to <i>Dipolydora brachycephala</i> except for morphology of larvae” (Blake and Ruff 2007) and is classified as cryptogenic by Sytsma et al. (2004).
<i>Lanassa venusta</i>	P	0.081	5.0	“Like many other northern European species reported from this coast, comparison to type or topotype material is needed to confirm the identity of NEP specimens.” (TNA, 2001).
<i>Philine auriformis</i>	G	0.031	2.3	“Unusual among California NIS for dispersing to offshore areas.” (TNA 2001).
<i>Heteromastus filiformis</i>	P	0.027	2.3	“Considered cosmopolitan although descriptions of animals from historical accounts in different parts of the world vary.” (TNA 2001). Classified as cryptogenic by TNA (2001).
<i>Pseudopolydora paucibranchiata</i>	P	0.012	0.8	Common estuarine invader on U.S. Pacific Coast.
<i>Monocorophium acherusicum</i>	AM	0.004	0.4	Common estuarine invader on U.S. Pacific Coast.
<i>Dipolydora quadrilobata</i>	P	0.004	0.4	“History & direction of introductions unknown.” (TNA 2001).

currently no such index that has been developed for application in shelf waters throughout the entire West Coast.

In the absence of a benthic index, we have attempted to assess potential stressor impacts in the present study by looking for obvious linkages between reduced values of key biological attributes (numbers of taxa, diversity, and abundance) and synoptically measured indicators of poor sediment or water quality. Benthic attributes in these offshore shelf waters showed significant variations among the three states. Thus, low values of species richness,  $H'$ , and density were defined for the purpose of the present analysis as the lower 10<sup>th</sup> percentile of values within each individual state. Thresholds for assessing poor sediment or water quality were defined as follows (*sensu* EPA 2000a for dissolved oxygen, EPA 2004 for other indicators):  $\geq 5$  chemicals in excess of ERLs (from Long et al. 1995),  $\geq 1$  chemical in excess of ERMs (from Long et al. 1995), TOC  $> 5\%$ , and DO in near-bottom water  $< 2.3$  mg/L. Appendix Table 4 provides a summary by station of each of these variables and flags those falling within the defined levels of concern.

This analysis revealed no major evidence of impaired benthic condition linked to measured stressors. There were only two stations, both in California, where low values of any of the three benthic attributes co-occurred with high sediment contamination or low DO in bottom water. One station (CA03-4039 off Los Angeles) had low benthic species richness and abundance accompanied by high sediment contamination, with eight chemicals in excess of corresponding ERL values and two in excess of ERM values. The other station (CA03-0059 north of San Francisco Bay) had low species richness and diversity accompanied by low DO. There were five other stations with DO in bottom water  $< 2.3$  mg/L; however, none of these had low values of the three benthic variables. There were two stations (CA03-4030, CA03-4417) that had TOC levels in a range ( $> 5\%$ ) potentially harmful to benthic fauna. A third station (CA03-4430) showed a potential concern level if the more conservative threshold of 3.6% TOC is used (Hyland et al. 2005), but low values of benthic community attributes were not observed at any of these sites. High sediment contamination was a more prevalent stressor, occurring at 23 stations (all in California), but not at any of the sites where low values of benthic attributes were observed. In fact, most of these latter stations with high sediment contamination had more than 100 species grab<sup>-1</sup>.

Such lack of concordance suggests that these offshore waters are currently in good condition, with the lower-end values of the various biological attributes representing parts of a normal reference range controlled by natural factors. Multiple linear regression was performed using full model procedures to test for the significance and direction of relationships between each of the benthic variables and various abiotic environmental factors (latitude, depth, percent fines). Data transformations were made where needed (i.e., square root for richness,  $\log_{10}$  for abundance) to meet analysis assumptions including normality and homoscedasticity of residuals. Results (graphics not shown) suggested that latitude and depth had significant influences on benthic variables region-wide. All three benthic variables showed significant inverse



relationships with latitude, i.e. with values increasing as latitude decreased ( $p < 0.01$ ). Depth had a significant direct influence on diversity ( $p < 0.001$ ) and a significant inverse effect on density ( $p < 0.01$ ). None of the three benthic variables varied significantly in relation to % fines (at  $p < 0.1$ ), though in general there was a tendency for muddier sediments (higher percent fines) to have lower species richness and diversity and higher densities than coarser sediments.

Alternatively, it is possible that for some of these sites the lower values of benthic variables reflect symptoms of disturbance induced by other unmeasured stressors. In efforts to be consistent with the underlying concepts and protocols of earlier EMAP and NCA programs, the indicators in this study included measures of stressors, such as chemical contaminants and symptoms of eutrophication, which are often associated with adverse biological impacts in shallower estuarine and inland ecosystems. However, there may be other sources of human-induced stress in these offshore systems that pose greater risks to living resources and which have not been adequately captured. One such activity is commercial trawling, which is a major industry in shelf waters, including NMSs, and which could have significant adverse effects on bottom habitats and benthic organisms (Jones 1992, Jennings and Kaiser 1998, Dayton et al. 1995, National Research Council 2002, Watling and Norse 1998). Future monitoring efforts in these offshore areas should include indicators of such alternative sources of disturbance.

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## 5.0 Appendix Tables

Appendix Table 1. Sampling coordinates for the 2003 West Coast Shelf Assessment. The “Frame km<sup>2</sup>” represents the represents the total area within a multi-density category. The weighting factor for computing CDFs is obtained by dividing the multi-density category area by the number of samples for a given parameter obtained in that category (see section 2.6).

EMAP Station ID	Sample Depth	Date	Latitude	Longitude	Multi-density Category	Frame km <sup>2</sup>
CA03-0001	106	10/16/2003	33.362	-118.307	CA-Other	6311.78
CA03-0007	70	6/25/2003	38.158	-123.056	CA-NMS	5863.69
CA03-0008	64.3	6/24/2003	37.248	-122.495	CA-NMS	5863.69
CA03-0012	40	6/26/2003	37.651	-122.711	CA-NMS	5863.69
CA03-0019	110	6/18/2003	39.990	-124.158	CA-Other	6311.78
CA03-0024	68	6/25/2003	37.598	-122.827	CA-NMS	5863.69
CA03-0027	84	6/19/2003	38.444	-123.258	CA-Other	6311.78
CA03-0028	94	6/25/2003	37.946	-123.145	CA-NMS	5863.69
CA03-0032	56	6/22/2003	34.908	-120.737	CA-Other	6311.78
CA03-0035	81	6/18/2003	39.510	-123.840	CA-Other	6311.78
CA03-0039	90	6/19/2003	38.311	-123.206	CA-Other	6311.78
CA03-0040	93	6/20/2003	37.373	-122.753	CA-NMS	5863.69
CA03-0043	78	6/14/2003	40.728	-124.445	CA-Other	6311.78
CA03-0044	61	6/25/2003	37.943	-123.028	CA-NMS	5863.69
CA03-0048	62	6/22/2003	34.590	-120.719	CA-Other	6311.78
CA03-0051	63	6/14/2003	41.636	-124.319	CA-Other	6311.78
CA03-0052	104	6/25/2003	37.908	-123.310	CA-NMS	5863.69
CA03-0056	95	6/21/2003	37.524	-122.874	CA-NMS	5863.69
CA03-0059	103	6/19/2003	38.465	-123.350	CA-Other	6311.78
CA03-0060	80	6/24/2003	36.823	-121.903	CA-NMS	5863.69
CA03-0064	50	6/22/2003	35.783	-121.375	CA-NMS	5863.69
CA03-0071	75	6/25/2003	38.303	-123.124	CA-Other	6311.78
CA03-0072	89	6/20/2003	37.317	-122.628	CA-NMS	5863.69
CA03-0075	69	6/15/2003	40.515	-124.521	CA-Other	6311.78
CA03-0076	54	6/25/2003	37.749	-122.877	CA-NMS	5863.69
CA03-0083	32.7	6/14/2003	41.442	-124.149	CA-Other	6311.78
CA03-0088	46	6/24/2003	37.611	-122.714	CA-NMS	5863.69
CA03-0091	115	6/19/2003	38.765	-123.702	CA-Other	6311.78
CA03-0092	89	6/20/2003	36.924	-122.236	CA-NMS	5863.69
CA03-0096	55	6/22/2003	35.042	-120.740	CA-Other	6311.78
CA03-0099	65	6/18/2003	39.621	-123.828	CA-Other	6311.78
CA03-0104	61.5	6/24/2003	37.444	-122.598	CA-NMS	5863.69
CA03-0112	61	6/22/2003	34.725	-120.730	CA-Other	6311.78
CA03-0116	89	6/21/2003	37.623	-122.933	CA-NMS	5863.69
CA03-0123	40.4	6/25/2003	37.927	-122.836	CA-NMS	5863.69
CA03-0124	104	6/20/2003	37.128	-122.577	CA-NMS	5863.69
CA03-0128	85	6/22/2003	35.933	-121.516	CA-NMS	5863.69
CA03-0135	94	6/25/2003	38.128	-123.180	CA-NMS	5863.69
CA03-0136	112	6/20/2003	36.980	-122.347	CA-NMS	5863.69

CA03-0139	75	6/14/2003	41.974	-124.405	CA-Other	6311.78
CA03-0140	49.6	6/25/2003	37.853	-122.825	CA-NMS	5863.69
CA03-0147	123	6/14/2003	41.184	-124.319	CA-Other	6311.78
CA03-0157	85	6/25/2003	37.980	-123.133	CA-NMS	5863.69
CA03-0158	53	6/24/2003	37.194	-122.457	CA-NMS	5863.69
CA03-0194	69	6/21/2003	37.777	-123.010	CA-NMS	5863.69
CA03-0210	102	6/24/2003	36.748	-121.939	CA-NMS	5863.69
CA03-0289	102	6/14/2003	41.058	-124.301	CA-Other	6311.78
CA03-4001	34	7/21/2003	32.550	-117.200	SPME-S	488.75
CA03-4007	60	7/21/2003	33.860	-118.448	SPME-C	385.46
CA03-4013	73	7/22/2003	32.695	-117.302	Large POTW Outfalls	163.22
CA03-4016	87	7/24/2003	34.334	-119.742	SPME-N	949.7
CA03-4020	83	8/18/2003	34.231	-119.512	SPME-N	949.7
CA03-4022	35	7/21/2003	33.928	-118.483	SPME-C	385.46
CA03-4027	43	8/19/2003	33.621	-118.195	SPME-C	385.46
CA03-4028	101	8/15/2003	34.116	-119.936	Channel Islands NMS	2160.8
CA03-4030	75	7/21/2003	34.034	-119.351	Channel Islands NMS	2160.8
CA03-4031	42	7/24/2003	33.512	-117.771	Small POTW Outfalls	25.81
CA03-4036	71	8/18/2003	34.284	-119.507	SPME-N	949.7
CA03-4037	48	7/23/2003	32.796	-117.305	SPME-S	488.75
CA03-4038	59	7/23/2003	33.998	-118.709	SPME-C	385.46
CA03-4039	131	8/20/2003	33.767	-118.460	Large POTW Outfalls	163.22
CA03-4041	56	8/6/2003	33.153	-117.387	Small POTW Outfalls	25.81
CA03-4042	70	7/29/2003	33.568	-117.990	Large POTW Outfalls	163.22
CA03-4043	28	8/19/2003	33.695	-118.296	Large POTW Outfalls	163.22
CA03-4046	57	7/22/2003	33.935	-118.539	Large POTW Outfalls	163.22
CA03-4049	72	8/5/2003	33.088	-117.351	SPME-S	488.75
CA03-4052	92	7/21/2003	34.076	-119.748	Channel Islands NMS	2160.8
CA03-4071	72	8/20/2003	33.759	-118.446	Large POTW Outfalls	163.22
CA03-4074	38	7/29/2003	33.598	-118.046	Large POTW Outfalls	163.22
CA03-4078	57	7/22/2003	33.922	-118.519	Large POTW Outfalls	163.22
CA03-4080	36.5	7/25/2003	34.384	-119.596	SPME-N	949.7
CA03-4081	63	8/7/2003	33.266	-117.534	SPME-S	488.75
CA03-4087	93	7/21/2003	33.835	-118.470	SPME-C	385.46
CA03-4090	80	7/21/2003	33.848	-118.568	SPME-C	385.46
CA03-4096	79	8/7/2003	33.270	-117.565	SPME-S	488.75
CA03-4099	72	8/18/2003	34.307	-119.558	SPME-N	949.7
CA03-4101	38	7/23/2003	33.998	-118.559	SPME-C	385.46
CA03-4102	42	8/20/2003	33.721	-118.365	Large POTW Outfalls	163.22
CA03-4109	42	7/22/2003	33.959	-118.520	Large POTW Outfalls	163.22
CA03-4113	41	7/29/2003	33.590	-117.971	SPME-S	488.75
CA03-4115	92	7/21/2003	34.078	-119.701	Channel Islands NMS	2160.8
CA03-4120	86	7/22/2003	32.658	-117.309	Large POTW Outfalls	163.22
CA03-4122	48	8/19/2003	33.604	-118.140	SPME-C	385.46
CA03-4123	56.5	7/30/2003	34.454	-120.198	SPME-N	949.7
CA03-4126	50	9/3/2003	33.354	-117.619	SPME-S	488.75
CA03-4134	78	8/21/2003	33.820	-118.427	SPME-C	385.46
CA03-4137	57	7/29/2003	33.577	-118.012	Large POTW Outfalls	163.22
CA03-4150	60	7/21/2003	33.877	-118.470	SPME-C	385.46

CA03-4152	98	8/5/2003	33.115	-117.357	Small POTW Outfalls	25.81
CA03-4154	34	7/23/2003	33.625	-118.075	SPME-C	385.46
CA03-4155	101	8/15/2003	34.102	-120.142	Channel Islands NMS	2160.8
CA03-4159	71	8/21/2003	33.994	-120.337	Channel Islands NMS	2160.8
CA03-4163	134	7/21/2003	34.078	-119.510	Channel Islands NMS	2160.8
CA03-4164	100	7/25/2003	32.730	-117.345	SPME-S	488.75
CA03-4165	34	7/23/2003	34.014	-118.592	SPME-C	385.46
CA03-4166	67	8/20/2003	33.708	-118.357	Large POTW Outfalls	163.22
CA03-4171	78	7/22/2003	33.856	-120.002	Channel Islands NMS	2160.8
CA03-4172	45	7/21/2003	32.595	-117.245	SPME-S	488.75
CA03-4173	121	7/22/2003	33.908	-118.567	SPME-C	385.46
CA03-4183	35.1	7/29/2003	34.400	-119.830	Small POTW Outfalls	25.81
CA03-4184	92	7/25/2003	32.688	-117.324	Large POTW Outfalls	163.22
CA03-4185	48	7/31/2003	33.992	-118.798	SPME-C	385.46
CA03-4186	111	8/19/2003	33.567	-118.191	SPME-C	385.46
CA03-4197	65	8/21/2003	33.790	-118.456	SPME-C	385.46
CA03-4199	56	8/6/2003	33.159	-117.398	Small POTW Outfalls	25.81
CA03-4204	65	7/22/2003	33.928	-118.543	Large POTW Outfalls	163.22
CA03-4215	50	8/19/2003	33.607	-118.125	SPME-C	385.46
CA03-4219	41.5	9/3/2003	33.428	-117.690	Small POTW Outfalls	25.81
CA03-4226	56	7/21/2003	33.898	-118.501	Large POTW Outfalls	163.22
CA03-4227	74	8/5/2003	33.107	-117.357	Small POTW Outfalls	25.81
CA03-4229	34	8/18/2003	33.672	-118.265	SPME-C	385.46
CA03-4230	56	7/22/2003	33.887	-120.010	Channel Islands NMS	2160.8
CA03-4236	32	7/29/2003	33.603	-118.036	Large POTW Outfalls	163.22
CA03-4238	82	7/22/2003	33.966	-119.605	Channel Islands NMS	2160.8
CA03-4239	57	7/22/2003	32.682	-117.282	Large POTW Outfalls	163.22
CA03-4243	58	7/22/2003	32.679	-117.282	Large POTW Outfalls	163.22
CA03-4245	84	8/19/2003	33.577	-118.210	SPME-C	385.46
CA03-4251	40	7/21/2003	32.590	-117.228	SPME-S	488.75
CA03-4255	125	7/22/2003	32.659	-117.336	SPME-S	488.75
CA03-4260	40	7/29/2003	33.592	-118.027	Large POTW Outfalls	163.22
CA03-4270	52	7/21/2003	33.910	-118.499	Large POTW Outfalls	163.22
CA03-4271	64	7/22/2003	33.878	-118.545	Large POTW Outfalls	163.22
CA03-4273	40	8/5/2003	33.115	-117.348	Small POTW Outfalls	25.81
CA03-4274	33	8/20/2003	33.636	-118.198	SPME-C	385.46
CA03-4278	41	7/24/2003	33.503	-117.765	Small POTW Outfalls	25.81
CA03-4288	48	8/6/2003	33.152	-117.383	Small POTW Outfalls	25.81
CA03-4291	82	7/22/2003	33.874	-119.948	Channel Islands NMS	2160.8
CA03-4293	62	7/22/2003	33.897	-118.540	Large POTW Outfalls	163.22
CA03-4302	119	7/25/2003	32.691	-117.336	Large POTW Outfalls	163.22
CA03-4303	46	8/20/2003	33.606	-118.190	SPME-C	385.46
CA03-4313	41	8/20/2003	33.743	-118.424	Large POTW Outfalls	163.22
CA03-4315	28	8/6/2003	33.162	-117.386	Small POTW Outfalls	25.81
CA03-4317	63	8/18/2003	33.617	-118.260	SPME-C	385.46
CA03-4324	64	7/22/2003	33.953	-119.687	Channel Islands NMS	2160.8
CA03-4329	64	8/19/2003	33.602	-118.117	SPME-C	385.46
CA03-4330	110	8/15/2003	34.113	-120.025	Channel Islands NMS	2160.8
CA03-4333	37.6	9/3/2003	33.428	-117.686	Small POTW Outfalls	25.81

CA03-4334	51	8/21/2003	34.071	-120.328	Channel Islands NMS	2160.8
CA03-4339	51	7/22/2003	33.881	-118.535	Large POTW Outfalls	163.22
CA03-4343	51	8/20/2003	33.637	-118.248	SPME-C	385.46
CA03-4346	48	7/23/2003	33.960	-118.529	Large POTW Outfalls	163.22
CA03-4350	56	7/29/2003	33.575	-117.985	Large POTW Outfalls	163.22
CA03-4352	78	7/21/2003	34.054	-119.528	Channel Islands NMS	2160.8
CA03-4357	92	7/22/2003	32.680	-117.324	Large POTW Outfalls	163.22
CA03-4365	41.5	8/4/2003	32.999	-117.301	Small POTW Outfalls	25.81
CA03-4377	46	7/22/2003	33.890	-120.082	Channel Islands NMS	2160.8
CA03-4380	95	8/21/2003	33.988	-120.380	Channel Islands NMS	2160.8
CA03-4389	100	8/19/2003	33.450	-119.053	Channel Islands NMS	2160.8
CA03-4390	52	8/21/2003	33.950	-120.237	Channel Islands NMS	2160.8
CA03-4396	99	8/18/2003	34.097	-120.123	Channel Islands NMS	2160.8
CA03-4411	84	8/22/2003	34.046	-119.439	Channel Islands NMS	2160.8
CA03-4417	119	8/19/2003	33.827	-120.076	Channel Islands NMS	2160.8
CA03-4425	100	8/22/2003	34.108	-120.205	Channel Islands NMS	2160.8
CA03-4427	85	8/23/2003	34.047	-119.655	Channel Islands NMS	2160.8
CA03-4430	83	8/28/2003	34.057	-119.475	Channel Islands NMS	2160.8
CA03-4435	63	8/27/2003	33.976	-119.881	Channel Islands NMS	2160.8
CA03-4444	100	8/28/2003	33.963	-119.586	Channel Islands NMS	2160.8
OR03-0001	50	6/13/2003	42.503	-124.539	OR-ALL	7994.69
OR03-0002	108	6/6/2003	45.959	-124.244	OR-ALL	7994.69
OR03-0003	102	6/11/2003	44.193	-124.485	OR-ALL	7994.69
OR03-0004	101	6/10/2003	44.819	-124.237	OR-ALL	7994.69
OR03-0005	47	6/14/2003	42.010	-124.354	OR-ALL	7994.69
OR03-0006	54	6/12/2003	44.014	-124.212	OR-ALL	7994.69
OR03-0007	119	6/11/2003	43.787	-124.437	OR-ALL	7994.69
OR03-0008	82	6/6/2003	45.658	-124.112	OR-ALL	7994.69
OR03-0009	70	6/10/2003	44.590	-124.253	OR-ALL	7994.69
OR03-0010	91	6/11/2003	44.034	-124.812	OR-ALL	7994.69
OR03-0011	64	6/13/2003	42.119	-124.400	OR-ALL	7994.69
OR03-0012	100	6/12/2003	43.525	-124.364	OR-ALL	7994.69
OR03-0013	84	6/6/2003	46.123	-124.214	OR-ALL	7994.69
OR03-0014	64	6/10/2003	44.460	-124.351	OR-ALL	7994.69
OR03-0015	77	6/9/2003	45.044	-124.104	OR-ALL	7994.69
OR03-0016	112	6/8/2003	45.421	-124.154	OR-ALL	7994.69
OR03-0017	80	6/9/2003	45.270	-124.088	OR-ALL	7994.69
OR03-0018	123	6/10/2003	44.639	-124.513	OR-ALL	7994.69
OR03-0019	93	6/10/2003	44.294	-124.517	OR-ALL	7994.69
OR03-0020	76	6/13/2003	42.302	-124.477	OR-ALL	7994.69
OR03-0021	120	6/6/2003	46.003	-124.304	OR-ALL	7994.69
OR03-0022	76	6/12/2003	43.164	-124.540	OR-ALL	7994.69
OR03-0023	92	6/13/2003	42.496	-124.620	OR-ALL	7994.69
OR03-0024	110	6/6/2003	46.118	-124.351	OR-ALL	7994.69
OR03-0025	57	6/10/2003	44.471	-124.212	OR-ALL	7994.69
OR03-0026	93	6/9/2003	44.922	-124.165	OR-ALL	7994.69
OR03-0027	102	6/12/2003	43.935	-124.310	OR-ALL	7994.69
OR03-0028	79	6/12/2003	43.754	-124.252	OR-ALL	7994.69
OR03-0029	52	6/6/2003	45.622	-124.011	OR-ALL	7994.69

OR03-0030	64	6/10/2003	44.686	-124.185	OR-ALL	7994.69
OR03-0031	74.7	6/11/2003	44.296	-124.307	OR-ALL	7994.69
OR03-0032	54	6/13/2003	42.078	-124.376	OR-ALL	7994.69
OR03-0033	107	6/12/2003	43.598	-124.381	OR-ALL	7994.69
OR03-0034	116	6/6/2003	46.190	-124.389	OR-ALL	7994.69
OR03-0035	118	6/10/2003	44.402	-124.449	OR-ALL	7994.69
OR03-0036	115	6/11/2003	44.189	-124.676	OR-ALL	7994.69
OR03-0037	106	6/6/2003	45.591	-124.161	OR-ALL	7994.69
OR03-0038	76	6/9/2003	45.138	-124.090	OR-ALL	7994.69
OR03-0039	73	6/11/2003	44.080	-124.257	OR-ALL	7994.69
OR03-0040	112	6/11/2003	44.095	-124.426	OR-ALL	7994.69
OR03-0041	92	6/13/2003	42.622	-124.567	OR-ALL	7994.69
OR03-0042	88	6/6/2003	46.030	-124.192	OR-ALL	7994.69
OR03-0043	106	6/12/2003	43.436	-124.466	OR-ALL	7994.69
OR03-0044	100	6/13/2003	42.489	-124.652	OR-ALL	7994.69
OR03-0045	81	6/6/2003	46.164	-124.228	OR-ALL	7994.69
OR03-0046	57	6/11/2003	44.224	-124.215	OR-ALL	7994.69
OR03-0047	64	6/10/2003	44.782	-124.191	OR-ALL	7994.69
OR03-0048	95	6/12/2003	43.885	-124.279	OR-ALL	7994.69
OR03-0049	69	6/12/2003	43.624	-124.266	OR-ALL	7994.69
OR03-0050	54	6/6/2003	45.655	-124.024	OR-ALL	7994.69
WA03-0001	28	6/2/2003	47.823	-124.645	Olympic Coast	3097.99
WA03-0002	75	6/4/2003	46.977	-124.509	WA-Other	2551.6
WA03-0003	60	6/3/2003	47.554	-124.642	Olympic Coast	3097.99
WA03-0004	88	6/5/2003	46.665	-124.428	WA-Other	2551.6
WA03-0005	46	6/3/2003	47.313	-124.494	Olympic Coast	3097.99
WA03-0006	60	6/2/2003	48.039	-124.883	Olympic Coast	3097.99
WA03-0007	54	6/4/2003	47.128	-124.441	WA-Other	2551.6
WA03-0008	116	6/3/2003	47.325	-124.717	Olympic Coast	3097.99
WA03-0009	104	6/4/2003	47.086	-124.702	WA-Other	2551.6
WA03-0010	61	6/5/2003	46.285	-124.244	WA-Other	2551.6
WA03-0011	30.6	6/2/2003	48.073	-124.797	Olympic Coast	3097.99
WA03-0012	91	6/2/2003	47.909	-124.908	Olympic Coast	3097.99
WA03-0013	55	6/3/2003	47.246	-124.505	Olympic Coast	3097.99
WA03-0014	32	6/2/2003	48.297	-124.766	Olympic Coast	3097.99
WA03-0015	64	6/5/2003	46.426	-124.293	WA-Other	2551.6
WA03-0017	30	6/3/2003	47.623	-124.543	Olympic Coast	3097.99
WA03-0018	57	6/5/2003	46.549	-124.267	WA-Other	2551.6
WA03-0019	52	6/3/2003	47.354	-124.533	Olympic Coast	3097.99
WA03-0020	60	6/4/2003	46.782	-124.344	WA-Other	2551.6
WA03-0021	91	6/3/2003	47.737	-124.828	Olympic Coast	3097.99
WA03-0022	65	6/2/2003	47.780	-124.753	Olympic Coast	3097.99
WA03-0023	100	6/5/2003	46.814	-124.551	WA-Other	2551.6
WA03-0024	31	6/2/2003	48.253	-124.815	Olympic Coast	3097.99
WA03-0025	39	6/4/2003	46.844	-124.242	WA-Other	2551.6
WA03-0026	110	6/3/2003	47.458	-124.754	Olympic Coast	3097.99
WA03-0027	54	6/2/2003	47.717	-124.685	Olympic Coast	3097.99
WA03-0029	44	6/3/2003	47.457	-124.558	Olympic Coast	3097.99
WA03-0030	107	6/4/2003	46.948	-124.641	WA-Other	2551.6

WA03-0031	54	6/5/2003	46.528	-124.263	WA-Other	2551.6
WA03-0032	118	6/3/2003	47.665	-124.907	Olympic Coast	3097.99
WA03-0033	106	6/2/2003	47.899	-124.965	Olympic Coast	3097.99
WA03-0034	89	6/4/2003	47.127	-124.645	WA-Other	2551.6
WA03-0035	103	6/4/2003	47.161	-124.693	Olympic Coast	3097.99
WA03-0037	98	6/5/2003	46.418	-124.409	WA-Other	2551.6
WA03-0038	47.3	6/2/2003	48.030	-124.843	Olympic Coast	3097.99
WA03-0039	82	6/3/2003	47.623	-124.754	Olympic Coast	3097.99
WA03-0041	81	6/3/2003	47.331	-124.617	Olympic Coast	3097.99
WA03-0042	48	6/4/2003	46.934	-124.359	WA-Other	2551.6
WA03-0043	102	6/2/2003	47.795	-124.896	Olympic Coast	3097.99
WA03-0044	67	6/2/2003	47.827	-124.788	Olympic Coast	3097.99
WA03-0046	53	6/2/2003	48.177	-124.878	Olympic Coast	3097.99
WA03-0047	61	6/4/2003	46.769	-124.345	WA-Other	2551.6
WA03-0048	113	6/3/2003	47.504	-124.795	Olympic Coast	3097.99
WA03-0051	94	6/2/2003	47.773	-124.841	Olympic Coast	3097.99
WA03-0053	45	6/3/2003	47.565	-124.598	Olympic Coast	3097.99
WA03-0060	29	6/5/2003	46.447	-124.177	WA-Other	2551.6
WA03-0068	28	6/4/2003	47.152	-124.289	Olympic Coast	3097.99
WA03-0070	50	6/4/2003	46.989	-124.488	WA-Other	2551.6
WA03-0081	108	6/5/2003	46.339	-124.395	WA-Other	2551.6
WA03-0086	71	6/5/2003	46.532	-124.331	WA-Other	2551.6

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Appendix Table 2. Sampling coordinates for the 2003 FRAM Groundfish Survey stations from which fish were analyzed for tissue contaminants by EPA.

EMAP Station ID	State	Sample Depth	Date	Latitude	Longitude	National Marine Sanctuary
CEW03419-001	CA	96	10/7/2003	39.248020	-123.835800	no
CEW03419-003	CA	36	7/31/2003	36.808020	-121.820760	Monterey Bay
CEW03419-004	CA	59	7/29/2003	37.795140	-122.882400	Gulf of the Farallones
CEW03419-006	CA	62	7/19/2003	41.604140	-124.294740	no
CEW03419-008	CA	102	7/27/2003	39.548520	-123.856450	no
CEW03419-016	CA	91	10/9/2003	37.211350	-122.560360	Monterey Bay
CEW03419-017	CA	116	10/8/2003	38.767360	-123.705910	no
CEW03419-018	CA	93	8/2/2003	35.507480	-121.133150	no
CEW03419-019	CA	83	7/19/2003	41.470380	-124.316410	no
CEW03419-022	CA	97	10/16/2003	34.668990	-120.791560	no
CEW03419-023	CA	68	8/7/2003	34.526280	-120.644900	no
CEW03419-026	CA	106	7/29/2003	38.007320	-123.195850	Cordell Bank
CEW03419-030	CA	61	7/31/2003	37.161140	-122.437850	Monterey Bay
CEW03419-031	CA	51	8/7/2003	34.757170	-120.692350	no
CEW03419-032	CA	94	7/21/2003	41.323850	-124.295010	no
CEW03419-036	CA	84	8/6/2003	34.965570	-120.773340	no
CEW03419-043	CA	73	7/28/2003	39.170940	-123.791370	no
CEW03419-044	CA	47	8/6/2003	34.733340	-120.681540	no
CEW03419-045	CA	80	9/29/2003	41.364890	-124.265620	no
CEW03419-047	CA	56	10/16/2003	35.089980	-120.752310	no
CEW03419-048	CA	72	9/28/2003	41.569970	-124.313020	no
CEW03419-054	CA	117	10/10/2003	37.064480	-122.512150	Monterey Bay
CEW03419-058	CA	100	7/31/2003	37.152230	-122.563930	Monterey Bay
CEW03419-059	CA	83	8/2/2003	35.501100	-121.111680	no
CEW03419-060	CA	64	7/30/2003	37.377030	-122.551340	Monterey Bay
CEW03419-071	CA	69	10/11/2003	35.728440	-121.376240	Monterey Bay
CEW03419-079	OR	110	9/24/2003	42.991690	-124.628400	no
CEW03419-082	OR	82	9/16/2003	44.335710	-124.390000	no
CEW03419-084	OR	103	9/16/2003	44.697040	-124.420680	no
CEW03419-085	OR	70	7/9/2003	44.925250	-124.126530	no
CEW03419-087	OR	95	9/17/2003	44.107350	-124.360670	no
CEW03419-089	OR	97	7/9/2003	44.881670	-124.185170	no
CEW03419-091	OR	99	9/16/2003	43.937380	-124.288410	no
CEW03419-092	OR	60	7/9/2003	44.208650	-124.210820	no
CEW03419-096	OR	64	9/24/2003	42.801400	-124.644780	no
CEW03419-097	OR	115	7/11/2003	43.546480	-124.408680	no
CEW03419-098	OR	92	7/6/2003	45.922470	-124.159120	no
CEW03419-099	OR	81	7/10/2003	44.187780	-124.303200	no
CEW03419-100	WA	115	6/29/2003	48.126430	-124.957210	Olympic Coast
CEW03419-103	WA	65	6/29/2003	47.995030	-124.879080	Olympic Coast
CEW03419-104	WA	99	9/3/2003	47.728780	-124.853600	Olympic Coast
CEW03419-105	WA	65	9/6/2003	48.160750	-124.895050	Olympic Coast
CEW03419-108	WA	115	7/11/2003	47.256030	-124.712740	Olympic Coast

CEW03419-109	WA	80	7/1/2003	46.394080	-124.324500	no
CEW03419-110	WA	69	6/30/2003	47.719490	-124.736600	Olympic Coast
CEW03419-112	WA	89	7/1/2003	47.225690	-124.629530	Olympic Coast
CEW03419-113	WA	97	6/29/2003	47.906270	-124.914910	Olympic Coast
CEW03419-114	WA	108	6/30/2003	47.775640	-124.910230	Olympic Coast
CEW03419-115	WA	99	9/7/2003	47.751500	-124.861750	Olympic Coast
CEW03419-116	WA	65	9/6/2003	48.016830	-124.890230	Olympic Coast
CEW03419-118	WA	88	9/8/2003	46.583160	-124.400940	no
CEW03419-119	WA	84	6/29/2003	48.186830	-124.918710	Olympic Coast
CEW03419-120	WA	99	9/6/2003	47.997830	-124.957630	Olympic Coast
CEW03419-121	WA	106	6/25/2003	47.602070	-124.815620	Olympic Coast
CEW03419-122	WA	57	7/1/2003	47.023160	-124.432590	no
CEW03419-125	WA	107	9/7/2003	47.653430	-124.854420	Olympic Coast
CEW03419-126	WA	111	9/6/2003	47.862850	-124.959860	Olympic Coast
CEW03419-127	WA	88	9/6/2003	48.145470	-124.921600	Olympic Coast
CEW03419-904	OR	87	7/9/2003	44.642220	-124.429540	no
CEW03419-931	OR	96	7/10/2003	44.350900	-124.600980	no

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Appendix Table 3a. Summary for Washington data of performance with regard to QC criteria for analysis of reference materials, matrix spike recoveries, and relative percent difference or coefficient of variation (RPD, CV) of replicates. SRM = Standard Reference Material, CRM = Certified Reference Material, LCM = Laboratory Control Material, NA = not applicable, none = this QC material was not analyzed or QC activity not done. Those values in red are averages failing DQO, borderline average values, or a significantly reduced number of analytes were reported.

Washington 2003		Reference Materials average recovery within: $\pm 30\%$ organics and $\pm 20\%$ metals of true value*; 70% of individuals within $\pm 35\%$ of true value**		Matrix spikes	RPDs and CVs of Matrix spikes and Reference Materials
Analytes (#)	Matrix	DQO met?	If no, average % different from true value (# analytes reported)	recovery DQO of 50%-120% met?	met DQO of average <30%?
PAHs (22)	Sediment	no* no** NIST 1941	44%* 59%** (22)	yes (22)	yes
	Tissue	NA	NA	NA	NA
Metals (tissues by GPL lab)	Sediment (15)	yes* yes** NIST 2711	29.8%* 80%** (15)	yes (15)	yes
	Tissue (13)	yes spiked cod	(7)	yes (13)	yes
PCBs (21) (tissues by GPL lab)	Sediment	no* yes** NIST 1941b	35%* 83%** (18)	yes (21)	yes
	Tissue	no* no** LCM	61%* 48%** cod & MS/MSD (10 & 11)	yes (21)	yes
Pesticides (20) (tissues by GPL lab)	Sediment	no* no** NIST 1941	43%* 58%** 1941 & MS/MSD (5 & 14)	yes (18)	yes
	Tissue	no* no** LCM	57%* 30%** cod & MS/MSD (12 & 8)	yes (19)	yes

Appendix Table 3b. Summary for Oregon data of performance with regard to QC criteria for analysis of reference materials, matrix spike recoveries, and relative percent difference or coefficient of variation (RPD, CV) of replicates. SRM = Standard Reference Material, CRM = Certified Reference Material, LCM = Laboratory Control Material, NA = not applicable, none = this QC material was not analyzed or QC activity not done. Those values in red are averages failing DQO, borderline average values, or a significantly reduced number of analytes were reported.

**Oregon 2003**

Analytes (#)	Matrix	Reference Materials average recovery within: ±30% organics and ±20% metals of true value*; 70% of individuals within ±35% of true value**		Matrix spikes	RPDs and CVs of Matrix spikes and Reference Materials
		DQO met?	If no, average % different from true value (# analytes reported)	recovery DQO of 50%- 120% met?	met DQO of average <30%?
PAHs (22)	Sediment	no* no** NIST 1944	40% 42% (19)	yes (22)	yes
	Tissue	NA	NA	NA	NA
Metals	Sediment (15)	yes MESS-2	(11)	yes (15)	yes
	Tissue (13)	yes NIST 2976	(10)	none	yes
PCBs (21)	Sediment	no* no** NIST 1944	115% 16% (19)	yes (18)	yes* *1944 = 37%
	Tissue	no* no** CARP-2	58% 18% (17)	yes	yes
Pesticides (20)	Sediment	no* no** NIST 1944	90% 47% 1944 & MS/MSD (8,11)	yes (19)	yes
	Tissue	no* no** CARP-2	36% 40% CARP & MS/MSD (6, 12)	yes	yes

Appendix Table 3c. Summary for California data of performance with regard to QC criteria for analysis of reference materials, matrix spike recoveries, and relative percent difference or coefficient of variation (RPD, CV) of replicates. SRM = Standard Reference Material, CRM = Certified Reference Material, LCM = Laboratory Control Material, NA = not applicable, none = this QC material was not analyzed or QC activity not done. Those values in red are averages failing DQO, borderline average values, or a significantly reduced number of analytes were reported.

**California 2003**

Analytes (#)	Matrix	Reference Materials average recovery within: ±30% organics and ±20% metals of true value*; 70% of individuals within ±35% of true value**		Matrix spikes  recovery DQO of 50%- 120% met?	RPDs and CVs of Matrix spikes and Reference Materials  met DQO of average <30%?
		DQO met?	If no, average % different from true value (# analytes reported)		
PAHs (22)	Sediment	yes NIST 1944	(18)	yes (22)	yes
	Tissue	NA	NA	NA	NA
Metals	Sediment (15)	yes 016-050	(11)	yes (15)	yes
	Tissue (13)	yes DORM-2	(10)	none	yes
PCBs (21)	Sediment	yes NIST 1944	(19)	yes (18)	yes
	Tissue	yes CARP-2	(17)	none	yes
Pesticides (20)	Sediment	yes NIST 1944	(6)	yes (19)	yes
	Tissue	yes CARP-2	(6)	none	yes

Appendix Table 4. Summary by station of key benthic variables and corresponding sediment and water-quality indicators. Bolded values indicate: Low species richness (lower 10<sup>th</sup> percentile of values for corresponding state), Low densities (lower 10<sup>th</sup> percentile of values for corresponding state), Low H' (lower 10<sup>th</sup> percentile of values for corresponding state), ≥ 5 chemicals in excess of ERLs, ≥ 1 chemical in excess of ERMs, TOC > 5%, DO in near-bottom water < 2.3 mg/L.

Station	Mean No. Taxa per Grab (0.1m <sup>2</sup> )	Mean Density (all fauna/m <sup>2</sup> )	Mean H' per Grab (0.1m <sup>2</sup> )	No. Chemicals > ERL	No. Chemicals > ERM	TOC (%)	DO (mg/L)	Silt+Clay (%)
CA03-0001	<b>51</b>	<b>1160</b>	5.146	1	0	1.501	4.27	22.819
CA03-0007	77	6930	4.744	0	0	0.75	3.62	90.1
CA03-0008	77	10340	4.59	0	0	0.61	2.84	81.58
CA03-0012	<b>56</b>	3240	4.544	0	0	0.24	2.95	24.95
CA03-0019	96	4350	5.555	0	0	0.64	2.45	37.78
CA03-0024	75	4600	5.177	1	0	0.45	2.31	46.48
CA03-0027	67	4810	<b>4.238</b>	2	0	1.58		89.18
CA03-0028	72	4780	4.652	1	0	1.11	<b>2.16</b>	73.06
CA03-0032	78	3030	5.417	0	0	0.23	6.1	6.24
CA03-0035	116	7330	5.77	0	0	1.25	3.06	60.42
CA03-0039	58	2380	<b>4.304</b>	1	0	0.96		70.8
CA03-0040	68	3790	5.074	0	0	0.32	2.49	7.39
CA03-0043	110.5	6845	5.317	1	0	0.69	4.61	74.82
CA03-0044	90	6610	5.155	0	0	0.49	3.54	27.895
CA03-0048	118	8880	5.643	0	0	0.68	3.77	57.48
CA03-0051	77	3080	5.236	1	0	0.29	<b>2.08</b>	51.45
CA03-0052	77	2510	5.545	0	0	0.36	2.64	5.34
CA03-0056	97	5690	5.202	0	0	0.37	<b>2.24</b>	9.42
CA03-0059	<b>48</b>	2610	<b>3.651</b>	2	0	1.16	<b>2.24</b>	64.59
CA03-0060	113	6010	5.776	0	0	0.36	2.45	30.15
CA03-0064	82	5350	5.271	1	0	0.53	4.23	6.32
CA03-0071	62	5960	<b>3.538</b>	1	0	1.22	2.87	88.16
CA03-0072	100	9390	4.822	1	0	0.59	2.71	39.15
CA03-0075	<b>40</b>	<b>1320</b>	4.63	0	0	0.35	4.8	6.03
CA03-0076	<b>25</b>	<b>690</b>	<b>3.788</b>	0	0	0.26	3.4	1.24
CA03-0083	<b>34</b>	<b>1720</b>	<b>3.877</b>	1	0	0.23	2.81	3.07
CA03-0088	<b>52</b>	1800	4.751	0	0	0.26	2.79	30.27
CA03-0091	64	3060	4.654	1	0	1.08		61.53
CA03-0092	113.5	8140	5.188	1	0	0.82	3.03	53.145
CA03-0096	105	4740	6.006	0	0	0.5	4.51	39.46
CA03-0099	<b>36</b>	<b>1150</b>	4.551	0	0	0.32	3.11	4.26
CA03-0104	78	6110	4.645	0	0	0.28	2.38	9.75
CA03-0112	92	4130	5.409	0	0	0.46	2.68	47.39
CA03-0116	85	7010	<b>4.335</b>	1	0	0.66	2.34	46.12
CA03-0123	60	4000	4.593	0	0	0.52	4.41	33.52
CA03-0124	90	4330	5.169	0	0	0.43	2.61	24.44
CA03-0128	71	3070	5.107	1	0	0.46	2.86	5.42
CA03-0135	66	4080	<b>4.409</b>	0	0	1.02	3.68	93.98

CA03-0136	119	9560	5.347	2	0	0.61		22.82
CA03-0139	92	8160	5.045	1	0	0.66	3.62	56.73
CA03-0140	78	3920	5.43	0	0	0.41	2.46	17.16
CA03-0147	90	2580	5.809	1	0	1.24		98.71
CA03-0157	76	5420	4.731	0	0	1.14	2.77	87.13
CA03-0158	103	7250	5.315	0	0	0.48	3.12	35.38
CA03-0194	<b>32</b>	<b>1130</b>	4.468	0	0	0.19	2.55	2.29
CA03-0210	106	11230	<b>4.233</b>	0	0	0.75	2.45	43.94
CA03-0289	63	2300	5.047	1	0	1.11	3.62	98.16
CA03-4001	79	2500	5.341	0	0	0.107		22.4505
CA03-4007	99	3640	5.711	3	<b>2</b>	0.55	6.3	35.45
CA03-4013	73	5010	<b>3.378</b>	0	0	0.735		60.046
CA03-4016	88	2470	5.895	2	0	0.512		48.08
CA03-4020	<b>49</b>	1890	4.646	3	0	1.366		80.31
CA03-4022	114	4170	5.989	3	<b>1</b>	0.477	6.44	40.92
CA03-4027	68	1960	5.398	2	0	0.234	6.31	13.7
CA03-4028	147	5160	6.187	2	0	0.814		41.606
CA03-4030	148	11520	5.929	0	0	<b>7.645</b>		
CA03-4031	106	4870	5.469	2	0	0.676		72.83
CA03-4036	<b>37</b>	<b>1290</b>	<b>4.168</b>	3	0	1.429		95.85
CA03-4037	119	3480	5.911	0	0	0.458	6.74	36.532
CA03-4038	81	3190	4.941	2	<b>1</b>	1.031	5.96	75.44
CA03-4039	<b>56</b>	<b>1530</b>	5.194	<b>8</b>	<b>2</b>	1.248		63.52
CA03-4041	87	2960	5.308	0	0	0.983		67.402
CA03-4042	93	2340	5.598	1	0	0.24		13.659
CA03-4043	124	6000	6.04	2	<b>2</b>	0.525		33.31
CA03-4046	92	2700	5.943	2	0	0.396		19.66
CA03-4049	87	3670	5.069	0	0	0.677	6.42	64.102
CA03-4052	122	4700	6.052	3	0	1.553		62.77
CA03-4071	92	3260	5.752	<b>7</b>	<b>2</b>	1.042		60.34
CA03-4074	128	5000	5.942	2	0	0.25		22.345
CA03-4078	127	4650	5.898	3	<b>1</b>	0.789		48.7
CA03-4080	<b>50</b>	<b>1270</b>	4.967	2	0	1.211		91.64
CA03-4081	81	2950	5.137	2	0	0.694		66.235
CA03-4087	122	5310	5.686	2	<b>2</b>	0.754	5.68	28.83
CA03-4090	102	2490	6.155	<b>5</b>	<b>2</b>	0.842	5.75	24.52
CA03-4096	100	2780	6.065	0	0	0.395		37.483
CA03-4099	<b>33</b>	<b>830</b>	4.545	2	0	1.485		95.26
CA03-4101	123	5430	5.784	2	0	0.739	6.36	53
CA03-4102	67	2990	5.063	<b>7</b>	<b>2</b>	1.288		75.16
CA03-4109	102	4610	5.48	3	<b>1</b>	0.566		47.37
CA03-4113	92	3810	5.23	2	0	0.444		44.132
CA03-4115	117	5280	5.881	1	0	2.33		48.064
CA03-4120	59	<b>1460</b>	4.651	0	0	0.583		56.207
CA03-4122	93	4860	5.249	3	0	0.244		19.88
CA03-4123	98	3660	5.855	0	0	0.747		48.87
CA03-4126	72	2490	5.207	2	0	0.631		61.187
CA03-4134	100	3830	5.813	4	<b>2</b>	0.957	6.1	59.31
CA03-4137	83	4000	4.915	2	0	0.361		17.2325

CA03-4150	141	5220	6.152	3	2	0.674		44.54
CA03-4152	75	2300	5.499	0	0	0.955		65.227
CA03-4154	55	2560	4.369	0	0	0.056		2.38
CA03-4155	86	2020	5.888	1	0	2.148		67.266
CA03-4159	167	5190	6.633	1	0	1.231		47.279
CA03-4163	160	9380	5.905	2	0	2.424		26.774
CA03-4164	86	3650	5.043	0	0	0.57		50.64
CA03-4165	123	4830	5.964	2	0	0.58	6.11	52.58
CA03-4166	75	3240	5.087	9	2	1.769		70.51
CA03-4171	119	4460	5.957	1	0	2.009		14.222
CA03-4172	83	1900	5.746	0	0	0.275		22.048
CA03-4173	121	3580	6.154	2	0	1.748	5.81	15.669
CA03-4183	126	6370	5.776	0	0	0.828		35.63
CA03-4184	91	3130	5.307	0	0	0.55		51.884
CA03-4185	137	6260	5.774	2	0	0.461	6.71	32.14
CA03-4186	83	2630	5.514	2	0	0.253		14.07
CA03-4197	111	3920	5.738	4	2	0.844	6.51	59.33
CA03-4199	67	1810	5.203	0	0	1.082		66.9835
CA03-4204	113	4430	5.636	6	2	1.075		33.35
CA03-4215	102	3970	5.619	2	0	0.28		22.18
CA03-4219	86	2420	5.671	2	0	0.674		75.375
CA03-4226	110	4150	5.711	3	2	0.695		53.42
CA03-4227	118	5430	5.644	0	0	0.675		66.426
CA03-4229	105	6190	4.415	2	0	0.129		3.429
CA03-4230	183	22980	5.137	2	0	1.348		20.574
CA03-4236	121	4440	6.148	1	0	0.195		14.713
CA03-4238	128	5140	5.989	5	0	2.911		21.9545
CA03-4239	94	3800	5.062	1	0	0.551		50.313
CA03-4243	101	5670	4.235	0	0	0.646		50.126
CA03-4245	97	3030	5.781	2	0	0.459		21.85
CA03-4251	58	1300	4.926	2	0	0.185		9.026
CA03-4255	97	2240	6.195	0	0	0.554		44.777
CA03-4260	98	2750	5.903	1	0	0.315		26.375
CA03-4270	135	5740	5.963	3	2	0.782		56.62
CA03-4271	85	2440	5.434	2	2	0.68		21.421
CA03-4273	157	6730	6.279	0	0	0.483		41.356
CA03-4274	157	9180	6.016	2	0	0.308		11.738
CA03-4278	150	7590	6.025	2	0	0.857		57.061
CA03-4288	75	1830	5.519	0	0	0.991		65.298
CA03-4291	142	6640	6.07	1	0	0.487		21.254
CA03-4293	91	2430	5.918	2	0	0.256		8.181
CA03-4302	85	2190	5.933	0	0	0.497		39.883
CA03-4303	87	3390	5.321	2	0	0.206		12.89
CA03-4313	128	6420	5.837	4	2	0.756		43.87
CA03-4315	156	6290	6.406	0	0	1.769		49.581
CA03-4317	66	1660	5.418	2	0	0.33		20.93
CA03-4324	119	4150	5.837	2	0	0.796		24.258
CA03-4329	76	3070	4.955	2	0	0.449		32.15
CA03-4330	95	2210	6.096	1	0	1.297		33.141

CA03-4333	116	4070	5.755	2	0	0.51		63.165
CA03-4334	94	2900	5.941	1	0			
CA03-4339	86	9520	<b>3.915</b>	2	0	2.394		8.316
CA03-4343	99	3760	5.761	2	<b>2</b>	0.44		29.41
CA03-4346	117	5030	5.696	3	<b>1</b>	0.649		50.48
CA03-4350	126	4620	5.798	1	0	0.363		21.786
CA03-4352	132	5370	6.057	2	0	0.454		17.034
CA03-4357	93	3440	5.579	0	0	0.457		46.811
CA03-4365	133	5670	5.856	0	0	0.467		44.477
CA03-4377	190	14820	6.328	0	0	0.564		16.386
CA03-4380	119	3180	6.249	1	0	0.84		46.422
CA03-4389	69	<b>1560</b>	5.26	0	0	2.771		12.8425
CA03-4390	<b>52</b>	3160	<b>3.039</b>	2	0	0.283		11.899
CA03-4396	113	3200	6.166	0	0	1.696		59.782
CA03-4411	<b>56</b>	<b>1530</b>	5.087	2	0	0.552		21.035
CA03-4417	105	2720	5.949	1	0	<b>6.036</b>		7.198
CA03-4425	61	<b>1300</b>	5.502	0	0	2.248		62.78
CA03-4427	64	1840	5.152	1	0	0.891		44.4
CA03-4430	108	3970	5.594	0	0	<b>4.176</b>		14.4555
CA03-4435	95	2940	5.888	1	0	0.455		47.115
CA03-4444	115	3640	5.856	4	0	2.193		20.98
OR03-0001	32	<b>640</b>	4.646	1	0	0.15	3.58	3.4
OR03-0002	83	2960	5.231	1	0	0.49		17.4
OR03-0003	63	3030	4.436	1	0	0.38	<b>2.27</b>	18.1
OR03-0004	33	1490	<b>3.38</b>	0	0	0.16	2.41	2.9
OR03-0005	31	1060	4.296	1	0	0.15	3.98	4.633333
OR03-0006	<b>30</b>	1090	3.607	0	0	0.055	2.81	1.1
OR03-0007	60	2100	5.195	1	0	0.7	2.71	33.6
OR03-0008	53	1140	5.155	1	0	0.18		3
OR03-0009	<b>26</b>	1160	3.924	0	0	0.085	2.56	1.1
OR03-0011	63	2030	5.01	1	0	0.35	3.78	14.2
OR03-0012	51	2300	4.242	1	0	0.76	2.57	39
OR03-0013	69	4170	4.81	0	0	0.39		10.1
OR03-0014	38	950	4.556	1	0	0.1	2.78	1.5
OR03-0015	64	4080	4.626	1	0	0.12	2.6	2.5
OR03-0016	47	1590	4.38	1	0	0.34		6.3
OR03-0017	37	<b>540</b>	5.023	0	0	0.15		2.4
OR03-0018	100	7260	4.492	2	0	1.1		26.8
OR03-0019	33	1250	4.222	0	0	0.15		2.7
OR03-0020	71	3310	4.897	1	0	0.615	3.44	22.9
OR03-0021	62	2050	4.847	1	0	0.95		33.2
OR03-0022	98	4270	5.88	2	0	0.6	2.76	26.8
OR03-0023	92	3320	5.93	1	0	0.55	2.82	29.3
OR03-0024	69	2780	4.973	0	0	0.345		12.55
OR03-0025	35	2510	<b>3.405</b>	0	0	0.082	2.59	0.9
OR03-0026	45	1180	4.957	0	0	0.15		2.6
OR03-0027	57	1980	4.931	1	0	1.1	2.62	37.5
OR03-0028	76	5320	4.651	0	0	0.57		14.2
OR03-0029	45	1620	4.6	1	0	0.084		2

OR03-0030	36	1960	3.839	0	0	0.089		1.55
OR03-0031	39	<b>760</b>	4.696	0	0	0.053	2.65	1.1
OR03-0032	56	3390	3.592	1	0	0.34	4.37	12.2
OR03-0033	38	1000	4.685	1	0	1.4	2.63	49.9
OR03-0034	67	2010	5.302	0	0	0.31		10.3
OR03-0035	92	3090	5.451	2	0	0.76		12.4
OR03-0036	90	2770	5.731	2	0	0.81		20.9
OR03-0037	62	2750	4.845	1	0	0.34		7.7
OR03-0038	43	<b>900</b>	5.027	0	0	0.13	2.36	2.4
OR03-0039	36	920	4.584	0	0	0.088	2.69	2
OR03-0040	56	1700	5.203	2	0	0.54	2.55	27.1
OR03-0041	43	1760	4.647	1	0	0.83	3.55	49.8
OR03-0042	63	1580	5.356	1	0	0.18		5.2
OR03-0043	73	1930	5.462	1	0	0.5	2.58	19.3
OR03-0044	83	2380	5.712	1	0	0.45	2.47	20.6
OR03-0045	72	4770	4.324	0	0	0.29		9.1
OR03-0046	<b>28</b>	2970	<b>3.28</b>	1	0	0.038	2.43	1.2
OR03-0047	<b>19</b>	<b>750</b>	<b>2.967</b>	1	0	0.039		1.1
OR03-0048	59	3130	4.889	1	0	1.1	2.72	41.3
OR03-0049	54	2220	4.675	0	0	0.43	3.28	13.2
OR03-0050	<b>27</b>	3290	<b>3.433</b>	1	0	0.087		2.3
WA03-0001	47	3550	4.132	0	0	0.1	4.99	3.600487
WA03-0002	84	4850	4.987	1	0	0.335	3.47	17.02132
WA03-0003	55	3830	3.942	0	0	0.16	4.52	4.34159
WA03-0004	67	2570	5.016	0	0	1.17	<b>2.28</b>	42.75506
WA03-0005	35	1410	4.032	0	0	0	3.28	0.751084
WA03-0006	53	2440	4.592	0	0	0.11		2.447882
WA03-0007	44	3610	<b>3.266</b>	1	0	0	3.18	1.873989
WA03-0008	40	1710	4.057	1	0	1.3	2.78	65.2519
WA03-0009	61	2250	4.707	0	0	1.3	3.1	55.69044
WA03-0010	72	3710	4.933	0	0	0.7	3.13	19.71789
WA03-0011	38	3970	<b>3.194</b>	0	0	0.12	5.68	5.568328
WA03-0012	71	3400	4.276	0	0	0.21	6.72	8.584751
WA03-0013	<b>26</b>	3850	<b>2.037</b>	0	0	0	3.27	2.59643
WA03-0014	<b>30</b>	<b>1110</b>	4.207	0	0	0.16	5.13	2.053567
WA03-0015	102	8620	4.723	0	0	0.9	2.98	25.03443
WA03-0017	70	9440	3.895	1	0	0	4.67	1.869526
WA03-0018	52	4000	4.49	0	0	0.33	2.58	25.94177
WA03-0019	46	1930	4.543	0	0	0	3.19	1.618769
WA03-0020	41	3070	3.969	0	0	0.24	2.9	17.6921
WA03-0021	75	2520	5.093	0	0	0.27	3.79	17.65717
WA03-0022	37	1780	3.966	1	0	0.14	4.46	4.703177
WA03-0023	<b>27</b>	<b>1270</b>	<b>3.387</b>	0	0	1.4	2.45	57.00271
WA03-0024	<b>30</b>	<b>860</b>	3.929	0	0	0.13	6.45	6.431472
WA03-0025	43	2580	4.085	0	0	0.16	3.11	7.842778
WA03-0026	38	1430	4.347	0	0	1.032	2.56	58.13735
WA03-0027	37	2480	3.723	1	0	0.14	4.28	5.368892
WA03-0029	44	3350	4.39	0	0	0	5.08	0.513504
WA03-0030	36	<b>1110</b>	4.19	0	0	1.32	2.97	55.00728



WA03-0031	72	4040	4.598	0	0	0.29	2.49	20.57284
WA03-0032	48	1510	4.854	0	0	1.05	3.67	60.30199
WA03-0033	70	3870	4.836	0	0	0.52	7.28	39.08816
WA03-0034	90	4650	4.569	0	0	0.39	3.14	20.18086
WA03-0035	59	2400	4.563	0	0	1.17	2.99	53.20249
WA03-0037	72	2680	5.191	0	0	0.54	2.31	16.90976
WA03-0038	52	3300	3.929	0	0	0.11	6.65	4.727134
WA03-0039	85	3500	4.757	0	0	0.19	8.28	7.7529
WA03-0041	87	3560	5.412	0	0	0.27	2.89	11.44192
WA03-0042	<b>23</b>	<b>770</b>	3.712	1	0	0	3.86	1.199462
WA03-0043	63	3320	4.707	0	0	0.61		48.8409
WA03-0044	83	3480	5.202	0	0	0.19	3.96	6.183616
WA03-0046	51	1830	4.507	0	0	0.13	6.91	4.115209
WA03-0047	56	3780	4.43	0	0	0.25	3.02	19.79299
WA03-0048	41	1390	4.164	0	0	1.01	2.62	61.43117
WA03-0051	99	4970	4.961	0	0	0.38	3.63	28.98603
WA03-0053	63	5700	3.931	1	0	0.1	4.67	2.172309
WA03-0060	49	3470	4.297	1	0	0	4.45	6.915079
WA03-0068	41	16060	<b>2.25</b>	0	0	0.13	3.53	4.089049
WA03-0070	42	2850	3.44	0	0	0	3.66	0.650744
WA03-0081	74	3340	4.649	0	0	0.74	2.56	21.87764
WA03-0086	95	6200	4.545	0	0	0.73	2.58	25.80202

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Appendix Table 5. Biogeographic distributions of the 39 most abundant benthic taxa identified to species in the West Coast shelf survey. Distributions are summarized by ecoregions based on the Marine Ecosystems of the World scheme (MEOW, Spalding et al. 2007). Only non-Arctic ecoregions bordering the United States Pacific Coast are included. “Coastal Estuaries” indicates whether the species has been reported from coastal estuaries of the Pacific Coast, excluding Puget Sound. Species marked with \* are those with taxonomic issues that may confound biogeographic distributions. Distributional data are from the present study, previous EMAP surveys including unpublished data from Alaska surveys (personal communication, Douglas Dasher and Max Hoberg), and data synthesized in PCEIS (Lee and Reusser 2008). Taxa Codes: AM = amphipod; B = bivalve; DEC = decapod; OP = ophiuroid; OS = ostracod; P = polychaete.

Species	Taxa Code	Aleutians	Gulf of Alaska	N. American Pacific Fjordland	Puget Trough / Georgia Basin	Oregon, Washington, Vancouver Shelf & Coast	Northern California	Southern California Bight	Coastal Estuaries
<i>Axinopsida serricata</i>	B	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Magelona longicornis</i>	P	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Amphiodia urtica</i>	OP	<b>No</b>	Yes	Yes	Yes	Yes	Yes	Yes	<b>No</b>
<i>Spiophanes berkeleyorum</i>	P	<b>No</b>	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Pinnixa occidentalis*</i>	DEC	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Spiophanes bombyx*</i>	P	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Euphilomedes carcharodonta</i>	OS	<b>No</b>	<b>No</b>	Yes	Yes	Yes	Yes	Yes	Yes
<i>Spiophanes duplex</i>	P	<b>No</b>	Yes	Yes	Yes	<b>No?</b>	Yes	Yes	Yes
<i>Prionospio jubata</i>	P	<b>No</b>	<b>No</b>	<b>No</b>	Yes	Yes	Yes	Yes	Yes
<i>Chloeia pinnata</i>	P	<b>No</b>	<b>No</b>	<b>No</b>	<b>No</b>	Yes	Yes	Yes	<b>No</b>
<i>Owenia fusiformis*</i>	P	Yes	Yes	Yes	Yes	Yes	Yes	<b>No</b>	Yes

<i>Myriochele striolata</i>	P	No	No	No	No	No	Yes	Yes	No
<i>Galathowenia oculata</i>	P	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Ampelisca agassizi*</i>	A	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Decamastus gracilis</i>	P	Yes	No?	Yes	Yes	Yes	Yes	Yes	Yes
<i>Paraprionospio pinnata*</i>	P	No	No	Yes	Yes	Yes	Yes	Yes	Yes
<i>Scoletoma luti</i>	P	No	No	Yes	Yes	Yes	Yes	Yes	Yes
<i>Euclymeninae sp. A*</i>	P	No	No	Yes	Yes	Yes	Yes	Yes	Yes
<i>Sternaspis fossor*</i>	P	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Rochefortia tumida</i>	B	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Lumbrineris cruzensis</i>	P	No	No	No	Yes	Yes	Yes	Yes	Yes
<i>Levinsenia gracilis*</i>	P	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Ampelisca careyi*</i>	AM	Yes?	Yes	Yes	Yes	Yes	Yes	Yes	No?
<i>Pholoe glabra*</i>	P	No	No	Yes	Yes	Yes	Yes	Yes	Yes
<i>Aphelochaeta glandaria</i>	P	No	No	No	Yes	Yes	Yes	Yes	Yes
<i>Paradiopatra parva</i>	P	No	No	No	No	Yes	Yes	Yes	Yes
<i>Prionospio lighti</i>	P	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Monticellina cryptica</i>	P	No	Yes?	No	No	No	Yes	Yes	Yes
<i>Aricidea catherinae*</i>	P	No	No	No	Yes	No	Yes	Yes	Yes
<i>Pseudofabriciola californica</i>	P	No	No	No	No	No	No	Yes	Yes

<i>Maldane sarsi</i> *	P	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Leptochelia dubia</i> *	TA	<b>No</b>	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Glycera nana</i> *	P	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Rhepoxynius boreovariatus</i>	AM	<b>No</b>	<b>No</b>	<b>No</b>	Yes	Yes	<b>No</b>	<b>No</b>	<b>No</b>
<i>Leitoscoloplos pugettensis</i> *	P	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Acila castrensis</i>	B	Yes	Yes	Yes	Yes	Yes	Yes	Yes	<b>No</b>
<i>Aphelochaeta monilaris</i> *	P	<b>No</b>	<b>No</b>	Yes	Yes	Yes	Yes	Yes	Yes
<i>Scalibregma californicum</i>	P	Yes	Yes	<b>No?</b>	Yes	Yes	Yes	Yes	Yes
<i>Ampelisca brevisimulata</i>	AM	<b>No</b>	Yes	Yes	Yes	Yes	Yes	Yes	Yes
TOTAL	39	14	23	28	34	34	37	37	33
TOTAL w/o problematic species	24	7	12	13	18	19	21	22	18





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