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The Condition of Tidal Wetlands of Washington, Oregon, and California - 2002

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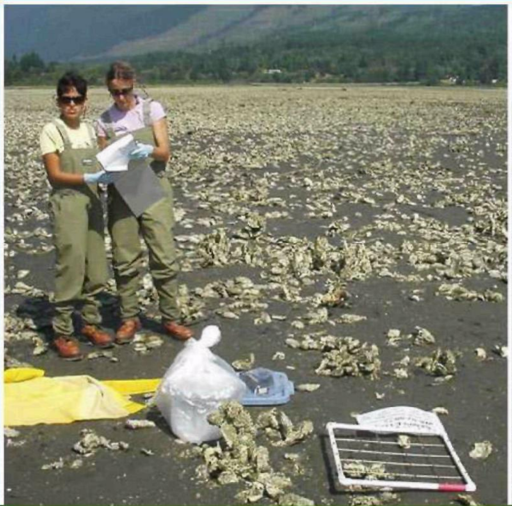

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Disclaimer

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Preface

This document is one of a series of summaries for the U.S. Environmental Protection Agency (EPA), National Coastal Assessment West Coast regional component (NCA-West). The NCA is the coastal component of the nationwide Environmental Monitoring and Assessment Program (EMAP). This document is a summary of a pilot assessment of the condition of estuarine intertidal, soft bottom habitat of the states of Washington, Oregon and California. The NCA in the West Coast region is a collaborative effort between EPA and the states of Hawaii, Alaska, California, Oregon and Washington, the territories of Guam and American Samoa, and the National Oceanic and Atmospheric Administration (NOAA). The program is administered through the EPA and implemented through partnerships with a combination of federal and state agencies, universities and the private sector. The West Coast Estuarine Intertidal Assessment involved the participation and collaboration of EPA, Washington Dept. of Ecology, Oregon Dept. of Environmental Quality, and the Southern California Coastal Water Research Project (SCCWRP), with additional contributions from personnel of Moss Landing Marine Laboratories and the San Francisco Estuary Institute.

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Many individuals within EPA made important contributions to NCA-West. Critical guidance and vision in establishing this program were provided by Kevin Summers of Gulf Ecology Division. Tony Olsen of Western Ecology Division (WED) provided the sampling designs utilized for various aspects of the continental shelf 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.

All members of the three state field crews are commended for their high level of technical expertise, teamwork and dedication to getting the required sampling completed. Project wide information management support during initial phases of the intertidal sampling effort was provided by SCCWRP as part of their cooperative agreement, and later by Computer Sciences Corporation (CSC) personnel.

Josh Collins provided leadership and direction for the field crews involved in the marsh habitat assessments in San Francisco Bay. The general assistance of the San Francisco Estuary Institute and its staff with the study are acknowledged. Martha Sutula of SCCWRP provided the leadership and direction for the field crews involved in the intertidal assessments in the Southern California region. Both individuals provided valuable insights into potential condition indicators, and were responsible for design and implementation of supplemental studies conducted in parallel in San Francisco Bay and Southern California.

Laura Brophy of Green Point Consulting provided training on marsh plant identification to field crews in Oregon and Washington.

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List of Acronyms

BEST	Biomonitoring of Environmental Status and Trends Program
CDF	Cumulative Distribution Function
CRM	Certified Reference Material
CVAA	Cold Vapor Atomic Adsorption
CWA	Clean Water Act
EMAP	Environmental Monitoring and Assessment Program
EPA	U.S. Environmental Protection Agency
ERL	Effects Range Low
ERM	Effects Range Median
GAO	U. S. General Accounting Office
GCECD	Gas Chromatography and Electron Capture Detection
GCMS	Gas Chromatography/Mass Spectroscopy
GIS	Geographic Information System
ICPAES	Inductively-Coupled Plasma Atomic Emission Spectrometer
ICPMS	Inductively Coupled Plasma-Mass Spectrometry
LCM	Laboratory Control Material
MDL	Method Detection Limit
NCA	National Coastal Assessment
NCA-West	National Coastal Assessment – West Coast regional component
NIS	Nonindigenous Species
NOAA	National Oceanic and Atmospheric Administration
ORD	EPA Office of Research and Development
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyls
QA/QC	Quality Assurance/Quality Control
RL	Reporting Limit
RPD	Relative Percent Difference
SCCWRP	Southern California Water Resources Research Project
SRM	Standard Reference Material
TOC	Total Organic Carbon
WED	Western Ecology Division

Executive Summary

An assessment of the condition of the intertidal, soft sediment habitat of the states of Washington, Oregon, and California was successfully conducted during the summer of 2002. The assessment survey was conducted under the EPA National Coastal Assessment Program (NCA), in partnership with Washington Department of Ecology, Oregon Department of Environmental Quality, and the Southern California Coastal Water Research Project (SCCWRP), with additional contributions from personnel of Moss Landing Marine Laboratories and the San Francisco Estuary Institute.

A major impetus for conducting the intertidal assessment is the fact that on the West Coast, the large tidal amplitude experienced over much of the region means that a large proportion of total estuarine area is intertidal. Methods and indicators for assessment of condition in the NCA program were primarily developed for sampling of subtidal habitats within estuaries of the Atlantic and Gulf coasts. The western regional component of the NCA therefore needed to develop a variety of modified methods and additional indicators to be able to assess condition in the extensive estuarine intertidal zones prevalent in West Coast estuaries. Additional emphasis was placed on site characterization metrics that included the occurrence of macroalgal beds/mats, submerged aquatic vegetation (SAV) or emergent vegetation, the presence of burrowing shrimp, the occurrence of marine debris, and obvious evidence of disruptive anthropogenic activities (e.g., dredging or landfill activity). Measurements of sediment nutrients (total N, total P) were added as potential indicators of site eutrophication where water column samples could not be taken. Where plants (seagrass, marsh plants, macroalgae) were encountered, percent cover and biomass estimates to lowest feasible taxonomic level were obtained. For rooted plants, maximum plant height was measured. Categorization of shoreline land use adjacent to sample sites was included as a potential indicator of land use stressors on the intertidal sites.

Data were successfully collected from a total of 217 out of 223 targeted sites in the intertidal zone of the three west coast states, with the exception of the estuarine zone of the Columbia River, which had been extensively sampled in previous NCA assessments. The definition of intertidal zone for the west-wide sampling included all intertidal area except that classified by the National Wetlands Inventory as hard substrate, high marsh, diked, or artificial substrate. The study utilized a stratified random sampling design, with sampling effort partitioned among states (Washington – 68, Oregon – 65, California – 90), and among regions within a state. Washington sites were divided among Puget Sound (25), Willapa Bay (30), and the remaining estuaries (13). Oregon sites were divided between Coos Bay (30) and the remaining estuaries (35). The California sites were divided among pilot study areas in Southern California (30), San Francisco Bay (30), and the remaining estuaries (30).

The San Francisco Bay pilot study differed from the remainder of the study by dividing sampling effort approximately equally between three habitat types, tide flats, low marsh, and high marsh (excluded elsewhere). For both the San Francisco and

Southern California pilot studies, a two stage randomization procedure was followed. As the first stage, wetland systems were randomly selected from a list of systems, and then a point sampling location was randomly selected within the selected wetland.

The area of different estuarine intertidal habitats varied somewhat among the three states, although uniformly, either unvegetated sand or mud flats occupied the greatest percentage of estuarine area. Shellfish beds (oysters), gravel bottom, and intertidal seagrasses were recorded only in Washington and Oregon. San Francisco Bay and the rest of California tended to have finer sediments, higher Total Organic Carbon, and higher concentrations of sediment nitrogen and phosphorus than estuarine intertidal areas in Washington and Oregon.

For sediment contaminants, there was a pattern of higher average Effects Range-Median Quotient (ERM-Q) within San Francisco Bay and the rest of California as compared with Washington and Oregon. All values of average ERM-Q for the five major areas in the present study were below guideline levels from other studies that have determined biotic effects associated with ERM-Q values. Levels of sediment contamination across the intertidal of the three western states were generally quite low, with only 0.21% of the intertidal area of the West Coast estuaries having exceedances of >5 Effects Range Low (ERL) concentrations, and only 0.3% of the intertidal area exceeding Effects Range Median (ERM) concentrations. In all cases, the exceedances of the ERMs were due to DDT and/or its congener 4,4' DDE. Some caution in interpretation of sediment contaminant results is warranted. While analyses of sediment metals met QA requirements in all states, analyses of PAHs, PCBs, and some pesticides from Oregon did not generally meet analytical targets.

Average densities of benthic infauna were highest in Oregon, with California and San Francisco having lower but similar abundances, and Washington having the lowest value. The benthic community was dominated by polychaetes, oligochaetes and amphipods. Surprisingly, the single most abundant polychaete in the West Coast intertidal was the nonindigenous *Manayunkia aestuarina*, introduced from the Northeast Atlantic. San Francisco habitats, other than the high marsh, were the most invaded, with an average of almost 50% of the classified species per sample consisting of nonindigenous species. Puget Sound samples contained about 26% nonindigenous species compared to 40% and 44% for coastal Oregon and Washington, respectively.

Vegetation was present in the quadrats at 150 of the 217 sites successfully sampled, and included 28 emergent macrophytes, 2 seagrasses, as well as macroalgae. Eighty-two percent of plant taxa occurred at three or fewer sites. The most frequently occurring emergent macrophyte taxa were marsh jaumea (*Jaumea carnosa*) and pickleweed (*Salicornia virginica*). The greatest number of emergent macrophyte species were observed in California (n = 11), and in San Francisco Bay (n = 17) where high marsh was included in the study. Mean cover of nonindigenous, emergent macrophyte species was low (8%) throughout the West. Mean cover by nonindigenous species was highest in Washington (21%), where both salt marsh cordgrass *Spartina alterniflora* and the introduced seagrass *Zostera japonica* were found. No nonindigenous macrophyte species were observed at California sites, except one high marsh site in San Francisco Bay.

Shoreline land use adjacent to sample sites showed much higher percentages of urban shoreline in California and San Francisco Bay than in Washington and Oregon. Much of the undeveloped land in the latter two states was in silviculture. Surprisingly, estimates of residential shoreline in the three states were relatively similar.

The study showed that further refinements of measurement approaches for plant community and shoreline development indicators are needed. Quadrat and transect sizes selected for plant community assessment proved too small for effectively capturing plant diversity at sample sites. While it was believed that available habitat maps for the west coast were insufficiently accurate to establish marsh-type strata for the sampling design, this proved false, and partitioning of sampling effort by habitat across the region may have improved the assessment. Better guidance on shoreline development classification is required to reduce variance among field crews. In spite of the costs for processing benthic samples with high levels of organic materials, volumetric sub sampling is not recommended because of the problems produced in intercomparison of data among sites for benthic community metrics.

The results of this assessment study represent the first regional scale survey of the condition of intertidal wetland habitats on the West Coast. Findings confirm results from previous National Coastal Assessment studies of West Coast estuaries that have shown that sediment contamination issues are limited in extent, but that West Coast estuaries have been broadly invaded by nonindigenous species.

1.0 Introduction

1.1 Program Background

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

The coastal assessment component of the EMAP Western Pilot began as a partnership with the states of California, Oregon and Washington, the National Oceanic and Atmospheric Administration, and the Biomonitoring of Environmental Status and Trends Program (BEST) of the U.S. Geological Survey to measure the condition of the estuaries of these three states. Sampling began during the summer of 1999 and the initial phase of estuarine sampling was completed in 2000. Beginning in 2000, the Western Coastal Assessment efforts became integrated into the EPA National Coastal Assessment Program (NCA).

The NCA is a multi-year effort led by EPA's Office of Research and Development to evaluate the assessment methods it has developed to advance the science of ecosystem condition monitoring. This program has surveyed the condition of the Nation's coastal resources (estuaries and offshore waters) by creating an integrated, comprehensive coastal monitoring program among the coastal states to assess coastal ecological condition. The NCA is accomplished through strategic partnerships with all 24 U.S. coastal states. Using a compatible, probabilistic design and a common set of survey indicators, each state conducts the survey and assesses the condition of their coastal resources independently. Because of the compatible design, these estimates can be aggregated to assess conditions at the EPA Regional, biogeographical, and national levels. Data from this program provide the basis for individual reports of coastal conditions for each state (Nelson et al., 2004, 2005, 2007; Hayslip et al., 2006, Wilson and Partridge, 2007), as well as providing data for a series of National Coastal Condition Reports (U.S. EPA 2001, 2004, 2006).

On the West Coast, the large tidal amplitude experienced over much of the region means that a large proportion of total estuarine area is intertidal. For example, intertidal habitat constitutes 52% of the estuarine area averaged over all Pacific Northwest estuaries, and can constitute as much as 90% in some systems (e.g., Netarts Bay; Lee et al., 2006). The initial development of methods and indicators for assessment of condition in the NCA were for sampling of subtidal habitats within estuaries of the Atlantic and Gulf coasts. Because the Western component of the NCA began as a pilot program, there was an opportunity to test development of a variety of modified methods and additional indicators for assessment of condition in the extensive estuarine intertidal zones prevalent in West Coast estuaries.

Therefore a pilot assessment of the intertidal habitat of the states of Washington, Oregon, and California was carried out in the summer of 2002. This report provides a technical summary of the data from this assessment.

2.0 Methods

Methods for the 2002 intertidal survey were in general the same as those developed for the EPA National Coastal Assessment (Nelson et al., 1999), with modifications to reflect the intertidal nature of the resource being assessed. Because of the intertidal focus of the survey, water quality and fish tissue samples were omitted while vegetational-quadrat and transect samples were added.

2.1 Sampling Design

The target resource assessed was the intertidal zone of the states of Washington, Oregon and California, with the exception of the estuarine portion of the Columbia River. The Columbia was extensively sampled by EMAP surveys conducted in 1999, 2000, and 2001, and additional sampling was deemed to be redundant.

The sample frame is a map defining the target resource. The principal map coverage used to develop the 2002 intertidal GIS data layer that was the sample frame was the National Wetlands Inventory (NWI) in ArcInfo format. An ArcInfo coverage of San Francisco Bay baylands, created by the San Francisco Estuary Institute (SFEI), was selected as the map source in the San Francisco Bay area. In some cases, digital coverage was lacking, and hard copy maps were scanned and georeferenced, and estuarine polygons were hand digitized.

In order for a polygon to be included in the sample frame coverage for all areas except San Francisco Bay (see below), the polygon had to have the following attributes: it had to be classified as intertidal, and not classified as hard substrate, high marsh, diked, or artificial substrate. Several codes within the NWI coverages were interpreted as follows: 'irregularly exposed' was interpreted as below Mean Lower Water, and 'irregularly flooded' was interpreted as above Mean Higher Water. Both categories were excluded from the frame.

The study utilized a stratified random sampling design. Within Washington, sampling effort was distributed such that Puget Sound received 25 stations, there was an intensification of effort in Willapa Bay for a total of 30 stations, and the remaining estuaries of the state received 13 stations, for a total of 68 stations. In Oregon, there was an intensification of sampling in Coos Bay (30 stations), while 35 stations were located within the remaining estuaries of the state, for a total of 65 stations.

The study design in California was more complex. Two pilot study areas were defined, Southern California (Point Conception to the Mexican border) and San Francisco Bay (downstream of the delta), each of which had 30 sampling stations. An additional 30 sites were randomly allocated along the California coastline outside of these intensification areas, for a total of 90 sites. The San Francisco Bay study area differed from the remainder of the study by dividing sampling effort approximately equally between three habitat types, tide flats, low marsh, and high marsh, with high marsh being a habitat type excluded from the remainder of the West Coast intertidal sampling frame. For both the San Francisco and Southern California pilot study areas, a two stage randomization procedure was followed. As the first stage, wetland systems were randomly selected from a list of systems, and then a point sampling location was randomly selected within the selected wetland. The advantage of this approach is that it allows condition estimates based on percentage of systems, while at the same time also allowing for the areal extent estimates of condition being used for all other geographic components of the intertidal survey. Wetlands systems are typically managed as discrete units rather than as continuous resources, and the two level randomization design provides the potential to report on the percentage of wetland systems that are meeting their management goals.

Each sampling region is termed a multidensity category. For each multidensity category (see Appendix Table 1), geographic coordinates for the number of primary target stations described above were determined during the study design process. Additionally, each multidensity category except for the California pilot studies had random coordinates for nine times the number of primary stations selected as alternate sampling locations. The two California pilot studies had 1.5 times the number of primary sites selected to serve as alternate locations. Alternate locations would be sampled in the event a primary site was rejected for any reason, such as safety concerns or access issues.

Table 2.1.1. Summary of the sampling design by state and multidensity category for the 2002 West Coast Intertidal Assessment.

State	Multidensity Category (Label)	Design Target Number of Primary Sample Sites	Design Actual No. of Sites	No. Sites Successfully Sampled	Number of Alternate Sample Sites
Washington	Puget Sound (Puget)	25	26	24	225
Washington	Willapa Bay (Willa)	30	30	30	271
Washington	Rest of State (Washi)	13	12	7	116
Oregon	Coos Bay (Coosb)	30	29	30	271
Oregon	Rest of State (Orego)	35	36	36	314
California	Rest of State (Calif)	30	29	30	271
California	San Francisco Bay Low Marsh (SF Low Marsh)	10	11	9	89
California	San Francisco Bay High Marsh (SF High Marsh)	10	10	12	91
California	San Francisco Bay Flat (SF Flat)	10	9	9	90
California	Southern California (Bight)	30	30	30	269

2.2 Biological and Sediment Sampling

Field sampling was performed independently by each state during a seasonal window spanning the period from July to mid-September. Intertidal sites were accessed, as appropriate, either by boat, hovercraft or on foot, at low tide to facilitate burrow counts, plant community, sediment chemistry and benthic community sampling. The core field data or sample types collected at each site included:

- general habitat-type description and anthropogenic debris or perturbation
- shoreline development
- presence and cover of burrowing shrimp and other megafauna.
- plant community composition and cover
- sediment consistency, composition, salinity and temperature
- sediment pollutants, including organics and trace metals; total organic carbon
- sediment nitrogen and phosphate concentrations
- benthic macroinvertebrate community structure

2.2.1 Site Location

The randomly selected sampling locations for each state were provided to the field crews, who located the sites by use of Global Positioning Satellite System (GPS).

Because EMAP's probabilistic sampling design is unbiased, potentially, some of the generated sites can fall in locations that are not amenable to sampling (e.g., outside the sampling frame, danger or risk to crew, excessive rocky bottom, currents, man-made obstructions, etc.). Field teams had a limited degree of onsite flexibility to randomly relocate sampling sites when confronted with unexpected obstacles or impediments, but the new site was to be no further than 100 m and preferably 40 m from the original designated site. Alternative sample sites determined during the initial design process were used if a site was found to be unsuitable.

2.2.2 Site Description - Station Occupation

Observations were made in the field to document certain attributes or conditions to help characterize the overall ecological condition of the site. These included the occurrence of macroalgal beds/mats, submerged aquatic vegetation (SAV), or emergent vegetation, the presence of burrowing shrimp, the occurrence of marine debris, and obvious evidence of disruptive anthropogenic activities (e.g., dredging or landfill activity).

Upon arrival at the sample site, the station number, GPS location, date, time, samplers' initials and agency were recorded. If the station was abandoned, the reason for abandonment was also recorded. Observations were made on sea state, weather, wind speed and direction, and estimated tidal level as well as air temperature and habitat type. Three to five photos and notes were taken to document site characteristics and anthropogenic impact such as shoreline construction, dredging or recreational use. Habitat was defined by the presence or absence of factors such as dominant plant (e.g., *Spartina sp.*, *Zostera marina* or *Z. japonica*) or animal (e.g. burrowing shrimp, or oysters) species that affect the abundance and number of species in the benthic infaunal community. The habitat was also defined by its geological type - rocky, gravel, coarse or fine sand, muddy sand, sandy mud or mud.

2.2.3 Plant Composition/Cover and Burrow Counts

A 0.25-m^2 quadrat was randomly placed at the GPS-located site and then turned over three times to define a 1-m square sampling site. The four adjacent 0.25-m^2 quadrats were used for: 1) burrow counts; 2) plant cover; 3) sediment chemistry samples; and 4) benthic samples. The number of burrow holes of burrowing shrimp (*Neotrypaea californiensis, Upogebia pugettensis*) was counted in one of the 0.25-m^2 quadrats at each site. If vegetation covered $\geq$50% of the quadrat, the vegetation was gently pulled back taking care to disturb the sediment surface as little as possible, and the density of burrow holes under the vegetation was visually estimated.

Where rooted plants (e.g. seagrasses, marsh plants, *Spartina*) or macroalgae were present, the plant community was quantified in one of the 0.25-m^2 quadrats. Percent plant cover within the 0.25-m^2 quadrat was visually estimated separately for green, brown or red macroalgae, *Zostera* spp., *Spartina* or other rooted plant genera present, and bare (i.e., open, unvegetated) substrate. The maximum total cover possible for all species of plants in a quadrat is 100% times the number of species of plants in the plot, and thus may be greater than 100% if several species overlapped at different layers of cover. For rooted species, the blade length of the longest blades was measured. The total biomass of each species of rooted plants and each type of algae in the quadrat was determined by cutting all vegetation at the sediment surface, sorting by species, and obtaining the dry weight (g dry weight) of biomass for each species. Plants were dried in the laboratory until they reached constant dry weight at 80° C. Plant composition and cover were also estimated using 25 random points along a 5-meter transect. Each plant species or open ground noted at the 25 random points along the 5-m transect was recorded, with the possibility of more than one plant species occurring at each point. In all cases, seagrasses and other rooted plants were identified to species if possible, or to the lowest practical taxonomic level. If the species of plant was not known with certainty by the field crew, a reference specimen was taken by the field crew for identification by a qualified plant taxonomist.

2.2.4 Surficial Sediment Sample

At each site, surficial sediment layer (top 2-3 cm) was collected by spatula or scoop from one of the 0.25-m^2 quadrats to provide sediment for the analyses of inorganic and organic chemical contaminants, total organic carbon (TOC), and grain size determinations. Surficial sediment was combined in a clean, high-grade stainless steel or Teflon vessel and composited by stirring well to ensure a homogenous sample before sub-samples for the various analyses were taken (Table 2.2.1).

2.2.5 Sediment Pollutant and Nutrient Analysis

Sediment collected from each site was analyzed for a suite of organic pollutants, metals and interstitial nutrients (Table 2.2.1). Fifteen metals were analyzed in all three states. California quantified sediment metals including mercury using inductively coupled plasma mass spectrometry (ICPMS). Washington quantified all metals except mercury using ICPMS, and used cold vapor atomic absorption (CVAA) for mercury. Oregon quantified all metals except mercury using inductively coupled plasma atomic emission spectrophotometry (ICPAES) and CVAA for mercury. For organic pollutants, a total of 21 PCB congeners (PCBs), DDT and its primary metabolites, and 14 chlorinated pesticides were measured. There were 21 polycyclic aromatic hydrocarbons (PAHs) measured by all three states out of the 23 target compounds (Table 2.2.1); phenanthrene and dibenzothiophene were not measured by all three states. California and Washington used GCMS to quantify the PCBs, DDTs, pesticides, and PAHs. Oregon used GCECD for the chlorinated compounds and GCMS for the PAHs. California quantified total nitrogen using EPA method 415.1 while Oregon and Washington used CHN analyzers. All three states used ICPAES to quantify total sediment phosphorus. Total organic carbon (TOC) was analyzed in Washington by combustion and CHN analyzers while California and Oregon used CHN analyzers.

2.2.6 Benthic Infaunal Samples

The objective was to collect a 0.1-m^2 benthic infaunal sample to a depth of 10 cm at all sites, with the sample processed through a 1.0 mm mesh sieve. A specially designed post-hole corer sampler was constructed to assist in obtaining these intertidal benthic samples, though other sampling methods were acceptable if they had the same nominal area as the post-hole sampler. During the course of the survey, however, it was discovered that the internal area of the post-hole corer was 0.09 m^2 but not before twelve samples were taken with other methods that had an actual area of 0.1 m^2. Additionally, the volume of residue retained on the 1.0 mesh sieve at several sites exceeded several liters, which was impractical to process. This volume of residue necessitated sub-sampling the residue in 78 of the 217 samples (36%). The samples were subsampled to the minimum practical extent. The occurrence of 0.1-m^2 samples and the subsampling resulted in twelve functional sample sizes, ranging from 0.0028 to 0.1 m^2, a 36-fold difference in sample area. Because the majority (56%) of the samples were taken with the post-hole sampler, all benthic abundances were normalized to 0.09 m^2 for analysis. Species richness does not scale linearly with area so no attempt was made to normalize the number of taxa per sample. Accordingly, we did not analyze species richness with the entire benthic data set.

Table 2.2.1. Compounds analyzed in all three states in sediments.

Polyaromatic Hydrocarbons (PAHs)	**PCB Congeners (Congener Number and Compound)**	**DDT and Other Chlorinated Pesticides**	**Metals and Misc.**
Low Molecular Weight PAHs	8: 2,4'-dichlorobiphenyl	DDTs	Metals
1-methylnaphthalene	18: 2,2',5-trichlorobiphenyl	2,4'-DDD	Aluminum
1-methylphenanthrene	28: 2,4,4'-trichlorobiphenyl	4,4'-DDD	Antimony
2-methylnaphthalene	44: 2,2',3,5'-tetrachlorobiphenyl	2,4'-DDE	Arsenic
2,6-dimethylnaphthalene	52: 2,2',5,5'-tetrachlorobiphenyl	4,4'-DDE	Cadmium
2,3,5-trimethylnaphthalene	66: 2,3',4,4'-tetrachlorobiphenyl	2,4'-DDT	Chromium
Acenaphthene	77: 3,3',4,4'-tetrachlorobiphenyl	4,4'-DDT	Copper
Acenaphthylene	101: 2,2',4,5,5'-pentachlorobiphenyl		Iron
Anthracene	105: 2,3,3',4,4'-pentachlorobiphenyl	Cyclopentadienes	Lead
Biphenyl	110: 2,3,3',4',6-pentachlorobiphenyl	Aldrin	Manganese
Dibenzothiophene	118: 2,3',4,4',5-pentachlorobiphenyl	Dieldrin	Mercury
Fluorene	126: 3,3',4,4',5-pentachlorobiphenyl	Endrin	Nickel
Naphthalene	128: 2,2',3,3',4,4'-hexachlorobiphenyl		Selenium
Phenanthrene	138: 2,2',3,4,4',5'-hexachlorobiphenyl	Chlordanes	Silver
	153: 2,2',4,4',5,5'-hexachlorobiphenyl	Alpha-Chlordane	Tin
High Molecular Weight PAHs	170: 2,2',3,3',4,4',5-heptachlorobiphenyl	Heptachlor	Zinc
Benz(a)anthracene	180: 2,2',3,4,4',5,5'-heptachlorobiphenyl	Heptachlor Epoxide	
Benzo(a)pyrene	187: 2,2',3,4',5,5',6-heptachlorobiphenyl	Trans-Nonachlor	
Benzo(b)fluoranthene	195: 2,2',3,3',4,4',5,6-octachlorobiphenyl		Miscellaneous
Benzo(k)fluoranthene	206: 2,2',3,3',4,4',5,5',6-nonachlorobiphenyl	Others	Total Organic Carbon
Benzo(g,h,i)perylene	209: 2,2'3,3',4,4',5,5',6,6 '-decachlorobiphenyl	Endosulfan I	
Chrysene		Endosulfan II	Total Nitrogen
Dibenz(a,h)anthracene		Endosulfan Sulfate	Total Phosphorus
Fluoranthene		Hexachlorobenzene	Percent Fines
Indeno(1,2,3-c,d)pyrene		Lindane (gamma-BHC)	
Pyrene		Mirex	
		Toxaphene	

2.3 Shoreline Land Use

Research has indicated that there tend to be relationships between land use or land cover types and indicators of estuarine condition. Both Comeleo et al. (1996) and Rodriguez et al. (2007) found significant associations between levels of urban land use and sediment contaminants in east coast estuaries. Generally such analyses require considerable effort in generating GIS coverages with associated land uses around the sampling points. The 2002 EMAP intertidal study included a pilot indicator of adjacent land use which was determined by the field crews at the time of the sample site visit. Crews provided a qualitative assessment of the dominant land use aspect for the shoreline most immediately adjacent to the sampling station by selecting a category from a list of land use types. Land use type was supplemented by additional descriptions in the form of comments and digital photos. Categories included agriculture, armored, commercial, highway, industrial, undeveloped, residential, urban, sanctuary, natural area, recreational, and fisheries uses. Several categories were combined in the final analysis with commercial being combined with industrial, and natural area plus sanctuary being combined with undeveloped. Fisheries use was only designated in Oregon and was relabeled oyster aquaculture to reflect the specific use noted.

2.4 Quality Assurance

2.4.1 Quality Assurance/ Quality Control of Chemical Analyses

The quality assurance/quality control (QA/QC) program for the National Coastal Assessment - West program is defined by the "Environmental Monitoring and Assessment Program (EMAP): National Coastal Assessment Quality Assurance Project Plan 2001-2004" (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.

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

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 accord 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 to 5 times the MDL. In these analyses, concentrations between the MDL and the RL were included in the generation of mean values for the analyte, while any values below the MDL were set to 0.

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, which is summarized here.

2.4.2 Metals in Sediments

The analytical methods for metals by the three states are those used in the NOAA NS&T Program (Lauenstein and Cantillo, 1993) or documented in the EMAP Laboratory Methods Manual (U.S. EPA, 1994). The recommended MDL (Table A7-2 in U.S. EPA, 2001) varies by metal, ranging from 0.01 µg/g for mercury to 1500 µg/g for aluminum. All three states met the MDL requirements for all the metals. The percent recovery from certified/standard materials, recovery from matrix spikes, and the average RPD for non-zero sample duplicates and matrix spikes for the sediment metals are summarized in Appendix Table 1.1. All three states met all the overall quality assurance requirements for metals. While Oregon met the overall requirements, the relative accuracy for chromium, nickel, and tin ranged from 22% to 41% compared to the requirement of 20% for metals.

2.4.3 Organics in Sediments

As with the metals, the analytical methods for organic compounds are those used *in the NOAA NS&T Program (Lauenstein and Cantillo, 1993) or documented in the* EMAP Laboratory Methods Manual (U.S. EPA, 1994). The recommended MDL (Table A7-2 in U.S. EPA, 2001) is 10 ng/g for PAH compounds and 1 ng/g for the PCBs, DDTs, and chlorinated pesticides. All three states met the MDL requirements for all the organic compounds.

The percent recovery from certified/standard materials, recovery from matrix spikes, and the average RPD for non-zero sample duplicates and matrix spikes for the sediment PAHs are summarized in Appendix Table 1.2. California met the requirements for the percent deviation from reference materials but slightly exceeded the RPD requirement among duplicate samples (33% vs. 30%). Washington slightly exceeded the requirement for the average deviation from reference materials (32% vs. 30%) but met the requirements for the number of PAH analytes within ±35% of the true value as well as the requirements for percent recovery from spiked sediment and the RPD of duplicates. While failing some of the requirements, the differences were relatively small, indicating that the total PAH data from both Washington and California can be used quantitatively. The Oregon results are more problematic, as they had a greater difference between the measured and true values (43% vs. requirement of 30%) and 47% of the PAH analytes deviated by more than ±35% from the true value. Also, for 13 of the 22 PAH compounds, the CV from the replicate reference samples was ≥30%. Because of these deviations with both accuracy and precision, the total PAH data from Oregon needs to be interpreted cautiously.

The QA results for sediment PCBs are summarized in Appendix Table 1.3. California met the requirements of deviation from the reference materials and the percent recovery of the matrix spikes. California did not have any duplicate non-zero reference values so it is not possible to evaluate this measure of precision. Washington slightly exceeded the requirements for the average deviation from reference materials (32% vs. 30%) and the percentage of analytes within ±35% of the true value (67% vs. 70%). Washington did meet the requirements for the percent recovery of matrix spikes and the RFP for duplicate samples. Because of these deviations, the Washington PCB results should be used with qualified caution. As with the PAHs, the PCB results for Oregon are problematic. The deviation from reference materials was 146% and only 38% of the PCB congeners were within ±35% of the true value. Because of the problems with accuracy, the total PCB data are best used qualitatively to identify locations with sediment PCBs. The subset of congeners that met the requirements for both accuracy and precision (PCB 28, 105, 110, 118, and 153) can be used to quantify differences in PCB concentrations among sites.

The QA results for sediment DDTs and other chlorinated pesticides are summarized in Appendix Table 1.4. For California, LCMs were only analyzed for two of the DDT compounds (4,4'-DDD and 4,4-DDE) though all the pesticides were analyzed using recovery from spiked sediments. In the absence of certified pesticide concentrations in a sediment matrix with the complete suite of pesticides, the excellent recovery of matrix spiked pesticides will have to suffice as indirect evidence that the methods employed by California yield results that meet the requirements for accuracy. Washington met all the requirements for the chlorinated pesticides (Appendix Table 1.4) though several of the individual pesticides showed deviations of up to 72% in the spiked blanks. Because of these deviations with the spiked blanks, the Washington pesticide data should be used with qualified caution. Oregon had problems with the analytical surrogate coeluting with hexachlorobenzene (HCB), which resulted in a large average deviation from the reference material (127%). Excluding HCB reduced the average extent of deviation from the reference material (57%) but it still did not meet the QA requirement of 30%, although three DDT compounds (2,4'-DDD, 4,4'-DDD, and 4,4'-DDE) and alpha-chlordane were quantified within 35% of the reference values. Overall, the poor performance with the reference materials indicates that the Oregon pesticide results are best used qualitatively to identify locations with sediment pesticides, with the exception of the four compounds that quantified within 35% of the reference concentrations.

2.5 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 intertidal resource that has any given observed indicator value. 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 are provided in Diaz-Ramos et al. (1996).

Data are presented in this report in several graphical forms. Comparisons among the three states Washington, Oregon, and California, the intensive study in San Francisco Bay, and the values for the entire Western intertidal region (omitting the high marsh samples from San Francisco Bay), are presented as bar charts of average values for the five categories plus 1 standard deviation as an estimate of error. Where there existed reasonable benchmarks to assign condition assessments to an indicator, estimates of the percentage area of the intertidal zone within the condition levels is provided in the text.

3.0. Results and Discussion

3.1 Sampling Locations

Samples were obtained from 217 stations located in the states of Washington, Oregon, and California ((Figs. 3.1.1- 3.1.13). Abbreviated station numbers are provided on Figs. 3.1.3-3.1.13, and complete station identification numbers, together with latitude and longitudes for sampling locations are given in Appendix Table 2. All stations were sampled during low tide, and most sites were completely exposed at the time of sampling.

Figure 3.1.1. Views of field sampling activities during the 2002 NCA Intertidal Assessment in Oregon (A), Washington (B,D) and California (C).

The substrate type varied widely and included salt marsh, oysters, and sand and mud flats (Fig. 3.1.2.). Percentage of area within the West Coast intertidal region sampled was statistically estimated for 9 habitat categories. The dominant types of estuarine intertidal habitat varied among the three states. Unvegetated tide flats, classified either as sand or mud flats, were the dominant habitat types for all three states, for San Francisco Bay, and for the west as a whole (Fig. 3.1.2.). Higher percentages of mud flats were recorded in California and San Francisco Bay versus Washington and Oregon, which possessed higher percentages of sand flats. Shellfish beds (oysters), gravel bottom, and intertidal seagrasses were recorded only in Washington and Oregon. The non-native marsh grass *Spartina alterniflora* was recorded in Washington in Willapa Bay, where efforts to eradicate the species are currently underway.

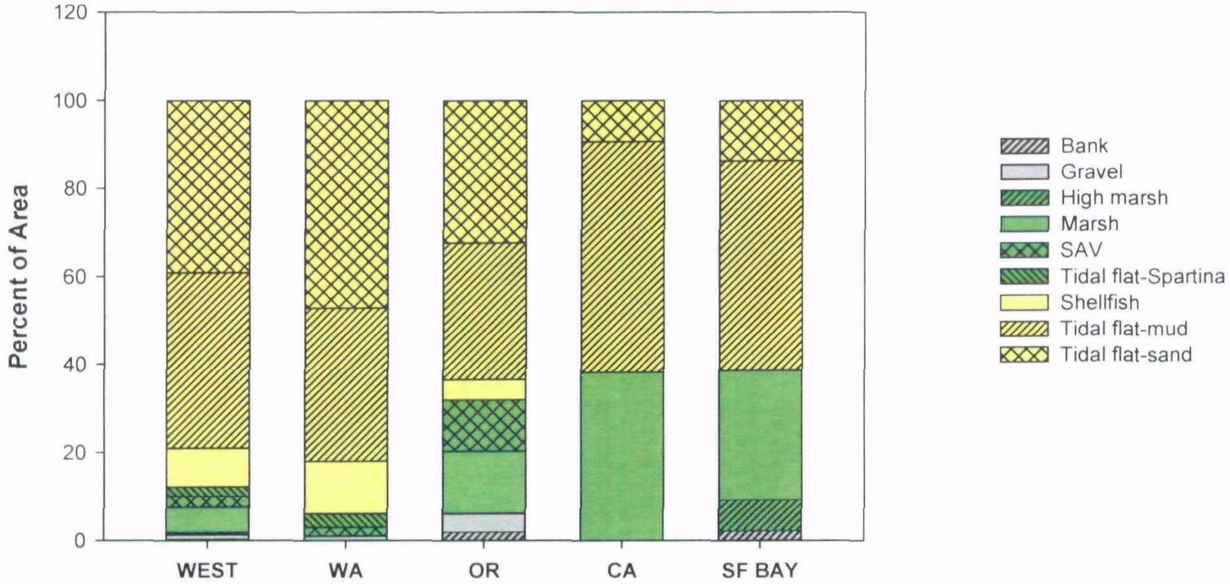

Figure 3.1.2. Percentage area of habitat types for the 2002 West Coast Intertidal Assessment. Values for California do not include San Francisco Bay.

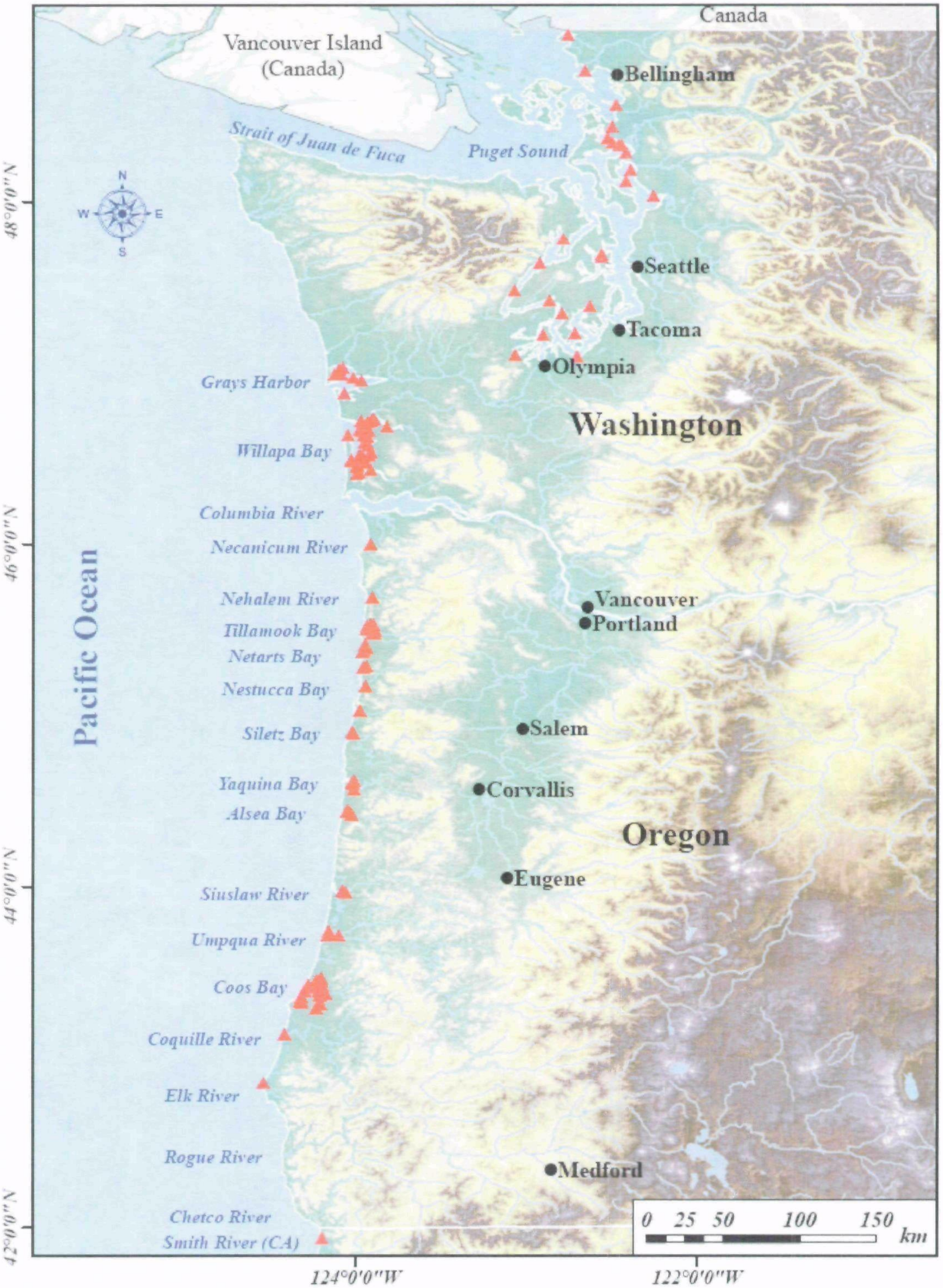

Figure 3.1.3. Distribution of sampling stations in Washington and Oregon for the 2002 West Coast Intertidal Assessment.

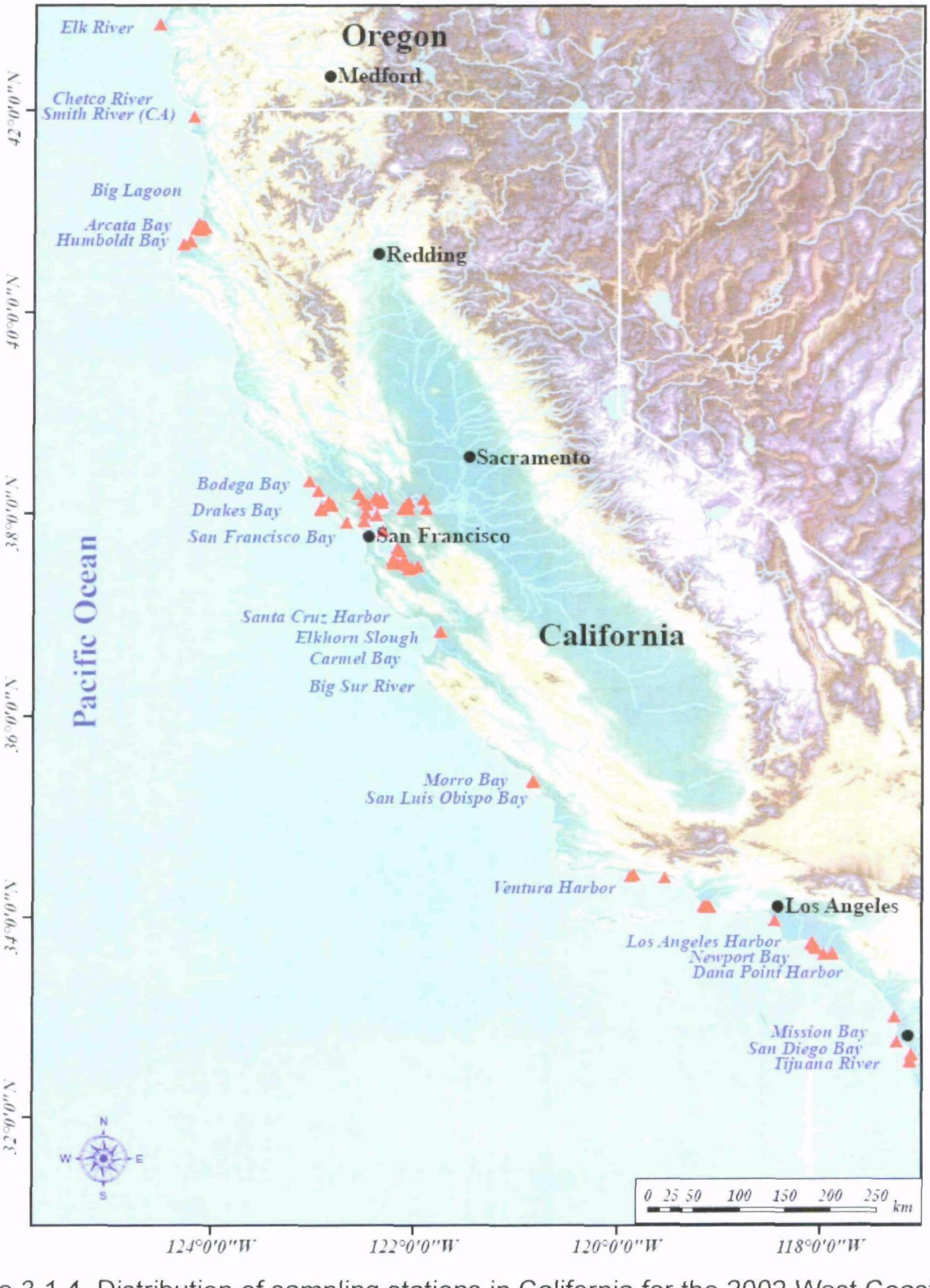

Figure 3.1.4. Distribution of sampling stations in California for the 2002 West Coast Intertidal Assessment.

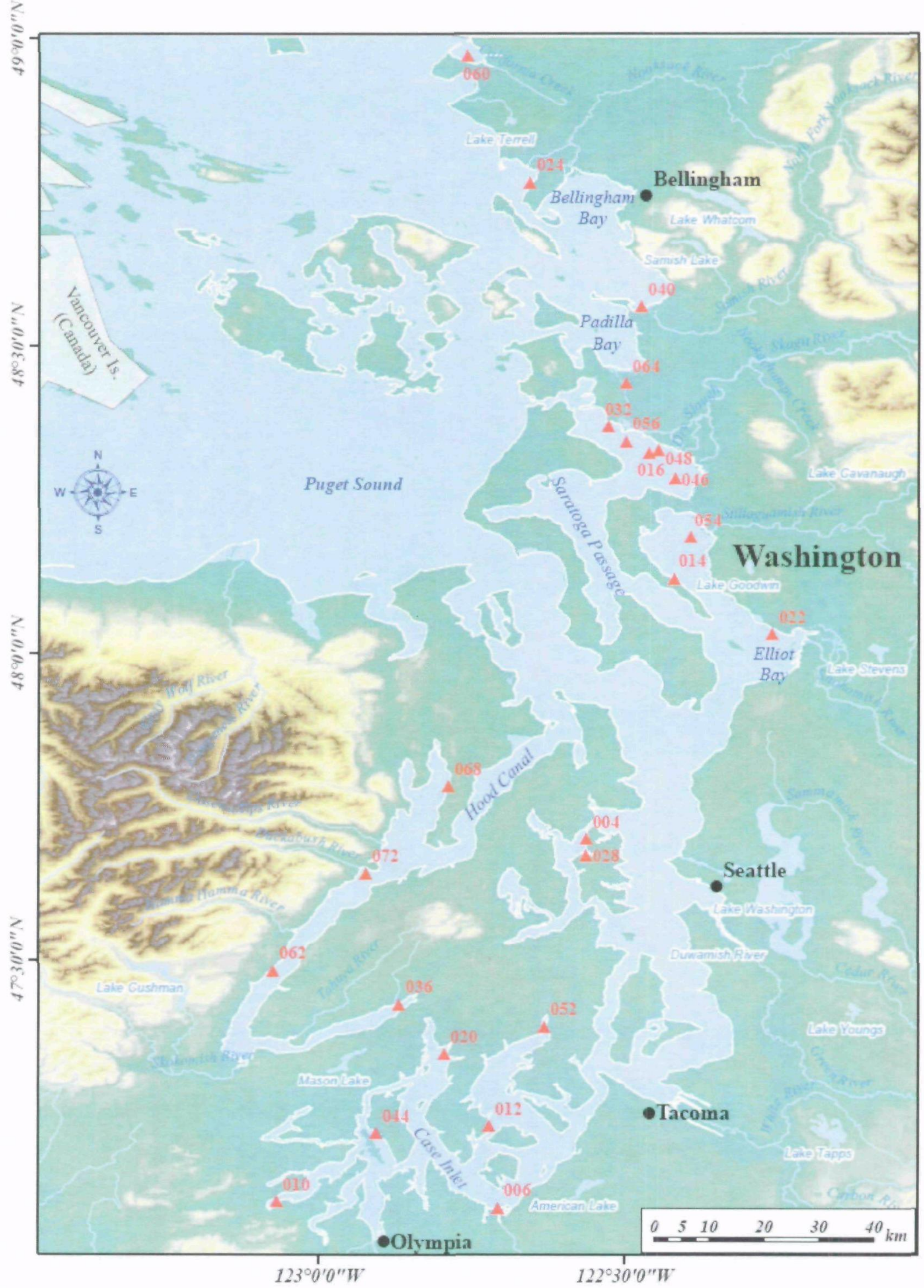

Figure 3.1.5. Distribution of sampling stations with station numbers in Puget Sound for the 2002 West Coast Intertidal Assessment.

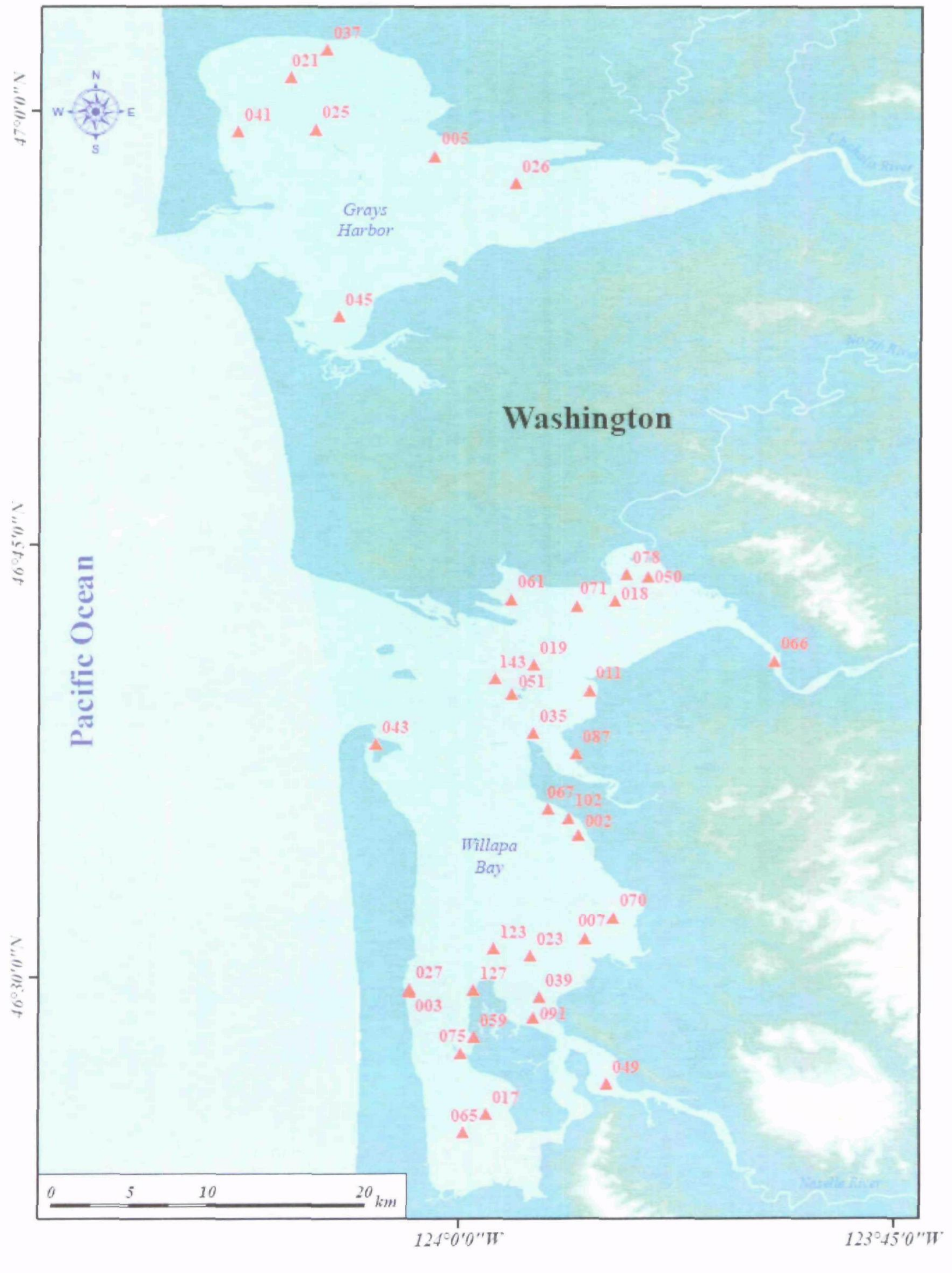

Figure 3.1.6. Distribution of sampling stations with station numbers for the outer coastal estuaries of Washington for the 2002 West Coast Intertidal Assessment.

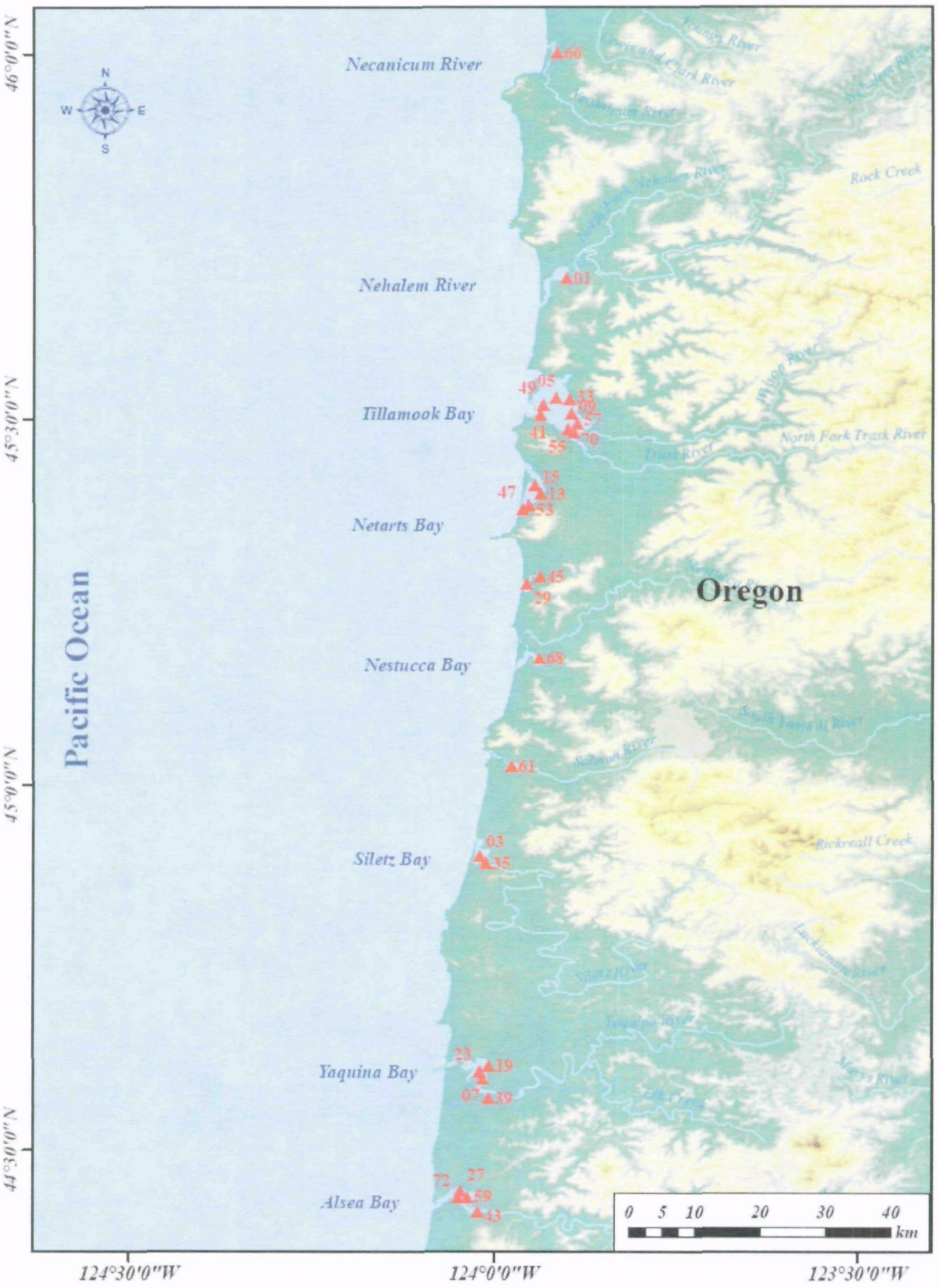

Figure 3.1.7. Distribution of sampling stations with station numbers for the northern half of Oregon for the 2002 West Coast Intertidal Assessment.

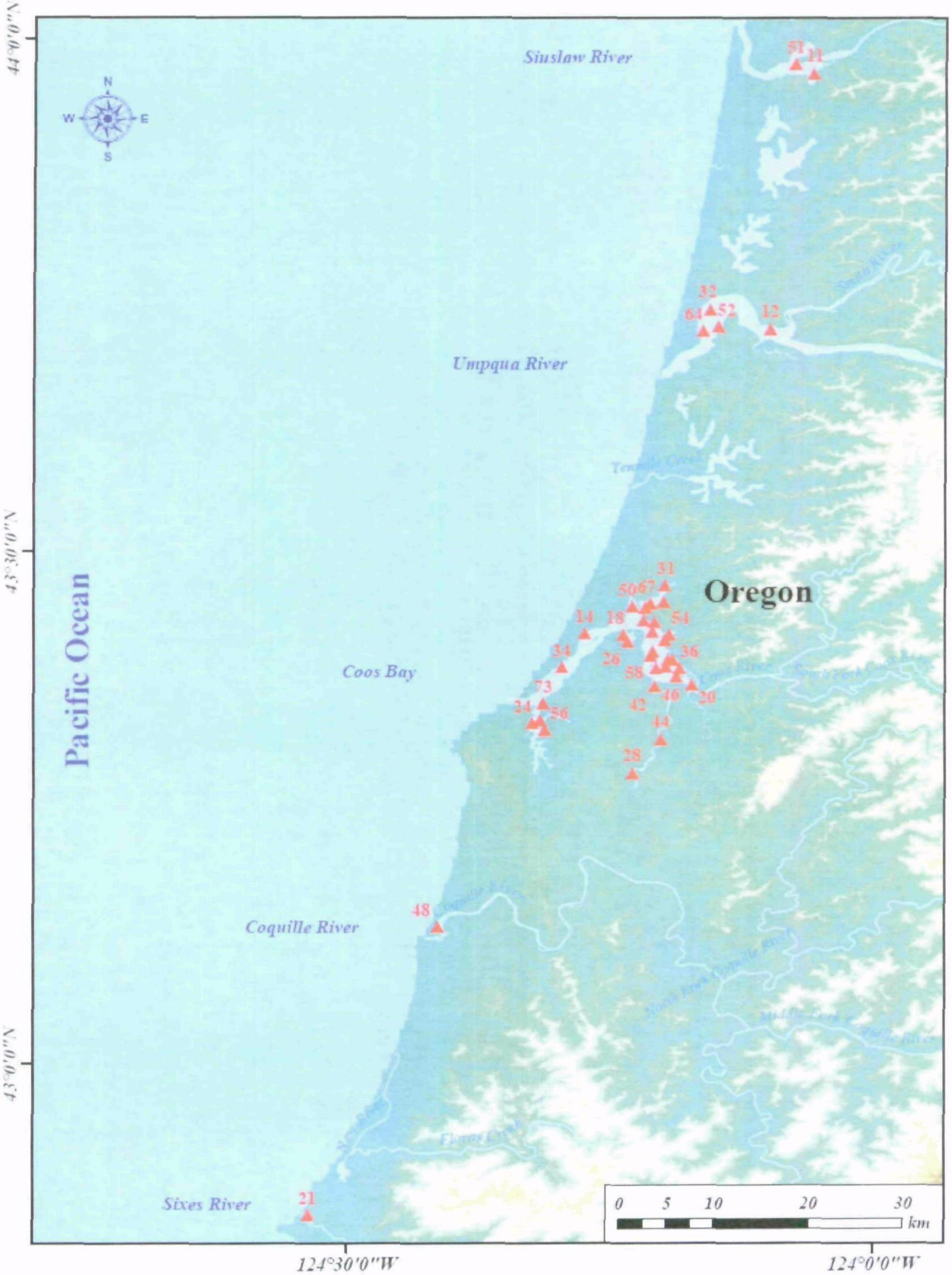

Figure 3.1.8. Distribution of sampling stations with station numbers for the southern half of Oregon for the 2002 West Coast Intertidal Assessment.

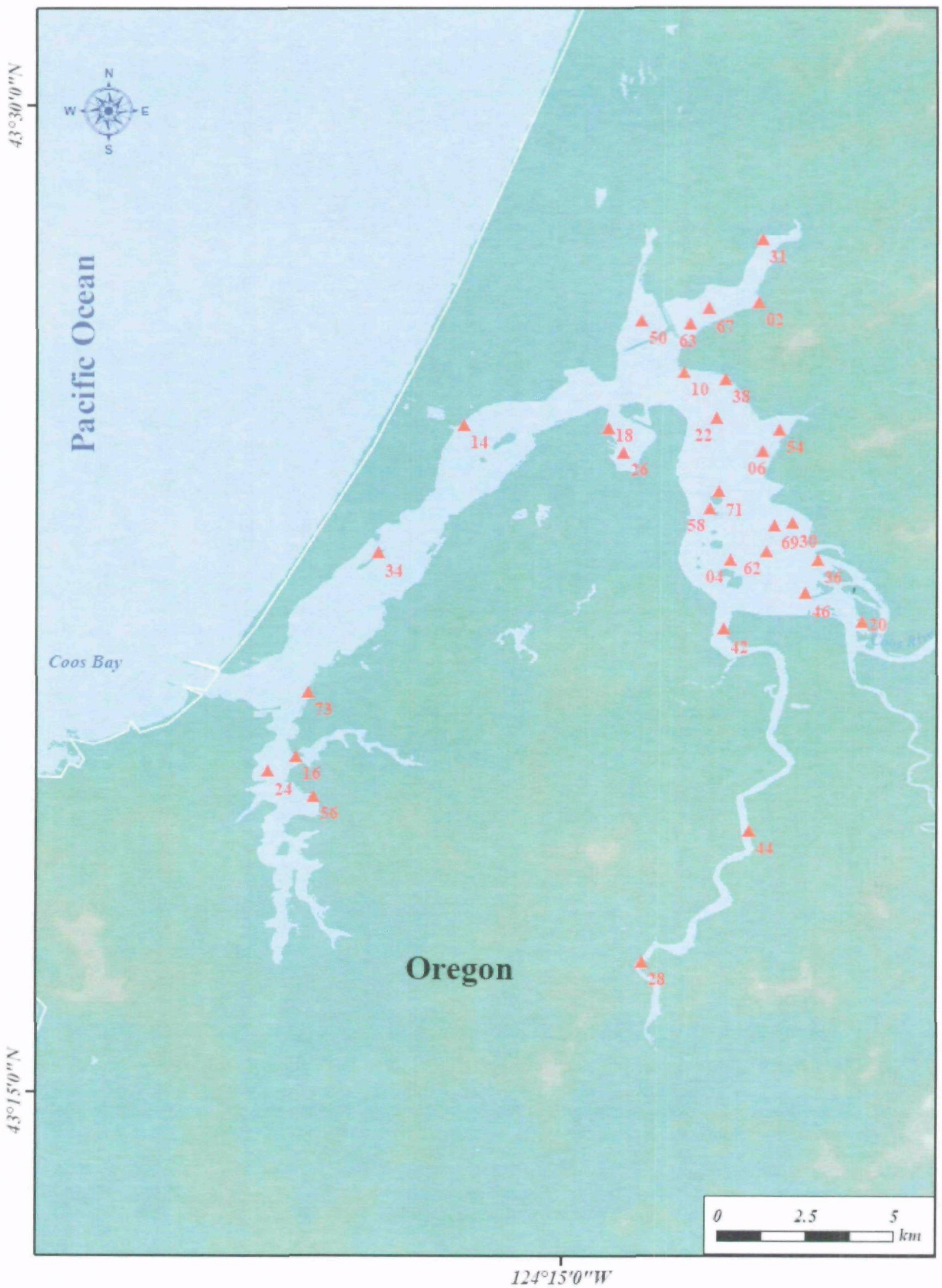

Figure 3.1.9. Distribution of sampling stations with station numbers for Coos Bay, Oregon for the 2002 West Coast Intertidal Assessment.

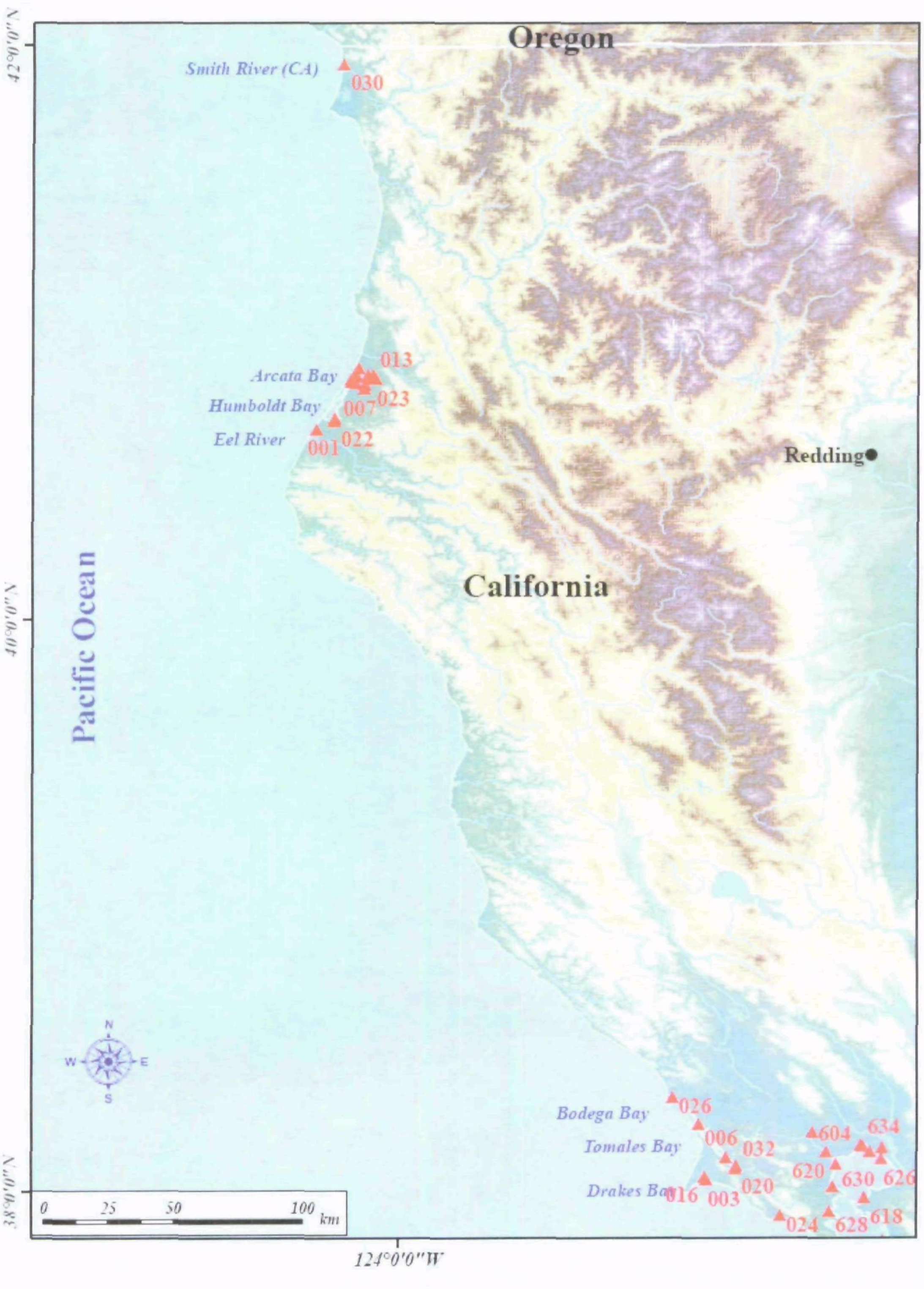

Figure 3.1.10. Distribution of sampling stations with station numbers for the northern half of California for the 2002 West Coast Intertidal Assessment.

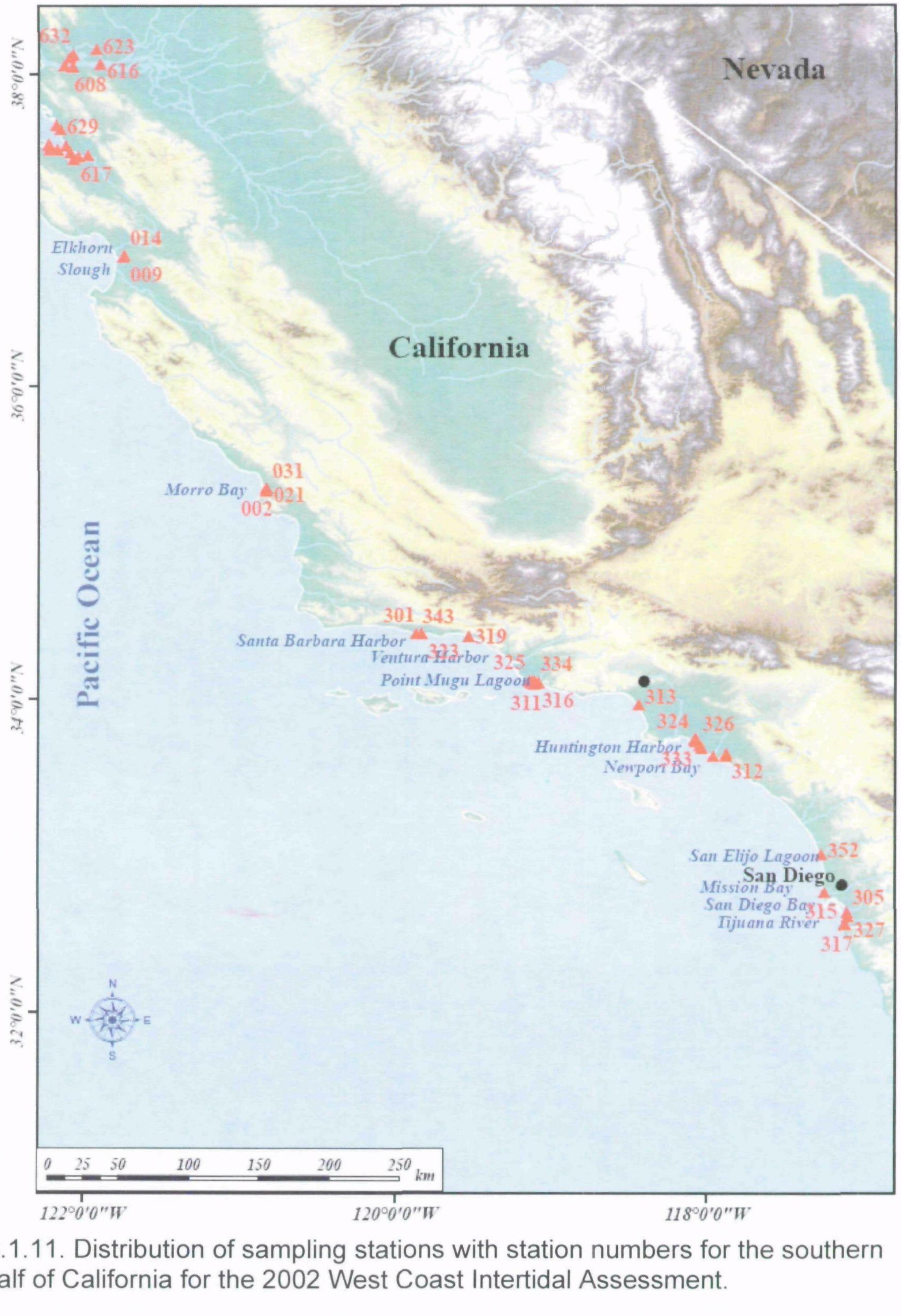

Figure 3.1.11. Distribution of sampling stations with station numbers for the southern half of California for the 2002 West Coast Intertidal Assessment.

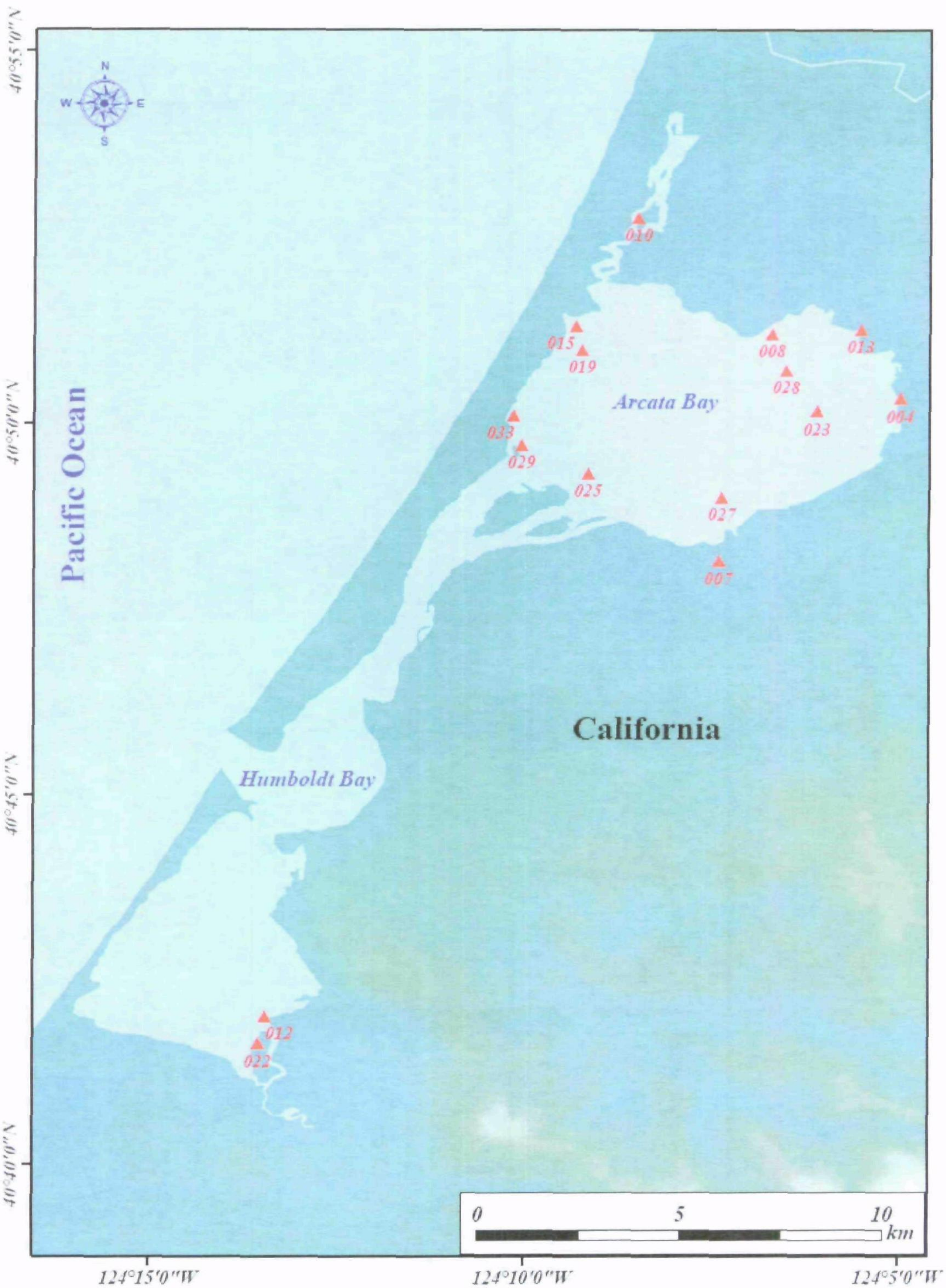

Figure 3.1.12. Distribution of sampling stations with station numbers for Arcata and Humboldt Bays, California for the 2002 West Coast Intertidal Assessment.

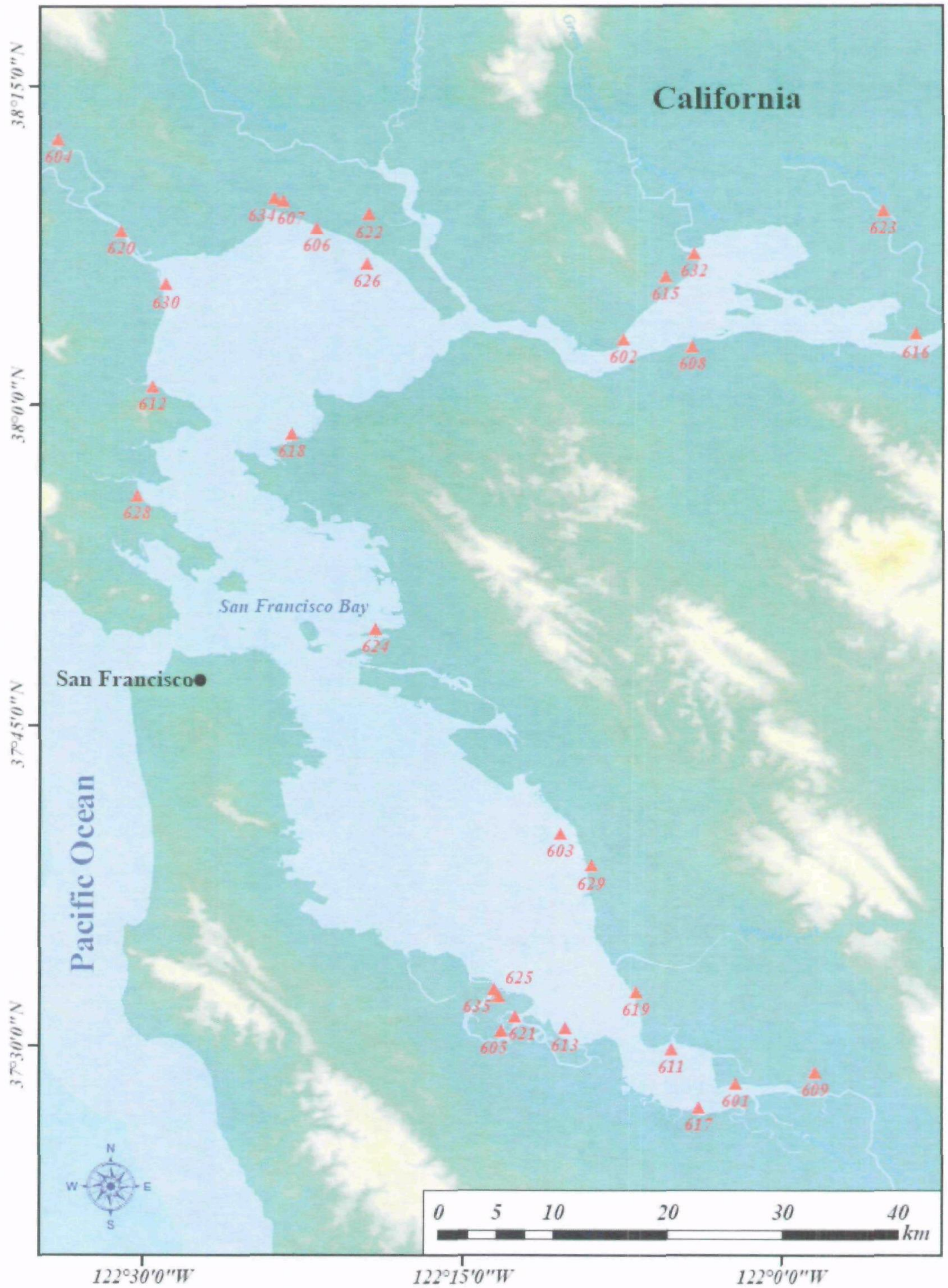

Figure 3.1.13. Distribution of sampling stations with station numbers for San Francisco Bay, California for the 2002 West Coast Intertidal Assessment.

3.2 Sediment Quality

3.2.1 Sediment Composition

The sediment grain size distribution can be an important indicator of the benthic environment, with the benthic community typically strongly responding to changes in grain size composition. Relative accumulation of sediment organic carbon and sediment contaminants may be correlated with sediment grain size, with finer grain sizes tending to accumulate in lower energy environments. The mean percentage of fine particles (silts, clays) in sediments was less than 60% in all five geographic categories (Fig. 3.2.1), but was approximately two times greater in samples for California and San Francisco Bay than in samples from Oregon and Washington. On an areal basis, 28% of western intertidal habitat consisted of sediments with >80% fines. Washington (5%) and Oregon (4%) had much lower areas with >80% fines than did California (50%) or San Francisco Bay (38%). Appendix Table 3 provides a summary of sediment grain size, total organic carbon (TOC), nutrient concentrations and contaminant concentrations for all stations.

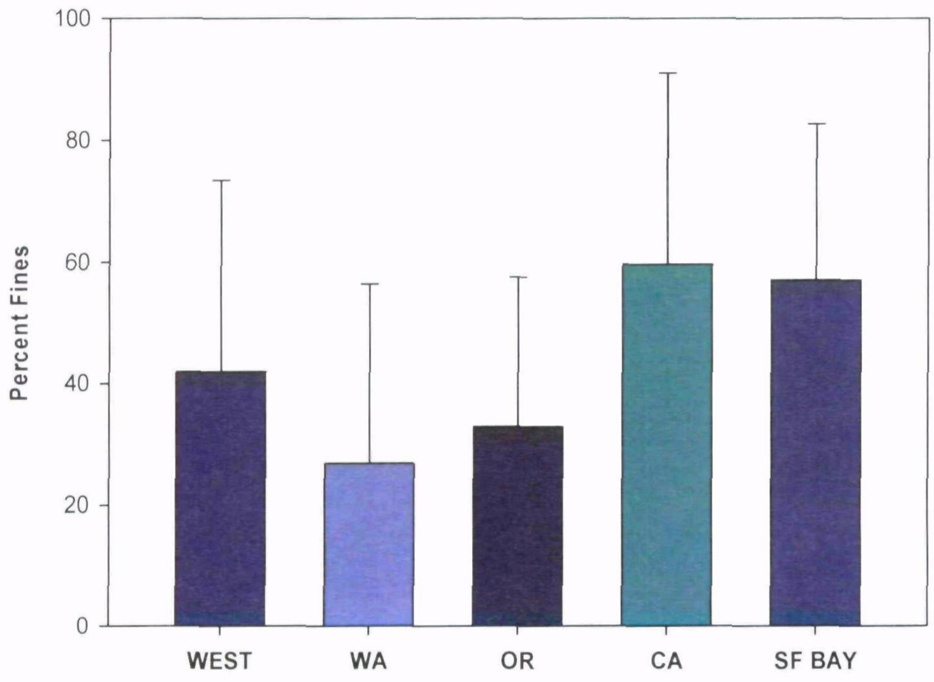

Figure 3.2.1. Percent fine sediments for the 2002 West Coast Intertidal Assessment (mean ± 1 sd).

3.2.2 Sediment Total Organic Carbon

Another measure of sediment condition is the percent Total Organic Carbon (TOC). In the NCCR II report (U.S. EPA 2004), values exceeding 5% TOC were ranked poor, values between 2% and 5% were ranked fair, and values less than 2% were ranked good. There was a distinct difference in the average value of TOC between sites in Washington and Oregon (means <2%) and sites in California, including San Francisco Bay (>4%) (Fig. 3.2.2, Appendix Table 3). West wide (excluding high marsh in San Francisco Bay), 2.9% of total estuarine intertidal area had values over 5% TOC. There was a similar distinction in the amount of intertidal area among states with high TOC values, with Washington and Oregon having <2% of area with values over 5% TOC, compared with >20% of area for California and San Francisco Bay.

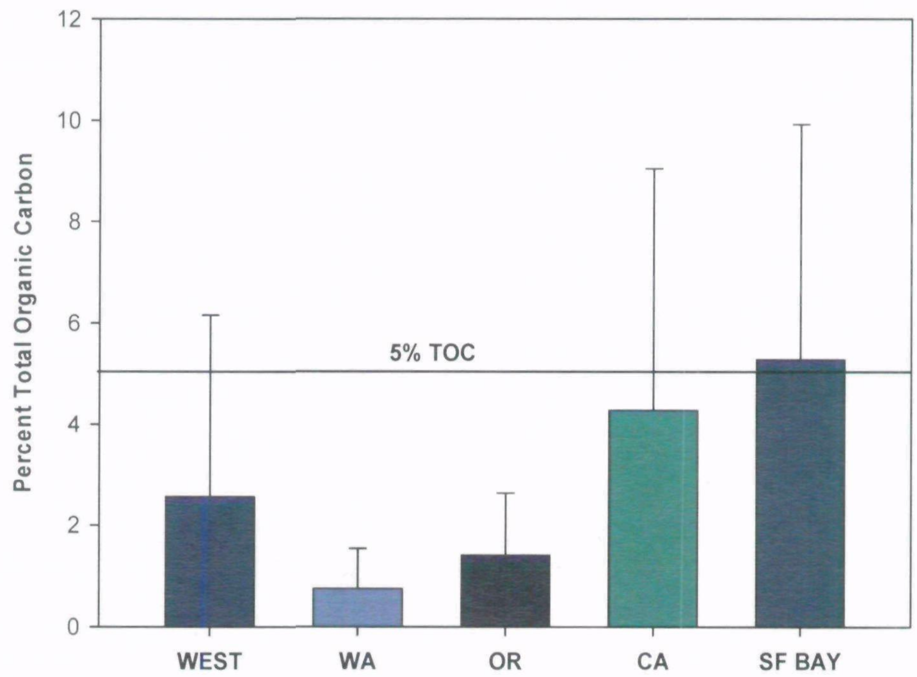

Figure 3.2.2. Percent sediment total organic carbon (TOC) for the 2002 West Coast Intertidal Assessment (mean ± 1 sd).

3.2.3 Sediment Nutrients

Sediments perform the function of removal of nitrogen and phosphorus from the water column through the process of sequestration of these nutrients in organic matter into the sediments. Nitrogen and phosphorus sequestered in sediments can also be a source of dissolved nutrients exported to the water column, where they are essential for phytoplankton growth, but in excess may lead to undesirable phytoplankton blooms.

Average percent sediment concentrations of both total nitrogen and total phosphorus were lowest in Washington and highest in California (Figs. 3.2.3, 3.2.4; Appendix Table 3). West wide (excluding high marsh in San Francisco Bay), the mean value of sediment total nitrogen was less than 0.5 percent in 96% of intertidal area, and sediment total phosphorus was less than 0.1 percent in 95% of intertidal area. The mean value of sediment total nitrogen was < 0.3 percent in 100% of Washington sediments but 0.5 percent or more in 13% of area in Oregon, 18% of San Francisco Bay area, and 23% of area in the rest of California. The mean value of sediment total phosphorus was 0.1 percent or less in 99% of area in Washington, 98% of area in Oregon, 77% of San Francisco Bay area, and 80% of area in the rest of California. The five highest values for sediment concentrations of both total nitrogen and total phosphorus occurred in sediments from estuary sites within the Southern California Bight and from San Francisco Bay (Appendix Table 3).

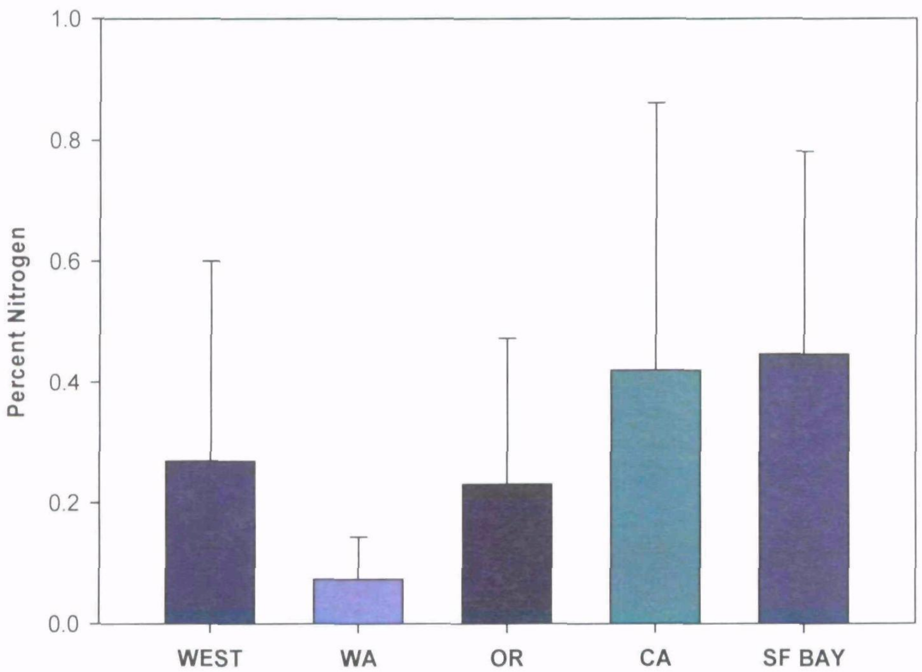

Figure 3.2.3. Average percent sediment total nitrogen for intertidal samples obtained in 2002 for the West Coast region, individual states, and San Francisco Bay (mean ± 1 sd).

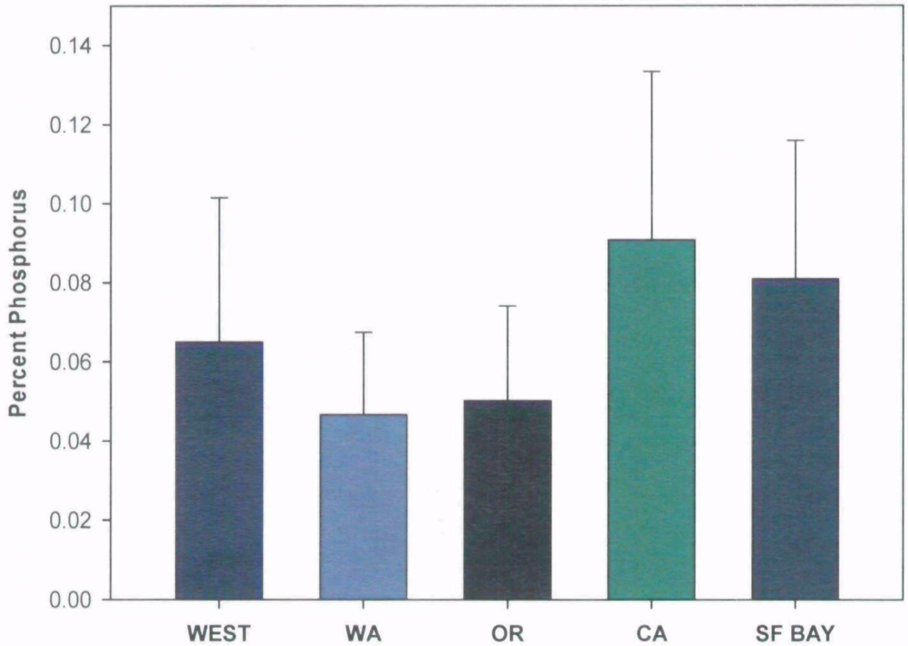

Figure 3.2.4. Average percent sediment total phosphorus for intertidal samples obtained in 2002 for the West Coast region, individual states, and San Francisco Bay (mean ± 1 sd).

3.2.4 Sediment Contaminants

To assess the degree of sediment contamination in West Coast estuaries, the sediment concentrations of contaminants were compared with both the ERM and ERL guidelines (Long et al., 1995). A total of 28 compounds or groups of compounds were included on the list of contaminants used by the NCCR II report (U.S. EPA 2004). The analysis of the 2002 intertidal data for West Coast estuaries excluded nickel and two PAHs, phenanthrene and dibenzothiophene. Phenanthrene and dibenzothiophene were excluded because values were not available from all three states. Nickel was excluded because the ERM value has a low reliability for West Coast conditions where high natural crustal concentrations of nickel exist (Long et al., 1995; Long et al., 2000; Lauenstein et al., 2000).

Sediment Contaminant Guidelines (Long et al., 1995)

ERM (Effects Range Median)—Determined for each chemical as the 50th percentile (median) in a database of ascending concentrations associated with adverse biological effects.

ERL (Effects Range Low)—Determined values for each chemical as the 10th percentile in a database of ascending concentrations associated with adverse biological effects.

Sediment concentrations exceeded their respective ERM values at only five stations, representing 0.3% of the intertidal estuarine area of the West Coast (Appendix Table 3). Four sites were located in Southern California (none in San Francisco Bay), one in Oregon, and none in Washington. In all cases, the exceedances of the ERMs were due to DDT and/or its congener 4,4' DDE. Three of the four California sites were in Point Mugu Lagoon, and the remaining site was in Newport Harbor.

Any site that had five or more compounds that exceeded their ERL values was classified as having fair condition in the NCCR II report (U.S. EPA 2004). As with the ERMs, nickel was excluded from the analysis. To ensure that the analysis was not biased by PAHs, only one exceedance was counted if a site exceeded the ERL for LMW PAHs, HMW PAHs, or total PAHs. A total of 14 stations had five or more pollutants exceeding the ERL value, of which 3 also exceeded one or more ERMs (Appendix Table 3). The 14 sites represent only 0.21% of the intertidal area of the West Coast estuaries. All of these sites occurred in California, with 5 sites located in either high or low marsh within the San Francisco Bay, while the remaining 9 sites were in Southern California. Two additional sites, one in California and one in Oregon, had sediments pollutants that exceeded one or more ERMs, but had less than five pollutants exceeding the ERL (Appendix Table 3).

Another indicator approach to evaluation of the level of potential problems resulting from sediment contamination is the use of the Effects Range Median Quotient (ERM-Q, Long and MacDonald, 1998).

Sediment Effects Range Median Quotient (Long and MacDonald, 1998)

ERM-Q — The average quotient of the measured concentration of a defined list of contaminants divided by their ERM values.

The ERM-Q index attempts to summarize the overall contaminant exposure resulting from a mixture of contaminants by dividing the measured sediment concentration of a contaminant by its ERM value, followed by taking an average value of these quotients. Average ERM-Q values for samples from California and San Francisco Bay were approximately two times higher than those for sites in Washington and Oregon (Fig.3.2.5). Thompson and Lowe (2004) have suggested that an average ERM-Q of ≤0.146 was a reasonable guideline for reference condition with regard to sediment contamination in the San Francisco Estuary. For a national data set, Long et al. (1998) suggested that values <0.1 indicate a low probability (11.6%) of having highly toxic sediments. All values of average ERM-Q for the five areas in the present study (Fig.3.2.5) are below these guidelines.

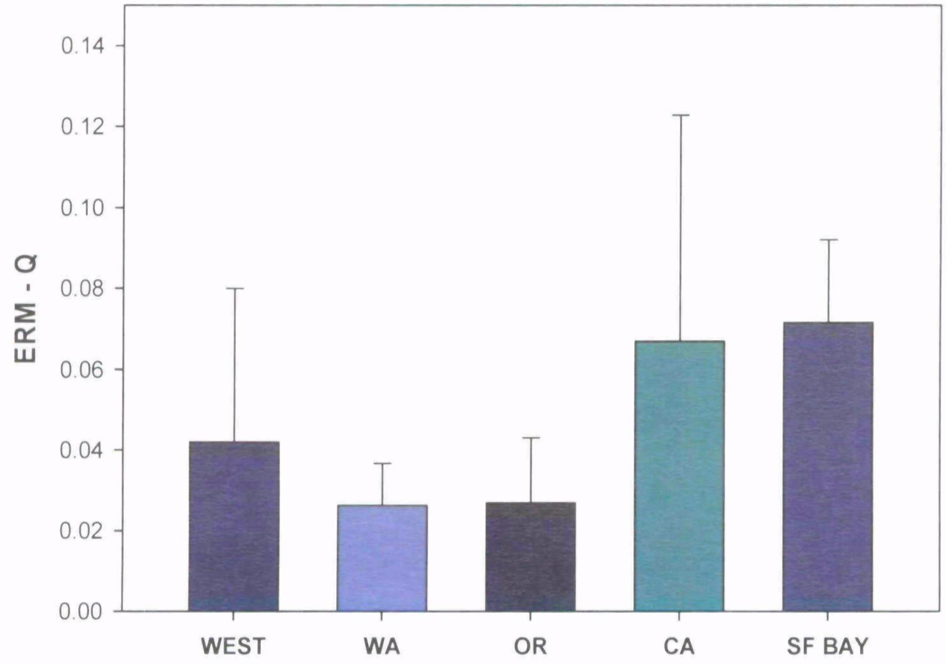

Figure 3.2.5. Average Effects Range-Median Quotient (ERM-Q) values for sediment contaminant concentrations for intertidal samples obtained in 2002 for the West Coast region, individual states, and San Francisco Bay (mean ± 1 sd).

3.3 Biological Condition

3.3.1 Benthic Infauna

A total of 217 samples were taken in the three states, with 60 samples taken in California other than San Francisco, 30 in San Francisco Bay, 66 in Oregon, and 61 in Washington. Twelve of the 30 San Francisco Bay samples were allocated to the "high marsh" frame. The West survey was defined as the 205 samples from the three states other than 12 high marsh samples in San Francisco. Although the goal was to obtain 0.1 m^2 samples at all these sites, the large volume of detritus retained necessitated subsampling 78 (36%) of the benthic samples. Additionally, the actual interior area of the post-hole sampler was 0.09 m^2 rather than 0.1 m^2. These two factors resulted in a total of twelve functional sample sizes with sizes ranging from 0.0028 to 0.1 m^2. While there was a wide range of sample sizes, the majority of the samples (122) were taken with the 0.09 m^2 post-hole digger and 196 of samples fell within four sizes (0.0056, 0.0225, 0.09, and 0.1 m^2). To account for the differences in sample size, all benthic abundances were normalized to 0.09 m^2. Abundance generally increases linearly with area, so this normalization should not introduce much additional uncertainty in densities. However, the number of species per sample does not increase linearly and accordingly we did analyze absolute species richness or H' on a per sample basis.

The median abundance in the West wide survey was 503 individuals per 0.09 m^2 (= 5589 m^2) with an average density of 1,802 individuals per 0.09 m^2 (=20,022/m^2). This intertidal density is approximately within the range found in the previous survey of primarily subtidal assemblages in the small and moderate sized West Coast estuaries (Nelson et al., 2004). Median benthic densities were highest in Oregon at about 1,245 individuals per 0.09 m^2 (=13,833/m^2) and lowest in Washington with 373 individuals per 0.09 m^2 (=4,144/m^2). Average densities showed the same trend, with Oregon having the highest average abundance, California and San Francisco having similar abundances, and Washington having the lowest average abundance (Figure 3.3.1). The lower density in Washington partially reflects the low density in Puget Sound (average = 617 individuals per 0.09 m^2) compared to the coastal estuaries (average = 1,256 individuals per 0.09 m^2).

A total of 420 taxa were identified from all 217 samples of which 248 were identified to the species level. Presumably the total number of species would have been greater if all the samples had been 0.1 m^2 in area and if the "problematic" taxa (e.g., oligochaetes, insect larvae) had been identified to species. Taxa were classified as native, nonindigenous, cryptogenic, indeterminate taxa, cosmopolitan, or unclassified. Cryptogenic species are species of unknown origin (Carlton, 1996) while indeterminate taxa are those not identified with sufficient taxonomic resolution to classify as native, nonindigenous, or cryptogenic (Lee et al., 2003). Cosmopolitan is used primarily for pelagic taxa that are widely dispersed across several oceans, while unclassified species are those that have yet to be sufficiently analyzed to render a final classification. The classifications used here follow the Pacific Ecosystem Information System (*PCEIS*), a georeferenced database of native and nonindigenous species of the Northeast Pacific being developed by the EPA and USGS (Lee and Reusser, 2007). Of the 420 taxa, there were 170 native species, 42 nonindigenous species (NIS), 32 cryptogenic species, 1 cosmopolitan pelagic copepod, 3 unclassified species, and 172 indeterminate taxa. In terms of relative abundance, polychaetes and oligochaetes were the dominant taxa, composing over 40% and 20% of the individuals, respectively (Figure 3.3.2). The only other taxa to comprise more than 5% of the individuals were the amphipods and bivalves (Table 3.3.1).

The oligochaetes were not identified to species, but are a reasonably diverse taxon with almost 200 species reported from marine, estuarine, and tidal fresh habitats in the Northeast Pacific (Lee and Reusser, 2007). Oligochaetes are a numerically dominant taxa in a number of Pacific Coast assemblages, including *Spartina* beds in San Francisco (Neira et al., 2005), "fresh-brackish sandy" and "estuarine margin" subtidal benthic assemblages in San Francisco (Lee et al., 2003), and *Zostera, Upogebia,* and *Spartina* habitats in Willapa Bay (Ferraro and Cole, 2007). In the present study, oligochaetes were abundant along the entire coast and constituted the most abundant or second most abundant taxon in California, San Francisco, Oregon, and Washington (Table 3.3.1). The highest oligochaete densities tended to be associated with the presence of macroalgae, *Zostera marina* or *Z. japonica* beds, or marsh habitat including *Spartina* though moderately high densities also occurred in unvegetated flats. Given the number of species on the West Coast, it is likely that species composition varied among the habitat types and/or geographically. Because certain families of oligochaetes, in particular tubificids, are associated with polluted conditions (Engle et al., 1994; Llanso et al., 2002) and because they constitute a major proportion of the total individuals in many intertidal assemblages (Figure 3.3.2) we recommend that future studies identify oligochaetes at least to the family level.

The high abundance of polychaetes in these assemblages is fairly typical of other soft-bottom assemblages (e.g., Nelson et al., 2004). Less expected was that the single most abundant polychaete in the West was the nonindigenous *Manayunkia aestuarina*, a sabellid introduced from the Northeast Atlantic. *Manayunkia aestuarina* was particularly dense in Oregon, much less so in Washington, and not recorded from California (Table 3.3.1) though a congener (*Manayunkia speciosa*) is abundant in lower salinity regions of the San Francisco Bay (Cohen and Carlton, 1995; Lee et al., 2003). In Willapa Bay, *M. aestuarina* has been reported as a numerical dominant primarily limited to *Spartina alterniflora* beds (Ferraro and Cole, 2007). In the present probabilistic survey, the greatest abundance of *M. aestuarina* (148,178/m^2) occurred in an unvegetated sand flat in Coos Bay, Oregon though high densities were also found in *Spartina alterniflora* in Washington and in *Carex lyngbyei* , a common shoreline sedge, in Oregon. Other abundant polychaetes (average $\geq$ 20 individuals per 0.09 m^2 sample) included two capitellids (*Capitella capitata, Mediomastus californiensis),* several spionids (*Streblospio benedicti, Pygospio elegans, Pseudopolydora paucibranchiata, Pseudopolydora kempi*, and *Polydora cornuta*), and a cirratulid (*Tharyx parvus*). Of these, four of the spionids (*S. benedicti, P. paucibranchiata, P. kempi*, and *P. cornuta*) are nonindigenous and *Capitella capitata* and *Pygospio elegans* are cryptogenic. All of these species are frequently found in subtidal and intertidal assemblages in the

Northeast Pacific (e.g., Nelson et al., 2004; Ferraro and Cole, 2007, Lee and Reusser, 2007).

The three abundant amphipods ($\geq$ 20 individuals per 0.09 m^2 sample) were *Grandidierella japonica*, *Monocorophium insidiosum,* and *Americorophium salmonis,* the first two of which are nonindigenous species. Both nonindigenous amphipods were widely distributed, ranging from Southern California up into Puget Sound. In comparison, the native *A. salmonis* was not found in California, though the 1999 EMAP survey found it as far south as the San Luis Obispo Bay (Latitude = 35.17) in California. The only bivalve with a high average abundance was the nonindigenous *Gemma gemma*, an East Coast species introduced with importation of Atlantic oysters (Cohen and Carlton, 1995). *Gemma gemma* has a limited distribution in the Northeast Pacific and has only been reported from nine California estuaries (Lee and Reusser, 2007). *Gemma gemma* was only found in 6% of the samples (Table 3.3.1), and the high average West wide abundance reflects its high densities in a few locations in San Francisco which reached 141,400/m^2.

With non-native species constituting the most abundant polychaete, bivalve, and amphipod, an obvious alteration to the intertidal benthic communities on the West Coast is the proliferation of nonindigenous species. On a regional scale, one measure of the extent of invasion is that 42 nonindigenous species were collected, in addition to another 32 cryptogenic, or possible nonindigenous species. Not only was a large number of nonindigenous species collected but they were widespread. Eighty-five percent of the samples contained at least one nonindigenous species (Figure 3.3.3). While nonindigenous species were widespread, the extent of invasion appeared to vary among sites. To evaluate patterns in invasion, we propose the following metric for the relative species richness of nonindigenous species on a per sample basis:

$$\%NIS_{Spp} = NIS_{Spp}/(NIS_{Spp} \& Nat_{Spp}) *100 \quad \text{(Equation 3.3.1)}$$

where:
$\%NIS_{Spp}$ = relative species richness of nonindigenous species per sample
NIS_{Spp} = number of nonindigenous species in sample
Nat_{Spp} = number of native species in sample

Only native and nonindigenous species are included so as to limit the analysis to species with "known" classifications. Inclusion of the cryptogenic species, unclassified species, and indeterminate taxa would increase the level of uncertainty, and make interpretation more difficult. By normalizing the number of nonindigenous species to the sum of nonindigenous and native species, the index is "well behaved" and scales between 0 (no NIS) and 100 (all NIS and no natives), though the metric is undefined if there are no nonindigenous or native species. Because the index is based on relative species richness rather than absolute numbers of nonindigenous species, the differences in sample size will not substantially affect the value of the index assuming that the relationship between sample area and number of species collected is similar for native and nonindigenous species. Over the small areas of the samples, this assumption should generally hold, though the assumption is likely to break down at large spatial scales such as comparing point samples to total assemblages (Lee et al., 2003).

The distribution of the extent of invasion based on the relative species richness of nonindigenous species for all 217 benthic samples is shown in Figure 3.3.3. Two thresholds seem intuitive in interpreting this metric. The first is simply that the site is "uninvaded" if there are no nonindigenous species. Across the West, nonindigenous species are absent in 15% of the samples. The second proposed threshold is samples in which nonindigenous species constitute $\geq$50% of the combined native and nonindigenous species. Since nonindigenous species constitute at least half of the classified taxa, these sites can be considered to constitute a non-native assemblage and are classified as "highly invaded". Approximately 42% of the samples are classified as highly invaded based on this threshold.

There appear to be substantial differences in the extent of invasion both geographically and by habitat type (Figure 3.3.4). To better highlight these differences, this analysis separates the San Francisco high marsh samples from the rest of the San Francisco habitats and Puget Sound from the rest of the Washington samples even though they were not originally identified as separate reporting units. To test for significance among locations, a Kruskal-Wallis one-way Analysis of Variance on ranks was performed on the values of $\%NIS_{Spp}$ from California without San Francisco, San Francisco without high marsh, San Francisco high marsh, Oregon, coastal Washington, and Puget Sound. Based on this nonparametric test, there is a significant difference in the median values of $\%NIS_{Spp}$ among these six geographical areas or habitat types ($p < 0.05$). San Francisco habitats other than the high marsh were the most invaded with an average of almost 50% of the classified species per sample consisting of nonindigenous species. The high marsh in San Francisco was less invaded, but this pattern may at least partially reflect that these sites had relatively high proportions of oligochaetes and insects that were not identified to species. The other apparent pattern is that the intertidal benthos in Puget Sound is less invaded. On average, Puget Sound samples contained about 26% nonindigenous species compared to 40% to 44% for coastal Oregon and Washington.

The extent of invasion can also be measured by the relative abundance of nonindigenous species. Using the same approach as with non-native species richness, the relative abundance of nonindigenous species is calculated as a percentage of the combined abundance of natives and nonindigenous species as:

$$\%NIS_{Abun} = NIS_{Abun}/(NIS_{Abun} \, \& \, Nat_{Abun}) *100 \qquad \text{(Equation 3.3.2)}$$

where:
$\%NIS_{Abun}$ = relative abundance of nonindigenous species per sample
NIS_{Abun} = abundance of nonindigenous species in sample normalized to 0.09 m^2
Nat_{Abun} = abundance of native species in sample normalized to 0.09 m^2

As with the metric based on relative species richness on nonindigenous species, 15% of the samples contained no nonindigenous species (Figure 3.3.5). Another 46% of the sites were "highly invaded" as defined by nonindigenous species constituting $\geq$50% of the individuals. The pattern of the relative abundance of non-native species (Figure 3.3.5) differs from that based on the relative species richness of invaders (Figure 3.3.3) by having peaks at both "low to moderate" levels of invasion (>0 and <25%) and another at "very high" levels of invasion ($\geq$75%). This bimodal pattern reflects, at least in part, apparent geographical and habitat differences in the extent of invasion (Figure 3.3.6). The significance of these geographical/habitat differences was tested using a Kruskal-Wallis one-way Analysis of Variance on ranks, which found a highly significant difference ($p < 0.01$) in the median values of $\%NIS_{Abun}$ among the six geographical areas or habitat types. The benthic assemblages in San Francisco exclusive of the high marsh were the most invaded, with an average of 61% of the individuals per sample consisting of nonindigenous species. The coastal estuaries of Oregon and Washington were also highly invaded with about 50% of the individuals per sample consisting of nonindigenous species. In comparison, nonindigenous species constituted less than 25% of the individuals in samples from Puget Sound, and less than 40% in samples from California other than San Francisco and in the San Francisco high marsh. Again the lower extent of invasion in the San Francisco high marsh may partially reflect that the oligochaetes and insects were not identified to species.

Based both on relative species richness and relative abundance, it is apparent that the community composition and structure of the intertidal assemblages of California, Oregon, and Washington have been substantially altered by the invasion of nonindigenous species. These alterations are likely to continue as existing nonindigenous species increase their range and/or abundance. For example, the nonindigenous amphipod *Grandidierella japonica* has expanded its range from its first sighting in San Francisco in 1966 (Chapman and Dorman, 1975) to 46 Northeast Pacific estuaries ranging from Tijuana Estuary to Puget Sound by 2002 (Lee and Reusser, 2007). After a major flood event in 1996, *G. japonica* became one of the numerically dominant amphipods in the Yaquina Estuary, Oregon (Lee et al., submitted) and it has become the most abundant intertidal amphipod on the West Coast (Table 3.3.1). Intertidal assemblages will also continue to change in response to new invasions. As recently as July, 2007, a "major new snail invasion" ("*Assiminea*" sp) was reported for Coos Bay, Oregon (J. Carlton, August 31, 2007 email). The present probabilistic survey provides a baseline of the structure of benthic assemblages as of 2002, and it will be important to conduct similar regional surveys in the future to assess the extent and nature of changes due to invasion as well as other regional drivers such as climate change, habitat alteration, and increased nutrient loading.

Table 3.3.1. Average abundance, percent frequency of occurrence, and maximum abundance of the fifty most abundant species in the West Coast Intertidal Assessment. All abundances have been normalized to number per 0.09 m^2. "West" = California other than the 12 high marsh samples in San Francisco Bay, Oregon, and Washington, "CA w/o San Francisco" = California other than San Francisco Bay, "San Francisco" = San Francisco Bay including 12 high marsh samples, OR = Oregon, WA = Washington. Classifications: Native = native species; NIS = nonindigenous species; Crypto = cryptogenic species, Indeter = indeterminate taxa. Taxa Code: AM = amphipods; AN = anthopleurans; B = bivalves; COP = copepods; CU = cumaceans; G = gastropods; IN = insects; ISO = isopods; NE = nemerteans; O = oligochaetes; OS = ostracods; P = polychaetes; TA = tanaids.

Species/Taxon	Taxa Code	Classification	West Average N = 205	West % Freq.	West Max.	CA wo/San Francisco Average N = 60	San Francisco Average N = 30	OR Average N = 66	WA Average N = 61
Oligochaeta	O	Indeter	343.3	80	11064	249.2	313.1	674.0	125.3
Manayunkia aestuarina	P	NIS	235.9	17	13336	0.0	0.0	717.4	16.7
Gemma gemma	B	NIS	112.4	6	12725	8.5	751.3	0.0	0.0
Grandidierella japonica	AM	NIS	89.7	50	5936	7.8	58.9	214.1	33.2
Capitella capitata	P	Crypto	89.0	48	6410	14.0	0.1	234.5	31.5
Streblospio benedicti	P	NIS	74.2	40	2520	27.2	7.6	157.1	49.1
Mediomastus californiensis	P	Native	71.8	27	3878	0.0	0.0	148.9	80.2
Leptochelia dubia	TA	Crypto	70.4	30	5894	86.2	0.0	123.4	18.3
Pygospio elegans	P	Crypto	49.7	32	1788	4.3	0.0	104.6	49.6
Americorophium salmonis	AM	Native	46.2	26	1440	0.0	0.0	134.5	9.7
Monocorophium insidiosum	AM	NIS	32.0	37	1044	20.1	37.2	44.1	23.5
Pseudopolydora paucibranchiata	P	NIS	25.9	16	940	0.0	0.0	9.5	76.8
Pseudopolydora kempi	P	NIS	24.5	48	456	7.2	2.3	35.0	36.5
Tharyx parvus	P	Native	22.1	22	1125	3.6	0.0	33.8	34.2
Macoma balthica	B	Native	21.8	50	785	0.0	13.7	38.1	25.3
Polydora cornuta	P	NIS	21.7	42	656	17.6	7.4	16.0	34.7
Hobsonia florida	P	NIS	19.8	10	1024	0.0	0.0	53.7	8.5

Paracorophium sp.	AM	Indeter	17.9	5	2496	61.1	0.0	0.0	0.0
Halcampidae	AN	Indeter	16.9	8	1758	0.0	0.0	51.7	0.8
Sinelobus stanfordi	TA	NIS	16.6	14	1304	23.5	0.0	25.9	4.6
Heteromastus filiformis	P	NIS	15.0	22	396	0.0	0.0	33.3	14.2
Assiminea californica	G	Native	14.4	7	1168	44.3	10.1	0.0	0.0
Americorophium stimpsoni	AM	Native	13.6	1	2780	46.5	0.0	0.0	0.0
Nippoleucon hinumensis	CU	NIS	12.6	21	1344	0.4	0.8	35.9	2.6
Harpacticoida	COP	Indeter	11.9	24	477	0.0	0.0	31.5	5.8
Exogone lourei	P	Crypto	11.5	11	864	35.1	0.2	2.8	0.8
Monocorophium acherusicum	AM	NIS	11.3	21	516	0.2	2.8	13.8	21.5
Americorophium spinicorne	AM	Native	9.7	11	619	0.4	0.0	21.1	9.5
Potamocorbula amurensis	B	NIS	9.3	2	1127	0.1	63.5	0.0	0.0
Mya arenaria	B	NIS	9.2	34	174	0.0	0.3	8.7	21.4
Eteone californica	P	Crypto	8.9	46	436	3.0	0.1	19.7	5.5
Ampithoe spp.	AM	Indeter	8.8	14	364	0.0	0.0	1.1	28.3
Chironomidae	IN	Indeter	8.8	20	281	22.1	0.0	4.5	2.9
Novafabricia brunnea	P	Native	8.6	1	1744	0.3	0.0	26.4	0.0
Cryptomya californica	B	Native	8.0	23	318	0.1	0.0	18.9	6.5
Heteromastus filobranchus	P	Native	7.7	13	554	20.9	10.8	0.0	0.0
Allorchestes angusta	AM	Native	7.3	13	364	18.4	0.0	4.7	1.2
Dipolydora socialis	P	Crypto	7.1	5	596	24.1	0.0	0.0	0.1
Chone duneri	P	Crypto	7.0	1	1428	0.0	0.0	0.0	23.4
Ceratopogonidae	IN	Indeter	6.5	6	965	0.0	0.0	20.1	0.0
Gnorimosphaeroma oregonense	ISO	Native	5.9	4	1058	19.8	0.0	0.0	0.3
Macoma nasuta	B	Native	5.8	30	192	0.2	0.0	13.9	4.4
Eobrolgus chumashi	AM	Native	5.7	5	616	0.0	0.0	17.6	0.0
Ampithoe valida	AM	NIS	5.6	20	335	0.5	0.3	14.4	2.6
Myosotella myosotis	G	NIS	5.3	3	672	6.5	26.4	0.0	0.0

Podocopida	OS	Indeter	5.3	9	570	0.3	0.5	16.0	0.0
Corophiidae	AM	Indeter	5.1	22	324	0.5	1.3	14.1	1.4
Gnorimosphaeroma insulare	ISO	Native	5.0	4	548	0.0	0.0	15.2	0.3
Glycinde polygnatha	P	Native	4.9	43	61	2.0	2.5	3.8	9.2
Nemertea	NE	Indeter	4.9	11	577	16.7	0.0	0.0	0.0

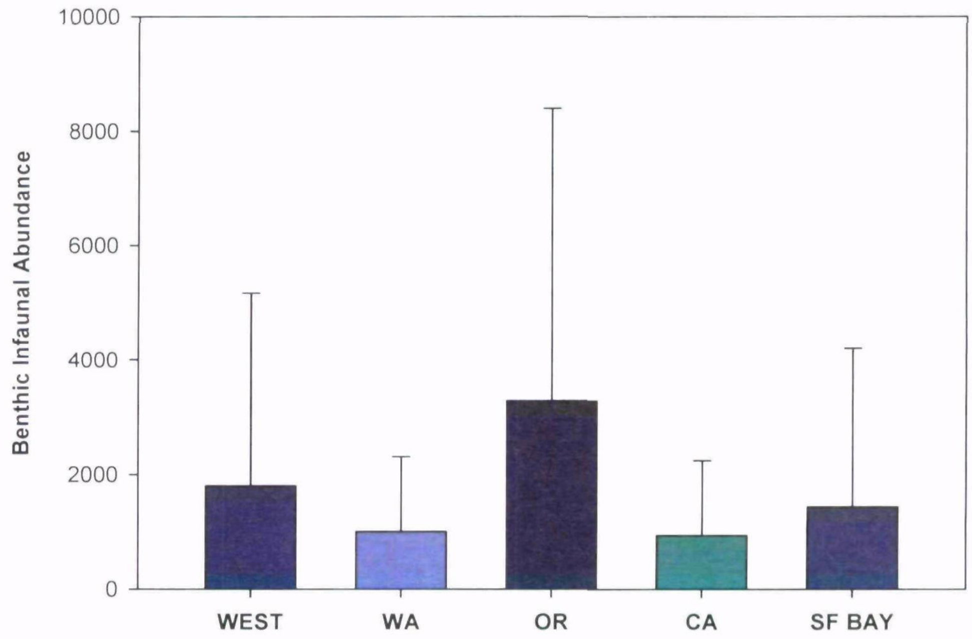

Figure 3.3.1. Average total benthic abundance for intertidal samples obtained in 2002 for the West Coast region, individual states, and San Francisco Bay (mean ± 1 sd).

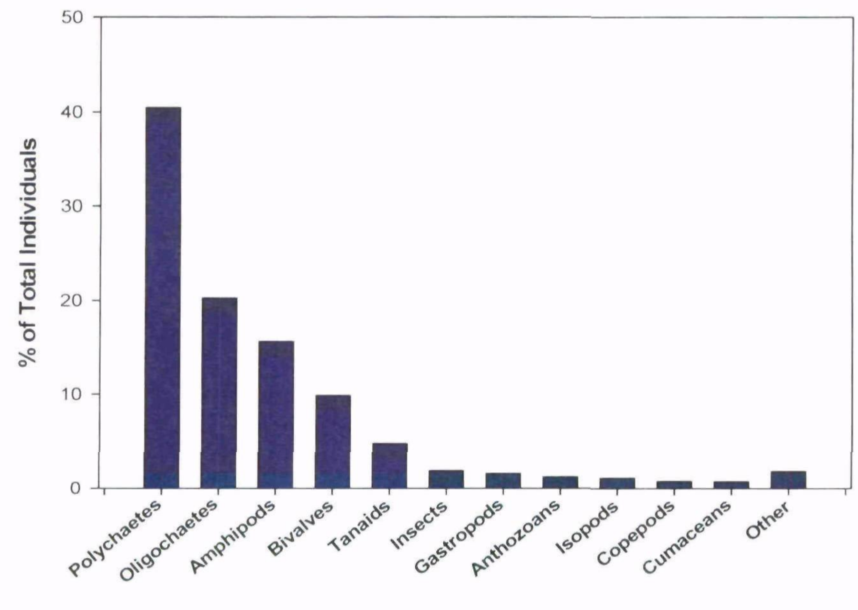

Figure 3.3.2. Relative abundance of the major taxa for intertidal samples obtained in 2002 for the West Coast region.

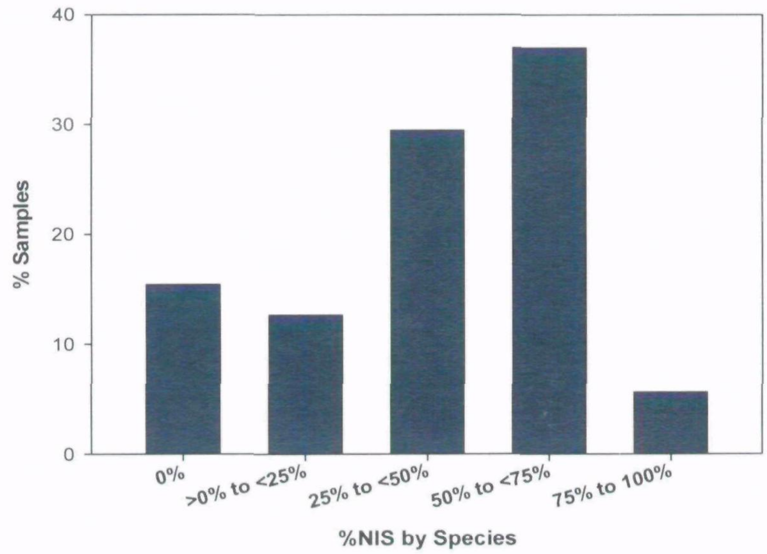

Figure 3.3.3. Percent of nonindigenous species relative to the number of nonindigenous and native species per sample (%NIS_{Spp}). Analysis based on all sites including the high marsh in San Francisco with the exception of three samples with no nonindigenous or native species (N = 214).

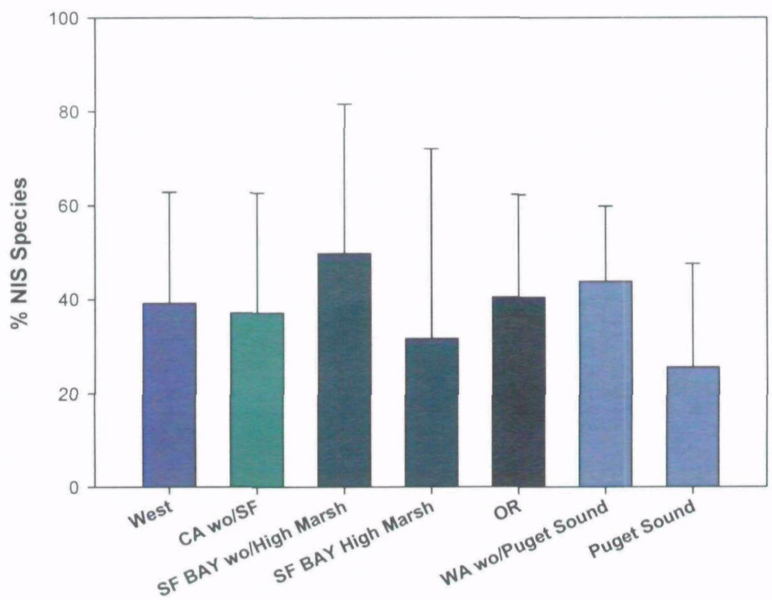

Figure 3.3.4. Average percent of nonindigenous species relative to the number of nonindigenous and native species per sample (%NIS_{Spp}) by location for intertidal samples obtained in 2002.

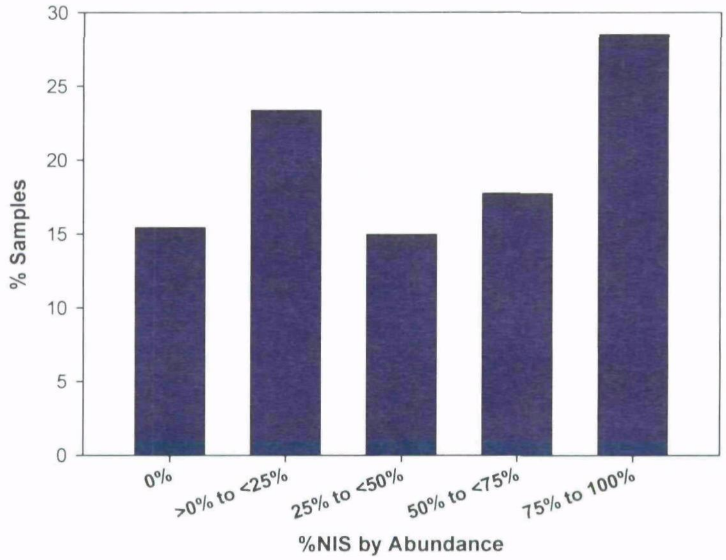

Figure 3.3.5. Relative abundance of nonindigenous species relative to the number of nonindigenous and native species per sample (%NIS_{Abun}). Analysis based on all sites including the high marsh in San Francisco with the exception of three samples with no nonindigenous or native species (N = 214).

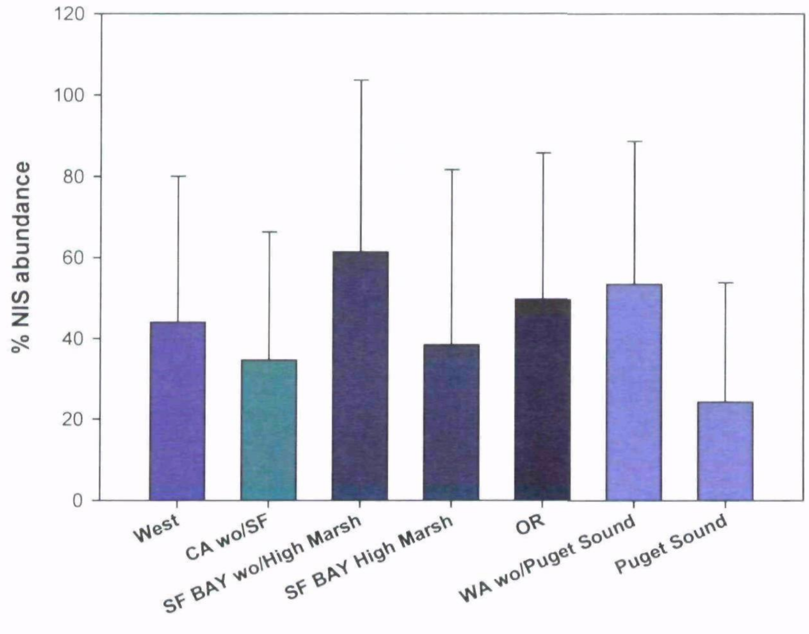

Figure 3.3.6. Average percent of nonindigenous species relative to the abundance of nonindigenous and native species per sample (%NIS_{Abun}) by location for intertidal samples obtained in 2002.

3.3.2 Plant Community

Vegetation data were collected from both a quadrat and along a transect at each site, and data from these two approaches are presented separately. Vegetation percent cover, maximum plant height (emergent macrophyte) or leaf length (seagrass), and biomass of each taxon were recorded from each vegetation quadrat. Only vegetation percent cover was estimated along each transect.

Quadrat Species Assemblages and Percent Cover

Vegetation was present in the quadrats at 150 of the 217 sites sampled. The types of vegetation recorded within the quadrats included 28 emergent macrophytes, 2 seagrasses, and macroalgal taxa (Appendix Table 4). Three emergent macrophytes, *Cotula coronopifolia, Lepidium latifolium,* and *Spartina alterniflora*, are nonindigenous species. Two species of seagrass, *Zostera marina* and *Z. japonica* (nonindigenous) were recorded. These seagrass species were found at 21 and 24 sites, respectively. Three groups of macroalgae, green algae, brown algae and red algae, were identified in the quadrats. Green algae (e.g., *Ulva, Cladophora, Enteromorpha*) occurred at 84 sites. Red algae were observed at one site and brown algae at six sites. As macroalgae were only identified to major taxonomic group, it could not be determined if any nonindigenous algal species were present.

Throughout the West, the vegetation quadrats were dominated by bare area (Figure 3.3.7). Relative cover by bare area ranged between 2 and 100% throughout the West (Appendix Table 5). Mean relative cover of emergent macrophytes (26%) was higher than that of seagrass (9%) or algae (16%) throughout the West (Figure 3.3.7). The relative cover of emergent macrophytes ranged between 1 and 100% in the West (including all San Francisco sites) (Appendix Table 5). Most emergent macrophyte taxa occurred at only a few sites (Appendix Table 4). Eighty-two percent of taxa occurred at three or fewer sites. The most frequently occurring emergent macrophyte taxa were *Jaumea carnosa* and *Salicornia virginica*. The paucity of emergent vegetation at most sites may be attributed to the fact that most of the sites in the sample frame were classified as unvegetated tide flats (Figure 3.1.2).

The relative cover by major plant groups (emergent macrophytes, seagrass, macroalgae) and bare area displayed geographic patterns (Figure 3.3.7). Bare area was highest for sites in Oregon and Washington, while cover by emergent macrophytes was highest in California and San Francisco Bay. Mean bare area was 62% in Oregon and 63% in Washington. Mean bare area was 42% in California and 42% for sites in San Francisco Bay. Mean relative cover of emergent macrophytes was 3% in Washington and 7% in Oregon and 38% in California and 62% in San Francisco Bay. Cover of emergent macrophytes was higher than that of algae or seagrass in California and San Francisco Bay sites. Relative cover of seagrass was higher than that of emergent macrophytes in Oregon and Washington sites. Mean relative cover of seagrass was less than that of emergent macrophytes or algae in California sites. Mean relative cover of algae (all types) was highest for Oregon sites (Figure 3.3.7).

Geographic patterns in cover of major plant groups may be attributed to differences in habitat types among states. Over 80% of Washington sites were classified as tidal flat and no sites were classified as marsh (Figure 3.1.2). In contrast, approximately 40% of sites in California and San Francisco Bay were classified as marsh. Oregon sites were a mixture of habitat sites, with more sites in the submerged aquatic vegetation (SAV) habitat class than other states.

Taxa occurrence and mean relative cover of common emergent taxa also displayed geographic patterns (Appendix Table 5). The greatest number of emergent macrophyte species were observed in California (n = 11) and San Francisco Bay (n = 17). Six emergent macrophyte species were observed in Oregon. The quadrats of only three sites in Washington had emergent macrophyte cover and only one species, *S. alterniflora*, was present in these quadrats. Because most taxa only occurred at a few sites, average percent cover of taxa was calculated as the average cover at sites where the taxa occurred and not across all sites. Mean cover of *S. virginica* was 39% in California sites and 70% in San Francisco Bay sites (Figure 3.3.8). This species occurred at one site in Oregon and was not present in Washington. Mean cover of *J. carnosa* was 43% in California sites and 30% in San Francisco Bay. This species was not present in Oregon or Washington sites. The three remaining species occurring at more than five sites, *Batis maritima, Distichlis spicata,* and *Spartina foliosa*, were only encountered in California and San Francisco Bay sites. Geographic patterns in occurrence and cover of common emergent macrophyte species may again be attributed to differences in habitat types among states. While tidal marsh macrophytes can tolerate inundation, these species can not tolerate the prolonged periods of inundation experienced on tidal flats and therefore are restricted to habitats receiving less inundation.

Seagrass species were observed in the quadrats of California, Oregon and Washington sites. *Zostera marina* was present in the vegetation quadrats of all three states (Appendix Table 5). Mean relative cover of *Z. marina* was highest for Washington sites (Figure 3.3.9). For Washington sites, mean relative cover of the invasive seagrass, *Z. japonica*, was higher than that of *Z. marina*, 44% and 27%, respectively. *Zostera japonica* did not occur in California or San Francisco Bay (Figure 3.3.10). Mean relative cover of green algae was highest in California (70%). Green algae did not occur in San Francisco Bay sites (Figure 3.3.11).

Nonindigenous species (emergent macrophytes and seagrass) were encountered in the quadrats at 29 sites throughout the study area. *Spartina alterniflora* was observed at three sites in Washington and *Z. japonica* was observed at sites in both Oregon and Washington. *Lepidium latifolium* was found at one site in San Francisco Bay. Mean relative cover of nonindigenous species was low (8%) throughout the West (Figure 3.3.12). Mean cover by nonindigenous species was highest in Washington (21%), with nonindigenous species being found at 20 sites. Sites in

Washington had both *S. alterniflora* and *Z. japonica*. No nonindigenous species were observed at California sites.

Quadrat Emergent Macrophyte Height and Seagrass Maximum Length

For most emergent species, maximum plant height/length were recorded at fewer than 5 sites throughout the study area, making this a problematic variable to evaluate as a potential indicator (Appendix Table 6). Maximum height of *S. virginica* was recorded at 29 sites throughout the West (not including San Francisco Bay), ranging between 6 and 76 cm. Maximum length of this species was recorded at 15 sites in San Francisco Bay. The mean value at these sites was 49 cm. Maximum blade length of seagrass was recorded at most sites when present. For the West overall, blade lengths of *Z. marina* (range 14 -122 cm) were longer than those of *Z. japonica* (range 7 – 38 cm).

Quadrat Biomass

Total biomass in the vegetation quadrat throughout the study ranged between 0 and 800 g/m^2 dry weight. Total biomass was greatest for sites in San Francisco Bay (mean = 350 g/m^2) and California (mean = 193 g/m^2; Figure 3.3.14). This can be attributed to the fact that these sites had greater cover by vegetation of all types while Oregon and Washington sites had more bare cover (Figure 3.3.7). For the West overall (not including San Francisco Bay), algae contributed the most to quadrat biomass (mean = 44%; Figure 3.3.14), followed by emergent macrophytes (mean = 38%) and seagrass (18%). This finding can be attributed to the fact that for many sites in Oregon and Washington, only macroalgae were present in the vegetation quadrats. In contrast, emergent macrophytes were the major contributor to quadrat biomass in San Francisco Bay and California sites. Emergent macrophytes contributed 99% on average to quadrat biomass in San Francisco Bay sites and 67% to quadrat biomass in California sites. The geographic patterns in relative contribution of different plant types to total quadrat biomass may again be attributed to differences in habitat types, and subsequently vegetation groups, among states. Tidal wetland habitat in California and San Francisco Bay is dominated by marsh habitat and emergent macrophyte vegetation. Oregon sites were a mixture of habitat types and thus different vegetation types contributed to quadrat biomass at different sites. Washington sites are classified primarily as tidal flat. Subsequently, seagrass and macroalgae are the major contributors to quadrat biomass.

Mean biomass of emergent macrophytes varied among the states, attributable to geographic differences in macrophyte taxa encountered. For example, the only emergent macrophyte observed in the quadrats of Washington sites was *S. alterniflora*, a relatively large, perennial grass. In contrast, sites in California, San Francisco Bay and Oregon had a mix of macrophyte taxa of different growth forms. Most emergent macrophyte taxa were only found at a few sites (and weights recorded at even fewer), making it difficult to evaluate geographic trends in biomass. Biomass of most emergent macrophyte taxa was greater than that of seagrass species or macroalgal taxa (Appendix Table 7). Mean biomass of *Z. marina* and *Z. japonica* in the West were similar; 14 and 13 g/m^2, respectively. Biomass of these species was similar in Oregon and Washington. Mean biomass of green algae was similar in California (mean = 26 g/m^2) and Oregon (mean = 30 g/m^2) and somewhat lower in Washington (mean = 9 g/m^2). As algae were only classified into large taxonomic groups, it is difficult to explain geographic differences in biomass.

Transect Species Assemblages and Percent Cover

Vegetation was present along the transects at 171 sites of the 217 sites sampled. Vegetation recorded on transects included 31 emergent macrophytes, including three nonindigenous species (*C. coronopifolia, L. latifolium,* and *S. alterniflora*), two seagrasses (*Z. marina* and *Z. japonica*), and algal taxa (Appendix Table 4). Seagrasses were found at 25 and 28 sites, respectively. Three groups of macroalgae, green algae, brown algae and red algae, were identified in the transects. Green algae (e.g., *Ulva, Cladophora, Enteromorpha*) were observed at 84 sites. Red algae were observed in one transect and brown algae in four transects.

Throughout the West, the vegetation quadrats were dominated by bare area (Figure 3.3.15). Relative bare area ranged between 4 and 100% throughout the West (Figure 3.3.15). Mean relative cover of emergent macrophytes (21%) and macroalgae (20%) were similar and higher than that of seagrass (9%) throughout the West (Figure 3.3.15). The relative cover of emergent macrophytes ranged between 1 and 100% in the West (including all San Francisco sites) (Appendix Table 8). Most emergent macrophyte taxa occurred in the transects of only a few sites (Appendix Table 4), with 84% of taxa occurring at three or fewer sites. The most frequently occurring emergent macrophyte taxa were *S. virginica, J. carnosa, D. spicata* and *Spartina foliosa.* Similar to the vegetation quadrats, the low emergent vegetation cover at most sites may be attributed to the fact that most of the sites in the sample frame were classified as unvegetated tide flats (Figure 3.1.2).

Percentage of bare area in the transects was higher for sites in Oregon and Washington than those in California (Figure 3.3.15). Mean percentage of bare area was 59% in Oregon and 60% in Washington. Mean bare area was 38% in California and 36% for sites in San Francisco Bay. The relative cover by major plant groups (emergent macrophytes, seagrass, algae) displayed geographic patterns. Relative abundance of emergent macrophytes was lower in Washington (mean = 3%) and Oregon (mean = 9%) than for sites in California (mean = 43%) and San Francisco Bay (mean = 78%). Relative cover of seagrass was higher than that of emergent macrophytes at Washington sites (Figure 3.3.15). Cover of emergent macrophytes was higher than that of algae or seagrass in California and San Francisco Bay sites. Mean relative cover of seagrass was 0% in California and San Francisco Bay sites. Mean relative cover of algae (all types) was higher than that of emergent macrophytes and seagrass in Oregon sites (Figure 3.3.15). Mean relative cover of algae (all types) was highest for Oregon sites. Cover of emergent macrophytes was higher than that of algae or seagrass in California and San Francisco Bay sites. Similar to vegetation quadrats, geographic patterns in transect vegetation cover of major plant groups can be attributed to differences in habitat types among states. Marsh habitat was more common in California and San Francisco Bay, while tidal flat habitat was more abundant in Washington and Oregon.

Taxa occurrence and mean relative cover of common vegetation taxa in the transects also displayed geographic patterns. The largest numbers of emergent macrophyte species were observed in the transects of sites in California (n = 11) and San Francisco Bay (n = 18), although most of these species occurred at fewer than 3 sites. Nine emergent macrophyte species were observed in the transects of Oregon sites. The transects of only four sites in Washington had emergent macrophyte cover and only two species, *Juncus gerardii* and *S. alterniflora*, were present in Washington. Because most taxa only occurred at a few sites, average percent cover of taxa was calculated as the average cover at sites where the taxa occurred and not across all sites. Mean cover of *S. virginica* was 48% in California sites and 76% in San Francisco Bay sites (Figure 3.3.16). This species occurred at one site in Oregon and was not found in Washington. Mean cover of *J. carnosa* was 39% in California sites. This species was present at one site in San Francisco Bay and was present in neither Oregon nor Washington sites. Of the three remaining species occurring at more than five sites, *B. maritima* and *S. foliosa* were only encountered in California and San Francisco Bay sites. *Distichlis spicata* was not observed in Washington. Again similar to vegetation quadrats, geographic patterns in occurrence of common emergent macrophyte taxa may be attributed to differences in habitat types among states.

Seagrass species were observed in the quadrats of California, Oregon and Washington sites. *Zostera marina* was present in the vegetation transects of all three states. Mean relative cover of *Z. marina* was similar for Washington and Oregon sites (Figure 3.3.17). For Washington sites, mean relative cover of the invasive seagrass, *Z. japonica*, was higher than that of *Z. marina,* 52% and 28%, respectively. *Zostera japonica* did not occur in California or San Francisco Bay (Figure 3.3.18). Mean relative cover of green macroalgae was highest at California sites (63%; Figure 3.3.19). Green macroalgae did not occur in San Francisco Bay.

Nonindigenous emergent macrophytes and seagrass were encountered in the transects at 33 sites throughout the study area. *Spartina alterniflora* was observed at three sites in Washington and *Z. japonica* was observed at sites in both Oregon and Washington. *Lepidium latifolium* was found at one site in San Francisco Bay. Mean relative cover of nonindigenous species was low (14%) throughout the West (Figure 3.3.20). Mean cover by nonindigenous species was highest in Washington (37%), with nonindigenous species being found at 21 sites. Sites in Washington had both *S. alterniflora* and *Z. japonica*. No nonindigenous species were observed at California sites.

Summary of Vegetation Results

Overall, cover by vegetation in tidal wetlands in the West was low, with bare area dominating both the quadrats and transects at many sites. The small number of vegetation species observed at each site makes it difficult to evaluate community patterns and the low frequency of occurrence of most species makes it difficult to evaluate patterns of individual species across the study area. Observed geographic patterns in major plant groups may be attributed to differences in habitat type among the three states. The higher abundance of emergent macrophytes in California and San Francisco Bay sites may be attributed to the predominance of marsh habitat in these areas. The higher abundance of seagrass and macroalgae in Washington may be attributed to the predominance of tidal flat habitat and lack of marsh habitat in this state. Oregon tidal wetlands were a mixture of habitat types and subsequently, these sites contained a mixture of vegetation groups.

Plant cover data generated from vegetation quadrats and vegetation transects were very similar throughout the study area. Geographic trends in major plant groups and common individual species were similar for quadrat and transect data. Species richness throughout the study area was slightly higher and relative cover of bare area was slightly lower for transect data than quadrat data. These findings may be attributed to the fact that sampling area was larger for transects (5-m length) than quadrats (0.25 m^2). Vegetation sampling in tidal wetlands often employs much longer transects (for example 30-m; Bertness and Ellison 1987) running perpendicular to the shoreline to capture heterogeneity in tidal wetland vegetation in response to gradients in inundation and salinity. As transects in this study were short and were established parallel to the shoreline, they would not be expected to capture this variation in vegetation, potentially resulting in the low number of species encountered at most sites.

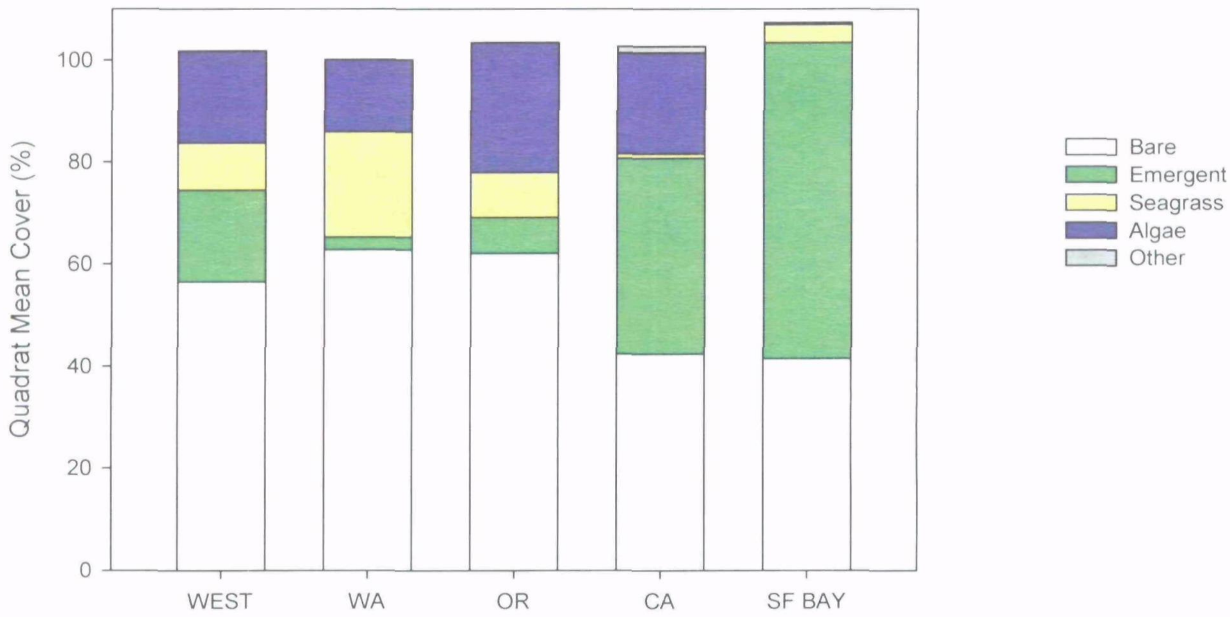

Figure 3.3.7. Mean relative abundance of vegetation groups and bare area in vegetation quadrats.

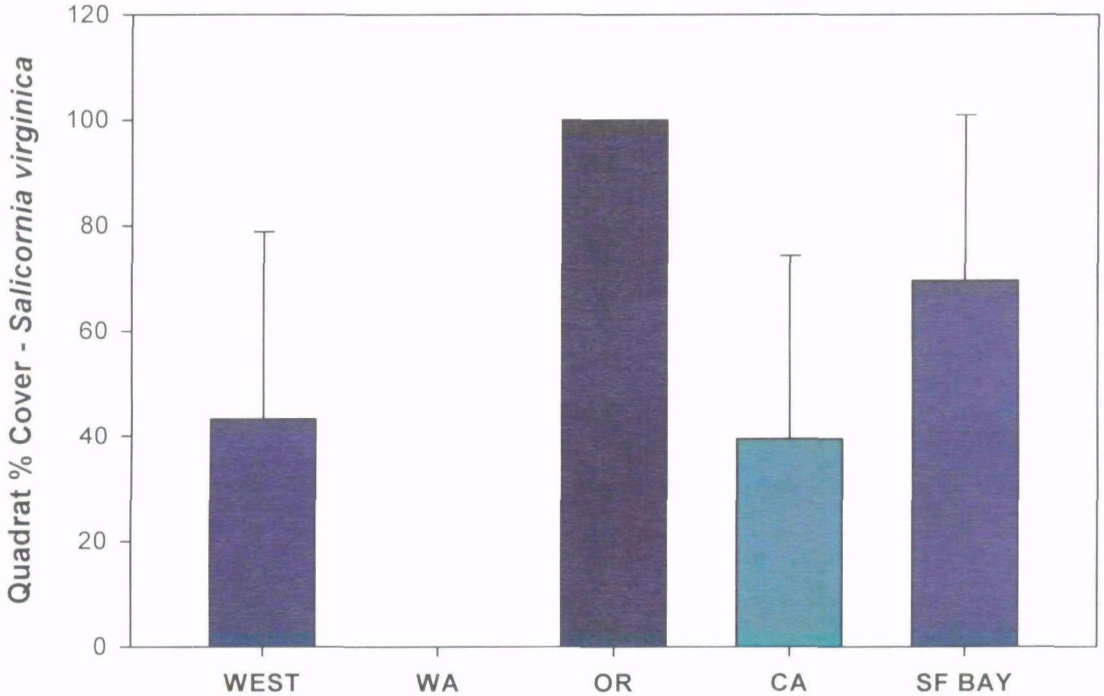

Figure 3.3.8. Relative percent cover of *Salicornia virginica* in the vegetation quadrats at sites where present (mean ± 1 sd).

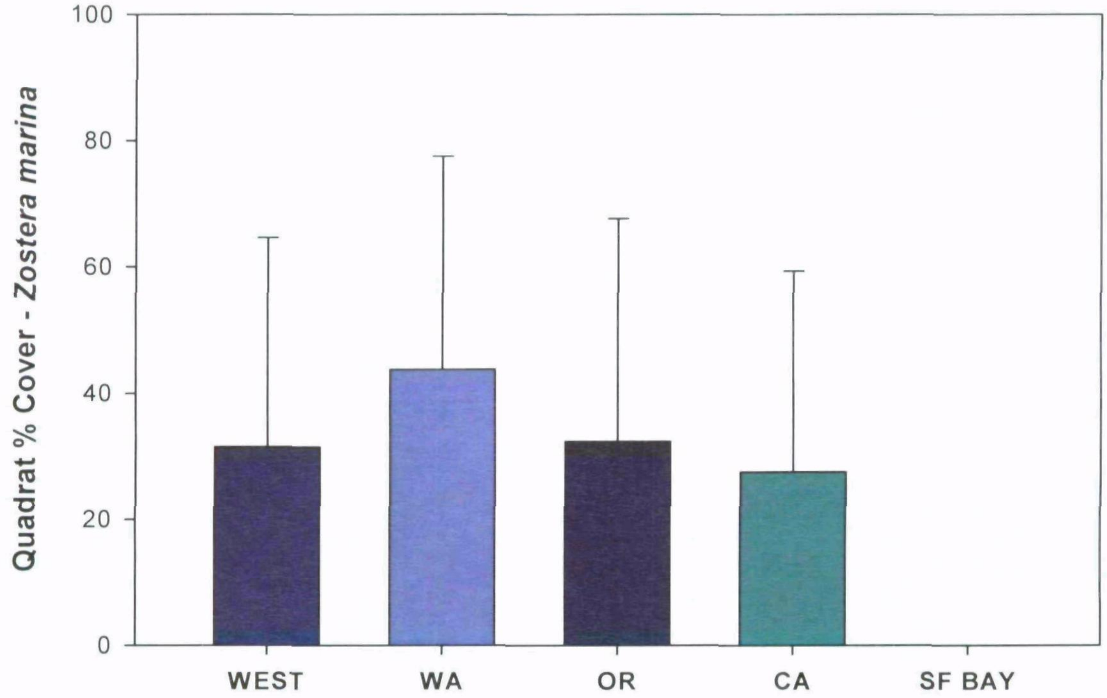

Figure 3.3.9. Relative percent cover of *Zostera marina* in the vegetation quadrats at sites where present (mean ± 1 sd).

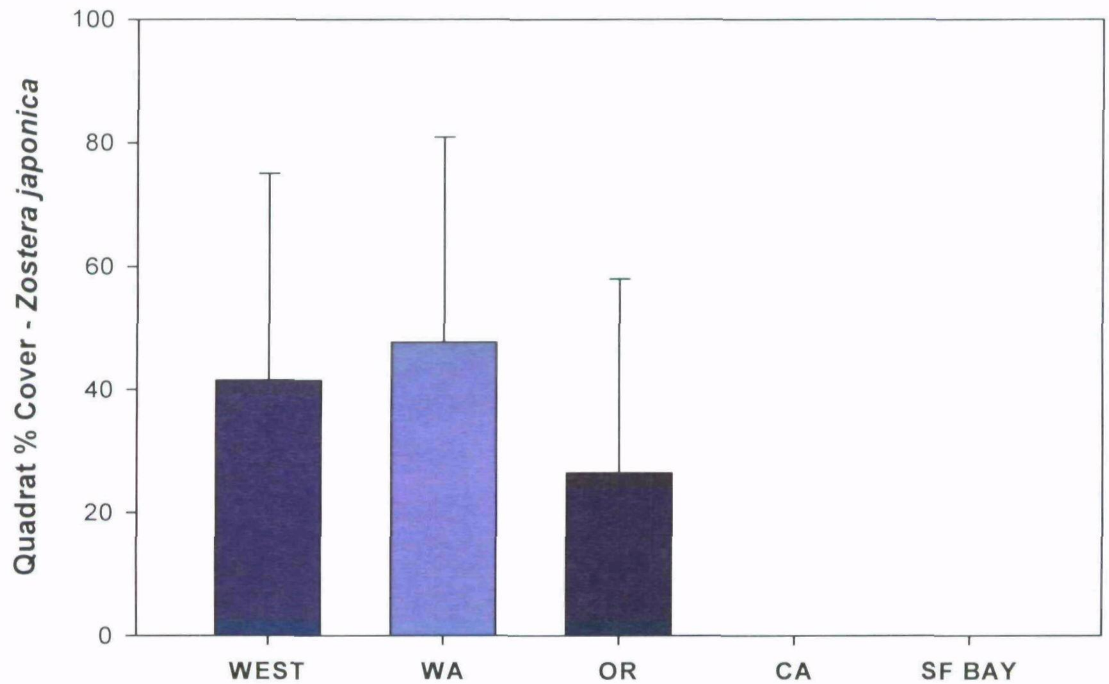

Figure 3.3.10. Relative percent cover of *Zostera japonica* in the vegetation quadrats at sites where present (mean ± 1 sd).

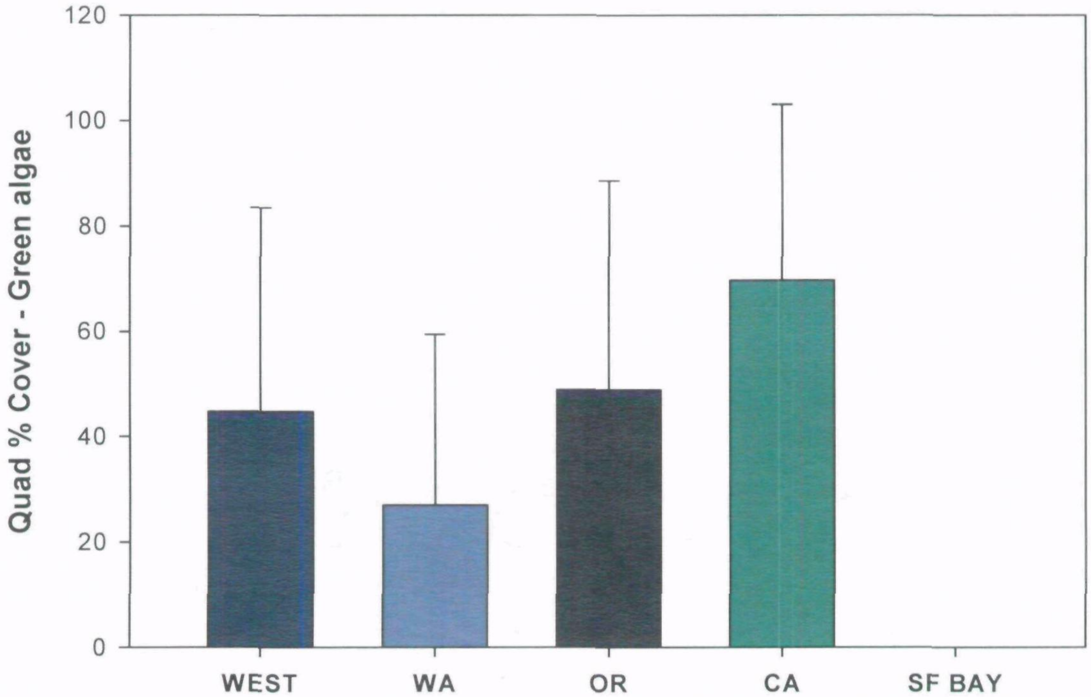

Figure 3.3.11. Relative percent cover of green algae in the vegetation quadrats at sites where present (mean ± 1 sd).

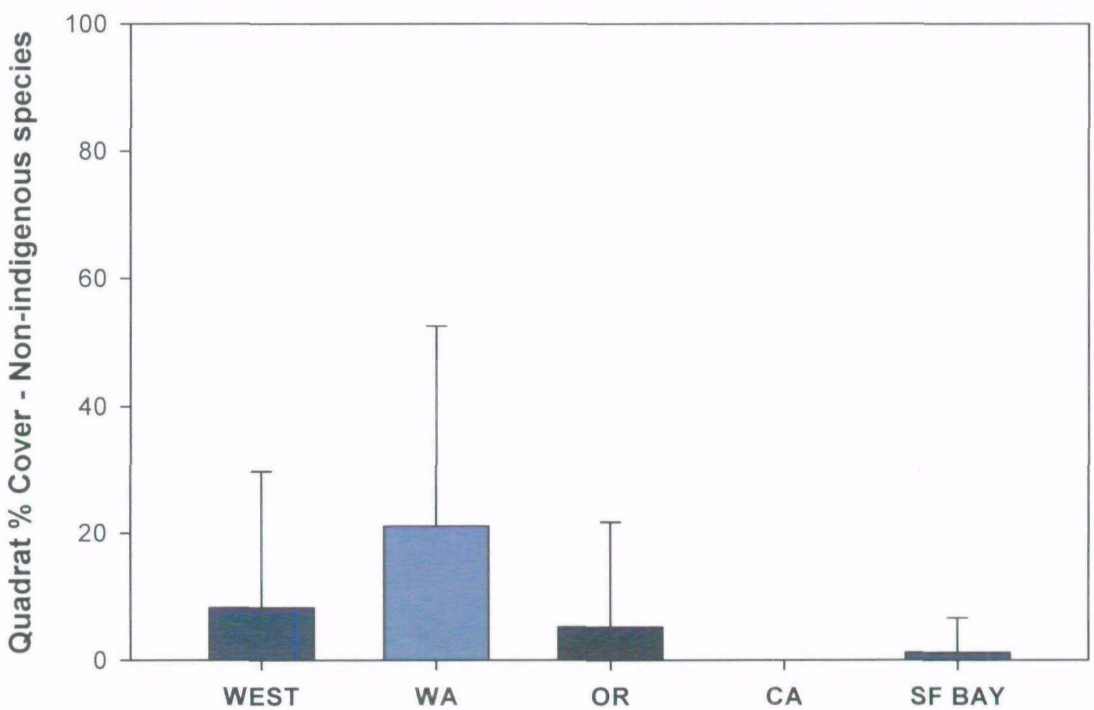

Figure 3.3.12. Relative percent cover of nonindigenous species in the vegetation quadrats at sites where plants are present (mean ± 1 sd).

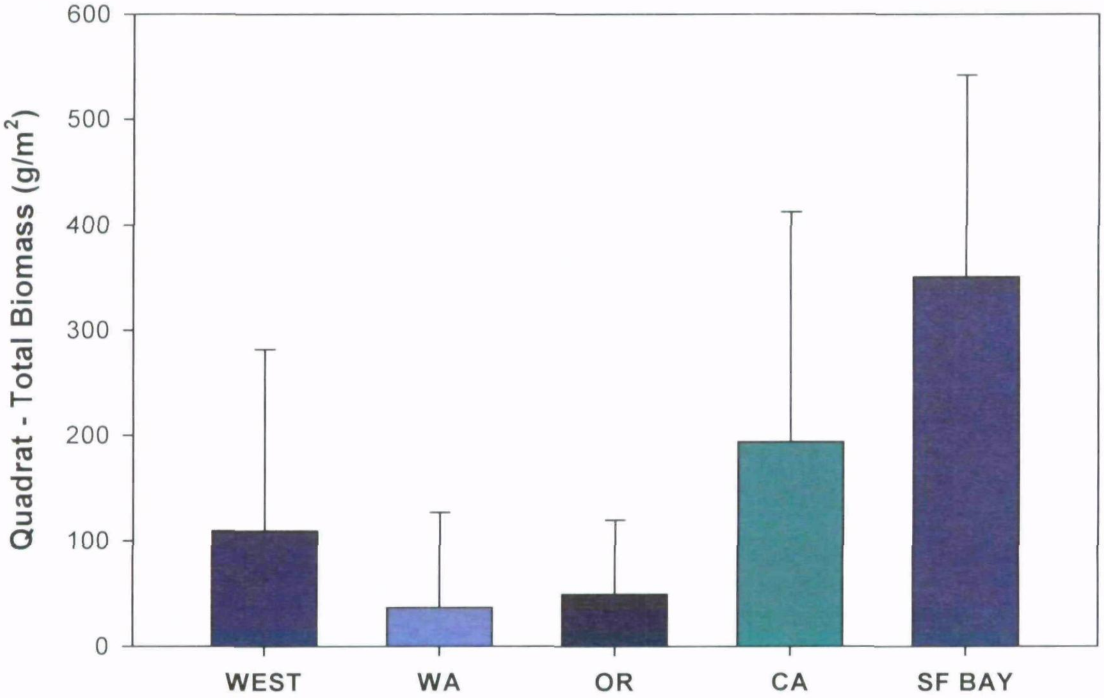

Figure 3.3.13. Total vegetation (emergent macrophytes, seagrass, algae) biomass in the vegetation quadrats (mean ± 1 sd).

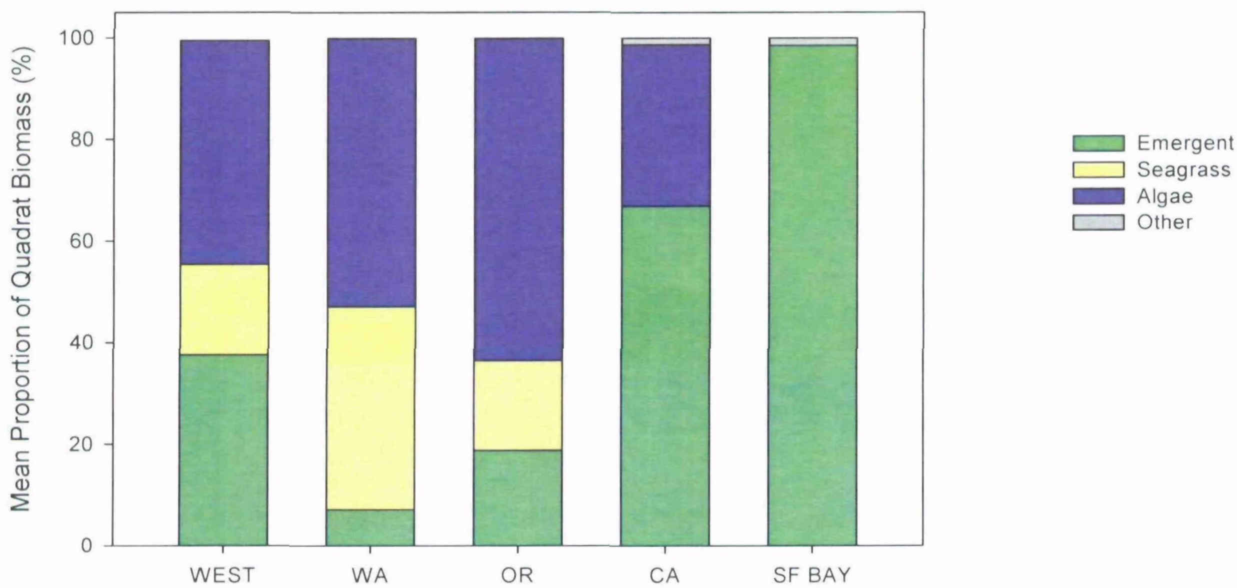

Figure 3.3.14. Mean proportion of quadrat biomass for each vegetation group.

Figure 3.3.15. Mean relative abundance of vegetation groups and bare area in vegetation transects.

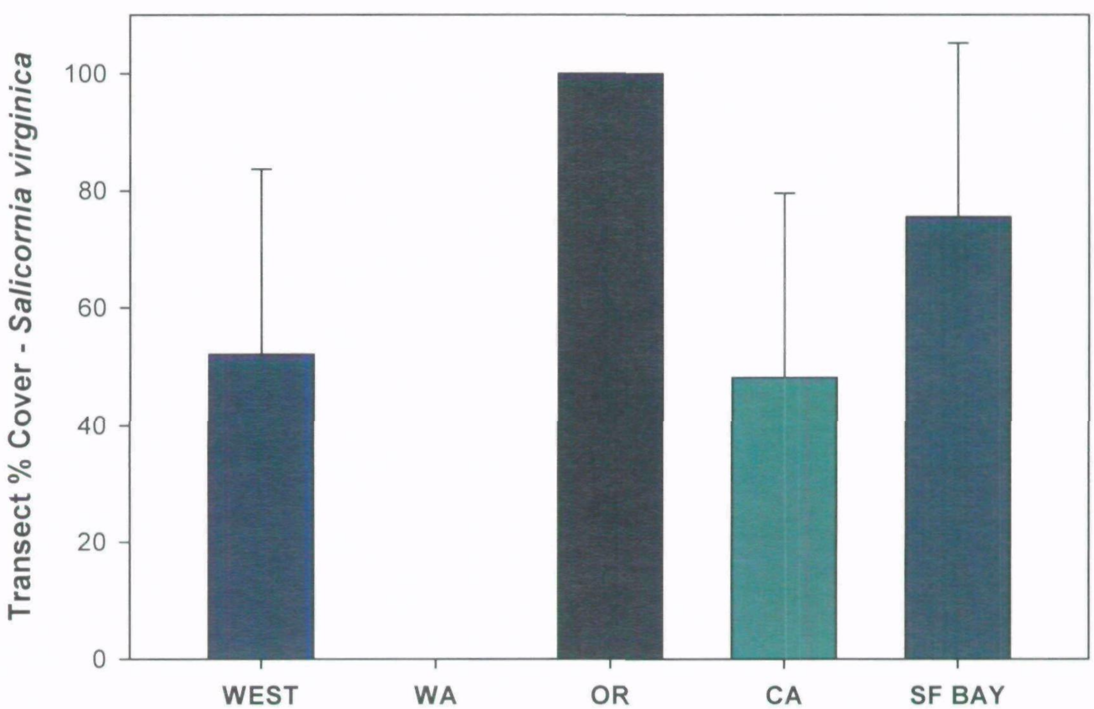

Figure 3.3.16. Relative percent cover of *Salicornia virginica* in the vegetation transects at sites where present (mean ± 1 sd).

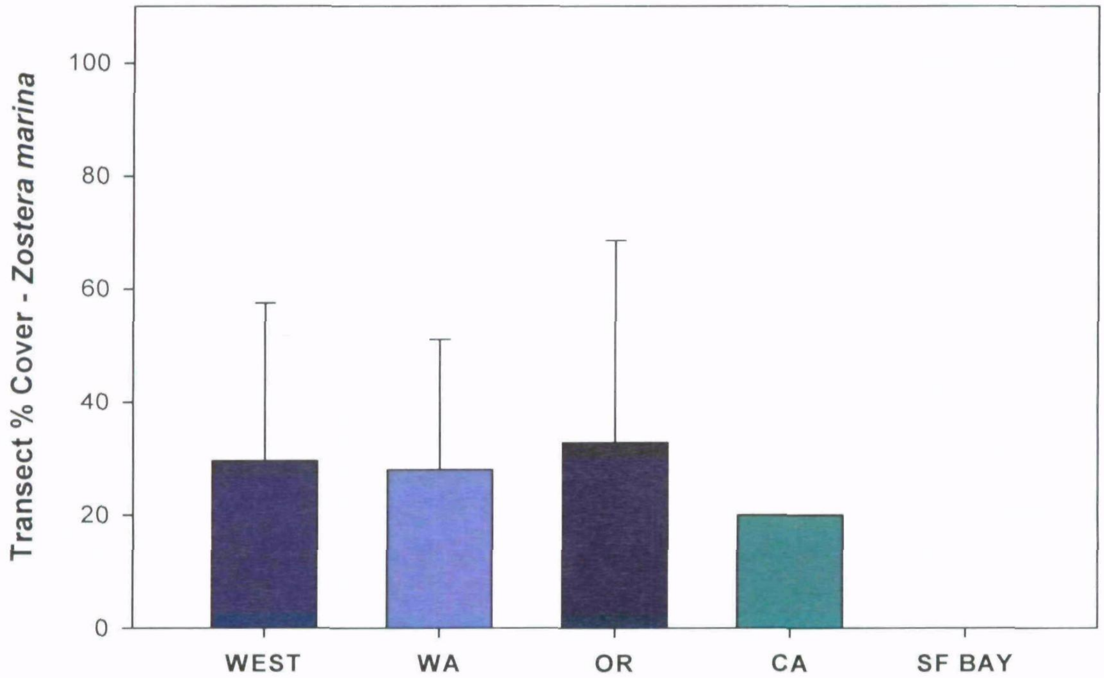

Figure 3.3.17. Relative percent cover of *Zostera marina* in the vegetation transects at sites where present (mean ± 1 sd).

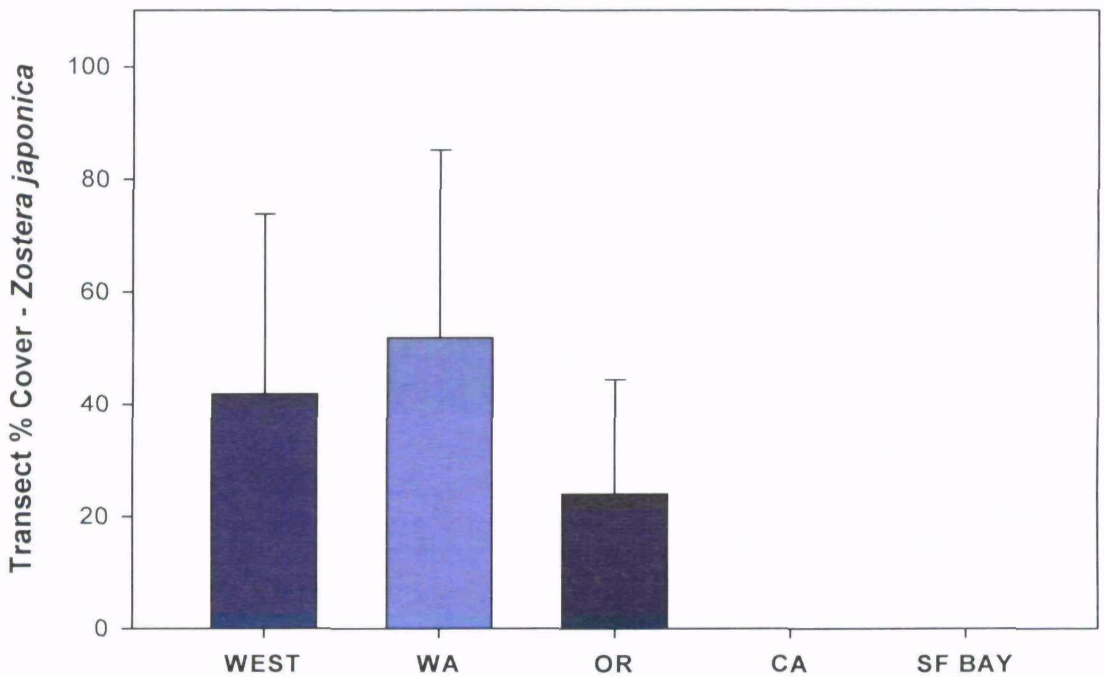

Figure 3.3.18. Relative percent cover of *Zostera japonica* in the vegetation transects at sites where present (mean ± 1 sd).

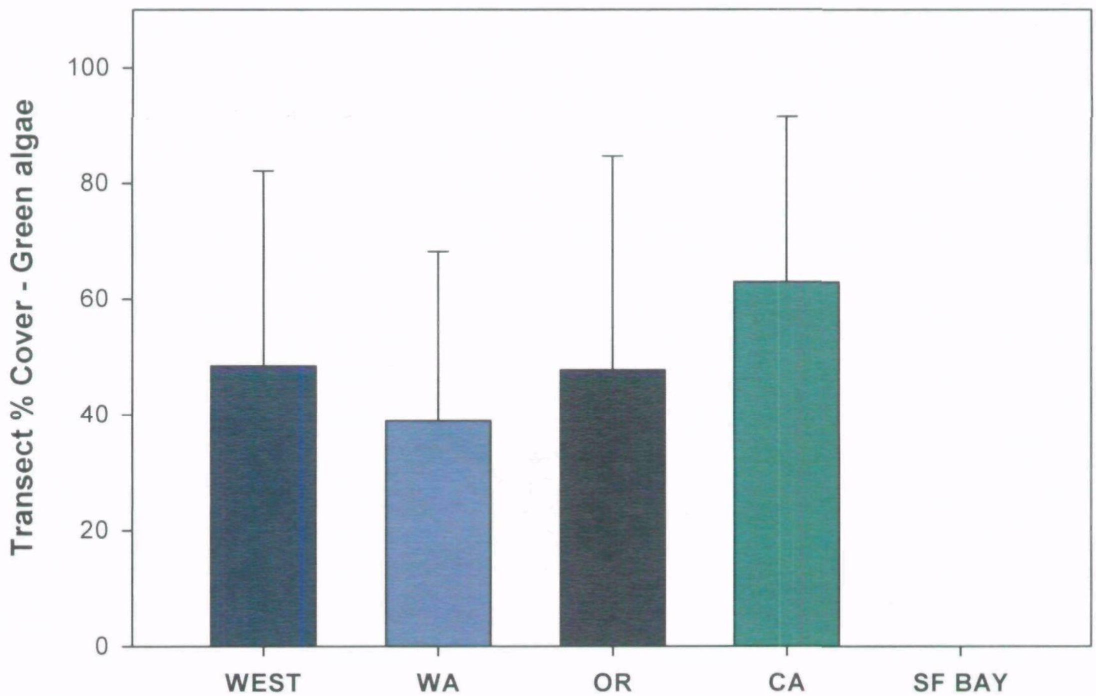

Figure 3.3.19. Relative percent cover of green algae in the vegetation transects at sites where present (mean ± 1 sd).

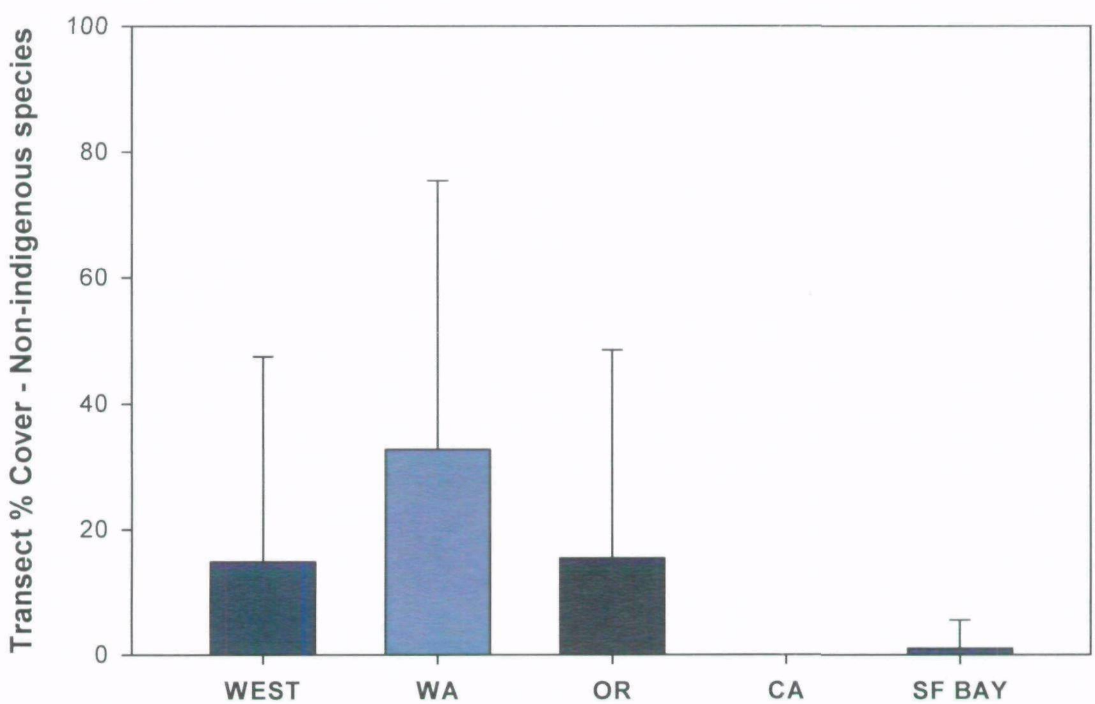

Figure 3.3.20. Relative percent cover of nonindigenous species in the vegetation transects at sites where plants are present (mean ± 1 sd).

3.4 Shoreline Land Use

West wide, approximately an estimated 55% of estuarine area had shoreline immediately adjacent that was classified by field crews as undeveloped. In Washington and Oregon, much of the undeveloped land was in silviculture. Somewhat surprisingly, across the three states, the percentage of area with adjacent shoreline classified as residential was very similar, on the order of 20%. California and San Francisco Bay had much higher area with urban shoreline adjacent to the intertidal sampling points than did Washington and Oregon.

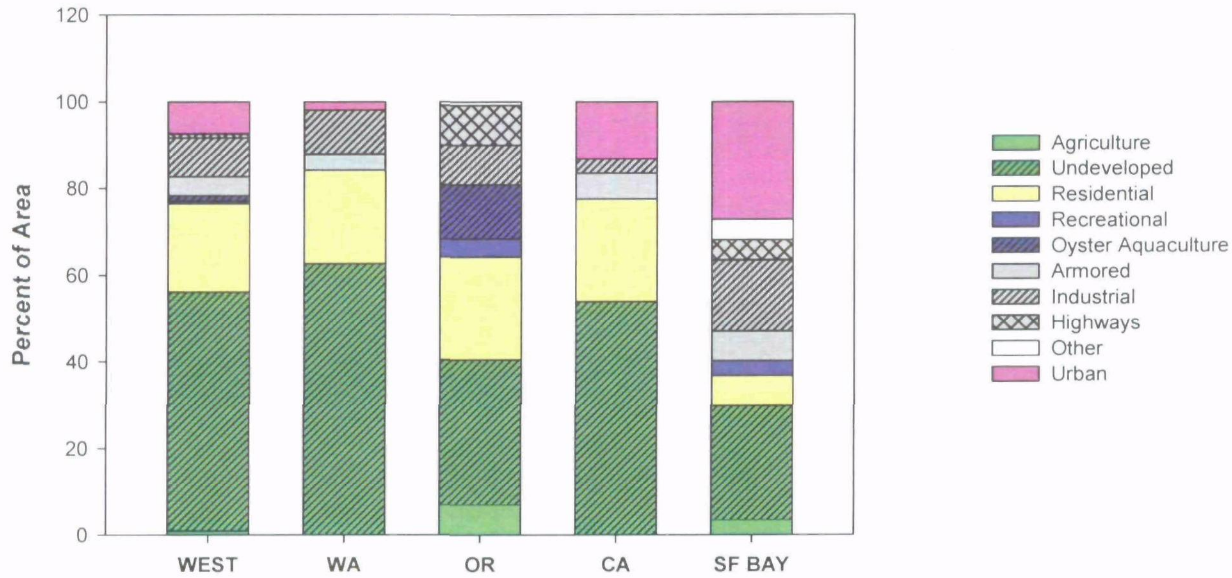

Figure 3.4.1. Percentage areas within assessment regions with shoreline adjacent to sample locations in different land use categories.

3.5 Lessons Learned

Tidal wetlands constitute critical habitats in West Coast estuaries, although their nature varies geographically. In the Pacific Northwest, tidal wetlands predominantly consist of unvegetated sand and mud flats, with marshes limited to a relatively narrow band along the upper edge of the bathymetric gradient. In comparison, vegetated wetlands constitute a much greater proportion of the total estuarine area in San Francisco Bay and in estuaries in Southern California. The results presented here represent the first regional scale survey of the condition of these habitat types on the West Coast and, to the best of our knowledge, anywhere. As such, these results constitute a critical baseline by which to evaluate changes in response to continued or increasing anthropogenic stress from excessive nutrient loading, urbanization, shoreline modification, invasion of nonindigenous species, and the host of potential alterations resulting from global climate change.

Sampling the range of vegetated and unvegetated tidal wetlands was not a simple endeavor but the approaches used in this survey, from use of hovercraft to quantifying burrowing shrimp, generally proved feasible for regional scale surveys of wetland condition. A slightly modified version of these approaches has since been used in another tidal wetland survey (Lee et al., 2006). This is not to say that improvements could not be made.

In the sample design, with the exception of San Francisco Bay, sample sites were selected at random, with no attempt to require that sample sites fell within marsh habitats within a given multidensity category. The sample distribution by habitat type thus reflects the relative distribution of habitat types in the estuarine intertidal of the West Coast, but does mean that marsh type habitats had relatively few samples from some states. In hind sight, the habitat maps available appear to have been sufficiently accurate to have allowed partitioning of sample effort by habitat type.

The use of the shoreline development indicator proved to be somewhat variable among field crews, suggesting a need for more careful a priori definition of shoreline development categories, and development of a photographic guide to assist field crews in providing a consistent classification.

A difficult issue that arose was the need to subsample benthic samples due to the extreme processing time for some samples, especially those collected in vegetated wetlands. The consequence of this practice, which was carried out with differing subsample sizes by different state laboratories and contractors, was the generation of biological samples based on effectively different surface areas. We recommend that if at all possible, sufficient dollar and time resources be allocated to fully process the 0.1 m^2 benthic samples regardless of the volume of residue. If that is not practical, then one possibility is to subsample all 0.1 m^2 benthic samples with a smaller core and process these independently. This approach would allow the comparison among all sites within a study using the smaller, standardized sample size, while maintaining the ability to compare the sites sampled with the 0.1 m^2 area with previous EMAP efforts. Another issue is the high abundance of oligochaetes and, to a lesser extent, insects in several tidal wetland habitats. Both of these are difficult taxa to identify, but to the extent practical they should be identified to species or at least to family.

The other major ecological endpoints used in this survey were tidal wetland plant composition, cover, and biomass. One goal of the plant survey was to evaluate the potential for development of wetland indicators. However, one of the lessons learned is that the number of plant species in the 0.25 m^2 quadrat or 5-m transect is too low for use in most of the standard benthic indicators based on species richness. Another lesson was that most plant species only occurred in a limited number of sites, making it difficult to develop generally applicable metrics based on indicator species. While the present effort was not sufficient to develop wetland indicators by itself, it did feed into the development of the California Rapid Assessment Method (CRAM; http://www.cramwetlands.org/) and to similar rapid assessment surveys being conducted by U.S. EPA in Oregon.

3.6 Summary

Condition of the soft sediment habitat within the intertidal zone of the states of Washington, Oregon and California, with the exception of the estuarine portion of the Columbia River, was successfully assessed at 217 sites during the summer of 2002. The dominant types of estuarine intertidal habitat varied among the three states, although unvegetated sand or mud flats were the dominant habitat types for all three states. Shellfish beds (oysters), gravel bottom, and intertidal seagrasses were recorded only in Washington and Oregon. San Francisco Bay and the rest of California tended to have finer sediments, higher Total Organic Carbon, higher concentrations of sediment nitrogen and phosphorus, and higher average Effects Range-Median Quotient (ERM-Q) values than estuarine intertidal areas in Washington and Oregon. Levels of sediment contamination West wide were low, with only 0.21% of the intertidal area of the West Coast estuaries having exceedances of >5 Effects Range Low (ERL) concentrations and 0.3% of the intertidal area exceeding Effects Range Median (ERM) concentrations.

Average densities of benthic infauna were highest in Oregon, with California and San Francisco having lower but similar abundances, and Washington having the lowest value. The benthic community was dominated by polychaetes, oligochaetes and amphipods. Surprisingly, the single most abundant polychaete in the West Coast intertidal was the nonindigenous *Manayunkia aestuarina*, introduced from the Northeast Atlantic. San Francisco habitats other than the high marsh were the most invaded with an average of almost 50% of the classified species per sample consisting of nonindigenous species. Puget Sound samples contained about 26% nonindigenous species compared to 40% to 44% for coastal Oregon and Washington.

Vegetation was present in the quadrats at 150 of the 217 sites sampled, and included 28 emergent macrophytes, 2 seagrasses, and macroalgal taxa. Eighty-two percent of macrophyte taxa occurred at three or fewer sites. The most frequently occurring emergent macrophyte taxa were marsh jaumea (*Jaumea carnosa*) and pickleweed (*Salicornia virginica*). The greatest numbesr of emergent macrophyte species were observed in California (n = 11), and in San Francisco Bay (n = 17) where high marsh was included in the study. Mean relative cover of nonindigenous emergent macrophyte species was low (8%) throughout the West. Mean cover by nonindigenous species was highest in Washington (21%), where both salt marsh cordgrass *Spartina alterniflora* and the introduced seagrass *Zostera japonica* were found. No nonindigenous macrophyte species were observed at California sites, except one high marsh site in San Francisco Bay.

The results of this assessment study represent the first regional scale survey of the condition of intertidal wetland habitats on the West Coast. Findings confirm results from previous National Coastal Assessment studies of West Coast estuaries that have indicated sediment contamination issues are limited in extent, but that West Coast estuaries have been broadly invaded by nonindigenous species. Further refinement of measurement approaches for plant community and shoreline development indicators are needed.

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5.0 Appendix Tables

Appendix Table 1.1. Summary of quality assurance results for sediment metals. RPD = relative percent difference of duplicate samples. CV = coefficient of variation.

State	Average % deviation from true value of reference material (# Analytes)	Average % deviation from reference material within ±20% of true value	% of analytes within ±35% of true value	70% of analytes within ±35% of true value?	Recovery of matrix spikes within 50%-120%?	RPDs and CVs of matrix spikes and reference materials <30%?
California	7% (15)	Yes	100%	Yes	Yes	Yes
Oregon	15% (15)	Yes	93%	Yes	Yes	Yes
Washington	4% (13)	Yes	100%	Yes	Yes	Yes

Appendix Table 1.2. Summary of quality assurance results for sediment PAHs. RPD = relative percent difference of duplicate samples. CV = coefficient of variation.

State	Average % deviation from true value of reference material (# Analytes)	Average % deviation from reference material within ±30% of true value	% of analytes within ±35% of true value	70% of analytes within ±35% of true value?	Recovery of matrix spikes within 50%-120%?	RPDs and CVs of matrix spikes and reference materials <30%?
California	16% (12)	Yes	100%	Yes	Yes	No (33%)
Oregon	43% (22)	No	53%	No	Yes	No (34%)
Washington	32% (19)	No	74%	Yes	Yes	Yes

Appendix Table 1.3. Summary of quality assurance results for sediment PCBs. RPD = relative percent difference of duplicate samples. CV = coefficient of variation.

State	Average % deviation from true value of reference material (# Analytes)	Average % deviation from reference material within ±30% of true value	% of analytes within ±35% of true value	70% of analytes within ±35% of true value?	Recovery of matrix spikes within 50%-120%?	RPDs and CVs of matrix spikes and reference materials <30%?
California	15% (14)	Yes	100%	Yes	Yes	No non-zero replicates
Oregon	146% (21)	No	38%	No	Yes	No (49%)
Washington	32% (18)	No	67%	No	Yes	Yes

Appendix Table 1.4. Summary of quality assurance results for sediment DDTs and other chlorinated pesticides. RPD = relative percent difference of duplicate samples. CV = coefficient of variation. HCB = hexachlorobenzene, which coeluted with analytical surrogate in the Oregon analyses.

State	Average % deviation from true value of reference material (# Analytes)	Average % deviation from reference material within ±30% of true value	% of analytes within ±35% of true value	70% of analytes within ±35% of true value?	Recovery of matrix spikes within 50%-120%?	RPDs and CVs of matrix spikes and reference materials <30%?
California	13% (2)	Yes (only 2 analytes)	100%	Yes (only 2 analytes)	Yes (19 analytes)	No non-zero replicates
Oregon	127% (8) 57% (w/o HCB)	No	50%	No	Yes	Yes
Washington	24% (7)	Yes	100%	Yes	Yes	Yes

Appendix Table 2. Sampling coordinates for the 2002 West Coast Intertidal Assessment. The Area Weight represents the represents the total estuarine area within a multidensity category divided by the number of samples obtained in that category.

EMAP Station ID	Location	Latitude	Longitude	Multidensity Category	Area Weight
WA02-0002	Willapa Bay	46.58	-123.93	Willa	7.74
WA02-0003	Willapa Bay	46.49	-124.03	Willa	7.74
WA02-0004	Port Orchard	47.70	-122.56	Puget	13.97
WA02-0005	Grays Harbor	46.97	-124.02	Washi	23.16
WA02-0006	Case Inlet	47.10	-122.71	Puget	13.97
WA02-0007	Willapa Bay	46.52	-123.93	Willa	7.74
WA02-0010	Oyster Bay	47.11	-123.07	Puget	13.97
WA02-0011	Willapa Bay	46.67	-123.93	Willa	7.74
WA02-0012	Drayton Passage	47.23	-122.72	Puget	13.97
WA02-0014	Port Susan	48.12	-122.42	Puget	13.97
WA02-0016	Skagit Bay	48.33	-122.46	Puget	13.97
WA02-0017	Willapa Bay	46.42	-123.98	Willa	7.74
WA02-0018	Willapa Bay	46.72	-123.91	Willa	7.74
WA02-0019	Willapa Bay	46.68	-123.96	Willa	7.74
WA02-0020	Case Inlet	47.35	-122.80	Puget	13.97
WA02-0021	Grays Harbor	47.02	-124.10	Washi	23.16
WA02-0022	Port Gardner	48.03	-122.26	Puget	13.97
WA02-0023	Willapa Bay	46.51	-123.96	Willa	7.74
WA02-0024	Lummi Bay	48.77	-122.66	Puget	13.97
WA02-0025	Grays Harbor	46.99	-124.08	Washi	23.16
WA02-0026	Grays Harbor	46.96	-123.97	Washi	23.16
WA02-0027	Willapa Bay	46.49	-124.03	Willa	7.74
WA02-0028	Port Orchard	47.67	-122.56	Puget	13.97
WA02-0032	Skagit Bay	48.37	-122.53	Puget	13.97
WA02-0035	Willapa Bay	46.64	-123.96	Willa	7.74
WA02-0036	Lynch Cove	47.43	-122.87	Puget	13.97
WA02-0037	Grays Harbor	47.04	-124.08	Washi	23.16
WA02-0039	Willapa Bay	46.49	-123.95	Willa	7.74
WA02-0040	Samish Bay	48.56	-122.47	Puget	13.97
WA02-0041	Grays Harbor	46.99	-124.13	Washi	23.16
WA02-0043	Willapa Bay	46.63	-124.05	Willa	7.74
WA02-0044	Peale Passage	47.22	-122.91	Puget	13.97
WA02-0045	Grays Harbor	46.88	-124.07	Washi	23.16
WA02-0046	Skagit Bay	48.29	-122.42	Puget	13.97
WA02-0048	Skagit Bay	48.33	-122.45	Puget	13.97
WA02-0049	Naselle River	46.44	-123.92	Willa	7.74
WA02-0050	Willapa Bay	46.73	-123.89	Willa	7.74
WA02-0051	Willapa Bay	46.66	-123.97	Willa	7.74
WA02-0052	Carr Inlet	47.39	-122.63	Puget	13.97
WA02-0054	Port Susan	48.19	-122.39	Puget	13.97

WA02-0056	Skagit Bay	48.34	-122.50	Puget	13.97
WA02-0059	Willapa Bay	46.46	-123.99	Willa	7.74
WA02-0060	Drayton Harbor	48.97	-122.76	Puget	13.97
WA02-0061	Willapa Bay	46.72	-123.97	Willa	7.74
WA02-0062	Lilliwaup Creek	47.48	-123.08	Puget	13.97
WA02-0064	Swinomish Cannel	48.44	-122.50	Puget	13.97
WA02-0065	Willapa Bay	46.41	-124.00	Willa	7.74
WA02-0066	Willapa River	46.68	-123.82	Willa	7.74
WA02-0067	Willapa Bay	46.60	-123.95	Willa	7.74
WA02-0068	Thorndike Bay	47.78	-122.79	Puget	13.97
WA02-0070	Willapa Bay	46.53	-123.91	Willa	7.74
WA02-0071	Willapa Bay	46.71	-123.93	Willa	7.74
WA02-0072	Duckabush River	47.64	-122.92	Puget	13.97
WA02-0075	Willapa Bay	46.46	-124.00	Willa	7.74
WA02-0078	Willapa Bay	46.73	-123.90	Willa	7.74
WA02-0087	Palix River	46.63	-123.93	Willa	7.74
WA02-0091	Willapa Bay	46.48	-123.96	Willa	7.74
WA02-0102	Willapa Bay	46.59	-123.94	Willa	7.74
WA02-0123	Willapa Bay	46.52	-123.98	Willa	7.74
WA02-0127	Willapa Bay	46.49	-123.99	Willa	7.74
WA02-0143	Willapa Bay	46.67	-123.98	Willa	7.74
OR02-0001	Nehalem Bay	45.69	-123.90	Orego	2.18
OR02-0002	Coos Bay	43.45	-124.20	Coosb	0.89
OR02-0003	Siletz Bay	44.90	-124.02	Orego	2.18
OR02-0004	Coos Bay	43.39	-124.21	Coosb	0.89
OR02-0005	Tillamook Bay	45.53	-123.92	Orego	2.18
OR02-0006	Coos Bay	43.41	-124.20	Coosb	0.89
OR02-0007	Yaquina Bay	44.60	-124.02	Orego	2.18
OR02-0009	Tillamook Bay	45.51	-123.90	Orego	2.18
OR02-0010	Coos Bay	43.43	-124.22	Coosb	0.89
OR02-0011	Siuslaw River	43.97	-124.06	Orego	2.18
OR02-0012	Umpqua River	43.72	-124.10	Orego	2.18
OR02-0013	Netarts Bay	45.40	-123.94	Orego	2.18
OR02-0014	Coos Bay	43.42	-124.28	Coosb	0.89
OR02-0015	Netarts Bay	45.41	-123.95	Orego	2.18
OR02-0016	Coos Bay	43.34	-124.32	Coosb	0.89
OR02-0018	Coos Bay	43.42	-124.24	Coosb	0.89
OR02-0019	Yaquina Bay	44.62	-124.01	Orego	2.18
OR02-0020	Coos Bay	43.37	-124.17	Coosb	0.89
OR02-0021	Sixes River	42.85	-124.54	Orego	2.18
OR02-0022	Coos Bay	43.42	-124.21	Coosb	0.89
OR02-0023	Yaquina Bay	44.61	-124.02	Orego	2.18
OR02-0024	Coos Bay	43.33	-124.32	Coosb	0.89
OR02-0026	Coos Bay	43.41	-124.23	Coosb	0.89
OR02-0027	Alsea Bay	44.45	-124.05	Orego	2.18
OR02-0028	Coos Bay	43.28	-124.23	Coosb	0.89

OR02-0029	Sand Lake	45.28	-123.96	Orego	2.18
OR02-0030	Coos Bay	43.39	-124.19	Coosb	0.89
OR02-0031	Coos Bay	43.47	-124.20	Coosb	0.89
OR02-0032	Umpqua River	43.74	-124.16	Orego	2.18
OR02-0033	Tillamook Bay	45.53	-123.90	Orego	2.18
OR02-0034	Coos Bay	43.39	-124.30	Coosb	0.89
OR02-0035	Siletz Bay	44.89	-124.01	Orego	2.18
OR02-0036	Coos Bay	43.39	-124.19	Coosb	0.89
OR02-0038	Coos Bay	43.43	-124.21	Coosb	0.89
OR02-0039	Yaquina River	44.57	-124.01	Orego	2.18
OR02-0041	Tillamook Bay	45.51	-123.94	Orego	2.18
OR02-0042	Coos Bay	43.37	-124.21	Coosb	0.89
OR02-0043	Alsea River	44.42	-124.02	Orego	2.18
OR02-0044	Coos Bay	43.32	-124.20	Coosb	0.89
OR02-0045	Sand Lake	45.29	-123.94	Orego	2.18
OR02-0046	Coos Bay	43.38	-124.19	Coosb	0.89
OR02-0047	Netarts Bay	45.38	-123.96	Orego	2.18
OR02-0048	Coquille River	43.13	-124.41	Orego	2.18
OR02-0049	Tillamook Bay	45.52	-123.93	Orego	2.18
OR02-0050	Coos Bay	43.45	-124.23	Coosb	0.89
OR02-0051	Siuslaw River	43.98	-124.08	Orego	2.18
OR02-0052	Umpqua River	43.72	-124.15	Orego	2.18
OR02-0053	Netarts Bay	45.38	-123.95	Orego	2.18
OR02-0054	Coos Bay	43.42	-124.19	Coosb	0.89
OR02-0055	Tillamook Bay	45.49	-123.90	Orego	2.18
OR02-0056	Coos Bay	43.33	-124.31	Coosb	0.89
OR02-0057	Tillamook Bay	45.50	-123.89	Orego	2.18
OR02-0058	Coos Bay	43.40	-124.21	Coosb	0.89
OR02-0059	Alsea Bay	44.43	-124.04	Orego	2.18
OR02-0061	Salmon River	45.03	-123.98	Orego	2.18
OR02-0062	Coos Bay	43.39	-124.20	Coosb	0.89
OR02-0063	Coos Bay	43.45	-124.22	Coosb	0.89
OR02-0064	Umpqua River	43.72	-124.16	Orego	2.18
OR02-0066	Neawanna Creek	46.00	-123.92	Orego	2.18
OR02-0067	Coos Bay	43.45	-124.21	Coosb	0.89
OR02-0068	Nestucca Bay	45.18	-123.94	Orego	2.18
OR02-0069	Coos Bay	43.39	-124.20	Coosb	0.89
OR02-0070	Tillamook Bay	45.48	-123.89	Orego	2.18
OR02-0071	Coos Bay	43.40	-124.21	Coosb	0.89
OR02-0072	Alsea Bay	44.44	-124.05	Orego	2.18
OR02-0073	Coos Bay	43.35	-124.31	Coosb	0.89
CA02-0001	Eel River	40.66	-124.29	Calif	2.04
CA02-0002	Morro Bay	35.33	-120.84	Calif	2.04
CA02-0003	Drakes Bay	38.04	-122.93	Calif	2.04
CA02-0004	Arcata Bay	40.84	-124.08	Calif	2.04
CA02-0006	Tomales Bay	38.23	-122.96	Calif	2.04

CA02-0007	Arcata Bay	40.80	-124.12	Calif	2.04
CA02-0008	Arcata Bay	40.85	-124.11	Calif	2.04
CA02-0009	Elkhorn Slough	36.83	-121.74	Calif	2.04
CA02-0010	Arcata Bay	40.88	-124.14	Calif	2.04
CA02-0011	Tomales Bay	38.12	-122.86	Calif	2.04
CA02-0012	Humboldt Bay	40.70	-124.22	Calif	2.04
CA02-0013	Arcata Bay	40.85	-124.09	Calif	2.04
CA02-0014	Elkhorn Slough	36.83	-121.75	Calif	2.04
CA02-0015	Arcata Bay	40.86	-124.16	Calif	2.04
CA02-0016	Drakes Estero	38.05	-122.94	Calif	2.04
CA02-0019	Arcata Bay	40.85	-124.15	Calif	2.04
CA02-0020	Drakes Bay	38.08	-122.83	Calif	2.04
CA02-0021	Chorro Creek	35.34	-120.83	Calif	2.04
CA02-0022	Humboldt Bay	40.69	-124.23	Calif	2.04
CA02-0023	Arcata Bay	40.84	-124.10	Calif	2.04
CA02-0024	Corte Madera Creek	37.92	-122.68	Calif	2.04
CA02-0025	Arcata Bay	40.82	-124.15	Calif	2.04
CA02-0026	Bodega Harbor	38.33	-123.05	Calif	2.04
CA02-0027	Arcata Bay	40.82	-124.12	Calif	2.04
CA02-0028	Arcata Bay	40.85	-124.11	Calif	2.04
CA02-0029	Arcata Bay	40.83	-124.17	Calif	2.04
CA02-0030	Smith River (CA)	41.94	-124.20	Calif	2.04
CA02-0031	Chorro Creek	35.35	-120.84	Calif	2.04
CA02-0032	Tomales Bay	38.09	-122.83	Calif	2.04
CA02-0033	Arcata Bay	40.83	-124.17	Calif	2.04
CA02-0301	Atascadero Creek	34.42	-119.84	Bight	0.55
CA02-0302	Huntington Harbour	33.70	-118.05	Bight	0.55
CA02-0303	Point Mugu Lagoon	34.12	-119.15	Bight	0.55
CA02-0304	Huntington Harbour	33.69	-118.04	Bight	0.55
CA02-0305	Sweetwater River	32.64	-117.11	Bight	0.55
CA02-0306	Point Mugu Lagoon	34.11	-119.14	Bight	0.55
CA02-0307	Newport Bay	33.65	-117.88	Bight	0.55
CA02-0308	Point Mugu Lagoon	34.11	-119.09	Bight	0.55
CA02-0309	Huntington Harbour	33.73	-118.07	Bight	0.55
CA02-0311	Point Mugu Lagoon	34.10	-119.12	Bight	0.55
CA02-0312	Newport Bay	33.63	-117.89	Bight	0.55
CA02-0313	Marina Del Rey	33.97	-118.45	Bight	0.55
CA02-0314	Anaheim Bay	33.74	-118.08	Bight	0.55
CA02-0315	San Diego River	32.77	-117.25	Bight	0.55
CA02-0316	Point Mugu Lagoon	34.11	-119.11	Bight	0.55
CA02-0317	Tijuana River	32.56	-117.12	Bight	0.55
CA02-0318	Santa Ana River	33.64	-117.97	Bight	0.55
CA02-0319	Carpinteria Creek	34.40	-119.54	Bight	0.55
CA02-0320	Anaheim Bay	33.74	-118.09	Bight	0.55
CA02-0323	Atascadero Creek	34.42	-119.84	Bight	0.55
CA02-0324	Anaheim Bay	33.75	-118.08	Bight	0.55

CA02-0325	Point Mugu Lagoon	34.11	-119.13	Bight	0.55
CA02-0326	Huntington Harbour	33.74	-118.08	Bight	0.55
CA02-0327	San Diego Bay	32.61	-117.11	Bight	0.55
CA02-0328	Point Mugu Lagoon	34.11	-119.12	Bight	0.55
CA02-0329	Tijuana River	32.57	-117.12	Bight	0.55
CA02-0333	Huntington Harbour	33.74	-118.08	Bight	0.55
CA02-0334	Point Mugu Lagoon	34.11	-119.11	Bight	0.55
CA02-0343	Atascadero Creek	34.42	-119.88	Bight	0.55
CA02-0352	San Elijo Lagoon	33.01	-117.27	Bight	0.55
CA02-0601	SF Bay - Coyote Creek	37.47	-122.04	SF High Marsh	4.50
CA02-0602	SF Bay -Dutchman Slough	38.05	-122.13	SF Flat	13.12
CA02-0603	SF Bay - San Leandro Creek	37.67	-122.17	SF Flat	13.12
CA02-0604	SF Bay - Petaluma River	38.21	-122.57	SF Low Marsh	2.28
CA02-0605	SF Bay - Redwood Creek	37.51	-122.22	SF Low Marsh	2.28
CA02-0606	SF Bay - Dutchman Slough	38.14	-122.37	SF High Marsh	4.50
CA02-0607	SF Bay - Dutchman Slough	38.16	-122.39	SF High Marsh	4.50
CA02-0608	SF Bay - Napa River	38.05	-122.07	SF Low Marsh	2.28
CA02-0609	SF Bay - Mud Slough	37.48	-121.97	SF High Marsh	4.50
CA02-0611	SF Bay - Newark SF Bay - Slough	37.50	-122.09	SF Flat	13.12
CA02-0612	SF Bay - Gallinas Creek	38.01	-122.49	SF High Marsh	4.50
CA02-0613	SF Bay - Redwood Creek	37.51	-122.17	SF Flat	13.12
CA02-0615	SF Bay - Napa River	38.10	-122.09	SF High Marsh	4.50
CA02-0616	SF Bay - Suisun Bay	38.06	-121.90	SF High Marsh	4.50
CA02-0617	SF Bay - Coyote Creek	37.45	-122.07	SF Flat	13.12
CA02-0618	SF Bay - San Rafael Bay	37.98	-122.38	SF Flat	13.12
CA02-0619	SF Bay - Coyote Hills Slough	37.54	-122.11	SF High Marsh	4.50
CA02-0620	SF Bay - Petaluma River	38.14	-122.52	SF High Marsh	4.50
CA02-0621	SF Bay - Redwood Creek	37.52	-122.21	SF Low Marsh	2.28
CA02-0622	SF Bay - Dutchman Slough	38.15	-122.32	SF Low Marsh	2.28
CA02-0623	SF Bay - Montezuma Slough	38.15	-121.92	SF Low Marsh	2.28
CA02-0624	SF Bay - Outer Oakland Harbor	37.83	-122.32	SF Flat	13.12
CA02-0625	SF Bay - Steinberger Slough	37.54	-122.22	SF Low Marsh	2.28
CA02-0626	SF Bay - Dutchman Slough	38.11	-122.33	SF Flat	13.12
CA02-0628	SF Bay - Corte Madera Creek	37.93	-122.51	SF High Marsh	4.50
CA02-0629	SF Bay - San Francisco Bay	37.64	-122.15	SF Low Marsh	2.28
CA02-0630	SF Bay - Petaluma River	38.09	-122.48	SF Flat	13.12
CA02-0632	SF Bay - Napa River	38.12	-122.07	SF Low Marsh	2.28
CA02-0634	SF Bay - Dutchman Slough	38.16	-122.40	SF High Marsh	4.50
CA02-0635	SF Bay - Steinberger Slough	37.54	-122.23	SF High Marsh	4.50

Appendix Table 3. Summary of sediment composition (percent fines), total organic carbon (TOC), total nitrogen (TN) and total phosphorus (TP) concentrations, and contaminant concentrations for all intertidal sites, including high marsh, sampled in 2002. ERL count and ERM count are the number of exceedances of ERL and ERM, respectively. * Number of analytes that exceed Effects Range Low (ERL) guidelines (Long et al., 1995). n/a = not available for this station.

	Characteristics				Contaminants						
EMAP Station ID	Percent Fines	Total Organic Carbon	Total Nitrogen	Total Phosphorus	ERMQ	Metals*	PAHs*	Pest*	PCBs*	ERL Count	ERM Count
CA02-0001	94.0	2.1	0.21	0.07	0.065	2	2			4	0
CA02-0002	89.0	1.8	0.23	0.07	0.058	2				2	0
CA02-0003	13.0	0.3	0.04	0.03	0.013					0	0
CA02-0004	4.0	10.9	0.89	0.13	0.058	2				2	0
CA02-0006	5.0	0.4	0.06	0.06	0.015					0	0
CA02-0007	90.0	2.3	0.28	0.08	0.058	2	1			3	0
CA02-0008	94.0	1.6	0.21	0.09	0.063	3	1			4	0
CA02-0009	n/a	8.7	0.84	0.10	0.049	2				2	0
CA02-0010	72.0	6.4	0.53	0.03	0.066	3				3	0
CA02-0011	10.0	0.3	0.04	0.08	0.041	2	1			3	0
CA02-0012	88.0	1.5	0.21	0.09	0.050	1	1			2	0
CA02-0013	90.0	2.1	0.27	0.09	0.056	2	1			3	0
CA02-0014	75.0	7.3	0.75	0.09	0.049	2				2	0
CA02-0015	83.0	1.6	0.21	0.02	0.053	2	1			3	0
CA02-0016	6.0	0.3	0.05	0.09	0.013					0	0
CA02-0019	86.0	1.8	0.24	0.08	0.058	3	1			4	0
CA02-0020	27.0	10.9	0.87	0.08	0.057	2				2	0
CA02-0021	92.0	4.4	0.39	0.06	0.065	2				2	0
CA02-0022	90.0	2.0	0.27	0.06	0.054	2				2	0
CA02-0023	92.0	1.5	0.18	0.04	0.062	3	1			4	0
CA02-0024	24.0	1.0	0.14	0.06	0.027	1				1	0
CA02-0025	72.0	1.0	0.12	0.07	0.049	1	1			2	0
CA02-0026	17.0	0.7	0.12	0.07	0.021					0	0
CA02-0027	89.0	1.1	0.13	0.04	0.055	1	1			2	0
CA02-0028	93.0	1.6	0.19	0.11	0.065	3	1			4	0
CA02-0029	89.0	1.5	0.19	0.07	0.055	2	1			3	0
CA02-0030	6.0	0.2	0.03	0.10	0.046	1				1	0
CA02-0031	83.0	7.1	0.61	0.17	0.070	2				2	0
CA02-0032	85.0	1.3	0.16	0.07	0.042	1				1	0
CA02-0033	92.0	2.7	0.37	0.11	0.058	3	1			4	0
CA02-0301	93.0	2.7	0.23	0.18	0.048	3				3	0
CA02-0302	22.0	1.0	0.12	0.05	0.070	1		2		3	0

CA02-0303	49.0	7.5	0.65	0.09	0.036	1			1	0
CA02-0304	51.0	8.6	0.86	0.10	0.092	5			5	0
CA02-0305	91.0	2.0	0.19	0.17	0.045	2			2	0
CA02-0306	72.0	6.9	0.60	0.12	0.357	3		2	5	2
CA02-0307	77.0	9.5	0.65	0.20	0.143	3		2	5	1
CA02-0308	62.0	8.1	0.71	0.06	0.164	3		2	5	1
CA02-0309	71.0	6.8	0.66	0.13	0.065	4			4	0
CA02-0311	19.0	18.0	2.30	0.17	0.042	1			1	0
CA02-0312	74.0	1.2	0.17	0.02	0.101	3		2	5	0
CA02-0313	82.0	3.1	0.38	0.08	0.121	6			6	0
CA02-0314	72.0	9.8	0.89	0.07	0.129	4		2	6	0
CA02-0315	4.0	0.0	0.00	0.06	0.005				0	0
CA02-0316	21.0	0.3	0.03	0.09	0.011				0	0
CA02-0317	81.0	1.6	0.19	0.10	0.070	3		2	5	0
CA02-0318	36.0	0.6	0.06	0.03	0.070			2	2	0
CA02-0319	33.0	2.1	0.18	0.17	0.032				0	0
CA02-0320	80.0	3.4	0.37	0.08	0.056	3			3	0
CA02-0321	75.0	0.9	0.10	0.06	n/a				n/a	n/a
CA02-0323	99.0	1.9	0.19	0.11	0.066	4			4	0
CA02-0324	52.0	1.8	0.18	0.03	0.033				0	0
CA02-0325	47.0	2.5	0.25	0.16	0.027	1			1	0
CA02-0326	69.0	7.1	0.81	0.16	0.068	3			3	0
CA02-0327	29.0	1.9	0.13	0.12	0.021				0	0
CA02-0328	85.0	3.1	0.31	0.13	0.130	4		2	6	0
CA02-0329	22.0	15.5	1.22	0.08	0.045	2			2	0
CA02-0333	29.0	16.0	1.54	0.14	0.049	2			2	0
CA02-0334	18.0	21.4	1.45	0.12	0.219	2		2	4	2
CA02-0343	73.0	0.9	0.12	0.06	0.040	2			2	0
CA02-0352	40.0	8.5	1.29	0.09	0.052	2			2	0
CA02-0601	46.0	8.7	0.81	0.07	0.084	5			5	0
CA02-0602	94.0	1.2	0.13	0.11	0.069	3			3	0
CA02-0603	10.0	0.2	0.03	0.09	0.025				0	0
CA02-0604	83.0	4.6	0.40	0.14	0.072	4			4	0
CA02-0605	40.0	2.6	0.41	0.11	0.084	5			5	0
CA02-0606	55.0	7.2	0.50	0.07	0.078	4			4	0
CA02-0607	69.0	4.9	0.41	0.07	0.059	4			4	0
CA02-0608	36.0	13.8	0.98	0.07	0.082	5			5	0
CA02-0609	87.0	2.6	0.26	0.11	0.078	3			3	0
CA02-0611	90.0	1.0	0.14	0.08	0.079	3			3	0
CA02-0612	62.0	3.3	0.31	0.07	0.087	5			5	0
CA02-0613	67.0	1.9	0.19	0.04	0.079	2	1		3	0
CA02-0615	31.0	11.4	0.89	0.13	0.108	6	1		7	0
CA02-0616	40.0	11.6	0.80	0.07	0.064	4			4	0
CA02-0617	91.0	1.1	0.14	0.17	0.083	3	1		4	0
CA02-0618	13.0	0.5	0.07	0.10	0.025				0	0

CA02-0619	61.0	7.9	0.73	0.11	0.076	4			4	0
CA02-0620	67.0	2.6	0.24	0.02	0.059	4			4	0
CA02-0621	46.0	16.2	1.36	0.09	0.082	3	1		4	0
CA02-0622	56.0	4.1	0.37	0.06	0.076	4			4	0
CA02-0623	42.0	13.0	0.81	0.10	0.068	4			4	0
CA02-0624	10.0	0.5	0.06	0.08	0.021	1			1	0
CA02-0625	64.0	3.1	0.36	0.06	0.070	2			2	0
CA02-0626	97.0	0.8	0.10	0.09	0.067	3			3	0
CA02-0628	34.0	12.3	0.94	0.09	0.101	4			4	0
CA02-0629	79.0	3.0	0.29	0.10	0.059	1			1	0
CA02-0630	96.0	1.0	0.13	0.02	0.078	3			3	0
CA02-0632	30.0	7.5	0.63	0.07	0.058	4			4	0
CA02-0634	52.0	6.6	0.52	0.02	0.046	2			2	0
CA02-0635	64.0	3.0	0.40	0.03	0.065	3			3	0
OR02-0001	41.7	2.2	0.19	0.06	0.034	1			1	0
OR02-0002	67.5	1.5	0.15	0.07	0.035	2			2	0
OR02-0003	22.4	1.2	0.11	0.07	0.032	1			1	0
OR02-0004	40.3	1.7	0.13	0.05	0.023				0	0
OR02-0005	6.2	0.3	0.03	0.04	0.017				0	0
OR02-0006	51.7	1.4	0.14	0.06	0.030	1			1	0
OR02-0007	46.3	4.3	0.40	0.10	0.027				0	0
OR02-0009	9.4	0.3	0.04	0.08	0.048	2			2	0
OR02-0010	11.1	0.4	0.05	0.05	0.022				0	0
OR02-0011	22.7	1.5	0.13	0.04	0.017				0	0
OR02-0012	73.7	2.9	0.26	0.06	0.033	1			1	0
OR02-0013	16.4	0.9	0.08	0.04	0.019				0	0
OR02-0014	1.2	0.1	0.01	0.01	0.006				0	0
OR02-0015	5.2	0.4	0.05	0.03	0.017				0	0
OR02-0016	16.0	0.4	0.04	0.02	0.027	1			1	0
OR02-0018	45.4	2.1	0.69	0.04	0.029				0	0
OR02-0019	48.4	1.6	0.16	0.06	0.026	1			1	0
OR02-0020	48.8	2.4	0.80	0.08	0.029	1			1	0
OR02-0021	9.5	0.7	0.47	0.03	0.040	1			1	0
OR02-0022	15.0	0.6	0.06	0.03	0.011				0	0
OR02-0023	56.6	2.4	0.22	0.07	0.030	1			1	0
OR02-0024	25.9	1.4	0.11	0.04	0.021				0	0
OR02-0026	64.8	2.7	0.22	0.05	0.105	1		1	2	1
OR02-0027	20.3	0.5	0.05	0.04	0.016				0	0
OR02-0028	71.2	5.1	0.35	0.09	0.041	2			2	0
OR02-0029	0.9	0.0	0.01	0.01	0.018	1			1	0
OR02-0030	28.3	1.1	0.50	0.04	0.020				0	0
OR02-0031	87.2	2.0	0.19	0.08	0.036	2			2	0
OR02-0032	11.1	0.5	0.46	0.03	0.024	1			1	0
OR02-0033	19.8	0.7	0.07	0.05	0.021				0	0
OR02-0034	64.5	5.4	0.51	0.08	0.025	1			1	0

OR02-0035	64.9	2.7	0.22	0.08	0.037	2		2	0
OR02-0036	18.3	1.0	0.09	0.03	0.014			0	0
OR02-0038	25.1	0.7	0.07	0.05	0.024			0	0
OR02-0039	83.4	2.8	0.28	0.10	0.036	1		1	0
OR02-0041	8.0	0.2	0.02	0.03	0.010			0	0
OR02-0042	22.9	1.2	0.08	0.03	0.021			0	0
OR02-0043	36.2	1.7	0.15	0.07	0.024			0	0
OR02-0044	70.4	4.0	1.16	0.06	0.088	1	2	3	0
OR02-0045	25.1	1.5	0.18	0.08	0.020	1		1	0
OR02-0046	7.4	0.3	0.03	0.02	0.012			0	0
OR02-0047	42.8	1.2	0.57	0.05	0.023	1		1	0
OR02-0048	1.7	0.1	0.02	n/a	0.009			0	0
OR02-0049	16.3	0.5	0.05	0.04	0.014			0	0
OR02-0050	55.5	1.5	0.12	0.05	0.030	1		1	0
OR02-0051	36.9	1.6	0.15	0.06	0.022			0	0
OR02-0052	47.0	1.1	0.09	0.04	0.031	1		1	0
OR02-0053	39.8	1.3	0.54	0.04	0.021			0	0
OR02-0054	33.5	1.1	0.57	0.04	0.026	1		1	0
OR02-0055	3.5	0.3	0.05	0.08	0.040	2		2	0
OR02-0056	83.4	1.3	0.13	0.05	0.031	1		1	0
OR02-0057	13.1	0.5	0.04	0.07	0.061	2		2	0
OR02-0058	23.5	1.2	0.07	0.04	0.024			0	0
OR02-0059	17.5	0.5	0.06	0.04	0.016			0	0
OR02-0061	70.2	2.1	0.68	0.06	0.041	2		2	0
OR02-0062	8.9	0.3	0.04	0.02	0.013			0	0
OR02-0063	41.3	1.3	0.10	0.04	0.025	1		1	0
OR02-0064	15.3	0.6	0.07	0.03	0.014			0	0
OR02-0066	46.7	3.9	0.36	0.12	0.020	1		1	0
OR02-0067	36.1	1.4	0.62	0.03	0.027			0	0
OR02-0068	4.8	0.3	0.17	0.02	0.017	1		1	0
OR02-0069	12.4	1.0	0.07	0.03	0.016			0	0
OR02-0070	84.7	3.9	0.77	0.10	0.041	2		2	0
OR02-0071	14.5	0.7	0.39	0.02	0.014			0	0
OR02-0072	9.6	0.6	0.50	0.04	0.022			0	0
OR02-0073	0.7	0.1	0.09	0.02	0.008			0	0
WA02-0002	3.6	0.2	0.03	0.02	0.017			0	0
WA02-0003	74.4	2.2	0.22	0.07	0.039	1		1	0
WA02-0004	6.1	0.1	0.02	0.02	0.012			0	0
WA02-0005	7.8	0.3	0.04	0.03	0.017			0	0
WA02-0006	95.2	0.6	0.05	0.06	0.025			0	0
WA02-0007	68.1	1.6	0.14	0.07	0.037			0	0
WA02-0010	91.7	2.4	0.26	0.10	0.051	2		2	0
WA02-0011	72.8	1.3	0.14	0.06	0.033			0	0
WA02-0012	2.2	0.0	0.01	0.02	0.019	1		1	0
WA02-0014	2.0	0.0	0.01	0.04	0.018	1		1	0

WA02-0016	2.6	0.2	0.02	0.05	0.019			0	0
WA02-0017	66.5	1.6	0.16	0.07	0.036	1		1	0
WA02-0018	4.4	0.3	0.03	0.03	0.020			0	0
WA02-0019	4.1	0.1	0.02	0.03	0.015			0	0
WA02-0020	1.9	0.0	0.01	0.03	0.016			0	0
WA02-0021	8.0	0.2	0.03	0.03	0.018			0	0
WA02-0022	2.2	0.2	0.02	0.04	0.023	1		1	0
WA02-0023	26.7	0.7	0.07	0.05	0.021			0	0
WA02-0024	12.2	0.4	0.05	0.04	0.018			0	0
WA02-0025	22.2	0.6	0.07	0.04	0.022			0	0
WA02-0026	11.9	0.3	0.04	0.03	0.044	2		2	0
WA02-0027	40.1	1.2	0.10	0.06	0.029			0	0
WA02-0028	9.6	0.2	0.03	0.03	0.017			0	0
WA02-0032	5.3	0.1	0.02	0.05	0.021			0	0
WA02-0035	13.0	0.5	0.06	0.04	0.018			0	0
WA02-0036	5.1	0.4	0.03	0.03	0.021			0	0
WA02-0037	72.2	1.4	0.13	0.06	0.050	2		2	0
WA02-0039	87.0	3.0	0.27	0.09	0.041	1		1	0
WA02-0040	33.6	0.6	0.08	0.07	0.025			0	0
WA02-0041	7.7	0.3	0.04	0.03	0.017			0	0
WA02-0043	17.3	0.6	0.07	0.08	0.019			0	0
WA02-0044	4.2	1.2	0.10	0.03	0.022	1		1	0
WA02-0045	21.4	0.8	0.07	0.04	0.025			0	0
WA02-0046	3.3	0.0	0.01	0.06	0.026	1		1	0
WA02-0048	3.9	0.1	0.03	0.06	0.024			0	0
WA02-0049	58.6	1.9	0.16	0.08	0.042	1		1	0
WA02-0050	62.8	1.3	0.11	0.05	0.032			0	0
WA02-0051	2.9	0.1	0.02	0.03	0.013			0	0
WA02-0052	15.7	0.7	0.06	0.02	0.015			0	0
WA02-0054	8.1	0.2	0.03	0.05	0.035	1		1	0
WA02-0056	5.2	0.1	0.02	0.04	0.020			0	0
WA02-0059	74.8	2.1	0.20	0.08	0.037	1		1	0
WA02-0060	40.5	1.2	0.13	0.05	0.031			0	0
WA02-0061	11.2	0.4	0.04	0.04	0.018			0	0
WA02-0062	0.6	0.3	0.03	0.04	0.029	2		2	0
WA02-0064	39.2	0.6	0.06	0.06	0.030			0	0
WA02-0065	2.3	0.0	0.01	0.03	0.013			0	0
WA02-0066	80.0	2.2	0.19	0.06	0.042			0	0
WA02-0067	3.0	0.1	0.02	0.02	0.015			0	0
WA02-0068	4.6	0.2	0.03	0.03	0.018			0	0
WA02-0070	56.1	2.0	0.14	0.06	0.040			0	0
WA02-0071	23.8	0.9	0.08	0.05	0.026			0	0
WA02-0072	4.2	0.3	0.05	0.05	0.028	2		2	0
WA02-0075	1.8	0.2	0.02	0.02	0.017			0	0
WA02-0078	63.6	1.7	0.14	0.05	0.035			0	0

WA02-0087	64.5	1.2	0.13	0.05	0.039	1				1	0
WA02-0091	73.1	3.1	0.28	0.11	0.042	1				1	0
WA02-0102	3.7	0.2	0.03	0.02	0.015					0	0
WA02-0123	6.9	0.2	0.03	0.04	0.016					0	0
WA02-0127	14.8	0.5	0.05	0.03	0.019					0	0
WA02-0143	2.8	0.0	0.02	0.03	0.014					0	0
					Total	**282**	**19**	**23**	**0**	**324**	**7**

Appendix Table 4. Vegetation type (EM = emergent macrophyte, SE = seagrass, AG = algae) and class (NIS = nonindigenous species) for all species encountered and frequency of occurrence in quadrats and transects. West = all sites except for San Francisco high marsh. CA = all California sites except for San Francisco Bay.

Species/Taxon	Type	Class	Quadrats					Transects				
			West	CA	SF	OR	WA	West	CA	SF	OR	WA
Artemisia douglasiana	EM	native	-	-	1	-	-	-	-	1	-	-
Atriplex triangularis	EM	native	-	-	1	-	-	1	-	2	-	-
Batis maritima	EM	native	9	9	-	-	-	9	9	-	-	-
Carex lyngbyei	EM	native	2	-	-	2	-	3	-	-	3	-
Cotula coronopifolia	EM	NIS	1	-	-	1	-	1	-	-	1	-
Cordylanthus maritimus ssp *palustris*	EM	native	1	1	-	-	-	2	2	-	-	-
Cuscuta salina	EM	native	-	-	1	-	-	3	1	2	-	-
Distichlis spicata	EM	native	8	7	2	-	-	9	7	1	1	-
Eleocharis palustris	EM	native	-	-	-	-	-	1	-	-	1	-
Eleocharis parvula	EM	native	-	-	-	-	-	2	-	-	2	-
Euthamia occidentalis	EM	native	1	-	2	-	-	1	-	2	-	-
Frankenia salina	EM	native	3	3	-	-	-	3	3	1	-	-
Grindelia stricta	EM	native	2	-	4	-	-	2	-	4	-	-
Jaumea carnosa	EM	native	11	11	1	-	-	10	10	1	-	-
Juncus gerardii	EM	native	-	-	-	-	-	1	-	-	-	1
Lepidium latifolium	EM	NIS	1	-	1	-	-	1	-	1	-	-
Limonium californicum	EM	native	3	3	-	-	-	2	2	-	-	-
Polygonum lapathifolium	EM	native	1	-	1	-	-	1	-	1	-	-
Rosa californica	EM	native	-	-	1	-	-	-	-	1	-	-
Salicornia bigelovii	EM	native	1	1	-	-	-	2	2	-	-	-
Salicornia virginica	EM	native	35	27	16	1	-	35	27	17	1	-
Scirpus acutus	EM	native	2	-	4	-	-	1	-	4	-	-
Scirpus americanus	EM	native	-	-	1	-	-	-	-	1	-	-
Scirpus maritimus	EM	native	3	-	3	1	-	3	-	2	1	-
Scirpus robustus	EM	native	-	-	1	-	-	-	-	1	-	-
Spartina alterniflora	EM	NIS	3	-	-	-	3	3	-	-	-	3
Spartina foliosa	EM	native	8	6	3	-	-	9	7	3	-	-
Spartina sp.	EM	-	2	2	-	-	-	3	3	-	-	-

Spergularia marina	EM	native	1	-	-	1	-	2	-	-	2	-
Triglochin maritima	EM	native	3	2	-	1	-	2	-	-	2	-
Typha latifolia	EM	native	2	-	2	-	-	2	-	2	-	-
Zostera japonica	SE	NIS	24	-	-	7	17	28	-	-	10	18
Zostera marina	SE	native	21	2	-	9	10	25	1	-	10	14
Green algae	AG	-	84	17	-	33	34	84	19	-	39	26
Brown algae	AG	-	6	-	-	4	2	4	-	-	4	-
Red algae	AG	-	1	-	-	-	1	1	1	-	-	-
Bare area	BARE	-	165	45	24	51	52	173	43	20	56	58

Appendix Table 5. Relative percent cover of vegetation taxa (mean and range at sites present) in quadrats. West = all sites except for San Francisco high marsh. CA = all California sites except for San Francisco Bay.

Species/Taxon	WEST mean	WEST range	CA mean	CA range	SF mean	SF Range	OR mean	OR Range	WA mean	WA range
Artemisia douglasiana	-	-	-	-	5		-	-	-	-
Atriplex triangularis	-	-	-	-	85		-	-	-	-
Batis maritima	16	5-35	16	5-35	-	-	-	-	-	-
Carex lyngbyei	100	100-100	-	-	-	-	100	100-100	-	-
Cotula coronopifolia	45		-	-	-	-	45		-	-
Cordylanthus maritimus ssp *palustris*	5		5		-	-	-	-	-	-
Cuscuta salina	-		-	-	20		-	-	-	-
Distichlis spicata	44	5-100	44	5-100	26	1-50	-	-	-	-
Euthamia occidentalis	5		-	-	43	5-80	-	-	-	-
Frankenia salina	37	10-60	37	10-60	-	-	-	-	-	-
Grindelia stricta	20	10-30	-	-	34	10-60	-	-	-	-
Jaumea carnosa	43	5-95	43	5-95	30		-	-	-	-
Lepidium latifolium	25		-	-	25		-	-	-	-
Limonium californicum	7	5-10	7	5-10	-	-	-	-	-	-
Polygonum lapathifolium	25		-	-	25		-	-	-	-
Rosa californica	-	-	-	-	10		-	-	-	-
Salicornia bigelovii	25		25		-	-	-	-	-	-
Salicornia virginica	43	5-100	39	5-100	70	10-100	100		-	-
Scirpus acutus	15	10-20	-	-	14	10-20	-	-	-	-
Scirpus americanus	-	-	-	-	5		-	-	-	-
Scirpus maritimus	76	55-92	-	-	53	25-80	92		-	-
Scirpus robustus	-	-	-	-	60		-	-	-	-
Spartina alterniflora	53	50-60	-	-	-	-	-	-	53	50-60
Spartina foliosa	12	5-30	13	5-30	13	5-20	-	-	-	-
Spartina sp.	55	20-90	55	20-90	-	-	-	-	-	-
Spergularia marina	56		-	-	-	-	56		-	-
Triglochin maritima	30	5-75	8	5-10	-	-	75		-	-
Typha latifolia	28	15-40	-	-	28	15-40	-	-	-	-
Zostera japonica	42	1-100	-	-	-	-	26	3-87	48	1-100
Zostera marina	37	3-100	28	5-50	-	-	32	3-100	44	5-100

Green algae	45	1-100	70	5-100	-	-	49	1-100	27	1-100
Brown algae	8	1-22	-	-	-	-	12	3-22	1	1-1
Red algae	1	1-1	-	-	-	-	12	3-22	1	1-1
Bare area	70	2-100	57	5-100	52	3-100	80	2-100	74	5-100

Appendix Table 6. Quadrat maximum leaf length (cm) of vegetation taxa (mean and range at sites present). West = all sites except for San Francisco high marsh. CA = all California sites except for San Francisco Bay.

Species/Taxon	WEST mean	WEST range	CA mean	CA range	SF mean	SF Range	OR mean	OR Range	WA mean	WA Range
Artemisia douglasiana	-	-	-	-	87		-	-	-	-
Atriplex triangularis	-	-	-	-	122		-	-	-	-
Batis maritima	nd	nd	nd	nd	-	-	-	-	-	-
Carex lyngbyei	107	74-140	-	-	-	-	107	74-140	-	-
Cotula coronopifolia	13		-	-	-	-	13		-	-
Cordylanthus maritimus ssp *palustris*	15		15		-	-	-	-	-	-
Distichlis spicata	23	16-27	23	16-27	nd	nd	-	-	-	-
Euthamia occidentalis	102		-	-	92	82-102	-	-	-	-
Frankenia salina	nd	nd	nd	nd	-	-	-	-	-	-
Grindelia stricta	124	124	-	-	112	100-124	-	-	-	-
Jaumea carnosa	13	10-16	13	10-16	nd	nd	-	-	-	-
Lepidium latifolium	nd	nd	-	-	nd	nd	-	-	-	-
Limonium californicum	9	5-12	9	5-12	-	-	-	-	-	-
Polygonum lapathifolium	nd	nd	-	-	nd	nd	-	-	-	-
Rosa californica	-		-	-	nd	nd	-	-	-	-
Salicornia bigelovii	nd	nd	nd	nd	-	-	-	-	-	-
Salicornia virginica	36	6-76	33	6-76	49	23-75	25		-	-
Scirpus acutus	149	140-158	-	-	156	140-171	-	-	-	-
Scirpus americanus	-		-	-	60		-	-	-	-
Scirpus maritimus	111	49-156	-	-	113	55-156	49		-	-
Scirpus robustus	-		-	-	130		-	-	-	-
Spartina alterniflora	177	157-188	-	-	-	-	-	-	177	157-188
Spartina foliosa	68	38-86	69	38-86	56	37-65	-	-	-	-
Spartina sp.	78	56-99	78	56-99	-	-	36		-	-
Spergularia marina	36		-	-	-	-	-	-	-	-
Triglochin maritima	39		-	-	-	-	39		-	-
Typha latifolia	nd	nd	-	-	-	-	-	-	-	-
Zostera japonica	22	7-38	-	-	-	-	20	10-28	23	7-38
Zostera marina	71	14-122	-	-	-	-	56	14-122	84	29-119

Appendix Table 7. Quadrat biomass (g/m^2) of vegetation taxa (mean and range at sites present). West = all sites except for San Francisco high marsh. CA = all California sites except for San Francisco Bay.

Species/Taxon	WEST mean	WEST range	CA mean	CA range	SF mean	SF Range	OR mean	OR Range	WA mean	WA range
Artemisia douglasiana	-	-	-	-	nd	nd	-	-	-	-
Atriplex triangularis	-	-	-	-	72		-	-	-	-
Batis maritima	49	5-202	49	5-202	-	-	-	-	-	-
Carex lyngbyei	255	174-336	-	-	-	-	255	174-336	-	-
Cotula coronopifolia	7		-	-	-	-	7		-	-
Cordylanthus maritimus ssp *palustris*	1		1		-	-	-	-	-	-
Cuscuta salina	-	-	-	-	197		-	-	-	-
Distichlis spicata	75	9-211	85	17-211	6	3-9	-	-	-	-
Euthamia occidentalis	10		-	-	135	10-260	-	-	-	-
Frankenia salina	23	0-61	23	0-61	-	-	-	-	-	-
Grindelia stricta	134		-	-	268	134-403	-	-	-	-
Jaumea carnosa	63	0-289	63	0-289	38		-	-	-	-
Lepidium latifolium	9		-	-	9		-	-	-	-
Limonium californicum	1	0-3	1	1-3	-	-	-	-	-	-
Polygonum lapathifolium	9		-	-	9		-	-	-	-
Rosa californica	-	-	-	-	nd	nd	-	-	-	-
Salicornia bigelovii	45		45		-	-	-	-	-	-
Salicornia virginica	175	1-800	186	1-800	253	1-622	203		-	-
Scirpus acutus	18		-	-	98	18-154	-	-	-	-
Scirpus americanus	-	-	-	-	30		-	-	-	-
Scirpus maritimus	358	34-555	-	-	520	484-555	34		-	-
Scirpus robustus	-	-	-	-	219		-	-	-	-
Spartina alterniflora	295	93-540	-	-	-	-	-	-	295	93-540
Spartina foliosa	58	2-265	57	2-265	45	7-111	-	-	-	-
Spartina sp.	425	58-793	425	58-793	-	-	-	-	-	-
Spergularia marina	68		-	-	-	-	68		-	-
Triglochin maritima	17	0-38	6	0-12	-	-	38		-	-
Typha latifolia	75	27-124	-	-	75	27-124	-	-	-	-
Zostera japonica	13	0-90	-	-	-	-	5	2-7	14	0-90

Zostera marina	14	1-44	nd	nd	-	-	14	1-33	14	1-44
Green algae	20	0-101	26	0-89	-	-	30	0-101	9	0-61
Brown algae	2	0-4	-	-	-	-	3	2-4	0	0
Red algae	0	0	-	-	-	-	-	-	0	0

Appendix Table 8. Relative cover of vegetation taxa (mean and range at sites present) in transects. West = all sites except for San Francisco high marsh. CA = all California sites except for San Francisco Bay.

Species/Taxon	West mean	West range	CA mean	CA range	SF mean	SF range	OR mean	OR range	WA mean	WA range
Artemisia douglasiana	-	-	-	-	32		-	-	-	-
Atriplex triangularis	4		-	-	36	4-68	-	-	-	-
Batis maritima	16	4-44	16	4-44	-	-	-	-	-	-
Carex lyngbyei	69	16-100	-	-	-	-	69	16-100	-	-
Cotula coronopifolia	36		-	-	-	-	36		-	-
Cordylanthus maritimus ssp palustris	4		4		-	-	-	-	-	-
Cuscuta salina	16		16		28	4-52	-	-	-	-
Distichlis spicata	37	4-100	40	4-100	20		32		-	-
Eleocharis palustris	12		-	-	-	-	12		-	-
Eleocharis parvula	14	4-24	-	-	-	-	14	4-24	-	-
Euthamia occidentalis	20		-		50	20-80	-	-	-	-
Frankenia salina	20	4-32	20	4-32	4		-	-	-	-
Grindelia stricta	22	4-40	-	-	34	4-80	-	-	-	-
Jaumea carnosa	39	4-80	39	4-80	4		-	-	-	-
Juncus gerardii	20		-	-	-	-	-	-	20	
Lepidium latifolium	24		-	-	24		-	-	-	-
Limonium californicum	10	4-16	10	4-16	-		-	-	-	-
Polygonum lapathifolium	24		-	-	24		-	-	-	-
Rosa californica	-	-	-	-	24		-	-	-	-
Salicornia bigelovii	18	12-24	18	12-24	-	-	-	-	-	-
Salicornia virginica	52	4-100	48	4-100	76	12-100	100		-	-
Scirpus acutus	84		-	-	43	4-84	-	-	-	-
Scirpus americanus	-		-	-	20		-	-	-	-
Scirpus maritimus	52	48-60	-	-	48	48-48	60		-	-
Scirpus robustus	-	-	-	-	76		-	-	-	-
Spartina alterniflora	53	48-60	-	-	-	-	-	-	53	48-60
Spartina foliosa	30	4-52	26	4-52	35	12-48	-	-	-	-
Spartina sp.	40	4-100	40	4-100	-	-	-	-	-	-

Spergularia marina	20	4-36	-	-	-	-	20	4-36	-	-
Triglochin maritima	38	12-64	-	-	-	-	38	12-64	-	-
Typha latifolia	42	12-72	-	-	42	12-72	-	-	-	-
Zostera japonica	42	4-100	-	-	-	-	24	4-60	52	4-100
Zostera marina	30	4-96	20		-	-	33	4-96	28	4-72
Green algae	50	4-100	63	4-100	-	-	47	4-100	39	4-100
Brown algae	17	4-32	-	-	-	-	17	4-32	-	-
Red algae	4		4		-	-	-	-	-	-
Bare area	63	4-100	53	4-100	54	4-100	70	4-100	64	4-100

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